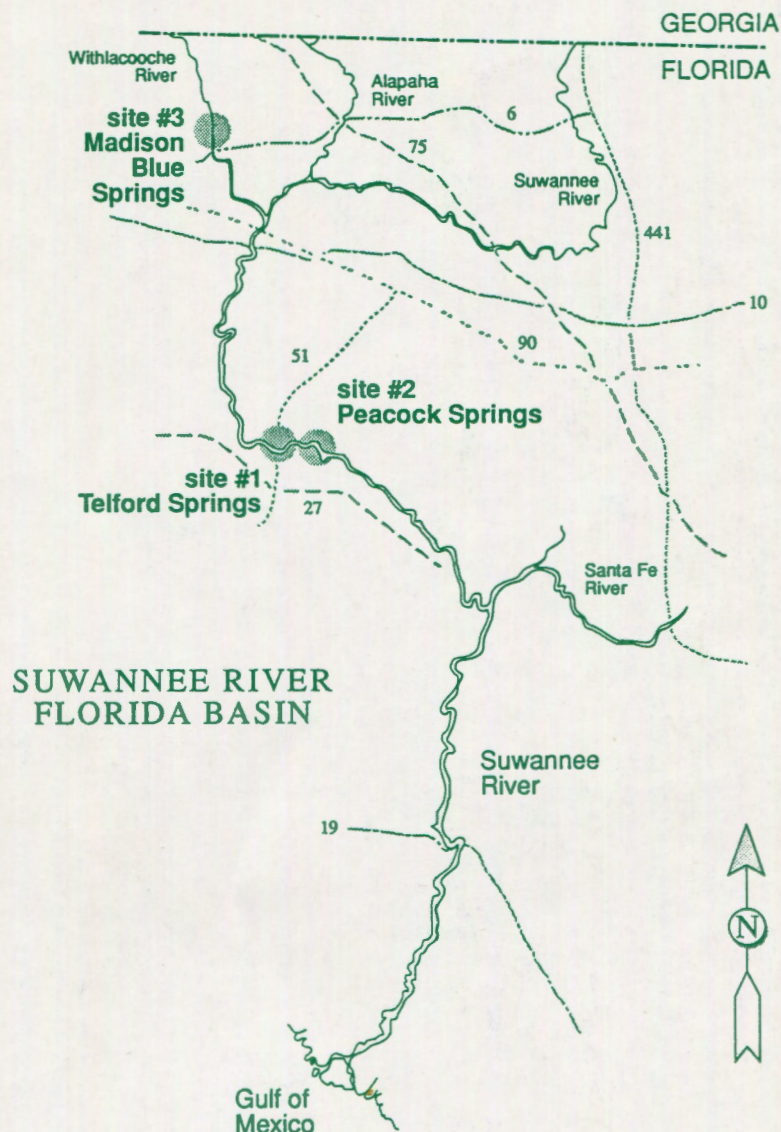


# THE NSS BULLETIN

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# A SYNOPSIS OF THE INVERTEBRATE CAVE FAUNA OF JAMAICA

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*Fifty-two Jamaican caves have been investigated for invertebrate faunas. This has resulted in the discovery of about 250 invertebrate species that are judged to be non-accidental residents of subterranean spaces or caves. Thirty-six species are considered to be troglobites (specialized for subterranean or cave life) and include 1 flatworm, 1 onychophoran, 1 schizomid, 9 spiders, 2 harvestmen, 4 pseudoscorpions, 1 grapsid crab, 1 palaemonid shrimp, 2 mysidaceans, 4 amphipods, 1 terrestrial isopod, 1 interstitial anthurid isopod, 2 collembolans, 1 cockroach, 2 cixiid bugs, and 2 carabid beetles. The vertebrate fauna may include an eyeless fish. After Cuba, this is the richest known diversity of cave faunas on any island in the West Indies.*

## INTRODUCTION

Jamaica, 240 km long and 64 km wide, is one of the smaller of the four islands of the Greater Antilles. The island first formed at least 60 million years ago but subsidence during the Eocene most probably resulted in its complete submergence. The island reemerged in the early Miocene, some 20 million years ago and reached its present size over the next 10 million years (Perfit and Williams, 1984). Soon after its emergence, Jamaica started to experience colonization by biotas that island-hopped from Central America along the Nicaraguan rise (Buskirk, 1985; Donnelly, 1988). Ultimately, a fascinating biota with many differences from that found elsewhere in the Caribbean was formed (Buskirk, 1985). Cuba, Hispaniola, and Puerto Rico are more similar to each other geologically and biologically than they are to Jamaica.

General aspects of physiography, climatology, etc. will not be presented because these can be found in more general reference books, especially the Handbook of Jamaica published by the Jamaica Information Service, or in encyclopedias. Details relating to field localities that will be of help to Jamaican caving are in Peck (1975), Peck and Kukalova-Peck (1975), Peck and Kukal (1975), and Wright and White (1969).

## SPELEOLOGY

About two-thirds of the island is underlain by limestones. This, together with an average of 188 cm rainfall, has yielded an abundance of caves. Over 900 caves have been catalogued (Fincham, 1977). Most of these occur in the White Limestone formation of Oligocene age, which reaches a thickness of up to 610 m. The White Limestone is underlain by middle Eocene Yellow Limestone and is folded along an east-west axis. Fewer caves have been formed in Cretaceous limestone, gypsine deposits, subrecent raised coral rock, and post-Miocene limestone.

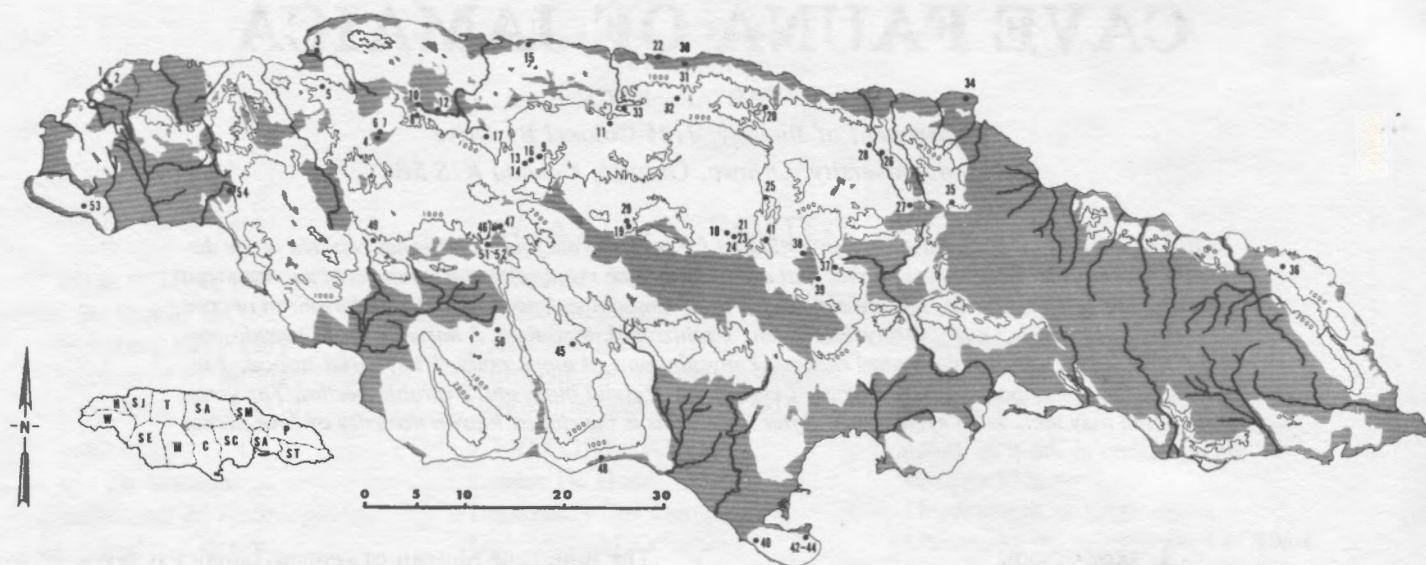
The limestone plateau of central Jamaica is favoured for cave development because of its watershed which has a gentle gradient off the 460 to 915 m high insoluble basement rocks of the Central Inlier. This metamorphic ridge (Fig. 1) separates the limestone plateau into two main watersheds and the water running north or south disappears in numerous sinkholes and closed valleys in the extremely porous White Limestone.

There have been many publications on Jamaican karst and hydrology. General references on Jamaican caves, cave exploration, karst, and hydrology are those of Aley (1964), Ashcroft (1969), Read (1963), Smith, Drew and Atkinson (1972), Sweeting (1957, 1958), Versey (1972), White and Dunn (1962), and Zans (1956). Studies of specific caves or cave regions are Ashcroft et al. (1965), Brown and Ford (1973), DiTonto (1989), and Zans (1953, 1954). Atkinson (1969) reports on some eight km of surveyed cave passages in 35 caves. Livesey (1966) reports on 24 km of surveyed passage in 47 caves. Fincham and Ashton (1967) report on about 20 caves, and include survey maps.

The Jamaican Caving Club, associated with the University of the West Indies, Mona, Jamaica, has done a considerable amount of cave exploration on the island. Alan Fincham (Department of Biochemistry, University of West Indies, Mona, Kingston 7, Jamaica) has been a prime organizer in the cave club and has compiled most of the available information. His book (Fincham, 1977) is an inventory of data on over 900 caves and is the most detailed compilation yet prepared on caves of a tropical region. The Jamaican geological survey has also mapped many caves in relation to their guano-phosphate deposits.

For precise cave localities and for aid in prospecting for new localities, the 1:250,000 scale and 1:50,000 scale geologic and topographic maps are necessary. They may be obtained from the Jamaica Survey Department 23½ Charles Street, Kingston, or Edward Stanford Ltd., 12-14 Long





**Figure 1.** Jamaica, showing all the cave sites that have been biologically investigated in relation to topography, drainage, and geology. The contour interval is 1000 and 2000 feet (= 305 and 610 m). The numbers correspond to cave descriptions in Peck (1975) and Peck and Kukal (1975). The dark regions are generally insoluble volcanic or metamorphic rocks, or alluviated valleys. The open regions are mostly Cretaceous, Eocene, and Miocene limestones. The coastal caves in a dark background are in elevated Miocene, Pliocene, and Quaternary coastal formations. All

major permanent streams and rivers are shown. The scale is in miles. Prepared from the 1:250,000 scale geology (1958) and topography (1966) base maps of the Geological Survey Department of Jamaica. The upper right hand insert shows the location of the Parishes into which Jamaica is divided. The Parish abbreviations are as follows, clockwise: H, Hanover; SJ, St. James; T, Trelawny; SA, St. Ann; SM, St. Mary; P, Portland; ST, St. Thomas; SA, St. Andrew; SC, St. Catherine; C, Clarendon; M, Manchester; SE, St. Elizabeth; W, Westmorland.

Acre, London W.C.2. Some maps at 1:12,500 (of superior size) are available from the Survey Department. These maps record distances and elevations in miles and feet.

#### THE VERTEBRATE FAUNA

The first biological study of Jamaican caves was made by Anthony (1920a, 1920b), but he limited his work to mammals and vertebrate paleontology. Later reports on Anthony's cave collections are those of Koopman and Williams (1951), Williams (1952), and Williams and Koopman (1952). Recent work on vertebrate fossils from cave deposits is that of Ford and Morgan (1986), Goodfriend and Mitterer (1987), Olson and Steadman (1977, 1979), and MacPhee (1984). The cave deposits also contain Pleistocene land snails (Goodfriend, 1989; Goodfriend and Mitterer, 1989). Several papers treat the 23 species of Jamaican bats (such as Baker and Genoways, 1978; Goodwin, 1970, Koopman, 1989; and Lewis, 1954).

Fishes occur in some Jamaican caves. Guppies (*Gambusia*, perhaps *G. gracilor*) are in the flooded mouth of Whyslip Water Cave. Sleepers (*Eleotris pisonis* (Gmelin),

(Eleotridae; or Gobiidae) have been captured in Jackson Bay Great Cave and Green Grotto Cave and were seen several times in Dairy Bull Cave. A blind fish, perhaps a bythitid (= brotulid), is supposed to be in Jackson Bay Great Cave (Ashford et al., 1965) but has not been captured and studied. This could be the fish that gave rise to early reports of Jamaican blind fish (Eigenmann, 1909: 188).

*Eleutherodactylus* frogs occur in some caves such as Jackson Bay, Cousins Cove number 2, and Monarva caves, and *E. cavernicola* Lynn is supposed to be found only in caves in Portland Ridge (Lynn, 1954).

#### BIOSPELEOLOGY FIELD WORK IN JAMAICA

Following the search by Anthony for caves containing bones, only a few sporadic collections were made in caves, mostly of aquatic crustaceans. A concerted cave faunal study was undertaken by S. Peck and colleagues in 1968, 1972, 1973, and 1974; for a total of 3 months of field study of 52 caves (Table 1). Russell Norton and R. Zimmerman made faunal collections in 1973 and studied 22 caves. The only other cave faunal work was by Jan Stock in 1979 and



Study Sites—Table I

Alphabetical listing of cave name by Parish, 1:50,000 map grid location, elevation, length, and type of cave surveyed for invertebrate faunas.

Cave name	Map grid location	Elevation (m)	Length (m)	Type
<b>Clarendon Parish</b>				
1. Jackson Bay Great Cave	H 472 303	0	3300	complex
2. Pedro Great Cave	G 476 468	500	520	moist
3. Portland Ridge Caves	H 495 310	13	500	dry
<b>Hanover Parish</b>				
4. Cousins Cove Cave no. 1	A 119 554	15	300	labyrinth
5. Cousins Cove Cave no. 2	A 119 553	50	100	complex
<b>Manchester Parish</b>				
6. Abbey Cave	D 364 406	44	700	moist
7. Coffee River Cave	D 333 476	275	2800	river
8. Oxford Cave	D 332 475	290	760	moist
9. Wyslip Water Cave	E 378 345	0	25	marine pool
<b>Portland Parish</b>				
10. Nonsuch Caves	M 750 455	182	76	moist
<b>St. Ann Parish</b>				
11. Brambribo Cave	G 454 478	610	335	moist
12. Cave River Cave	G 409 483	550	700	river
13. Chesterfield Cave	F 475 536	550	240	moist
14. Cricket Cave	G 456 475	680	100	stream
15. Dairy Bull Cave	F 415 569	3	100	marine pool
16. Douglas Castle Cave	G 456 477	685	40	moist
17. Falling Cave	G 456 475	685	100	moist
18. Green Grotto (of Runaway Caves)	F 420 566	0	500	marine pool
19. Ken Connell Hole	F 476 491	530	300	moist
20. Moseley Hall Cave	F 539 493	533	243	moist
21. Mount Plenty Cave	F 529 521	335	160	moist
22. Norwood Rat Bat Hole	G 410 487	530	134	moist
23. Runaway Bay Caves	F 420 566	10	1000	labyrinth
24. Thatchfield Great Cave (= Thatchfield Light Hole)	F 444 548	414	1400	complex
25. Thunder Cave	F 400 540	380	50	moist
<b>St. Catherine Parish</b>				
26. St. Claire Cave	G 518 454	235	2900	river
27. Swansea Caves	G 497 464	460	1170	moist
28. Worthy Park Cave (no. 2)	G 504 453	380	716	stream
<b>St. Elizabeth Parish</b>				
29. Duanwarie Cave (no. 1)	D 256 476	260	90	moist
30. Peru Cave	D 332 428	80	213	labyrinth
31. Wallingford Cave	D 326 466	228	64	moist
32. Wallingford Sink Cave	D 326 465	213	413	river
<b>St. James Parish</b>				
33. Brandon Hill Cave (= Sewell Cave)	C 233 527	69	127	moist
34. Maldon School Cave	C 270 526	579	152	stream
35. Mocho Cave	C 239 549	344	130	moist
36. Peterkin Cave	C 270 527	344	419	stream
37. Rota Cave	C 272 528	335	975	moist
38. Spring Vale Cave (= South Rising Cave)	C 284 536	158	38	moist
<b>St. Mary Parish</b>				
39. Lucky Hill Farm Cave	F 538 519	260	150	stream
40. Idlewild Caves	K 582 547	15	30	dry
41. Rock Springs Cavern	K 574 489	290	2590	river
<b>Trelawny Parish</b>				
42. Burnt Hill Cave	C 354 515	396	26	moist
43. Carambie Cave	C 354 511	503	335	labyrinth
44. Deeside River Cave	C 290 541	182	335	moist
45. Drip Cave	F 392 531	390	300	moist
46. Dromilly Cave	C 302 537	118	100	moist
47. Harties Caves (no. 1 and no. 2)	C 351 510	533	1313	complex
48. Hope Gate Cave	C 337 573	6	213	labyrinth
49. Printed Circuit Cave	C 352 510	533	3220	labyrinth
50. Windsor Great Cave	C 326 528	114	2977	complex
<b>Westmorland Parish</b>				
51. Monarva Cave	B 103 486	60	300	moist
52. Roaring River Cave	B 184 503	82	152	stream



1982 during the Amsterdam Expeditions to the West Indian Islands (Stock, 1983), investigating groundwater faunas. The Peck and Norton collections are deposited in the collections of S. Peck, the Museum of Comparative Zoology (Harvard University), the American Museum of Natural History, the Canadian Museum of Nature (Ottawa), the Biosystematics Research Centre, Agriculture Canada (Ottawa), or the collections of the specialists who supplied determinations. The caves that have been biologically studied are described in Peck (1975) and Peck and Kukal (1975). Their locations and characteristics are summarized in Table 1.

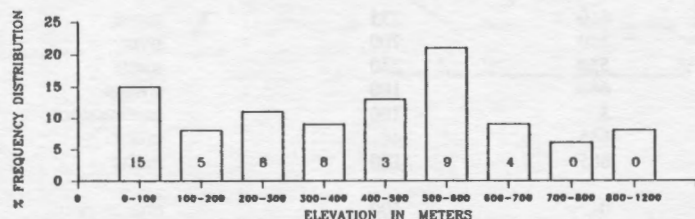


Figure 2. Percent frequency distribution of altitude of Jamaican caves. Inset number in each altitude category shows number of caves sampled in this study.

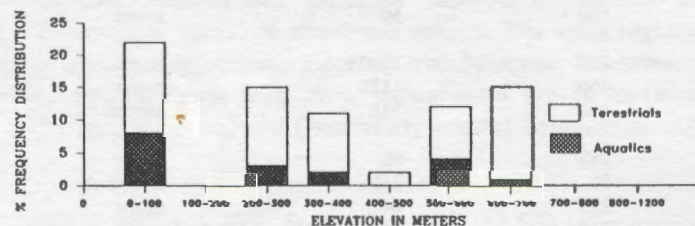


Figure 3. Percent frequency distribution of total occurrences of Jamaican groundwater and cave troglobites. The upland aquatic records are for two species only, a crab and a shrimp. A large number of terrestrial troglobites occurs in the 0-100 m altitude range, which may be a rare situation in tropical cave faunas.

Over 900 caves sites are known in Jamaica and 613 of these are precisely located (Fincham, 1977). These caves offer a variety of habitat types to cave faunas. Some are wet, some dry. Some are food-poor, and others have large deposits of organic food materials such as flood-debris or bat guano (Fig. 4). The altitude is known for 613 caves and these are relatively evenly distributed (by 100 m groupings) from sea level to over 800 m (Fig. 2). Between 600 m and 1200 m there are progressively fewer caves in each 100 m group.

#### SYSTEMATIC LISTING OF JAMAICAN CAVE INVERTEBRATES

The following is an annotated listing of the invertebrate



Figure 4. A large accumulation of insectivorous bat guano in Oxford Cave. Bat guano deposits are a focus for troglomorphic arthropod scavengers and predators. Troglobites do not occur near (seem to avoid) large food accumulations.

fauna now known to occur in caves and groundwaters in Jamaica from both literature records and new collections. The ecological-evolutionary association of each species with caves is indicated by use of the standard terms accidental, troglone, troglophile, and troglobite. A summary of the species biology and distribution given if possible. Numbers in collections are given when this seems to help document the abundance of the population. Cave names follow those used by Fincham (1977).

#### Phylum Platyhelminthes Class Turbellaria Order Tricladida

Family and genus undetermined, troglobite

Trelawny: Carambie Cave. An eyeless white species from rimstone pools.

#### Phylum Nematomorpha

Family and genus undetermined, troglone?

St. Ann: Lucky Hill Pen Cave, 1 in cricket; Mosley Hall Cave, 1 in pool. St. Catherine: St. Claire Cave, 1 in drip pool on guano floor; Swansea Cave. These gordian worms are probably *Uvaroviella* cricket parasites.

#### Phylum Annelida Class Oligochaeta

Family Enchytraeidae (?)

St. Ann: Ken Connell Hole Cave, 3.



## Family Megascolecidae

*Diplocardia* sp., edaphophile

Trelawny: Windsor Great Cave. Westmorland: Monarva Cave, Roaring River Cave.

## Family Lumbricidae

*Dendrobaena octaedra* (Savigny), edaphophile

Trelawny: Windsor Great Cave.

## Phylum Mollusca

Large accumulations of snail shells, most commonly of *Pleurodonte acuta*, *P. jamaicensis*, *Thelidomus acuta*, *Anularia pulchrum*, *Sagda* sp. (all Sagdidae) and *Dentellaria* sp. (Camaenidae), are found near the entrances of caves such as Idlewild, Worthy Park number 2, Dromilly, and Falling caves, but these snails have never been found living in the dark zones of any Jamaican caves. The following snail records are from the dark zone of caves. Goodfriend and Mitterer (1988) and Goodfriend (1989) reported Pleistocene land snails from deposits in four caves.

## Class Gastropoda

## Order Mesogastropoda

## Family Hydrobiidae

*Pyrgophorus* sp. troglophile

Clarendon: Jackson Bay Cave (in stagnant saline waters). St. Ann: Spring near Crater Lake, E of Discovery Bay (in fast flowing fresh water) (Stock, 1983).

*Potamopyrus* cf. *corolla* or n.sp., troglophile

St. Ann: Green Grotto, on rocks and wood near surface of deep pools.

## Order Stylommatophora

## Family Sagdidae

*Hyalosagda haldemeniana* (C.B. Adams), troglophile?

St. Ann: Ken Connell Hole, 1 juvenile. St. Mary: Rock Springs Cave, 8.

*Sagda connectedens* Pilsbury, accidental

St. James: Brandon Hill Cave, 4 juveniles.

*Thysanophora omissa* Pilsbury, troglophile

St. Ann: Ken Connell Hole, 2.

## Family Subulinidae

*Leptinaria lamellata* Poleez and Michaud, accidental  
Westmorland: Roaring River Cave, 1. This is a widespread Caribbean species.*Opeas micra* (Orbigny), troglophile

Clarendon: Pedro Great Cave, 2. St. Mary: Rock Springs Cave. Trelawny: Dromilly Cave, 12. Westmorland: Monarva Cave, 1; Roaring River Cave, 1. This species is widespread in the Caribbean.

*Subulina octona* Bracquiére, troglophile

Clarendon: Pedro Great Cave. Hanover: Cousins

Cove Cave no. 1. Manchester: Oxford Cave, on guano. St. Ann: Chesterfield Cave; Lucky Hill Farm Cave; Moseley Hall Cave; Runaway Caves. Thatchfield Light Hole. St. James: Brandon Hill Cave. Trelawny: Deeside River Cave. Westmorland: Monarva Cave, Roaring River Cave. This is a circumtropical species, distributed by commerce, and often found in moist tropical caves.

## Order Basommatophora

## Family Physidae

*Physa jamaicensis* C.B. Adams, troglophile

St. Catherine: St. Claire Cave, 13 in stagnant pool of cave river in 1968, absent in 1973.

## Class Pelecypoda

## Order Anisomyaria

## Family Dreissenidae

*Mytilopsis leucophaea* (Conrad), troglophile

St. Ann: Green Grotto, attached to rocks near surface of deep pools. The family of this clam is marine, but this genus inhabits fresh water.

## Phylum Onychophora

## Family Peripatidae

*Plicatoperipatus jamaicensis* (Grabham and Cockerell), accidental

St. Ann: Moseley Hall Cave (Arnett, 1961). This species is more commonly known from Jamaican epigeal localities.

*Speleoperipatus spelaus* Peck (1975), troglobite (Fig. 5).

Figure 5. *Speleoperipatus spelaus* from Pedro Great Cave. Troglobitic onychophorans ("peripatus") are otherwise known only from a cave in Table Mountain, Cape Town, South Africa.



Clarendon: Pedro Great Cave. This species has no eyes, and no pigmentation. It is the only known troglobitic member of its family. A troglobitic onychophoran in the family Peripatopsidae lives in caves in Table Mountain, Cape Town, South Africa.

Phylum Arthropoda  
Class Arachnida  
Order Scorpiones

Family Diplocentridae

*Diplocentrus* sp., accidental

Hanover: Cousins Cove Cave no. 1.

Order Schizomida

Family Schizomidae

The following species, except for *Schizomus portoricensis*, are in the *dumitrescoae* group, which also occurs in Costa Rica and the West Indies.

*Schizomus cousinensis* Rowland and Reddell (1979), troglophile

Hanover: Cousins Cove Cave no. 1.

*Schizomus primibiconourus* Rowland and Reddell (1979), troglophile

Manchester: Oxford Cave. St. Catherine: St. Claire Cave.

*Schizomus peckorum* Rowland and Reddell (1979), troglophile

St. Ann: Moseley Hall Cave. Trelawny: Windsor Great Cave.

*Schizomus viridis* Rowland and Reddell (1979), troglophile

Clarendon: Jackson Bay Cave, Pedro Great Cave. Manchester: Abbey Cave. St. Ann: Brambribo Cave, Cave River Cave, Chesterfield Cave, Falling Cave, Ken Connell (Hutchinson) Hole, Mt. Plenty Cave, Thatchfield Great Cave. St. Catherine: St. Claire Cave, Swansea Cave. St. Elizabeth: Peru Cave, Wallingford Sink Cave. Trelawny: Drip Cave, Windsor Great Cave. This endemic species is also known from Jamaican forests.

*Schizomus portoricensis* (Chamberlin), troglophile  
Manchester: Oxford Cave. St. Ann: Brambribo Cave, Falling Cave, Ken Connell (Hutchinson) Hole, Lucky Hill Farm Cave. St. Catherine: St. Claire Cave. St. Elizabeth: Wallingford Cave. St. James: Brandon Hill Cave, Maldon School Cave. Trelawny: Carambie Cave, Deeside Cave, Dromilly Cave, Harties Cave, Printed Circuit Cave. Westmoreland: Roaring River Cave. The species is widely spread from Florida, through the West Indies, Central America and into the Southern parts of South America, including the Galapagos Islands,

and even England. In part it was spread by commerce (Rowland and Reddell, 1977). The species is in the *mexicanus* species group naturally occurring otherwise in Texas, Mexico, and Guatemala.

*Schizomus troglobius* Rowland and Reddell, troglobite

Clarendon: Jackson Bay Cave (type locality). The species is known only from this cave (Rowland and Reddell, 1981).

Order Amblypgi

Family Phrynidae

*Phrynus marginemaculatus* C.L. Koch, troglophile

Clarendon: Jackson Bay Cave, Portland Ridge Caves, Pedro Great Cave. Hanover: Cousins Cove Cave no. 1 and no. 2. Manchester: Oxford Cave. Portland: Nonsuch Cave. St. Ann: Brambribo Cave, Cave River Cave, Dairy Bull Cave, Ken Connell Hole Cave, Mount Plenty Cave. St. Catherine: St. Claire Cave, Swansea Cave. St. Elizabeth: Wallingford Cave, and Wallingford Sink Cave. St. Mary: Rock Springs Cavern. St. James: Brandon Hill Cave, Maldon School Cave. Trelawny: Carambie Cave, Dromilly Cave, Harties Cave, Hope Gate Cave, Printed Circuit Cave, Windsor Great Cave, Westmorland: Monarva Cave, Roaring River Cave. The species is widely distributed in the West Indies and southern Florida (Quintero, 1981).

*Phrynus levii* Quintero, troglophile

Reported from a cave at Montego Bay (the only Jamaican locality), and Cuba (Quintero, 1980). Some of the above records may actually be this species.

Order Aranea

Family Dipluridae

*Masteria lewisi* (Chickering), troglophile

Clarendon: Pedro Great Cave. Manchester: Abbey Cave, Oxford Cave. St. Ann: Cave River Cave, Mt. Plenty Cave, Moseley Hall Cave, Thatchfield Light Hole. St. Catherine: St. Claire Cave. St. Elizabeth: Duanwarie Cave, Wallingford Sink Cave. St. James: Brandon Hill Cave, Maldon School Cave, Mocho Cave, Peterkin Cave, Rota Cave. Trelawny: Dromilly Cave, Harties Cave, Windsor Great Cave. Westmorland: Roaring River Cave.

*Masteria pecki* Gertsch 1982a, troglobite

St. Ann: Falling Cave. This species is essentially eyeless. The genus is better known under the junior synonym *Accola*. The only other eyeless species is *Masteria caeca* Simon of the Philippines (Gertsch, 1982a). Other eyeless diplurids occur in caves in Mexico and Australia.



## Family Barychelidae

*Psalistops*, sp. troglophile

Clarendon: Pedro Great Cave. Hanover: Cousins Cove Cave no. 1. Manchester: Oxford Cave. St. Ann: Brambribo Cave, Lucky Hill Pen Cave, Mt. Plenty Cave, Thatchfield Light Hole. St. Catherine: St. Clair Cave; Swansea Cave. Trelawny: Carambie Cave. This species is undescribed. *Troglithele coeca* Fage is an eyeless barychelid troglobite in Cuba (Gertsch, 1982a).

## Family Scytodidae

*Loxosceles caribbaea* Gertsch, troglophile

Clarendon: Jackson Bay Cave, Portland Caves. Hanover: Cousins Cove Cave no. 1. St. Ann: Runaway Caves, Mt. Plenty Cave. St. James: Providence Cave (Montego Bay, AMNH record). St. Mary: Rock Springs Cave. Trelawny: Carambie Cave, Hope Gate Cave.

*Scytodes* sp. troglophile

Clarendon: Portland Caves. Hanover: Cousins Cove Cave no. 1. St. Ann: Drip Cave, Hutchinson Hole Cave, Ken Connell Hole, Runaway Caves. Trelawny: Drip Cave, Harties Cave, Windsor Great Cave. Westmorland: Monarva Cave. This species is undescribed.

*Scytodes longipes* Lucas, troglophile

Westmorland: Roaring River Cave, 5.

## Family Oonopidae

*Triaeris stenaspis* Simon, troglophile

Hanover: Cousins Cove Cave no. 2. St. Ann: Worthy Park Cave no. 2. Westmorland: Roaring River Cave.

*Oonops castellus* Chickering, troglophile

Clarendon: Jackson Bay Cave.

*Oonops* sp., accidental

Clarendon: Portland Ridge Caves.

## Family Dysderidae

*Ariadna arthuri* Petrunkevitch, troglophile

Hanover: Cousins Cove Cave no. 1. St. James: Rota Cave. Westmorland: Monarva Cave.

## Family Ochyroceratidae

*Theotima* sp., troglobite

St. Catherine: St. Claire Cave. This species is eyeless and undescribed.

*Theotima minutissima* (Petrunkevitch), troglophile

Hanover: Cousins Cove Cave no. 1. St. Ann: Mt. Plenty Cave. St. Catherine: St. Claire Cave. St. Elizabeth: Wallingford Caves. Trelawny: Harties Cave. The species is known from outside of caves.

*Ochyrocera* sp., troglophile

Clarendon: Pedro Great Cave. Hanover: Cousins

Cove Cave. St. Ann: Moseley Hall Cave. St. Catherine: St. Claire Cave. St. James: Brandon Hill Cave. This species is undescribed.

## Family Pholcidae

These long-legged spiders clearly show a relationship to eastern Mexico and the Yucatan (Gertsch, 1986).

*Metagonia jamaica* Gersch 1986, troglobite

Clarendon: Jackson Bay Cave. This eyeless species is the only member of the genus known from the West Indies, while 46 species are known from North and Central America, of which 12 are eyeless troglobites (Gertsch, 1986).

*Anopsicus quatuorculus* Gertsch, troglophile

St. Ann: Chesterfield Cave; Norwood Rat Bat Hole; Thatchfield Light Hole. St. Catherine: Swansea Cave. Trelawny: Drip Cave, Harties Cave, Windsor Great Cave. The genus contains 63 species of these small pholcids, 31 of which are known from caves and are eyeless in caves in Mexico (6), Jamaica (5), and Cuba (1) (Gertsch, 1982b). The adaptive radiation into caves in Jamaica is most interesting. They may be a group in which to study the process and sequence of eye loss in cave adaptation.

*Anopsicus nebulosus* Gertsch, troglobite

St. Elizabeth: Duanwarie Cave. This essentially eyeless and long legged species is known only from this cave (Gertsch, 1982b).

*Anopsicus jarmila* Gertsch, troglobite

St. Catherine: Worthy Park Cave no. 2. This eyeless species is known only from this cave (Gertsch, 1982b).

*Anopsicus limpidus* Gertsch, troglobite

St. Ann: Cricket Cave. This species has rudimentary eyes and long legs (Gertsch, 1982b).

*Anopsicus pecki* Gertsch, troglobite (?)

Clarendon: Portland Cave. This probable troglobite is sympatric with the troglobite *A. clarus* from the same cave (Gertsch, 1982b).

*Anopsicus clarus* Gertsch, troglobite

Clarendon: Jackson Bay Cave. Portland Caves. This species is eyeless.

*Anopsicus nortoni* Gertsch, troglophile

Hanover: Cousins Cove Cave.

*Anopsicus zimmermani* Gertsch, troglophile

Trelawny: Carambie Cave, Printed Circuit Cave.

*Anopsicus* undetermined, troglophile

St. Ann: Brambribo Cave, Runaway Caves. St. Elizabeth: Peru Cave.

*Modisimus* sp., troglophile

Clarendon: Jackson Bay Cave, Portland Caves. Hanover: Cousins Cove Cave. St. Ann: Brambribo Cave, Dairy Bull Cave, Mt. Plenty Cave, Runaway Bay Caves. St. Elizabeth: Peru Cave. St. James:



Brandon Hill Cave, Mocho Cave. St. Mary: Rock Springs Cave. Trelawny: Windsor Great Cave. This is probably a new species but may be *M. glaucus* of Bryant but not of Simon.

*Modisimus* sp., troglophile?

Hanover: Cousins Cove Cave.

*Physocyclus globosus* Taczanowski, troglophile

Clarendon: Portland Caves. St. Ann: Runaway Caves.

#### Family Prodidomidae

*Zimiris* sp., troglobite

St. Ann: Falling Cave. St. Catherine: Worthy Park Cave.

#### Family Nesticidae

*Gaucelmus cavernicola* (Petrunkevitch), troglophile

Clarendon: Pedro Great Cave. Manchester: Oxford Cave. St. Ann: Brambribo Cave, Cave River Cave, Hutchinson Hole Cave, Ken Connell Hole, Lucky Hill Farm Cave, Moseley Hall Cave, Mount Plenty Cave, Runaway Caves. St. Catherine: St. Claire Cave, Swansea Cave. St. Elizabeth: Duanwarie Cave, Peru Cave, Wallingford Caves. St. Mary: Rock Springs Cave. St. James: Mocho Cave, Rota Cave. Trelawny: Carambie Cave, Drip Cave, Deeside Cave, Dromilly Cave, Harties Cave, Printed Circuit Cave. Westmorland: Roaring River Cave. The species is closely related to *G. augustinus* of the southeastern USA. The species was described originally as *Theridionexus cavernicolus*. It was previously recorded from Peru Cave and Oxford Cave (Petrunkevitch, 1928).

*Eidmannella suggerens* (Chamberlin), troglophile

Hanover: Cousins Cove Cave no. 1.

#### Family Symphytognathidae

*Maymena* sp. troglophile

St. Ann: Brambribo Cave, Cricket Cave, Falling Cave. Trelawny: Carambie Cave. This species is undescribed. The genus is otherwise known from Mexico, and Trinidad.

#### Family Theridiidae

*Theridion rufipes* Lucas, troglophile

Clarendon: Jackson Bay Cave, Portland Caves. Hanover: Cousins Cove Cave no. 2. St. Ann Runaway Caves. St. Catherine: St. Claire Cave. St. Elizabeth: Peru Cave, Wallingford Cave. St. James: Brandon Hill Cave, Rota Cave. Trelawny: Drip Cave. Westmorland: Monarva Cave, Roaring River Cave. This is a widespread species.

#### Family Araneidae

*Pseudometa* sp., troglophile

St. Ann: Mt. Plenty Cave. Trelawny: Drip Cave.

#### Family Tetragnathidae

*Tetragnatha* sp., troglophile?

St. Ann: Mt. Plenty Cave, 1. St. Elizabeth: Wallingford Sink Cave, 1.

#### Family Linyphiidae

*Grammonota* sp., accidental

St. Catherine: St. Claire Cave, 1.

*Eperigone* sp., troglophile

St. Catherine: St. Claire Cave, 5.

#### Family Clubionidae

*Corinna abnormalis* Petrunkevitch, troglophile

Clarendon: Jackson Bay Cave, Portland Caves. Hanover: Cousins Cove Cave no. 1. St. Ann: Runaway Caves. St. Catherine: St. Claire Cave. Trelawny: Hope Gate Cave, Printed Circuit Cave. Westmorland: Monarva Cave, Roaring River Cave.

*Phrurolithus* sp., accidental?

Hanover: Cousins Cove Cave, 4. Trelawny: Harties Cave, 1.

#### Family Ctenidae

*Ctenus* sp., troglophile

Clarendon: Pedro Great Cave. St. Ann: Chesterfield Cave, Ken Connell Hole, Lucky Hill Farm Cave, Thatchfield Great Cave. St. Catherine: St. Claire Cave, Worthy Park Cave no. 2. Trelawny: Drip Cave, Dromilly Cave. Westmorland: Roaring River Cave. This is a pigmented species.

*Ctenus* sp. troglophile

Clarendon: Portland Caves. Hanover: Cousins Cove Cave. St. Ann: Hutchinson Hole Cave. Trelawny: Windsor Great Cave. This is a striped species.

#### Family Gnaphosidae

*Lygromma gertschi* Platnick and Shadab (1976), troglobite

St. Ann: Falling Cave. St. Catherine: Worthy Park Cave no. 2. Trelawny: Drip Cave. This was the first eyeless species known for this widely distributed American genus with 12 species. Since then an eyeless species has been described from the Galapagos Islands (Peck and Shear, 1987).

#### Order Opiliones

#### Family Phalangodidae

*Cynortina goodnighti* Rambla (1969), troglophile

Clarendon: Lucky Hill Pen Cave. Hanover: Cousins Cove Cave. Manchester: Oxford Cave. St. Ann: Moseley Hall Cave, Mount Plenty Cave, Pedro Great Cave. St. Elizabeth: Wallingford Sink Cave. St. Claire Cave, (type locality). St. Mary: Rock Spring Cave. The species has also been collected in forested habitats.



*Cynortina pecki* Rambla (1969) troglobite

Clarendon: Pedro Great Cave. Manchester: Oxford Cave. St. Ann: Cricket Cave, Falling Cave. St. Catherine: Worthy Park Cave no. 2 (type locality). Trelawny: Carambie Cave.

*Stygnomma fiskei* Rambla (1969), troglobite

Clarendon: Jackson Bay Cave. Manchester: Coffee River Cave (type locality), Oxford Cave. Because of the isolation of the first cave, its population may prove to be a separate species.

*Stygnomma spinifera* (Packard), troglophile

Clarendon: Jackson Bay Cave, (on decayed roots). St. Ann: Dairy Bull Cave, Ken Connell Hole. This species also occurs in coastal Florida, the Yucatan, and Belize.

## Order Pseudoscorpionida

## Family Bochicidae

*Troglobochica jamaicensis* Muchmore 1984, troglobite

Clarendon: Jackson Bay Great Cave (type locality). The genus is endemic to Jamaica but related to *Bochica* of Grenada and Trinidad.

*Troglobochica pecki* Muchmore 1984, troglobite

Trelawny: Drip Cave (type locality).

## Family Chernetidae

*Lustrochernes* sp., troglophile

St. Ann: Mount Plenty Cave. Manchester: Oxford Cave. Trelawny: Dromilly Cave. This is a thick clawed species, found under boards in guano.

## Genus undet.

Clarendon: Pedro Great Cave. Manchester: Oxford Cave. St. Ann: Brambribo Cave, Moseley Hall Cave. Trelawny: Hope Gate Cave, Windsor Great Cave.

## Family Chthoniidae

*Lagynochthonius cavicolus* Muchmore 1991, troglophile

Hanover: Cousins Cove Cave no. 2.

*Lagynochthonius typhlus* Muchmore 1991, troglobite

St. James: Maldon School Cave. These are the first records of the genus from the Caribbean area.

*Tyranochthonius hoffi* Muchmore 1991, troglobite

Hanover: Cousins Cove Cave no. 2. St. Elizabeth: Wallingford Sink Cave. Trelawny: Carambie Cave. More than one species may be present. The widespread genus contains troglobites in the USA, Mexico, and Hawaii.

## Genus undetermined, troglophile

St. James: Maldon School Cave.

## Superorder Acari

Mites can be extraordinarily abundant in Jamaican caves,

especially in association with piles of moist bat guano. While very few of the collections have been taxonomically identified, the few identifications that are available show that Jamaican caves harbor an appreciable diversity of at least 25 genera, and they merit additional study to determine true diversity of mites in the caves.

## Order Parasitiformes

## Suborder Gamasida

## Cohort Gamasina

## Family Veigaiidae

*Veigaia uncata* Farrier, troglophile

St. Ann: Moseley Hall Cave. This is a predator, probably on nematodes; it is not known to be phoretic.

## Family Laelapidae

*Hypoaspis (Stratiolaelaps)* sp., nr. *miles* (Berlese), troglophile

Manchester: Oxford Cave. St. Ann: Moseley Hall Cave. St. Elizabeth: Peru Cave. This is a predator, probably on nematodes; it is probably phoretic as adult females on insects.

## Family, Genus undetermined, Dermanyssoidea, troglophile

Hanover: Cousins Cove Cave.

## Family Ascidae

*Proctolaelaps* sp., troglophile

Manchester: Oxford Cave. This is a predator, probably on nematodes, and possibly is also facultatively fungivorous; it is phoretic as adult females on insects.

## Cohort Uropodina

Members of this assemblage are generally thought to be fungivores or scavenging omnivores; the deutonymphs are phoretic on insects.

## Family Polyaspididae

*Polyaspis* sp., troglophile

St. Ann: Moseley Hall Cave. St. Elizabeth: Peru Cave.

## Family Uropodidae, s. lat.

*Cyllibula (Baloghicyllibula)* sp., troglophile

Manchester: Oxford Cave.

*Oplitis* sp. 1, troglophile

Clarendon: Pedro Great Cave. Hanover: Cousins Cove Cave. St. Ann: Brambribo Cave, Moseley Hall Cave, Runaway Bay Cave. St. Catherine: St. Claire Cave. St. Mary: Mt. Plenty Cave.

*Trichouropoda* sp. 1, troglophile

St. Catherine: St. Claire Cave.

*Trichouropoda* sp. 2, troglophile

St. Ann: Moseley Hall Cave.



*Uroactinia* sp., troglophile

St. Elizabeth: Peru Cave.

*Uroobovella* sp. 1, troglophile

St. Ann: Moseley Hall Cave.

*Uroobovella* sp. 2, troglophile

St. Catherine: St. Claire Cave.

*Uropoda* (*Phaulodinychnus*) sp., troglophile

St. Ann: Thatchfield Great Cave.

#### Order Acariformes

##### Suborder Actinedida (Prostigmata)

##### Family Pygmephoridae

*Bakerdania* sp., troglophile

St. Ann: Moseley Hall Cave. This is probably a fungivore; phoretic as adult females on insects.

##### Family Stigmaeidae

*Stigmaeus* sp., troglophile

Manchester: Oxford Cave. This is probably predacious; and probably phoretic as adult females on insects.

#### Suborder Oribatida

The following group of oribatid genera are not known to be specific to cave habitats. This assemblage is possible in any grassland to forest-edge habitat.

##### Family Cepheidae

*Cepheus* sp., troglophile

St. Ann: Moseley Hall Cave. This is probably fungivorous.

##### Family Xenillidae

*Xenillus* sp., troglophile

St. Ann: Moseley Hall Cave. This is a fungivorous genus.

##### Family Oppiidae

*Oppia* sp., troglophile

St. Ann: Moseley Hall Cave. This genus is fungivorous.

*Multioppia* sp. ?, troglophile

St. Catherine: St. Claire Cave.

##### Family Scheloribatidae

*Scheloribates* sp., troglophile

St. Ann: Moseley Hall Cave. Members of this genus are saprophagous and fungivorous.

##### Family Mochlozetidae

*Unguizetes* sp. ?, troglophile

St. Ann: Moseley Hall Cave. This is probably saprophagous.

##### Family Galumnidae

*Galumna* sp., troglophile

St. Ann: Moseley Hall Cave. This may be saprophagous or a predator on nematodes.

Genus undetermined, troglophile

St. Ann: Moseley Hall Cave.

#### Suborder Astigmata (Acaridida)

##### Family Histiostomatidae (= Anoetidae)

*Histiostoma* sp., troglophile

Manchester: Oxford Cave. These are filter feeders on microorganisms in water films on moist substrates; and phoretic as deutonymphs (hypopodes) on insects.

#### Class Ostracoda

##### Order and Family undetermined

Genus and species undetermined, troglophile

Manchester: Oxford Cave, in floor pools. St. Ann: Brambribo Cave, 10 in guano pools. Trelawny: Drip Cave, in pool at cave entrance, several; Printed Circuit Cave. St. Catherine: St. Claire Cave, many in pools with guano and cat bones. St. Elizabeth: Duanwarie Cave.

#### Class Maxillopoda

##### Order Harpacticoidea

##### Family Harpacticidae

*Elaphoidella sewelli* Chappuis, troglophile

St. Ann: Brambribo Cave, abundant (especially males) in drip pools on guano slope. The species is widespread in the West Indies and may occur in bromeliads.

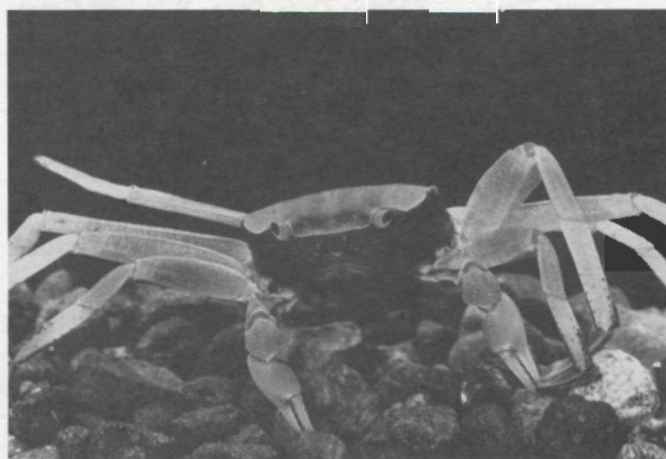


Figure 6. The troglobitic grapsid crab *Sesarma verleyi*. Grapsids are marine everywhere else in the world, but on Jamaica they live in freshwater, terrestrial, and cave habitats. This species has functional eyes but shows many other cave-specializations, such as depigmentation, appendage elongation, and complete restriction to cave habitats.



Class Malacostraca  
Order Decapoda

Family Gecarcinidae

*Cardisoma guanhumi* Latreille, troglonexene

Clarendon: Jackson Bay Cave, 1 male in brackish pools. St. Ann: Dairy Bull Cave, in sea water pool.

*Gecarcinus ruricola* (Linn.), troglonexene

Clarendon: Jackson Bay Cave, in brackish pool. St. Ann: Dairy Bull Cave, in sea water pool. Westmorland: Monarva Cave.

Family Grapsidae

*Sesarma bidentatum* Benedict, troglophile (Fig. 7)

St. Ann: Cave River Cave, Lucky Hill Farm Cave. St. Elizabeth: Wallingford Sink Cave. Trelawny: Printed Circuit Cave. Mentioned by Hartnoll (1963) in stream flowing through unnamed cave on

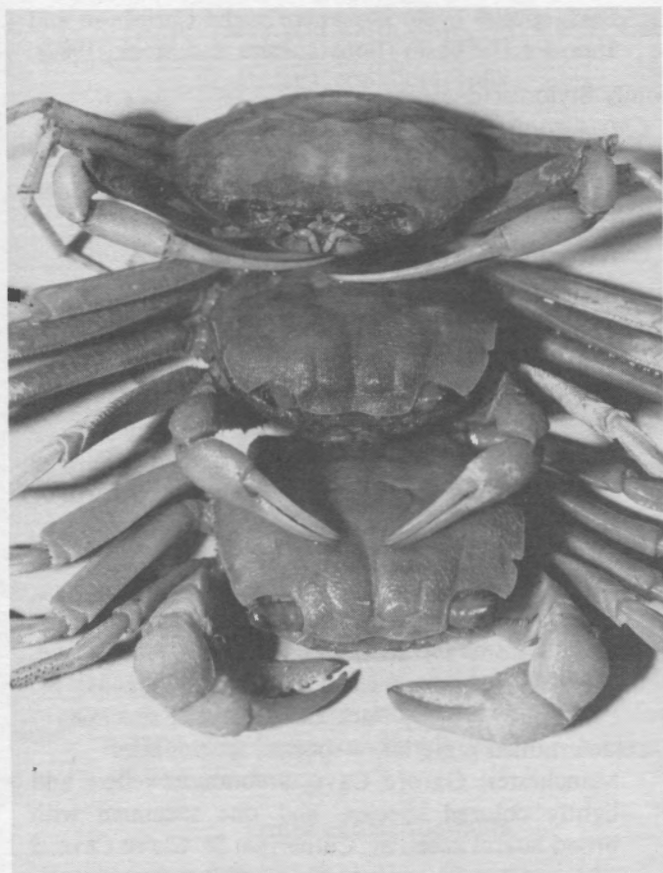


Figure 7. Comparison of cave crabs, showing progressive elongation of chelae (pinchers) and reduction of eyes. Bottom; *Sesarma bidentatum*, a troglophile in Jamaica. Middle; *Sesarma verleyi*, a troglomite from Jamaica. Top; *Typhlopseudothelphusa mocinoi*, a highly developed pseudoscorpionid troglomite from Cueva del Tio Ticho, Chiapas, Mexico.

Lucky Hill Cooperative Farm (Chace and Hobbs, 1969).

*Sesarma verleyi* Rathbun, troglomite (Figs. 6, 7)

Manchester: Coffee River Cave. St. Ann: Cave River Cave, Cricket Cave. St. Catherine: St. Claire Cave, Worthy Park Cave no. 2. St. James: Peterkin Cave. St. Mary: Lucky Hill Pen Cave. Trelawny: Harties Cave, Printed Circuit Cave. Described from unspecified habitat at Mulgrave (St. Elizabeth) and reported from Lucky Hill Cave, Bakers Pot Cave and a cave at Worthy Park (Worthy Park no. 2) by Hartnoll (1963-1964, 1964), and Chace and Hobbs (1969). The species has very reduced eyes and long, thin chelae, and longer legs. Two other cavernicolous species are known from Java and Amboina (Holthuis, 1964) but *S. verleyi* is the most cave evolved.

*Sesarma (Holometopus) miersii* Rathbun, troglophile

St. Ann: Runaway Caves (Green Grotto). One male from burrow at edge of pool deep in cave. This is the first record of the species from Jamaica (see Chace and Hobbs, 1969).

Family Atyidae

*Atya lanipes* Holthuis, troglonexene

St. Mary: Rock Springs Cavern, 1. Also known from epigean waters in Jamaica (Hunte, 1975), Cuba, Hispaniola, Puerto Rico, St. Croix and St. Thomas (Hobbs and Hart, 1982).

*Atya innocous* (Herbst), troglophile

St. Elizabeth: Wallingford Sink Cave. St. Mary: Rock Spring Cavern, especially abundant clinging to side of waterfall. Fincham and Ashton (1967) wrongly reported *A. occidentalis* Newport from this cave. The species also occurs in epigean water in Central America, and on Cuba, Puerto Rico, Hispaniola, the Lesser Antilles, Trinidad, and Curacao (Hobbs and Hart, 1982). The very widely distributed *A. scabra* (Leach) also occurs in Jamaica but there are no cave records.

Family Palaemonidae

*Troglocubanus jamaicensis* Holthuis (1963), troglomite

St. Mary: Lucky Hill Pen Cave. Known only from the type locality, "a cave near Goshen, on Lucky Hill Cooperative Farm" (Hartnoll, 1964; Chace and Hobbs, 1969). The genus contains only 4 other species, all Cuban troglomites (Botosaneanu and Holthuis, 1970).

*Macrobrachium carcinum* (Linnaeus), troglophile

Manchester: Wyslip Water Cave. St. Ann: Runaway Caves (Green Grotto), 11. St. Mary: Rock Springs Cavern, 3 females.

*Macrobrachium faustinum lucifugum* Holthuis (1974), troglophile



St. Ann: Runaway Caves (Green Grotto), 3 with carapace lengths 37, 37, 41 mm. The subspecies is also known from Cuba and Curacao and Bonaire, and the nominate subspecies also has a wide West Indian distribution (Holthuis, 1974). The species of Jamaica all occur in other parts of the Caribbean Basin, probably because the larvae can or must develop in the sea (Hunte, 1978). Five species of *Macrobrachium* shrimps are known from Jamaica, and all occur on other islands as well.

*Macrobrachium heterochirus* Wiegmann, troglophile  
St. Ann: Dairy Bull Cave, 6 immatures; Runaway Caves, Green Grotto, 1 with carapace length 37 mm.

#### Order Amphipoda

##### Family Talitridae

*Hyaella azteca* group, troglophile

St. Catherine: St. Claire Cave, abundant in guano-rich pools in 1968, scarce in 1973. The 1973 specimens had eye facets but no eye pigment. This is probably an ecophenotype because reduction or loss of eye pigment has been noted for other cave populations of *H. azteca*.

##### Family Hadziidae

*Metaniphargus jamaicae* (Holsinger) 1974, troglobite  
Clarendon: Jackson Bay Cave (type locality); Milk Spring Well, near Springfield (Stock, 1977, 1983).

*Metaniphargus craterensis* Stock (1983), troglobite  
St. Ann: Small spring on south shore of Crater Lake, east of Discovery Bay (a fast flowing fresh-water spring).

*Metaniphargus hyporheicus* Stock (1983), troglobite  
St. Ann: Discovery Bay; in coarse gravel, 15 m from sea at Rio Seco mouth; Hanover; in coarse sand and gravel, 5 m from sea, mouth of small brook on breach between Flint and Great Rivers, Orchard.

*Metaniphargus anchihalinus* Stock (1983), troglobite  
St. Ann: Discovery Bay; in anchihaline cleft in limestone terrace, University West Indies Marine Laboratory, near pumphouse.

#### Order Mysidacea

##### Family Stygiomysidae

*Stygiomysis major* Bowman 1976, troglobite  
Clarendon: Jackson Bay Cave (type locality), 7 in shallow brackish pools. The genus is otherwise represented by the cavernicolous species *S. holthuisi* (Gordon, 1960) from Devils Hole, St. Martin (Lesser Antilles) and Cueva Murcielagos, Guanica, Puerto Rico, and *S. hydruntina* Caroli of Italy (Bowman, 1976). New World cavernicolous species

in the families Lepidomysidae and Mysidae occur in Mexico, the Yucatan, and Cuba (Gordon, 1960 and Ingle, 1972).

##### Family Mysidae

*Antromysis peckorum* Bowman (1977), troglobite  
Clarendon: Jackson Bay Cave (type locality), in brackish pools with tidal fluctuation. The genus has other blind species in Yucatan and Oaxaca (Mexico), Cuba, and eyed species in Costa Rica, Bahamas, and Surinam (Bowman, 1977).

#### Order Isopoda

##### Family Anthuridae

*Cyathura parapotamica* Botosaneanu and Stock (1982), troglobite

Portland: in riverside sand of Buff Bay River, near Cotton Tree Pen, at 80 m. These small isopods live between sand grains along rivers and are interstitial. Such species occur elsewhere in the Caribbean and Indo-Pacific basin (Botosaneanu and Stock, 1982).

##### Family Styloniscidae

*Clavigeroniscus* sp. 1, troglobite

St. Catherine: Swansea Cave, Worthy Park Cave no. 2. An unpigmented, eyeless, undescribed species.

*Clavigeroniscus* sp. 2, troglophile

St. Catherine: Swansea Cave, in roof collapse area, Worthy Park Cave no. 2. A pigmented and eyed species.

##### Family Armadillidae

*Cubaris* sp., troglophile

St. Catherine: Swansea Cave. An undescribed large reddish species which restricts itself to cave earth or reddish breccia even in the dark zone of the cave.

*Venezillo* sp., troglophile or troglone

An undescribed species with well developed eyes, which is pure white, and moves out of caves at night on limestone surfaces. Manchester: Oxford Cave. St. Ann: Thunder Cave, several specimens. St. Catherine: Worthy Park Cave no. 2, 1 specimen.

Undetermined material, 5 species, troglophiles

Manchester: Oxford Cave, a common yellow and lightly colored species, and one specimen with broad lateral keels. St. Catherine: St. Claire Cave, 5 of a small pale, rugose species with tiny eye spots. Trelawny: Windsor Great Cave, 2 species, both which are white and with small eyes.

#### Class Chilopoda

##### Order Lithobiomorpha

##### Family Henicopidae

Genus undetermined, accidental  
St. Ann: Falling Cave.



## Order Scutigeromorpha

## Family Scutigeridae

*Scutigera* sp., troglophile

Clarendon: Jackson Bay Cave. Hanover: Cousins Cove Cave no. 1. Manchester: Oxford Cave, 1 caught, several seen. St. Ann: Brambribo Cave, Runaway Caves. St. Catherine: St. Claire Cave. St. James: Mocho Cave. Trelawny: Hope Gate Cave. This could be the widely distributed synanthropic *S. coleoptrata* Linn.

## Order Scolopendromorpha

## Family Cryptopidae

*Cryptops* sp., accidental

Trelawny: Drip Cave.

*Newportia* sp., accidental

Westmorland: Roaring River Cave.

*Scolopocryptops* sp., troglophile

St. Ann: Lucky Hill Farm Cave, Mt. Plenty Cave.

## Order Geophilomorpha

## Family Schendylidae

*Tanophilus* sp. (?) troglophile

St. James: Brandon Hill Cave. St. Mary: Nonsuch Cave.

## Genus undet.

Clarendon: Jackson Bay Cave. St. Ann: Ken Connell Hole. Westmorland: Monarva Cave.

## Chilenophilidae

## Genus undet., troglophile (?)

Clarendon: Jackson Bay Cave. St. Catherine: Swansea Cave. Trelawny: Carambie Cave.

## Class Diplopoda

## Order Polyxenida

## Family Polyxenidae

## Genus and species undetermined, troglophile

Clarendon: Jackson Bay Cave, Portland Caves. Manchester: Abbey Cave. St. Ann: Moseley Hall Cave. St. James: Brandon Hill Cave. St. Mary: Rock Spring Cave. Polyxenids scavenge in caves in dry organic matter.

## Order Glomeridesmida

## Family Glomeridesmidae

*Glomeridesmus* sp., troglophile

St. Catherine: Worthy Park Cave.

## Order Polydesmida

## Family Chelodesmidae

*Caraibodesmus pictus* Loomis (1969), troglophile

Manchester: Oxford Cave (type locality).

*Platyurodesmus parallelus* Loomis, troglophile

Clarendon: Jackson Bay Cave (type locality). Loomis (1977) placed the genus in Eurydesmidae and this was corrected by Hoffman (1979) who also noted how similar this genus is to *Caraibodesmus*. Actually, the family name used above is obsolete, but neither of these genera can be presently assigned to an existing family.

## Family Chytodesmidae

*Peckfiskia cavernicola* Loomis (1969), troglophile

Manchester: Coffee River Cave, Oxford Cave. Trelawny: Windsor Great Cave.

*Docodesmus coxalis* Loomis, troglophile

St. Ann: Moseley Hall Cave. This species is also known from epigeal localities on the island (Loomis, 1975). The genus also occurs on Cuba and Hispaniola and is one of the few millipeds with more West Indian than Central American affinities.

## Family Comodesmidae

*Inodesmus jamaicensis* Cook, troglophile

Hanover: Cousins Cove Cave no. 2. St. Ann: Brambribo Cave, Moseley Hall Cave, Mt. Plenty Cave. St. James: Rota Cave. Trelawny: Drip Cave, Dromilly Cave, Windsore Great Cave. The species is also known in the Blue Mountains from 1280-2438 m Loomis, 1969; 1975).

## Family Sphaeriodesmidae

*Cyclodesmus hubbardi* Cook, troglophile

Manchester: Abbey Cave. "In small damp cave at Mandeville" (Chamberlin, 1918).

*Sphaeriodesmus secundus* Loomis, troglophile

Trelawny: Dromilly Cave, Harties Cave, Windsor Great Cave. This is the second known Jamaican species (Loomis, 1977).

## Genus and species undetermined, troglophile

Manchester: Oxford Cave, one specimen, which appears to be a new genus (Loomis, 1969).

## Family Fuhrmannodesmidae

*Barathrodesmus inflatus* Loomis, troglophile

St. Ann: Cricket Cave, Moseley Hall Cave. St. Catherine: St. Claire Cave, Worthy Park Cave. This species is also known from forests from 640-2250 m (Loomis, 1977).

## Family Haplodesmidae

*Prosopodesmus parvus* (Chamberlin), troglophile

St. James: Brandon Hill Cave (as *P. jacobsoni* Silvestri). Trelawny: Windsor Great Cave. Westmorland: Monarva Cave. This species is introduced (Loomis, 1977) from Indonesia.



Family Paradoxosomatidae

*Chondromorpha kelaarti* (Humbert), troglophile  
St. Ann: Cave River Cave. St. Catherine: St. Claire Cave, many males and females on guano. St. Elizabeth: Wallingford Sink Cave. St. James: Brandon Hill Cave, Maldon School Cave. This is an introduced species from the Old World tropics.

Order Spirobolida

Family Rhinocricidae

*Rhinocricus* sp., troglophile  
Hanover: Cousins Cove Cave no. 1. Manchester: Oxford Cave. St. Catherine: St. Claire Cave, females. St. Elizabeth: Peru Cave, females. Trelawny: Harties Cave. Westmorland: Roaring River Cave.

Class Insecta

Order Collembola

The Collembola fauna of Jamaica is poorly known. Marimutt and Bellinger (1990) list only 37 species from Jamaica.

Family Entomobryidae

*Metasinella* sp., troglomite  
Clarendon: Jackson Bay Cave. An eyeless, white species with long antennae. This genus has not previously been reported from Jamaica.  
*Pseudosinella violenta* group, troglophile?  
Hanover: Cousins Cove Cave no. 2. Trelawny: Drip Cave, poor condition specimen. Westmorland: Monarva Cave. *P. violenta* (Folsom) has been reported from Jamaica, Mexico, and the United States.

Family Paronellidae

*Troglopedetes jamaicanus* Palacios-Vargas *et al.* 1985, troglomite (?)  
Clarendon: Jackson Bay Cave, Pedro Great Cave. Hanover: Cousins Cove Cave no. 2. Manchester: Abbey Cave, Coffee River Cave, Oxford Cave. St. Ann: Brambribo Cave, Cricket Cave, Moseley Hall Cave. St. Catherine: St. Claire Cave, Worthy Park Cave no. 2. St. Elizabeth: Peru Cave. St. Mary: Lucky Hill Pen Cave. This species is at a low level of troglomorphy and could occur in habitats other than caves, but has not yet been discovered in them.  
*Paronella* sp., troglophile?  
Hanover: Cousins Cove Cave. St. Ann: Norwood Rat Bat Cave, Cave River Cave, Falling Cave, Ken Connell Cave, Mt. Plenty Cave. St. James: Peterkin Cave, Maldon School Cave. St. Elizabeth: Wallingford Cave. Trelawny: Dromilly Cave, Deeside Cave, Carambie Cave, Harties Cave. Westmorland: Roaring River Cave.

Family Hypogastruridae

*Xenylla cavernarum* Jackson, troglomene  
St. Ann: Moseley Hall Cave, abundant in guano.

Family Isotomidae

*Isotomurus* sp., troglomene  
St. Ann: Lucky Hill Farm Cave. This genus has not been previously reported from Jamaica.

Family Cyphoderidae

*Cyphoderus similis* Folsom, troglophile  
Hanover: Cousins Cove Cave no. 2. This widespread Neotropical species has not been previously reported from Jamaica.

Order Diplura

Family Campodeidae

Genus and species undetermined, troglophile?  
Clarendon: Jackson Bay Cave, Pedro Great Cave, Portland Caves. Hanover: Cousins Cove Cave no. 2. Manchester: Oxford Cave, 24, eyeless. St. Ann: Dairy Bull Cave, Falling Cave, Mt. Plenty Cave, Thatchfield Light Hole. St. Elizabeth: St. Claire Cave. St. James: Brandon Hill Cave. St. Mary: Rock Spring Cave. Trelawny: Carambie Cave, Windsor Great Cave.

Order Thysanura

Family Nicoletiidae

*Nicoletia meinerti* Silvestri, troglophile  
St. Catherine: Swansea Cave. This species is tropicopolitan and most populations are parthenogenetic.  
*Grassilla* sp., troglophile  
Westmorland: Roaring River Cave. These silverfish are subterranean and often myrmecophilous.

Order Blattodea

Family Blaberidae

*Pycnoscelus surinamensis* (Linnaeus), troglophile  
Clarendon: Portland Ridge Caves. Hanover: Cousins Cove Cave no. 1. St. Ann: Mt. Plenty Cave, Runaway Bay Cave. St. James: Brandon Hill Cave, Maldon School Cave. Trelawny: Printed Circuit Cave. Westmorland: Monarva Cave, Roaring River Cave. In the Americas this introduced African species is parthenogenetic.  
*Epilampra* sp., accidental  
Trelawny: Printed Circuit Cave, 1 nymph.  
*Panchlora?* sp., troglophile  
Clarendon: Portland Caves. St. Ann: Runaway Caves.

Family Blattellidae

*Ischnoptera* sp. (probably), troglophile



St. Ann: Bambribo Cave; Lucky Hill Farm Cave.  
St. Mary: Rock Springs Cave.

*Nelipophygus* sp. 1, troglobite (Fig. 9)

Manchester: Oxford Cave. St. Ann: Brambribo Cave, Cricket Cave, Falling Cave. St. Catherine: St. Claire Cave, Swansea Cave, Worthy Park Cave no. 2. St. Elizabeth: Duanwarie Cave. Trelawny: Dromilly Cave, Harties Cave. Westmorland: Roaring River Cave. This species is one of the world's few completely eyeless and apterous cave roaches. Others occur in Australia, Burma, the Galapagos, etc.



Figure 9. This undescribed species of eyeless troglotitic *Nelipophygus* cockroach is found in many Jamaican caves, in wet and food-poor areas. Another species, a troglophile with eyes, also occurs but more frequently near conspicuous food sources. This is the only eyeless cave cockroach in the New World except for one on the Galapagos Islands.

*Nelipophygus* sp. 2, troglophile

Clarendon: Pedro Great Cave. St. Ann: Brambribo Cave. Lucky Hill Cave. St. Catherine: Swansea Cave. St. Elizabeth: Duanwarie Cave. St. James: Peterkin Cave, Maldon School Cave. Trelawny: Burnt Hill Cave, Carambie Cave, Printed Circuit Cave. This species, with reduced eyes is also known from epigean localities. There is also an undescribed epigean montane species which does not occur in caves.

Family Blattidae

*Periplanetta americana* (Linnaeus), troglophile (Fig. 8)

Hanover: Cousins Cove Cave no. 2. Manchester: Oxford Cave, abundant. St. Ann: Runaway Cave. St. Elizabeth: Wallingford Caves. St. James: Brandon Hill Cave, Rota Cave. Trelawny: Hope Gate



Figure 8. Scavenging trogliphilic cockroaches, *Periplaneta americana*, can aggregate in large numbers near moist bat guano such as in Oxford Cave.

Cave, Printed Circuit Cave. Westmorland: Monarva Cave. This is a widespread synanthropic species.

*Periplaneta australasiae* (Fabricius), accidental  
St. James: Maldon School Cave.

Order Dermaptera

Family Carcinophoridae

*Euborellia annulipes* (Lucas), troglophile

St. Ann: Mt. Plenty Cave.

*Carcinophora americana* (P. de Beauvois), troglophile

St. James: Mt. Plenty Cave, Rota Cave.

Family Labiidae

*Marava jamaicana* (Rehn and Hebbard), troglophile

St. Ann: Cave River Cave, Mt. Plenty Cave, Thatchfield Light Hole Cave.

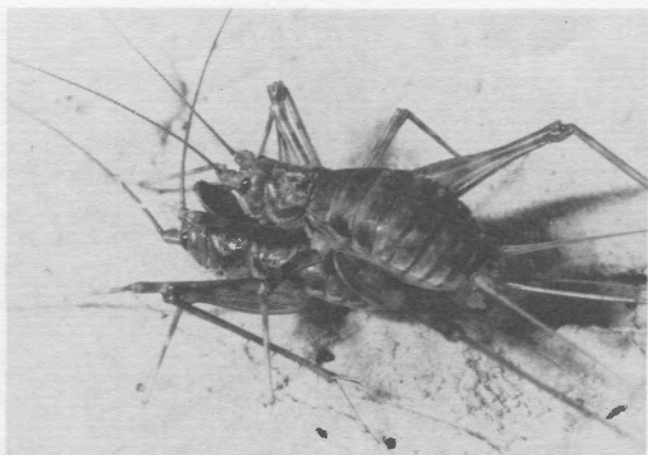
Order Orthoptera

Family Gryllidae

*Uvaroviella cavicola* Chopard (1923), troglophile (Fig. 10)

Clarendon: Jackson Bay Cave, Pedro Great Cave. Hanover: Cousins Cove Cave no. 1. Manchester: Oxford Cave. St. Ann: Brambribo Cave, Cave River Cave, Chesterfield Cave, Cricket Cave, Dairy Bull Cave, Ken Connell Hole Cave, Lucky Hill Farm Cave, Moseley Hall Cave, Mt. Plenty Cave, Runaway Caves, Thatchfield Light Hole Cave. St. Elizabeth: Peru Cave. St. Catherine: St. Claire Cave, Swansea Cave. St. James: Brandon Hill Cave. St. John: Mocho Cave. St. Mary: Idlewild Cave, Rocksprings Cavern. Trelawny: Burnt Hill





**Figure 10.** The gryllid cricket *Uvaroviella cavicola* is known only from caves in Jamaica. Crickets in the genus *Amphiacusta* occur elsewhere in caves in the Caribbean basin, but in Jamaica they are only in non-cave habitats. The male, below, has raised its short wings to stridulate and to attract the female. The female has no remnants of wings.

Cave, Drip Cave, Dromilly Cave, Printed Circuit Cave, Windsor Great Cave. Westmorland: Monarva Cave, Roaring River Cave. The genus and species is endemic to the island, and may be expected in virtually every cave. The cricket genus *Amphiacusta*, normally found in West Indian Island caves, is represented by 3 species on Jamaica, but has not been found in Jamaican caves. The absence may suggest ecological exclusion.

#### Order Psocoptera

##### Family Psocidae

*Psyllipsocus* sp., troglophile  
Trelawny: Harties Cave.

#### Order Hemiptera

##### Family Aradidae

Genus and species undetermined, troglophile  
St. Ann: Moseley Hall Cave, 3 immatures taken in guano.

##### Family Kinnaridae

*Oecliidius antricola* Fennah 1980, troglobite  
Clarendon: Jackson Bay Cave (type locality), on tree roots on moist clay floor. This greatly modified eyeless species and the next were taken together.  
*Oecliidius minos* Fennah 1980, troglobite  
Clarendon: Jackson Bay Cave (type locality), on tree roots on moist clay floor. Other eyeless cave species have been described from Hawaii, Mexico, and Australia.

##### Family Cydnidae

*Amnestus trimaculatus* Froeschner, troglophile  
Clarendon: Pedro Great Cave. St. Ann: Lucky Hill Farm Cave, Mt. Plenty Cave. St. Catherine: St. Claire Cave. St. Elizabeth: Wallingford Sink Cave. St. James: Brandon Hill Cave, Rota Cave. Trelawny: Deeside Cave.

*Rhytidoporus indentatus* Uhler, troglophile  
St. Elizabeth: Wallingford Cave. St. James: Brandon Hill Cave, Maldon School Cave. St. Ann: Lucky Hill Farm Cave. This species is also known from caves in Puerto Rico.

##### Family Veliidae

Bugs in this family live on the surface of pools and act as predators or scavengers.

*Mesovelia amoena* Uhlrich, troglophile  
Trelawny: Harties Cave.

*Microvelia cubana* Drake, troglophile  
St. Ann: Runaway Bay Caves. St. Catherine: St. Claire Cave. St. Mary: Rock Springs Cave.

*Microvelia albonotata* Champion, troglophile  
Clarendon: Jackson Bay Cave. St. Ann: Runaway Bay Caves. Trelawny: Printed Circuit Cave. Drake and Hussey (1955) note this species to occur in caves in Florida.

*Microvelia argusta* Draken and Maldonado, troglophile  
St. Catherine: St. Claire Cave.

##### Family Reduviidae, Subfamily Esmesinae

*Ploiaria umbrarum* McA. y Maldonado, troglophile  
Clarendon: Pedro Great Cave. Manchester: Oxford Cave. St. Ann: Brambribo Cave. St. Elizabeth: St. Claire Cave. Trelawny: Drip Cave, 1; Dromilly Cave, Windsor Cave. This predatory thread-legged bug is occasionally found in tropical caves (Wygodzinsky, 1966; 52).

#### Order Coleoptera

##### Family Carabidae

*Ardistomis* sp. 1, troglobite  
St. Ann: Falling Cave, 1 specimen, of an undescribed eyeless species.

*Ardistomis* sp. 2, troglobite  
Clarendon: Pedro Great Cave, 21. St. Ann: Falling Cave, 9 specimens taken on rotten wood with above undescribed eyeless species (Peck and separate Norton collections).

*Colpodes cavicola* Darlington, troglophile  
Clarendon: Pedro Great Cave. St. Ann: Lucky Hill Farm Cave, 1. St. Elizabeth: St. Claire Cave (previously known only from this cave, the type locality (Darlington, 1964)). Trelawny: Drip Cave.



*Perigona laevigata* (Bates), troglophile

Clarendon: Pedro Great Cave, 30. Trelawny: Drip Cave. These beetles are normally associated with rotted vegetation and under bark (Darlington, 1953).

*Paratachys* sp., accidental

St. Elizabeth: St. Claire Cave one-winged female.

## Family Dytiscidae

Genus and species undetermined, troglophile

St. Elizabeth: St. Claire, 10 from cave stream-pools.

## Family Hydrophilidae

*Omicrus lateralis* Smetana, troglophile

Clarendon: Pedro Great Cave, abundant in moist guano. St. Ann: Mt. Plenty Cave, Thatchfield Great Cave. St. Mary: Rock Springs Cave. Manchester: Oxford Cave. Trelawny: Windsor Great Cave. The species is known only from Jamaica, and also from montane forests (Smetana, 1975). Sixteen species are known in the genus in the Neotropics and all scavenge in moist decaying materials.

*Enochrus* sp., troglophile

St. Mary: Rock Springs Cave, 6 in cave pools.

*Dactylosternum* sp., troglophile

St. Mary: Rock Springs Cave, 1 in wet guano. These scavengers are common in wet caves in other Neotropical countries, but not Jamaica.

*Phaenonotum* near *dubium* Sharp, troglophile

St. Elizabeth: St. Claire Cave, abundant on wet guano.

## Family Leiodidae

*Aglyptinus dimorphicus* Peck, troglophile

Clarendon: Pedro Great Cave. St. Ann: Ken Connell Hole, Lucky Hill Farm Cave, Mt. Plenty Cave, Moseley Hall Cave, Thatchfield Great Cave. St. Catherine: Swansea Cave. St. Elizabeth: Peru Cave. St. James: Mocho Cave, Brandon Hill Cave, Maldon School Cave. St. Mary: Rock Springs Cave. Trelawny: Drip Cave, Windsor Great Cave. The species occurs in cave and epigeal habitats from sea level to 2250 m elevation. Cave populations are short-winged as are those from upper elevation forests. Lower elevation forests have long-winged individuals (Peck, 1977).

## Family Scydmaenidae

*Euconnus (Noctophus)* sp., troglophile

St. Ann: Hutchinson Hole Cave, Mt. Plenty Cave. Trelawny: Deeside River Cave, Drip Cave.

## Family Pselaphidae

Genus and species undetermined, troglophile

St. Ann: Ken Connell Hole, 25. Trelawny: Drip Cave, 5.

## Family Ptiliidae

Genus and species undetermined.

St. Elizabeth: Peru Cave, many in dryish guano.

## Family Histeridae

*Saprinus* sp., troglophile

St. Ann: Mt. Plenty Cave, 30; Norwood Rat Bat Cave, 1. St. James: Brandon Hill Cave, 20.

## Family Staphylinidae

*Aleochara* sp., accidental

Manchester: Oxford Cave, 4 specimens, cave entrance zone.

*Atheta* sp., troglophile

Clarendon: Pedro Great Cave, on wet guano. Manchester: Oxford Cave. St. Ann: Brambribo Cave, many on guano; Cave River Cave, Ken Connell Hole, Mt. Plenty Cave, common in guano; Norwood Rat Bat Hole, Thatchfield Cave. St. Elizabeth: Peru Cave; Windsor Great Cave, on guano. St. James: Brandon Hill Cave, Mocho Cave. Trelawny: Carambie Cave; Drip Cave, abundant; Dromilly Cave, Windsor Great Cave.

*Belonuchus gagates* Erichson, troglophile

St. Ann: Mt. Plenty Cave, common on guano piles.

*Medon* sp., troglophile

St. James: Brandon Hill Cave, many in guano piles.

*Gyrophæna* sp., accidental

St. Ann: Moseley Hall Cave, Berlese of guano.

*Proteinus peckorum* Frank, accidental

Clarendon: Jackson Bay Cave, 1 specimen in guano. This is the only West Indian record for this genus (Frank and Thomas, 1983).

## Family Lampyridae

*Microdiphot cavernarum* Barber, accidental?

Trelawny: Windsor Cave (type locality), described from unique specimen found 350 m inside the cave and not found since. Another species (*M. barberi* Buck) occurs in the Blue Mts. at Morces Gap, 1400 m in July (Buck, 1959).

## Family Cerylonidae

*Euxestus erithacus* Chevrolat, troglophile

St. James: Brandon Hill Cave, abundant in guano. This is a widely distributed Neotropical species (see Lawrence and Stephan, 1975).

## Family Nitidulidae

*Stelidota* sp., troglophile

St. James: Brandon Hill Cave. These sap-feeding beetles occur occasionally in tropical caves, where they can feed on carrion as well as fruit debris and guano.



Family Elateridae

*Neotrichophorus* ? sp., troglophile

Westmorland: Monarva Cave. Larvae were found in guano. The genus is known from Cuba but not reported from Jamaica.

*Ischiodontus* sp.

Trelawny: Dromilly Cave, several larvae. Some 15 species in this genus are known to occur in Jamaica.

Family Tenebrionidae

*Alphitobius diaperinus* Panzer, troglophile

Trelawny: Windsor Great Cave, 1.

*Alphitobius laevigatus* (Fabricius), troglophile

Trelawny: Windsor Great Cave. The species is known from bat caves in Texas, Mexico, and the British West Indies.

*Caecomenimopsis jamaicensis* Dajoz, endogean

St. Ann: Mt. Plenty Cave, under dead toad. This is an eyeless soil inhabiting genus of forest soils, also known in Brazil, Galapagos, and Trinidad (Dajoz, 1975). *Caecophloeus* is another eyeless soil inhabiting genus, known from mountain forests (Dajoz, 1972) in Jamaica, Haiti, Panama, and Mexico.

Family Alleculidae

Genus undetermined, troglophile

Clarendon: Jackson Bay Cave. Hanover: Cousins Cove Cave. Larvae were found in guano.

Family Euglenidae

Genus and species undetermined, accidental

Clarendon: Portland Ridge Cave, 1.

Family Anobiidae

Genus and species undetermined, accidental

Clarendon: Portland Ridge Cave, 1.

Family Scolytidae

Genus and species undetermined, accidental

St. Ann: Mt. Plenty Cave, 3 in twigs in litter sample. Some species of bark beetles do establish cave populations in fruits and seeds discarded by bats or oil birds.

Family Curculionidae

*Acalles*, or near, accidental

St. Ann: Moseley Hall Cave, 1 in guano.

*Phace*, near *carinirostris* Champion, accidental

St. Ann: Moseley Hall Cave, 2 in guano.

Order Lepidoptera

Family Tineidae

*Decadarchis* sp., troglophile

Manchester: Oxford Cave, 13. Trelawny: Windsor Great Cave, several. These moths probably feed on larvae on plant debris or fruit refuse.

*Tinea* sp., troglophile

Clarendon: Jackson Bay Cave, Pedro Great Cave, Portland Ridge Caves. St. Ann: Brambribo Cave, 12; Hutchinson Hole Cave, 4; Mt. Plenty Cave, 30; Moseley Hall Cave, 10; Pedro Great Cave. St. Catherine: St. Claire Cave. St. Elizabeth: Peru Cave, 7; Runaway Cave. Trelawny: Drip Cave, 4. Westmorland: Monarva Cave, 4. These moths likely feed as larvae on insect remains in bat guano piles, where they are very common (see Robinson, 1980). *Praeacedes seminoella* (Beutenmuller) is a widespread and probably widely-introduced species described from caves in Cuba as *Tinea decui* Capuse and Georgescu. It is known from Jamaica, but not yet from Jamaican caves (Robinson, 1980).

Order Hymenoptera

Family Formicidae

Ants are frequent as scavengers and predators (Carroll and Janzen, 1973) in Neotropical caves with abundant moist guano, but none are cave-limited. Wilson (1988) reports Jamaica to have 29 genera and 59 species of ants. Any ant species that makes subterranean nests could probably be expected to be able to occupy caves (Wilson, 1962). The following records represent colonies or foragers from cave dark-zones. Most of the cave collections are of widespread "tramp" species, recently distributed by human commerce.

*Crematogaster* sp., troglophile

St. Ann: Runaway Bay Caves.

*Cyphomyrmex rimosus* (Spinola), troglophile

St. Ann: Mt. Plenty Cave. Westmorland: Roaring River Cave.

*Dorymyrmex* sp., troglophile

St. Ann: Lucky Hill Farm Cave.

*Gnamptogenys continua* Mayr, troglophile

St. Ann: Mt. Plenty Cave.

*Gnamptogenys striatula* Mayr, troglophile

Hanover: Cousins Cove Cave. Westmorland: Monawa Cave, Roaring River Cave.

*Hypoconera opaciceps* (Forel), troglophile

Manchester: Oxford Cave. St. Ann: Hutchinson Hole Cave, Mt. Plenty Cave. St. James: Rota Cave. St. Mary: Rock Spring Cave. This is a tramp species.

*Hypoconera* sp. 2, troglophile

Hanover: Cousins Cove Cave no. 1.

*Hypoconera* sp. 3, troglophile

St. Ann: Bambribo Cave, Cave River Cave.

*Odontomachus bauri* Emery, troglophile

St. Elizabeth: Peru Cave. Westmorland: Roaring River Cave.

*Pachycondyla stigma* (Fabricius), troglophile

St. James: Mocho Cave.



*Paratrechina longicornis* (Latreille), troglophile

St. Ann: Lucky Hill Farm Cave. This is a tramp species.

*Pheidole* sp., troglophile

St. Ann: Moseley Hall Cave.

*Platythyrea punctata* (Fr. Smith), troglophile

St. James: Brandon Hill Cave.

*Pseudomyrmex gracilis* (Fabr.), accidental

Trelawny: Drip Cave.

*Rogeria inermis* Mann, troglophile

Westmorland: Monawa Cave.

*Solenopsis geminata* (Fabr.), troglophile

Manchester: Oxford Cave. St. Ann: Moseley Hall Cave. St. Elizabeth: Wallingford Caves. St. James: Brandon Hill Cave. This is a tramp species.

*Strumigenys rogeri* Emery, troglophile

Manchester: Oxford Cave. Trelawny: Windsor Cave. This small pale ant was introduced from West Africa. This is a tramp species.

*Tetramorium lucayanus* Wheeler, troglophile

Hanover: Cousins Cove Cave. Manchester: Oxford Cave. St. Ann: Mt. Plenty Cave, Runaway Bay Caves. St. Catherine: St. Claire Cave. St. James: Brandon Hill Cave. This ant was introduced from West Africa and is now widespread in the West Indies.

*Tetramorium simillimum* (Fr. Smith), troglophile

Hanover: Cousins Cove Cave. St. James: Brandon Hill Cave. This is a tramp species.

*Wasmannia auropunctata* (Roger), troglophile

Manchester: Oxford Cave. St. Ann: Moseley Hall Cave, Mt. Plenty Cave, Runaway Bay Caves. This is a tramp species.

## Family Scelionidae

*Probarryconus* sp., troglophile

Clarendon: Pedro Great Cave. Manchester: Oxford Cave, 8 males and females. This species is an egg parasite of Gryllidae, probably *Uvariola* crickets. St. Ann: Brambribo Cave, Cave River Cave. St. Catherine: St. Claire Cave. St. James: Rota Cave. St. Mary: Rock Springs Cave. Trelawny: Dromilly Cave.

## Family Cynipidae

*Pseudoeucoila (rugipunctata Yoshimoto ?)*, troglophile?

Trelawny: Windsor Great Cave, 1 female. The species is a parasite on Acalypterate diptera larvae probably those living in guano.

## Family Pteromalidae

*Macromesurus* sp., troglophile

Hanover: Cousins Cove Cave no. 2. Probably a parasite on fly larvae.

## Family Torymidae

*Sycophaga* sp., accidental

St. James: Brandon Hill Cave, 1 female. Although some members of this family parasitize insect eggs and larvae, this genus is phytophagous and may have been carried into the cave by bats on a fruit.

## Order Diptera

## Family Tipulidae

*Polymera (Polymera) cavernicola* Alexander, troglophile?

St. Catherine: St. Clair Cave, 12 on wall 2/5 mile from entrance, forming the type series, and not found in caves since. The species is also known from Jamaican epigeal sites from 530 m to 1300 m in elevation (Alexander, 1964). The species is characterized by males with long antennae with long setae.

*Shannonomyia nudipennis* Alexander, troglaxene

St. James: Mocho Cave, 1.

*Trentepohlia niveitarsis* (Alexander), troglaxene

St. Ann: Lucky Hill Farm Cave, 4; Mt. Plenty Cave, 1. St. James: Mocho Cave, 1. St. Mary: Rock Springs Cave, 1.

## Genus and species undetermined

St. Ann: Lucky Hill Farm Cave, Mt. Plenty Cave. St. Mary: Rock Springs Cave.

## Family Mycetophilidae

*Neoditomyia* sp., troglophile

Manchester: Abbey Cave; Oxford Cave, larva and pupae in hanging web. St. Ann: Brambribo Cave, with larvae; Dairy Bull Cave, Ken Connell Hole, Mt. Plenty Cave, Moseley Hall Cave, Thatchfield Light Hole Cave. St. John: Mocho Cave. St. Mary: Idlewild Cave. Trelawny: Burnt Hill Cave, Carambie Cave, Dromilly Cave, Windsor Great Cave. These flies, as larvae, all make hanging webs with which they catch their prey. *N. troglophila* (1977) was described by Matile (1977) from Cuba. I have seen similar fly webs in caves in Belize, which were identified as the genus *Orfelio* (Jackson, 1974).

## Family Sciaridae

*Sciara* ? sp., troglophile

St. Ann: Runaway Bay Caves. St. James: Brandon Hill Cave. St. Mary: Rock Springs Cave, Mt. Plenty Cave. Trelawny: Windsor Great Cave.

## Family Psychodidae

## Tribe Pericomini, undet. genus, troglophile

Clarendon: Pedro Great Cave. St. Ann: Brambribo Cave, 25 larvae in wet guano; Cricket Cave, Mt. Plenty Cave. St. Elizabeth: St. Claire Cave. St. Mary: Rock Springs Cavern, larvae abundant in wet guano. St. James: Rota Cave.



Family Scatopsidae

*Reichertella* sp., troglophile

Clarendon: Pedro Great Cave. Hanover: Cousins Cove Cave no. 2. St. Ann: Cave River Cave, Hutchinson Hole Cave, Moseley Hall Cave. St. Catherine: St. Claire Cave. St. James: Mocho Cave, Rota Cave. Trelawny: Drip Cave, Dromilly Cave, Windsor Great Cave.

*Scatopse* sp., troglophile

St. Ann: Brambibo Cave.

Family Ceratopogonidae

*Dasyhelea* sp. 1, troglophile

St. James: Mocho Cave. Trelawny: Windsor Great Cave (1961).

*Dasyhelea* sp. 2, troglophile

St. James: Mocho Cave. Trelawny: Windsor Great Cave (1973). These small flies can be very common at lights in caves with wet guano. The larvae live in aquatic and semiaquatic habitats rich in decaying organic matter. Blood sucking is not known in this genus (Waugh and Wirth, 1976), and some may be important pollinators of Cacao (Wirth and Waugh, 1976). The cave material does not match known epigeal species.

Family Empididae

*Drapetis (Elaphropeza) pleuralis* Melander, troglophile

St. Ann: Brambibo Cave, 5; Chesterfield Cave, 1; Drip Cave, 3; Norwood Rat Bat Hole, Mt. Plenty Cave. St. Elizabeth: Peru Cave, 8. St. James: Mocho Cave, 1. Trelawny: Windsor Great Cave, 11. Both larvae and adults of this fly are predaceous and probably feed on other small flies.

Family Dolichopodidae

*Peloropecodes* sp., troglophile

Clarendon: Pedro Great Cave. Trelawny: Drip Cave.

Family Phoridae

Genus undetermined, troglophile

Clarendon: Pedro Great Cave, Thatchfield Light Hole. Manchester: Oxford Cave, abundant in entrance zone trap, and in trap 600 feet and 900 feet inside. St. Ann: Brambibo Cave, Hutchinson Hole Cave, Norwood Rat Bat Hole. St. Elizabeth: Peru Cave. St. James: Rota Cave. St. Mary: Rock Springs Cavern. Trelawny: Harties Cave, Windsor Great Cave. Westmorland: Monarva Cave.

*Conicera (Hypocerina)* sp., troglophile

St. Ann: Lucky Hill Farm Cave.

Family Milichiidae

*Leptometopa* sp., troglophile

St. Ann: Cave River Cave, abundant on guano.

*Phleomyia* sp., troglophile

Clarendon: Pedro Great Cave. Hanover: Cousins Cove Cave no. 1. Manchester: Oxford Cave. St. Ann: Brambibo Cave, Cave River Cave, Drip Cave, Ken Connell Hole, Mt. Plenty Cave, Mocho Cave, Norwood Rat Bat Hole, Runaway Bay Cave. St. Catherine: St. Claire Cave. St. Elizabeth: Peru Cave. Trelawny: Dromilly Cave, Windsor Cave. Westmorland: Monarva Cave. The larvae of these flies are saprophagous and coprophagous. Their presence in caves probably relates to their feeding on guano.

Family Sphaeroceridae

*Leptocera* sp., troglophile

Manchester: Oxford Cave, abundant in trap at cave entrance. Trelawny: Hope Gate Cave, Windsor Great Cave. St. Mary: Rock Springs Cave. These flies are associated with guano.

Family Drosophilidae

*Drosophila* sp., troglophile

St. Ann: Norwood Rat Bat Hole. Larvae of these flies are occasionally found feeding in wet guano in Neotropical caves.

SUMMARY

As a result of all field work on Jamaican invertebrate cave faunas, about 250 free-living macroscopic species are now known from Jamaican caves. A complete and final list of Jamaican cave invertebrates will contain more species when all collections and other caves are fully studied. Most of the species are troglophiles associated with guano as scavengers or predators. It is of interest that some groups which are often found in caves, such as Diplopods, (represented by 14 genera) contain no troglobites in Jamaica (Loomis, 1969; 1975; 1977). Many species of troglobites are present; 25 are terrestrial and 11 are aquatic (Tables 2 and 3). Since some of the troglobites are not yet described, the exact total number is unknown, but it is over 36. Other species undoubtedly remain to be discovered, because only 50 of the some 600 precisely located caves in Jamaica have been studied biologically.

Jamaica, with an area of 11,700 km<sup>2</sup>, has the largest density of troglobites on an island in the West Indian tropics. By contrast, somewhat smaller Puerto Rico (including Mona Island) with an area of 8800 km<sup>2</sup> has only eight troglobites (Peck, 1974; 1981; Peck and Kukalova-Peck, 1981).

Cuba is a much larger island, with an area of 105,000 km<sup>2</sup>. Originally, few troglobites were known there (Nicholas, 1962). Taboada (1974) listed 228 animal species (including 61 species of vertebrates) (8 phyla, 17 classes, 48 orders) as known from 185 Cuban caves. There was no list of troglobites. Cuba has now seen extensive biospeleological investi-



Table 2. Summary of freshwater, groundwater, and anchialine troglobites of Jamaica and cave locality (from Table 1).

Taxon	Cave localities (from Table 1)
Platyhelminthes, Tricladida, Turbellaria	
1. Family, genus undetermined	43
Crustacea, Mysidaceae, Stygiomysidae	
2. <i>Stygiomysis major</i> Bowman (1976)	1
Crustacea, Mysidaceae, Mysidae	
3. <i>Antromysis peckorum</i> Bowman (1977)	1
Crustacea, Amphipoda, Gammaridae	
4. <i>Metaniphargus jamaicae</i> (Holsinger), Stock (1983)	1, Springfield (0m)
5. <i>Metaniphargus craterensis</i> Stock (1983)	Crater Lake (1m)
6. <i>Metaniphargus hyporheicus</i> Stock (1983)	Rio Seco (0m)
7. <i>Metaniphargus anchihalinus</i> Stock (1983)	Discovery Bay (0m)
Crustacea, Isopoda, Anthuridae	
8. <i>Cyathura parapatamica</i> Botosaneanu and Stock (1982)	Buff Bay River (80m)
Crustacea, Decapoda, Grapsidae	
9. <i>Sesarma verleyi</i> Rathbun (Hartnoll 1964)	7, 12, 14, 26, 28, 36, 47, 49
Crustacea, Decapoda, Palaemonidae	
10. <i>Troglocubanus jamaicensis</i> Holthuis (1963)	39
Vertebrata, Pisces, Bythitidae (= Brotulidae)	
11. <i>Lucifuga</i> sp?	1

gations by Cuban and Rumanian workers and many of their results are now published (Orghidan et al., 1973; 1977; 1981; 1983). Decu (1981) summarized data on Cuban troglobites, based on the new Cuban and Rumanian surveys. Thirty two terrestrial invertebrates (isopods, arachnids, centipedes, and insects) were considered to be troglobites, including two mites which parasitize bats. Twenty one aquatic and anchialine troglobites were listed, of which all are crustaceans except for three species of fish.

Analysis of the elevational distribution of Jamaican troglobites (Fig. 3) shows them to occur from sea level to 600 or 700 m. Most of the aquatic-anchialine species (9) (Table 2) occur near sea level and only two species (a crab and a shrimp) occur at altitudes above 200 m. Terrestrial troglobites occur from almost sea level, up to 600-700 m. The diversity of troglobites is higher in upland caves, but several occur in both lowland and upland sites. This is an exception to the generalization that terrestrial troglobites are absent to rare in low altitude tropical caves.

Because of space limitations, an analysis of the evolution and zoogeography of this important fauna will be presented elsewhere.

As the cave faunas of the American tropics become better known, it is becoming more apparent that earlier generalizations, such as those about the absence of tropical terrestrial troglobites, will have to be revised. Island faunas may also present different generalizations about the origin of troglobites than on continents (Peck, 1990).

Table 3. Summary of terrestrial troglobites of Jamaica and cave locality (from Table 1).

Taxon	Cave localities (from Table 1)
Onychophora, Peripatidae	
1. <i>Speleoperipatus spelaeus</i> Peck (1975a)	2
Araneae, Dipluridae	
2. <i>Masteria pecki</i> Gertsch (1982a)	17
Araneae, Ochyroceratidae	
3. <i>Theotima</i> sp.	26
Araneae, Pholcidae	
4. <i>Metagonia jamaica</i> Gertsch (1986)	1
5. <i>Anopsicus clarus</i> Gertsch (1982b)	1
6. <i>Anopsicus jarmila</i> Gertsch (1982b)	28
7. <i>Anopsicus limpidus</i> Gertsch (1982b)	14
8. <i>Anopsicus nebulosus</i> Gertsch (1982b)	29
9. <i>Anopsicus pecki</i> Gertsch (1982b)	3
Araneae, Gnaphosidae	
10. <i>Lygromma gertschi</i> Platnick and Shadab (1976)	17, 28, 45
Opiliones, Phalangodidae	
11. <i>Cynortina pecki</i> Rambla (1969)	2, 8, 14, 17, 28, 43
12. <i>Stygnumma fiskei</i> Rambla (1969)	1, 7, 8
Pseudoscorpionida, Bochicidae	
13. <i>Troglobochica jamaicensis</i> Muchmore (1984)	1
14. <i>Troglobochica pecki</i> Muchmore (1984)	45
Pseudoscorpionida, Chthoniidae	
15. <i>Tyrranochthonius hoffi</i> Muchmore (1991)	5, 32, 43
16. <i>Lagynochthonius typhlus</i> Muchmore (1991)	34
Schizomida, Schizomidae	
17. <i>Schizomus troglobius</i> Rowland and Reddell (1981)	1
Crustacea, Isopoda, Styloniscidae	
18. <i>Clavigeroniscus</i> sp.	27, 28
Hexapoda, Collembola, Entomobryidae	
19. <i>Metasinella</i> sp.	1
Hexapoda, Collembola, Paronellidae	
20. <i>Troglopedetes jamaicanus</i> Palacios-Vargas (1985)	1, 2, 5, 6, 7, 8, 11, 14, 20, 26, 28, 30, 39
Insecta, Blattodea, Blattellidae	
21. <i>Nelipophygus</i> sp.	8, 11, 14, 17, 26, 27, 28, 29, 46, 47, 52
Insecta, Hemiptera, Kinnaridae	
22. <i>Oecleidius antricola</i> Fennah (1980)	1
23. <i>Oecleidius minos</i> Fennah (1980)	1
Insecta, Coleoptera, Carabidae	
24. <i>Ardistomis</i> sp. 1	17
25. <i>Ardistomis</i> sp. 2	17

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## REFERENCES

- Alexander, C. P. 1964. The crane flies of Jamaica (Diptera, Tipulidae). *Bull. Inst. Jam. Science Ser.* #14.
- Aley, T. 1964. Origin and hydrology of caves in the White Limestone of north central Jamaica. Unpublished report available from Dept. Geography, University Calif., Berkeley, performed under ONR Contract Nonr 3656(3), Project NR 388 067, 29 pp.
- Anthony, H. E. 1920a. New mammals from Jamaica. *Amer. Mus. Nat. Hist. Bull.* 42:469-475.
- Anthony, H. E. 1920b. A zoologist in Jamaica. *Natural History (Amer. Mus. Nat. Hist.)*, 20:156-168.
- Arnett, R. H., Jr. 1961. The Onchophora of Jamaica. *Ent. News*, Vol. LXXII, No. 8:213-220.
- Ashcroft, M. 1969. Caves of Jamaica. *Jamaica Journal*, The Quarterly of the Institute of Jamaica, 3(2):32-36.
- Ashcroft, M., Hendricks, D. W. A., Herbert, E. J., Hodgson, D. P., Lodge, E., Perry, J. H. E. and Swindells, R. 1965. Jackson's Bay Great Cave. Information, *Bull. Sci. Research Council of Jamaica*, 6(1):13-19.
- Atkinson, T. C. 1969. Report on cave exploration in Jamaica, 1967. *J. British Speleol. Ass.* 6(43):151-166.
- Baker, R. J., and Genoways, H. H. 1978. Zoogeography of Antillean bats. *Acad. Natur. Sci. Philadelphia, Spec. Publ.* 13:53-97.
- Bengry, R. P. 1953. Cave notes, with special reference to Moseley Hall Cave. *Nat. Hist. Notes, Nat. Hist. Soc. Jamaica*, Kingston, 58:165-167.
- Botosaneanu, L., and Holthuis, L. B. 1970. Subterranean shrimps from Cuba (Crustacea: Decapoda: Natantia). *Tran. Inst. Speol. Emile Racovitza (Bucarest)* 9:121-133.
- Botosaneanu, L. and Stock, J. M. 1982. Les *Cyathura stygobies* (Isopoda, Anthuridae) et surtout celles des Grandes et Petit Antilles. *Bijdragen tot de Dierkunde* 52:13-42.
- Bowman, T. E. 1976. *Stygiomysis major*, a new troglobitic Mysid from Jamaica and extension of the range of *S. holthuisi* to Puerto Rico (Crustacea: Mysidaceae: Stygiomysidae). *Int. J. Speleo.* 8:365-373.
- Bowman, T. E. 1977. A review of the genus *Antromysis* (Crustacea; Mysidaceae), including new species from Jamaica and Oaxaca, Mexico, and a redescription and new records of *A. cenotensis*. *Assn. Mex. Cave. Stud. Bull.* 6:27-38.
- Brown, M. C., and Ford, D. C. 1973. Caves and groundwater patterns in a tropical karst environment: Jamaica, West Indies. *Amer. J. Sci.* 273:622-633.
- Buck, J. B. 1959. The Lampyrid Fireflies of Jamaica. *Trans. Amer. Ent. Soc.* 85:1-112.
- Buskirk, R. E. 1985. Zoogeographic patterns and tectonic history of Jamaica and the northern Caribbean. *J. Biogeogr.* 12:445-461.
- Carroll, W. and Janzen, D. 1973. Ecology of foraging by ants. *Ann. Rev. Ecol. Syst.* 4:231-257.
- Chace, F. A., Jr., and Hobbs, H. H., Jr. 1969. The Freshwater and Terrestrial Decapod Crustaceans of West Indies with Special Reference to Dominica. U.S. National Museum Bulletin No. 292:1-258.
- Chamberlin, R. V. 1918. The Chilopoda and Diplopoda of the West Indies. *Bull. of the Museum of Comp. Zool. Vol. LXII. No.* 5:211-215.
- Chopard, L. 1923. Description of d'un Gryllide cavernicole de la Jamique (Orth.) *Bulletin de la Societe entomologique de France.* pp. 84-87.
- Dajoz, R. 1972. Nouveaux Coleopteres Tenebrionidae endogues. *Rev. Ecol. Biol. Soc.* 9:273-280.
- Dajoz, R. 1975. Coleopteres Colydiidae et Tenebrionidae anophthalmes nouveaux de la region neotropique. *Acta Biol. Par. (Curitiba)* 4:91-124.
- Darlington, P. J., Jr. 1953. West Indian Carabidae (IX). More about the Jamaican species. *Occasional papers of the Museum of the Institute of Jamaica*, No. 8:1-14.
- Darlington, P. J., Jr. 1964. West Indian Carabidae X. Three more species from Jamaica, including a new cave *Colpodes*. *Psyche.* pp. 181-182.
- Decu, V. 1981. Quelques aspects de la biospeleologie tropicale resultant des expeditions biospeleologique cubano-roumain a Cuba. pp. 9-15. *Resultat des espeditions biospeleologique cubano-roumains a Cuba. vol. 3. Ed. Acad. Rep. Social. Romania.*
- DiTonto, M. A. 1989. The 1987 Cockpits Expedition. *NSS News July 1989:* 158-168.
- Donnelly, T. W. 1988. Geologic constraints on Caribbean biogeography, pp. 15-37. In Liebherr, J. K. (ed.), *Zoogeography of Caribbean Insects.* Cornell Univ. Press, Ithaca, NY 285 pp.
- Drake, C. J., and Hussey, R. F. 1955. Concerning the genus *Microvelia* Westwood, with descriptions of two new species and a checklist of the American forms (Hemiptera: Veliidae). *Florida Entomol.* 38:107-108.
- Eigenmann, C. H. 1909. Cave vertebrates of America. *Carnegie Institution of Washington, Publ.* 104, 241 pp.
- Farr, T. H. 1954. Arthropod life in the St. Claire Cave. *Nat. Hist. Notes, Nat. Hist. Soc. Jamaica*, 6:146-147.
- Fennah, R. G. 1980. New and little-known Neotropical Kinnaridae (Homoptera: Fulgoroidea). *Proc. Biol. Soc. Wash.* 93:674-696.
- Fincham, A. 1977. Jamaica Underground; a register of data regarding the caves, sinkholes and underground rivers of the island; including geology of Jamaican caves (by G. Wadge and G. Draper). *Geol. Soc. Jamaica*, 238 pp. and 140 cave maps. Available from: Treasurer, Geological Society of Jamaica, Geology Department, University of the West Indies, Mona, Kingston 7, Jamaica.
- Fincham, A., and Ashton, K. 1967. The University of Leeds Hydrological Expedition to Jamaica 1963 *Trans. Cave Research Group Great Britain*, 9(1):60 pp.
- Ford, S. M., and Morgan, G. S. 1986. A new ceboid femur from the late Pleistocene of Jamaica. *J. Vert. Paleont.* 6:281-289.
- Frank, J. H., and Thomas, M. C. 1983. A new species of *Proteinus* from a Jamaican cave (Coleoptera; Staphylinidae). *NSS Bull.* 45:98-100.
- Gertsch, W. J. 1982a. The troglobitic mygalomorphs of the Americas (Arachnida, Araneae). *Assoc. Mexican Cave Stud. Bull.* 8:79-94/Texas Mem. Mus. Bull. 28:79-94.
- Gertsch, W. J. 1982b. The spider genera *Pholcophora* and *Anopsicus* (Araneae, Pholcidae) in North America, Central America and the West Indies. *Assoc. Mexican Cave Stud. Bull.* 8:95-144/Texas Mem. Mus. Bull. 28:95-144.
- Gertsch, W. J. 1986. The spider genus *Metagonia* (Araneae: Pholcidae) in North America, Central America and the West Indies. *Texas Mem. Mus., Speleol. Monogr.* 1:39-62.
- Goodfriend, G. A., and Mitterer, R. M. 1987. Age of the ceboid femur from Coco Ree, Jamaica. *J. Vert. Paleont.* 7:344-345.



- Goodfriend, G. A., and Mitterer, R. M. 1988. Late Quaternary land snails from the north coast of Jamaica: local extinctions and climatic change. *Paleogeogr. Paleoclimat. Paleoecol.* 63:293-311.
- Goodfriend, G. A. 1989. Quaternary biogeographical history of land snails in Jamaica, pp. 201-216. In C. A. Woods (ed.), *Biogeography of the West Indies*. Sandhill Crane Press, Gainesville, Florida, 878 pp.
- Goodwin, R. E. 1970. The ecology of Jamaican Bats. *J. Mammalogy* 52(3): 571-579.
- Gordon, Isabella. 1960. On a *Stygiomysis* from the West Indies, with a note on *Spelaeogriphus* (Crustacea, Peracarida). *Bull. Br. Mus. Nat. Hist. (Zool.)*, 6:285-324.
- Hartnoll, R. G. 1963. The freshwater Grapsid crabs of Jamaica. *Proc. Linn. Soc. Lond.* 175(2):145-169.
- Hartnoll, R. G. 1964. Two cavernicolous decapods from Jamaica. *Crustaceana* 7(1):78-79.
- Hobbs, H. H., Jr., and Hart, C. W., Jr. 1982. The shrimp genus *Atya* (Decapoda: Atyidae). *Smithson. Contr. Zool.* 364.
- Hoffman, R. L. 1979. Chelodesmid studies. XIV. On the systematic status of the genera *Caraibodesmus* and *Platyurodesmus*, and the proposal of the new tribe Caraibodesmini. *Myriopodologica* 1:9-18.
- Holsinger, J. R. 1974. A new Cavernicolous amphipod crustacean of the genus *Hadzia* (Gammaridae) from Jamaica, with notes on the distribution and taxonomic status of the genus. *Annls. Speleol.* 29:647-655.
- Holsinger, J. R., and Peck, S. B. 1968. A new genus and species of subterranean amphipod (Gammaridae) from Puerto Rico, with notes on its ecology, evolution and relationship to other Caribbean amphipods. *Crustaceana* 15(3):249-262.
- Holthuis, L. B. 1963. Two new species of fresh water shrimp (Crustacea Decapoda) from the West Indies. *Proc. Kon. Ned. Akad. Wetensch., Amsterdam, (C)* 66:61-69.
- Holthuis, L. B. 1964. *Sesarma* (*Sesarma*) *cerberus*, a new cavernicolous crab from Amblina. *Zool. Meded. (Leiden)* 40:65-72.
- Holthuis, L. B. 1974. Subterranean Crustacea Decapoda Macrura collected by Mr. L. Botosaneanu during the 1973 Cuban-Roumanian biospeological expedition to Cuba. *Int. J. Speleol.* 6:231-242.
- Hunte, W. 1975. *Atya lanipes* Holthuis in Jamaica, including taxonomic notes and a description of the first larval stage (Decapoda, Atyidae). *Crustaceana* 28:66-72.
- Hunte, W. 1978. The distribution of freshwater shrimps (Atyidae and Palaemonidae) in Jamaica. *Zool. J. Linn. Soc.* 64:135-150.
- Ingle, R. W. 1972. A redescription of *Speleomysis servatus* (Fage) Comb. Nov. (Mysidacea: Lepidomysidae) from the material collected on Aldabra Atoll, with a key to the species of Lepidomysidae. *Bull. Br. Mus. (Nat. Hist.) Zool.* 22(7):199-210.
- Jackson, J. F. 1974. Goldschmidt's dilemma resolved: Notes on the larval behavior of a new Neotropical web-spinning Mycelophilid (Ditera). *Amer. Midl. Natur.* 92:240-245.
- Koopman, K. F. 1989. A review and analysis of the bats of the West Indies, pp. 635-644. In C. A. Woods (ed.), *Biogeography of the West Indies*. Sandhill Crane Press, Gainesville, Florida, 878 pp.
- Koopman, K. F., and Williams, E. E. 1951. Florida Chiroptera collected by H. E. Anthony in Jamaica, 1919-1920. *Amer. Mus. Nov.* 1519:1-29.
- Lawrence, J. F., and Stephan, K. 1975. The North American Cerylonidae (Coleoptera: Clavicornia). *Psyche* 82:131-166.
- Lewis, C. B. 1954. The bat fauna of the St. Claire Cave. *Nat. Hist. Notes, Nat. Hist. Soc. Jamaica*, 6:143-146.
- Livesey, P. 1966. Full report of the 1965-1966 Karst hydrology expedition to Jamaica. Huddersfield, England, privately published, 67 pp.
- Loomis, H. F. 1969. Millipeds from Jamaican caves. *Florida Entomol.* 52: 141-145.
- Loomis, H. F. 1975. New millipeds in a noteworthy collection from Jamaica. *Florida Entomol.* 58:167-185.
- Loomis, H. F. 1977. Three new millipeds from West Indian caves. *Florida Entomol.* 60:21-25.
- Lynn, W. G. 1954. Description of a new frog of the genus *Eleutherodactylus* from Jamaica. *B.W.I. Jr. Washington Acad. Sci.*, 44(12):400-402.
- MacPhee, R. D. E. 1984. Quarternary mammal localities and heptaxodontid rodents of Jamaica. *Amer. Mus. Novitates* 2803, 34 pp.
- Mari-Mutt, J. A., and Bellinger, P. F. 1990. A catalog of the Neotropical Collembola. *Flora and Fauna Handbook 5*, Sandhill Crane Press, Gainesville, Florida.
- Matile, L. 1977. Un Keroplatinae cavernicole nouveau de Cuba (Diptera, Mycetophilidae). *Results des Expeditions Biospeologiques Cubano-Rounvacines* 2:369-371. Ed. Acad. Repub. Social. Romania (Bucarest).
- Muchmore, W. B. 1984. *Troglobochica*, a new genus from caves in Jamaica and redescription of the genus *Bochica* Chamberlin (Pseudoscorpionida, Bochiridae). *J. Arachnol.* 12:61-68.
- Muchmore, W. B. 1991. Pseudoscorpions from Florida and the Caribbean area. 14. New species of *Tyrannochthonius* and *Lagynochthonius* from caves in Jamaica, with discussion of the genera (Chthoniidae). *Florida Entomol.* 74:110-121.
- Nicholas, G. 1962. Checklist of troglotic organisms of Middle America. *Amer. Midland Natur.* 68(1):165-188.
- Olson, S. L., and Steadman, D. W. 1977. A new genus of flightless Ibis (Threskiornithidae) and other fossil birds from cave deposits in Jamaica. *Proc. Biol. Soc. Wash.* 90:447-457.
- Olson, S. L., and Steadman, D. W. 1979. The humerus of *Xenicibus*, the extinct flightless Ibis of Jamaica. *Proc. Biol. Soc. Wash.* 92:23-27.
- Orghidan, T., Nunez Jiminez, A., Botosaneanu, L., Decou, V., Negrea, St., and Vina-Bayes, N. 1973. Resultats des expeditions biospeologiques cubano-roumaines a Cuba, Editura Academiei Republicii Socialiste Romania, Bucuresti, 1, 424 p.
- Orghidan, T., Nunez Jiminez, A., Decou, V., Negrea, St., and Vina-Bayes, N. 1977. Resultats des expeditions biospeologiques cubano-romaines a Cuba. Editura Academiei Republicii Socialiste Rojmania, Bucuresti, 2, 420 p.
- Orghidan, T., Nunez Jiminez, A., Decou, V., Negrea, St., and Vina-Bayes, N. 1981. Resultats des expeditions biospeologiques cubano-roumaines a Cuba. Editura Academiei Republicii Socialiste Romania, Bucuresti, 3, 191 p.
- Orghidan, T., Nunez Jiminez, A., Decou, V., Negrea, St., and Vina-Bayes, N. 1983. Resultats des expeditions biospeologiques cubano-roumaines a Cuba. Editura Academiei Republicii Socialiste Romania, Bucuresti, 4, 219 p.
- Palacios-Vargas, J. G., Ojeda, M., and Christiansen, K. A. 1985. Taxonomia y biogeographia de *Troglopedetes* (Collembola: Paronellidae) en America, con enfasis en las especies cavernicolas. *Folia Entomol. Mexicana* 65:3-35.
- Peck, S. B. 1972. Leiodinae and Catopinae (Coleoptera: Leioididae) from Jamaica and Puerto Rico. *Psyche*, 79(1-2):49-57.
- Peck, S. B. 1974. The invertebrate fauna of tropical American caves, Part II: Puerto Rico, an ecological and zoogeographic analysis. *Biotropica*, 6(1):14-31.
- Peck, S. B. 1975a. A review of the New World Onchophora with the description of a new cavernicolous genus and species from Jamaica. *Psyche* 82:341-358.
- Peck, S. B. 1975b. The invertebrate fauna of tropical American caves, Part III: Jamaica, an introduction. *Int. J. Speleol.* 7:303-326.
- Peck, S. B. 1977. New records and species of Leiodinae and Catopinae (Coleoptera: Leioididae) from Jamaica and Puerto Rico, with a discussion of wing dimorphism. *Psyche* 83:243-254.
- Peck, S. B. 1981. Zoogeography of invertebrate cave faunas in southwestern Puerto Rico. *NSS Bull.* 43:70-79.
- Peck, S. B. 1990. Eyeless arthropods of the Galapagos Islands, Ecuador: composition and origin of the cryptozoic faunas of a young, tropical, oceanic archipelago. *Biotropica* 22:366-381.
- Peck, S. B., and Kukulova-Peck, J. 1975. A guide to natural history field localities in Jamaica. *Studies of the Neotropical Fauna*, 10:105-116.



- Peck, S. B., and Kukalova-Peck, J. 1981. The subterranean fauna and conservation of Mona Island (Puerto Rico): a Caribbean karst environment. *NSS Bull.* 43:59-68.
- Peck, S. B., and Kukal, O. 1975. Jamaican caves and caving, a preliminary report. *Canadian Caver*, 7:47-77.
- Peck, S. B., and Shear, W. A. 1987. A new blind cavernicolous *Lygromma* (Aranea, Gnaphosidae) from the Galapagos Islands. *Can. Entomol.* 119:105-108.
- Perfit, M. R., and Williams, E. E. 1989. Geological constraints and biological retrodictions in the evolution of the Caribbean Sea and its islands, pp. 47-102. In C. A. Woods (ed.), *Biogeography of the West Indies*. Sandhill Crane Press, Gainesville, Florida, 878 pp.
- Petrunkевич, A. 1928. *Systema araneorum*. Trans. Conn. Acad. Arts & Sci. 29:1-270.
- Platnick, N. I., and Shadab, M. U. 1976. A revision of the spider genera *Lygromma* and *Neozimiris* (Aranea, Gnaphosidae). *Amer. Mus. Novitates* 2598, 23 pp.
- Quintero, D., Jr. 1980. The amblypygid genus *Phytinus* in the Americas (Amblypygi, Phrynidae). *J. Archnol.* 9:117-166.
- Rambla, M. 1969. Cave harvestmen from Jamaica (Opiliones: Phalangodidae). *Psyche*, 76(4):390-406.
- Read, R. 1963. Caves and cave men. *Bull. Sci. Research Council of Jamaica*, 4(2):21-28.
- Robinson, G. S. 1980. Cave-dwelling tineid moths: a taxonomic review of world species (Lepidoptera: Tineidae). *Trans. Brit. Cave Res. Assoc.* 7:83-120.
- Rowland, J. M., and Reddell, J. R. 1977. A review of the cavernicole Schizomida (Arachnida) of Mexico, Guatemala, and Belize. *Assoc. Mex. Cave Stud. Bull.* 6:79-102.
- Rowland, J. M., and Reddell, J. R. 1979. The order Schizomida (Arachnida) in the New World. I. Protoschizomidae and Dumitrescoae group (Schizomidae: *Schizomus*). *J. Arachnol.* 6:161-196.
- Rowland, J. M., and Reddell, J. R. 1981. The order Schizomida (Arachnida) in the New World. IV. *Goodnightorum* and *briggsi* groups and unplaced species (Schizomidae: *Schizomus*). *J. Arachnol.* 9:19-46.
- Smetana, A. 1975. Revision of the New World Genera of the tribe Omicrini trib. nov. of the hydrophilid subfamily Sphaeridiinae (Coleoptera). *Stud. Neotrop. Fauna* 10:153-182.
- Smith, D. I., Drew, D. P., and Atkinson, T. C. 1972. Hypotheses of karst landform development in Jamaica. *Trans. Cave Research Group Great Britain*, 14(2):159-173.
- Stock, J. H. 1977. The taxonomy and zoogeography of the hadziid Amphipoda with emphasis on the West Indian taxa. *Studies Fauna Curacao and other Caribbean Islands* 55(177):1-130.
- Stock, J. H. 1983. The stygobiont Amphipoda of Jamaica. *Bijdragen tot de Dierkunde* 53:267-286.
- Sweeting, M. 1957. Notes on the caves of Jamaica. *Trans. Cave Research Group Britain* 5(1):1-11.
- Sweeting, M. 1958. The karstlands of Jamaica. *Geogr. J.*, 124:184-199.
- Taboada, G. S. 1974. Sinopsis de la espeleofauna Cubana. *Serie Espeologica y Carsologica*, no. 43. *Inst. Geog., Acad. Ciencias Cuba*, Habana, 65 pp.
- Versey, H. R. 1972. Karst of Jamaica. In Herak, M. and V. T. Stringfield eds., *Karst; Important Karst Regions of the Northern Hemisphere*. Elsevier Publ. Co., Amsterdam, 445-466.
- Waugh, W. T., and Wirth, W. W. 1976. A revision of the genus *Dasybelea* Kieffer of the eastern United States north of Florida (Diptera: Ceratopogonidae). *Ann. Entomol. Soc. Amer.* 69:219-247.
- White, W. B., and Dunn, J. R. 1962. Notes on the caves of Jamaica. *Natl. Speleol. Soc. Bull.*, 24(1):9-21.
- Williams, E. E. 1952. Additional notes on fossil and subfossil bats from Jamaica. *J. Mamm.* 33(2):171-179.
- Williams, E. E., and Koopman, K. F. 1952. West Indian fossil monkeys. *American Museum Novitates*, no. 1546, 16 pp.
- Wilson, E. O. 1962. The Trinidad cave ant *Erebomyrma* (= *Spelaemyrmex*) *urichi* (Wheeler) with a comment on cavernicolous ants in general. *Psyche* 69:63-72.
- Wilson, E. O. 1988. The biogeography of the West Indian Ants (Hymenoptera: Formicidae), pp. 214-230. In Liebherr, J. K. (ed.), *Zoogeography of Caribbean Insects*. Cornell Univ. Press, Ithaca, NY.
- Wirth, W. W., and Waugh, W. T. 1976. Five new Neotropical *Dasyhelea* midges (Diptera: Ceratopogonidae) associated with culture of caco. *Studia Entomol.* 19:223-236.
- Wright, P., and White, P. F. 1969. *Exploring Jamaica, a guide for motorists*. Andre Deutsch Ltd. London, 254 pp.
- Wygodzinsky, P. 1966. A monograph of the Emesinae (Reduviidae, Hemiptera). *Bull. Amer. Mus. Nat. Hist.* 133:1-614.
- Zans, V. Z. 1953. The geology of the Moseley Hall Cave, Jamaica. *Nat. Hist. Notes, Nat. Hist. Soc. Jamaica*, 5:156-163.
- Zans, V. A. 1954. The St. Claire cave in St. Catherine. *Nat. Hist. Notes, Nat. Hist. Soc. Jamaica*, 6:137-141.
- Zans, V. Z. 1956. Caves and Sinkholes. In *Handbook of Jamaica*, Jamaica Information Service, Kingston, 18-19.



# DISTRIBUTION AND ABUNDANCE OF BATS (MAMMALIA: CHIROPTERA) IN COASTAL PLAIN CAVES OF SOUTHERN ALABAMA

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*A survey of bat fauna of caves located on the Coastal Plain of Alabama was conducted to determine species occupying the caves and their seasonal abundance. Three species of bats occupy the caves; *Myotis austroriparius*, *Pipistrellus subflavus*, and *Plecotus rafinesquii*. Most caves contained few or no bats in summer; however, relatively large numbers occurred in the caves during winter months. The only maternity colony known to occur in these caves was of *M. austroriparius*; the only maternity colony of this species known from Alabama.*

## INTRODUCTION

Alabama's bat fauna includes 16 species; southeastern myotis (*Myotis austroriparius*), gray myotis (*M. grisescens*), small-footed myotis (*M. leibii*), little brown myotis (*M. lucifugus*), northern myotis (*M. septentrionalis*), Indiana myotis (*M. sodalis*), eastern pipistrelle (*Pipistrellus subflavus*), big brown bat (*Eptesicus fuscus*), silver-haired bat (*Lasionycteris noctivagans*), red bat (*Lasiurus borealis*), hoary bat (*L. cinereus*), northern yellow bat (*L. intermedius*), Seminole bat (*L. seminolus*), evening bat (*Nycticeius humeralis*), Rafinesque's big-eared bat (*Plecotus rafinesquii*), and Brazilian free-tailed bat (*Tadarida brasiliensis*—modified from Hall, 1981).

Examination of listings of threatened and endangered species revealed six species of bats in Alabama that may be in danger of extinction. The United States Fish and Wildlife Service lists two endangered bat species; *M. grisescens* and *M. sodalis*. Five species are protected under regulations of the state of Alabama; *M. austroriparius*, *M. grisescens*, *M. sodalis*, *P. rafinesquii*, and *T. brasiliensis*. Species of "special concern" and "poorly known" include *L. intermedius*, *M. austroriparius*, *P. rafinesquii*, and *T. brasiliensis* (Mount, 1986). Little is known about the biology of these species within Alabama, and most of the information regarding them has been gleaned from studies in other states (e.g., Sherman, 1939; Quay, 1949; Rice, 1955, 1957; Hall, 1962; Crain and Cliburn, 1965; Crain and Packard, 1966; Barbour and Davis, 1969; Watkins, 1972; LaVal, 1973; Kennedy et al., 1974; Lowery, 1974; Humphrey, 1975; Jones

and Suttkus, 1975; Tuttle, 1976, 1979; Humphrey et al., 1977; Jones, 1977; Fitch and Shump, 1979; Fenton and Barclay, 1980; LaVal and LaVal, 1980; Webster et al., 1980; Kunz, 1982; Shump and Shump, 1982a, 1982b; Thomson, 1982; Fugita and Kunz, 1984; Wilkins, 1987, 1989; Jones and Manning, 1989; Kurta and Baker, 1990).

Although there is an overall paucity of information regarding bats in Alabama, there is a conspicuous lack of information for Coastal Plain species (e.g., Howell, 1921; LaVal, 1967; Linzey and Linzey, 1969; Linzey, 1970). In 1986, the Nongame Program of the Alabama Game and Fish Division listed the Coastal Plain caves as the highest-priority sites for future research and survey needs. Species identified to be in need of special attention in Coastal Plain caves include five species of bats; *M. austroriparius*, *M. grisescens*, *M. sodalis*, *P. rafinesquii*, and *T. brasiliensis*. The objectives of our research were to determine what species of bats occupy Coastal Plain caves of Alabama and to determine the relative abundance of bats in each cave. Herein, we list the species of bats found in Coastal Plain caves, present information on relative abundance of bats in each cave, and identify the most important caves for bats in southern Alabama.

## *Methods and Materials*

Bat traps and mist nets were placed inside, at the entrance, or outside caves to capture bats for species identification, estimates of relative abundance, etc. Caves where this was especially important were those that are large, those



with numerous crevices where bats could remain undetected, and those that could not be entered safely. In caves where the bat fauna could accurately be determined without capturing bats, no nets and traps were used.

During surveys of caves, a bat detector was used to locate bats, and visual inspections of potential roosting places were made. For large colonies of bats, the area occupied by the colony was measured, and an estimate of abundance was determined. Otherwise, individual bats were identified and counted. An effort was made not to disturb hibernating bats, as this could cause them to arouse, burn up fat reserves, and die of starvation before spring. Caves were examined during both summer and winter to determine their use.

Numbers in parentheses following names of caves are those assigned by the Alabama Cave Survey (McGill, 1992). Researchers requesting information about Alabama caves should direct inquiries to the Alabama Cave Survey, P.O. Box 360231, Birmingham, AL 35236-0231.

## RESULTS AND DISCUSSION

Preliminary investigations indicated that ca. 20 caves occurred in the coastal plains of Alabama. However, soon after the study was initiated, interviews with scientists from throughout the southeastern United States, information from landowners, and data from local residents indicated there were >50 caves in the region. As expected, several caves are known by a variety of names and others had never been visited by the person providing information (thus the precise locality was not known). Most of the cave-locating activity was concentrated in June, July, and August 1990. Because of dense summer vegetation, it was difficult to find many of the caves. In winter (February and March 1991), efforts were concentrated on revisiting the caves located in the summer of 1990.

Over 3,000 caves are known in Alabama (McGill, 1992); most occur in Paleozoic limestones of the Valley and Ridge, Cumberland Plateau, and Interior Low Plateau provinces in the northern half of the state. Caves there are numerous, and some are large or are part of extensive cave systems. Younger rocks of Cretaceous and Tertiary age crop out in the Coastal Plain. Caves here are fewer and smaller (almost all are <65 m in length) because the limestones in which they are developed generally are thin-bedded, discontinuous, and structurally incompetent. Sanders Cave (AL 167), Conecuh Co., is one of the largest and best known Coastal Plain caves. A spacious entrance room (height of ceiling, ca. 7 m) leads to ca. 360 m of passage, much >1.5 m in height. The entrance room is floored by breakdown; the passages by sandy clay and several deposits of bat guano. Unlike most Coastal Plain caves, Sanders Cave lacks a stream; however, water impounded behind beaver dams near the main en-

trance occasionally inundates the floor to a depth of 1 m.

Since 1982, S. D. Carey (SDC) has been involved in locating and mapping caves, and in recording species of invertebrates and vertebrates encountered in Coastal Plain caves. Preliminary data on caves visited by SDC, dates of observations, and numbers and kinds of bats are presented in Table 1. These data indicate that three species of bats currently oc-

**Table 1**  
Preliminary Data on the Number of Bats Observed in Coastal Plain Caves of Southern Alabama During 1982-1990. Numbers in Parentheses Following Names of Caves are Those Assigned by the Alabama Cave Survey (McGill, 1992).

Cave	Date	Number and Kinds of Bats Observed
Buzzard's Den Cave, Clarke Co. (AL 2835)	12 November 1988 20 January 1989 24 February 1990	12 <i>P. subflavus</i> 2 <i>P. rafinesquii</i> 20 <i>P. subflavus</i> 100 <i>P. subflavus</i> 1 <i>P. rafinesquii</i>
Broadenax Cave, Clarke Co. (AL 128)	11 February 1989	0 bats
Broughton Cave, Monroe Co. (AL 2722)	12 February 1983	12 <i>P. subflavus</i>
February Cave, Monroe Co. (AL 2919)	25 February 1990	20 <i>P. subflavus</i>
Kimbrough Cave, Clarke Co. (AL 2920)	25 March 1990	3 <i>P. subflavus</i>
Lion's Den Cave, Clarke Co. (AL 2806)	22 October 1988	10 <i>P. subflavus</i>
Locklin Cave, Monroe Co. (AL 2853)	29 July 1989 24 February 1990	1 <i>M. austroriparius</i> 30 <i>M. austroriparius</i> 20 <i>P. subflavus</i>
McLean's Cave, Clarke Co. (AL 2738)	13 September 1986	1 <i>P. subflavus</i>
McVay Cave, Clarke Co. (AL 129)	21 April 1989	1 <i>P. subflavus</i>
Myrick's Cave, Clarke Co.	18 March 1989	2 <i>P. subflavus</i>
Oscar Braun Cave, Washington Co.	12 June 1989	0 bats
Rabbit Creek Cave, Clarke Co. (AL 2267)	19 March 1983	3 <i>P. subflavus</i>
Randon's Creek Cave, Monroe Co. (AL 2833)	13 February 1982	10 <i>P. subflavus</i>
Rock House Cave, Covington Co. (AL 1011)	3 May 1989 12 June 1989	0 bats 0 bats
Rock Pit Cave, Monroe Co. (AL 1013)	11 May 1985 25 February 1990	0 bats several <i>P. subflavus</i>
Smith Cave, Clarke Co. (AL 2266)	19 March 1983	1 <i>P. subflavus</i>
Steve's Solo Hole, Monroe Co. (AL 2918)	6 March 1990	3 <i>P. subflavus</i>
Stallworth Cave, Clarke Co. (AL 2832)	13 September 1986	0 bats
Upper Rabbit Creek Cave, Clarke Co.	18 March 1989	0 bats
Walker Cave, Clarke Co.	18 March 1989	0 bats
Whitehead Cave, Clarke Co. (AL 2834)	13 September 1986	0 bats



Table II

Numbers of Southeastern *Myotis* (*Myotis austroriparius*) and Eastern Pipistrelle Bats (*Pipistrellus subflavus*) Observed in Caves in Southern Alabama During Summer 1990 and Winter 1991. Numbers in Parentheses Following Names of Caves are Those Assigned by the Alabama Cave Survey (McGill, 1992).

Cave	Summer (June, July, and August 1990)	Winter (February and March 1991)
B. C. Barganier Cave, Butler Co.	2 <i>P. subflavus</i>	45 <i>P. subflavus</i>
Buzzard's Den Cave, Clarke Co. (AL 2835)	0 bats	175 <i>P. subflavus</i>
Cary Cave, Conecuh Co. (AL 1424)	0 bats	105 <i>P. subflavus</i>
Chimney Cave, Covington Co.	0 bats	8 <i>P. subflavus</i>
Broadenax Cave, Clarke Co. (AL 128)	0 bats	0 bats
Davis Hunting Club Cave, Monroe Co.	no data	9 <i>M. austroriparius</i>
		176 <i>P. subflavus</i>
February Cave, Monroe Co. (AL 2919)	0 bats	no data
Hodges Cave, Conecuh Co.	0 bats	8 <i>M. austroriparius</i>
		59 <i>P. subflavus</i>
Lion's Den Cave, Clarke Co. (AL 2806)	1 <i>P. subflavus</i>	517 <i>P. subflavus</i>
Locklin Cave, Monroe Co. (AL 2853)	3 <i>M. austroriparius</i>	40 <i>M. austroriparius</i>
		83 <i>P. subflavus</i>
Mt. Moriah Cave, Wilcox Co. (AL 134)	0 bats	25 <i>P. subflavus</i>
Myrock's Cave, Clarke Co.	0 bats	29 <i>P. subflavus</i>
Rock House Cave, Covington Co. (AL 1011)	1 <i>M. austroriparius</i>	8 <i>M. austroriparius</i>
		21 <i>P. subflavus</i>
Rock Pit Cave, Monroe Co. (AL 1013)	0 bats	19 <i>P. subflavus</i>
Sanders Cave, Conecuh Co. (AL 167)	ca. 8,000 <i>M. austroriparius</i>	47 <i>M. austroriparius</i>
	2 <i>P. subflavus</i>	314 <i>P. subflavus</i>
Sleaze Hole, Monroe Co. (AL 2921)	0 bats	no data
Stallworth Cave, Clarke Co. (AL 2832)	0 bats	7 <i>P. subflavus</i>
Stone's Cave, Wilcox Co. (AL 1110)	0 bats	no data
Walker Cave, Clarke Co.	0 bats	0 bats
Whitehead Cave, Clarke Co. (AL 2834)	0 bats	19 <i>P. subflavus</i>

cur in Coastal Plain caves (*M. austroriparius*, *P. subflavus*, and *P. rafinesquii*), and that most bats are observed during the cooler months of the year.

In the present survey, bats were absent from most Coastal Plain caves during the summer (Table 2). Attempts were made to trap or net bats as they entered or exited caves during the summer months. This effort yielded one *P. subflavus* from B. C. Barganier Cave. Sanders Cave contains a maternity colony of ca. 8,000 *M. austroriparius* during summer; additionally, one or two *P. subflavus* were observed in this cave during each visit. The maternity colony of *M. austroriparius* in Sanders Cave is the largest known concentration of bats and the only known maternity colony in any Coastal Plain cave in Alabama. Although a few *M. austroriparius* were observed during winter months, Sanders Cave is not used as a hibernaculum by this species. Caves that contained few or no *P. subflavus* during summer months had large numbers during winter months (Table 2); the number of *M. austroriparius* was also greater in winter. *P. subflavus* uses caves as hibernacula during the winter (the *P. subflavus* we observed were in deep hibernation); however, *M. austroriparius* was active (usually making noise and flying when disturbed) and apparently this species hibernates elsewhere.

Previously, *M. austroriparius* has been reported from Baldwin and Conecuh (Sanders Cave) counties (Linzey, 1970). Howell (1921:25) reported that *P. subflavus* "is

scarce or absent in southern Alabama." Subsequently, *P. subflavus* was reported from Cat Cave, Clarke Co. (Brennan and White, 1960).

*Myotis lucifugus*, *M. septentrionalis* (= *M. keenii*), and *M. grisescens* have been reported from Sanders Cave (LaVal, 1967). *M. grisescens* has been reported from "the cave near Fort Deposit" (Howell, 1921:24), which could be B. C. Barganier Cave (B. Autry, the landowner, indicated that J. S. White had collected parasites from bats there in the 1950s, but he was unaware of previous visits by scientists). No *M. lucifugus*, *M. septentrionalis*, and *M. grisescens* were observed during our study.

There are no records of occurrence of *M. sodalis* south of the Tennessee River Valley in Alabama (Barbour and Davis, 1969). However, populations are known to occur in northwestern Florida (Thomson, 1982).

*Plecotus rafinesquii* has been reported from southern Alabama at Greensboro, Hale Co., and Autaugaville, Autauga Co. (Howell, 1921). Two were observed at Buzzard's Den Cave (AL 2835), Clarke Co., on 12 November 1988 (Table 1), and one was observed there on 24 February 1990 (Table 1). These sightings represent the only records of this species from Coastal Plain caves in Alabama.

*Tadarida brasiliensis* has been reported from Mobile, Baldwin (Linzey, 1970), and Hale counties (Howell, 1921). This species often occupies buildings. Several old buildings



were examined in Clarke, Conecuh, Covington, and Monroe counties, but no bats were discovered. However, we were able to locate a small colony of *T. brasiliensis* (cohabitating with *E. fuscus*) under a bridge near Georgiana, Butler Co.

Data obtained during our research has helped elucidate the distribution and relative abundance of *M. grisescens*, *M. sodalis*, *M. austroriparius*, *P. subflavus*, *P. rafinesquii*, and *T. brasiliensis* in Coastal Plain caves of Alabama. Unfortunately, all but *M. austroriparius* and *P. subflavus* are extremely rare or extirpated from the region. The maternity colony of *M. austroriparius* at Sanders Cave is extremely vulnerable to destruction. One report on *M. austroriparius* indicates that "the largest summer colony in Alabama, formerly inhabiting a limestone cave in Conecuh County, has reportedly been extirpated by vandals and careless cave explorers" (Mount, 1986:112). It is clear from the well-traveled trail through the woods to the cave, thrown mud that is stuck to the walls, and scattered litter, that there is considerable human traffic at Sanders Cave. This important bat cave was once occupied by *M. septentrionalis*, now one of the rarest bats in Alabama, and *M. grisescens*, a federally listed endangered species. Today it is occupied by the only maternity colony of *M. austroriparius* known to occur in Alabama and it serves as an important hibernaculum for *P. subflavus*, previously thought to be uncommon in southern Alabama.

The usefulness of the results of our research encompasses an area that is geographically larger than Alabama, and may have significant implications regarding the conservation of these and other species of bats in the southeastern United States. Future research should address the reproductive biology, habitat requirements, and food habits of *M. austroriparius* and *P. subflavus*. Special emphasis should be placed on determining hibernacula of *M. austroriparius* and summer roosting sites of *P. subflavus*. Because many of the hibernating *P. subflavus* were <1 m above the floor of caves, it would also be of interest to determine the influence that raccoons and other predators have on the survival of bats in Coastal Plain caves.

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#### REFERENCES

- Barbour, R. W. and W. H. Davis. 1969. *Bats of America*. University Press of Kentucky, Lexington, KY.
- Brennan, J. M. and J. S. White. 1960. New records and descriptions of chiggers (Acarina: Trombiculidae) on bats in Alabama. *The Journal of Parasitology* 46:346-350.
- Crain, J. L. and J. W. Cliburn. 1965. A preliminary study of the mammals of southeastern Mississippi. *Journal of the Mississippi Academy of Sciences* 11:271-280.
- Crain, J. L. and R. L. Packard. 1966. Notes on mammals from Washington Parish, Louisiana. *Journal of Mammalogy* 47:323-325.
- Fenton, M. B. and R. M. R. Barclay. 1980. *Myotis lucifugus*. *Mammalian Species* 142:1-8.
- Fitch, J. H. and K. A. Shump, Jr. 1979. *Myotis keenii*. *Mammalian Species* 121:1-3.
- Fujita, M. S. and T. H. Kunz. 1984. *Pipistrellus subflavus*. *Mammalian Species* 228:1-6.
- Hall, E. R. 1981. *The mammals of North America*, 2nd ed. John Wiley & Sons, New York, NY, 1:1-600 + 90.
- Hall, J. S. 1962. A life history and taxonomic study of the Indiana bat, *Myotis sodalis*. *Science Publications, Reading Public Museum and Art Gallery* 12:1-68.
- Howell, A. H. 1921. A biological survey of Alabama. *North American Fauna* 45:1-88.
- Humphrey, S. R. 1975. Status, winter habitat, and management of the endangered Indiana bat, *Myotis sodalis*. *Florida Scientist* 41:65-76.
- Humphrey, S. R., A. R. Richter, and J. B. Cope. 1977. Summer habitat and ecology of the endangered bat, *Myotis sodalis*. *Journal of Mammalogy* 58:334-346.
- Jones, C. 1977. *Plecotus rafinesquii*. *Mammalian Species* 69:1-4.
- Jones, C. and R. W. Manning. 1989. *Myotis austroriparius*. *Mammalian Species* 332:1-3.
- Jones, C. and R. D. Suttus. 1975. Notes on the natural history of *Plecotus rafinesquii*. *Occasional Papers of the Museum of Zoology, Louisiana State University* 47:1-14.
- Kennedy, M. L., K. N. Randolph, and T. L. Best. 1974. A review of Mississippi mammals. *Studies in Natural Science, Eastern New Mexico University (Portales, New Mexico)* 2(1):1-36.
- Kunz, T. H. 1982. *Lasiurus noctivagans*. *Mammalian Species* 172:1-5.
- Kurta, A. and R. H. Baker. 1990. *Eptesicus fuscus*. *Mammalian Species* 356:1-10.
- LaVal, R. K. 1967. Records of bats from the southeastern United States. *Journal of Mammalogy* 48:645-648.
- LaVal, R. K. 1973. Observations on the biology of *Tadarida brasiliensis cynocephala* in southeastern Louisiana. *The American Midland Naturalist* 89:112-120.
- LaVal, R. K. and M. L. LaVal. 1980. Ecological studies and management of Missouri bats, with emphasis on cave dwelling species. *Terrestrial Series, Missouri Department of Conservation, Jefferson City* 8:1-53.
- Linzey, D. W. 1970. Mammals of Mobile and Baldwin counties, Alabama. *Journal of the Alabama Academy of Science* 41:64-99.
- Linzey, D. W. and A. V. Linzey. 1969. First record of the yellow bat in Alabama. *Journal of Mammalogy* 50:845.



- Lowery, G. H., Jr. 1974. *The mammals of Louisiana and its adjacent waters*. Louisiana State University Press, Baton Rouge, LA.
- McGill, G. A. 1992. *Alabama caves*. Alabama Cave Survey, Birmingham, AL.
- Mount, R. M. (ed.). 1986. *Vertebrate animals of Alabama in need of special attention*. Alabama Agriculture Experiment Station, Auburn University, AL.
- Quay, W. B. 1949. Notes on mammals of Thomas County, Georgia, with two state records. *Journal of Mammalogy* 30:66-68.
- Rice, D. W. 1955. Status of *Myotis grisescens* in Florida. *Journal of Mammalogy* 36:289-290.
- Rice, D. W. 1957. Life history and ecology of *Myotis austroriparius* in Florida. *Journal of Mammalogy* 38:15-32.
- Sherman, H. B. 1939. The Florida yellow bat, *Dasypterus floridanus*. *Proceedings of the Florida Academy of Sciences* 7:193-197.
- Shump, K. A., Jr. and A. U. Shump. 1982a. *Lasiurus borealis*. *Mammalian Species* 183:1-6.
- Shump, K. A., Jr. and A. U. Shump. 1982b. *Lasiurus cinereus*. *Mammalian Species* 185:1-5.
- Thomson, C. E. 1982. *Myotis sodalis*. *Mammalian Species* 163:1-5.
- Tuttle, M. D. 1976. Population ecology of the gray bat (*Myotis grisescens*): factors influencing growth and survival of newly volant young. *Ecology* 57:587-595.
- Tuttle, M. D. 1979. Status, causes of decline, and management of endangered gray bats. *Journal of Wildlife Management* 43:1-17.
- Watkins, L. C. 1972. *Nycticeius humeralis*. *Mammalian Species* 23:1-4.
- Webster, W. D., J. K. Jones, Jr., and R. J. Baker. 1980. *Lasiurus intermedius*. *Mammalian Species* 132:1-3.
- Wilkins, K. T. 1987. *Lasiurus seminolus*. *Mammalian Species* 280:1-5.
- Wilkins, K. T. 1989. *Tadarida brasiliensis*. *Mammalian Species* 331:1-10.



# RECOVERY OF MICROFOSSILS FROM CARBONATE SPELEOTHEMS

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*Numerous microfossils were recovered from carbonate speleothems collected in caves of the Guadalupe Mountains, New Mexico. The speleothems consisted of a fragment of rimstone dam and four stalagmites that were dissolved with 5% hydrochloric acid. Treatment with 2% potassium hydroxide removed unwanted organic matter that entrapped many of the fossils. The fossils are remarkably well preserved. Mites are the only arthropods that were recovered intact. Moth scales, arthropod fecal pellets, appendage fragments of other arthropods, algae, fungi, pollen, minute fragments of plant material, and hairs of mammals were observed. The speleothems are probably Pleistocene in age.*

## INTRODUCTION

Little has been published on microfossils in carbonate speleothems. Bastin (1978) extracted a sufficient number of pollen grains from stalagmites to construct pollen diagrams comparing vegetation to past climates. Smith (1987), Jones and Motyka (1987), Jones and MacDonald (1989), and Davis *et al.* (1991) all mentioned evidence of microflora and/or algae preserved within carbonate speleothems. This paper offers a preliminary notice of microfossils in carbonate speleothems from caves in the Guadalupe Mountains, New Mexico, and more importantly presents the method of fossil extraction. This is the first report of the recovery of fossil invertebrates from carbonate speleothems.

## MATERIALS AND METHODS

Five samples from three caves in southeastern Eddy County, New Mexico, were selected for fossil extraction. All five speleothem samples were located in twilight zones (areas in a cave receiving some indirect sunlight) or the dark zone at the fringes of the twilight zones. Fossils were recovered from a fragment of rimstone dam from Cottonwood Cave, and small (about 5-8 cm wide at base and 15-30 cm long) stalagmites from Gunsight and Hidden caves. Speleothems in the area where samples were collected are currently inactive; in-place samples were not collected. Carbonate speleothems from Carlsbad Cavern and other Guadalupe Mountains caves previously studied are Pleistocene and Holocene in age with most dripstone growth occurring during the Pleistocene (Hill, 1987). Our samples are also from caves formed in the Capitan Reef complex but higher in elevation in the Guadalupe Mountains. They are also probably Pleistocene in age.

Fossils were extracted and processed using the following procedures: Portions of the speleothems were selected and removed with a rock saw. Speleothem surfaces were carefully trimmed off to avoid any surface contamination. Approximately, 7-40 g of carbonate material per sample was processed. Each sample was dissolved in 5% hydrochloric acid (HCl), approximately 30 ml of acid per gram of material was sufficient. Dissolution time varied from 90 minutes to 3 hours. Low magnesian calcite with less than 2 mole%  $MgCO_3$  seems to have a longer dissolution time.

In some cases, mites and larger materials were removed from solutions immediately after acid treatment. Otherwise, the acidic solution was transferred to centrifuge tubes and centrifuged at 2000 rpm for two minutes. The acid was decanted and de-ionized water was added and the samples were centrifuged again. The acid and water was decanted, and the previous procedure was repeated twice. Some fossil material was extracted after washing. If the sample contained an abundance of unwanted matter, then the sample was treated with 2% potassium hydroxide (KOH) for 10 minutes. The solution was gently agitated so that most of the unwanted matter was dissolved. After KOH treatment, the sample was rinsed three times. The final 5-10 ml of water with organic residue was transferred to a glass vial and ethanol was added to a concentration of about 70%. The resulting solution was pH 4.5-5. CMC-10 (lactic acid-polyvinyl alcohol solution: Master's Chemical Company, Elk Grove, Illinois 60007) was found to be an effective media for mounting fossils directly from the alcoholic solution without dehydration.

Thin-sections were prepared from the samples and each was stained with alizarin red-S and Feigl's solution for identification of calcite and aragonite. Microscopic observations of the thin-sections provided confirmation of fossil organic material.



Observations were made in Hidden Cave of the incorporation of organic material into active speleothems. Some speleothems considered to be actively growing were swabbed with cotton swabs to remove any organic debris which is currently being engulfed by calcium carbonate. These were rinsed in 70% ethanol and the resulting materials were slide mounted using CMC-10.

## RESULTS

Carbonate speleothems from caves of the Guadalupe Mountains, New Mexico, were examined and found to contain small arthropods, parts and fecal pellets of larger arthropods, pollen, microflora, and parts of other plants and animals all of which are considered in this paper as microfossils. The most distinctive fossils recovered from the speleothems were mites.

Mites or mite parts were extracted from three of the samples. The mites from the speleothems are primarily oribatids (11 of the 12 species recovered), a group which goes back to the Paleozoic (Norton *et al.*, 1988). The mites are the only mostly-intact arthropods recovered and in some cases most of the appendages are still attached. Although some of the setae are well preserved, others were either lost before the animal was engulfed in the developing speleothem or they were destroyed during the extraction procedure. Other arthropod parts were present in the acid-insoluble organic residue. Moth scales were found in abundance in all of the samples. Segments of appendages and other highly sclerotized areas of the body from arthropods were recovered, some had several segments still attached.

Small organic peloids were observed in thin sections. These are interpreted as fecal pellets of small arthropods. Larger peloids were dissolved from the samples. These partly consist of fragments of small arthropods and fungi. The size of the larger peloids (1.5-2 mm in diameter) match fecal pellets of cave crickets (*Ceuthophilus* spp.) and opilions (*Leiobunum townsendi*), which occur in the caves today. The smaller peloids observed in thin section are generally 50-200 microns in diameter.

Some fragments of algae were observed; these were sometimes located in fecal pellets. Algae is probably abundant in the entrance and twilight zones of caves. The algae extracted from some of the samples may have been introduced by arthropods that ingested it nearer the cave entrance and deposited it within feces where it was engulfed by calcium carbonate and preserved.

Fungi and bacteria are likely the most prolific of all the cave-inhabiting organisms. They probably make up the majority of microfossils in carbonate speleothems from caves in the Guadalupe Mountains. Most of these are difficult to recognize or they are preserved as trace fossils (i.e., fluid inclusions). At least one type of fungus was recovered from

the stalagmites of Hidden Cave. Yeast spores were evident in some of the arthropod fecal pellets. Pollen grains were also recovered from the samples.

An amorphous, white material was extracted from the samples during acid dissolution. When in water or 70% ethanol, it is sticky and gelatin-like; when dry it is powdery. The material dissolved out as sheets along speleothem layers in most cases. It sometimes formed molds of calcite sub-crystal terminations and aragonite fibers. It also contains many of the other recognizable organic materials such as pollen, fungi, and mite leg segments. It is soluble in basic solutions. Because of its gelatin-like nature and because we are unaware of any minerals which occur in carbonate speleothems that are soluble in weak alkaline, but not acid, solutions; we inferred that the amorphous material is organic and probably a byproduct of decaying fungi, algae, and arthropods. We ruled out inorganic byproducts produced during acid treatment, as the same material results regardless of the acid used to dissolve the speleothem. The white color of the material is perplexing as humic materials are generally brown to black in color.

Greater than 99% of each of the speleothems studied consisted of carbonate minerals such as calcite, aragonite, and dolomite. Less than 1% makes up the acid-insoluble organic and inorganic component. The acid-insoluble inorganic component consists predominately of silt-sized quartz grains.

## DISCUSSION

To trap arthropods, parts of other animals and plants, fungi, and pollen, precipitation of calcium carbonate must occur at a rate faster than the decay of the material being engulfed. Most speleothems in the Guadalupe Mountains caves are now essentially inactive. Even so, current growth of speleothems and engulfment of organic matter can be observed. Cricket feces and other organic materials were observed being engulfed and preserved by calcium carbonate on flowstone and stalagmites in the twilight zone of Hidden Cave. Swabs from speleothems from deeper in the cave revealed no organic material. Swabs of active flowstone and stalagmites from nearer the entrance removed debris consisting of intact juvenile insect (Collembola) as well as other fragments of arthropods (especially small flies) and fungi. Too small to detect with the naked eye, these materials are quickly engulfed by active growth of speleothems. The organic matter does not appear to inhibit the precipitation of calcium carbonate.

Petrunkovitch (1945) reported fossil arthropods (arachnids) from a calcium carbonate deposit in northern Arizona referred to as onyx marble. According to Edwin D. McKee (in Petrunkovitch, 1945), the deposit of middle Cenozoic or later age was emplaced within bedding planes and vertical



cracks of a Permian siltstone. In-place stalactites were located within a few open cavities. Pierce (1950, 1951) described additional fossil arachnids and insects from the same carbonate material and also referred to it as onyx marble. Pierce attributed the origin of the carbonate deposit to hot springs and provided a contemporary example from California in which insects were being engulfed by calcium carbonate at a well producing thermal waters. Closer examination of some of the arthropods by Rowland and Sissom (1980) revealed that they, as well as the other arthropods from the deposit, might be cavernicoles. We agree with Rowland and Sissom, and evidence from the literature suggests that the onyx marble is probably a karst or paleokarst feature, not the result of thermal springs.

Reports of arthropods preserved in carbonate deposits are few. However, deposits such as speleothems and travertine should, in many cases, contain such fossils if diagenesis has not destroyed them. Possibly digestion of some of the "onyx marble" of Arizona could reveal further undescribed microfossils. Acid digestion could reveal details of fossils that were mentioned by previous authors as being too deep in the matrix for adequate descriptions.

Although our method for obtaining fossils from calcite is not unique, it is much simplified over that used by paleopalynologists (Traverse, 1988). It is rapid and some of the specimens obtained are preserved well enough for detailed study and description. Our results are the first report of arthropods being digested from speleothems and suggest that this could be a new source of material for arthropod paleontologists.

Because the acid reacts rather violently with the carbonate, we suspected some of the bubbles could damage the fossils. More dilute solutions and acetic acid were tried but they did not result in significantly better specimens. Our worries were apparently unfounded as paleopalynologists use 10% HCl with good results (Traverse, 1988). Treating the samples with dilute KOH to remove the white gelatin-like material did not seem to damage the microfossils.

Many cave speleothems are protected from collection. Researchers wishing to use cave resources for studies should consult with local and national cave groups. Cave resources on federal lands in the U.S.A. are protected by the Cave Resources Protection Act of 1988 (US Congress, 1988). Researchers are urged to contact the appropriate agencies to obtain permits before removing or altering any cave formations.

#### CONCLUSIONS

Reports of arthropods preserved in carbonate deposits are few. However, deposits such as speleothems and travertine should, in many cases, contain such fossils if diagenesis has not destroyed them. Acid digestion could reveal these fos-

sils. Although our method for obtaining fossils from calcite is not unique, it is much simplified over that used by paleopalynologists. It is rapid and some of the specimens obtained are preserved well enough for detailed study and description.

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#### REFERENCES

- Bastin, B. (1978). L'analyse pollinique des stalagmites: une nouvelle possibilité d'approche des fluctuations climatiques du Quaternaire. *Annales de la Société Géologique de Belgique*, Vol. 101, pp. 13-19.
- Davis, D. G., Palmer, M. V. and Palmer, A. N. (1991). Extraordinary subaqueous speleothems in Lechuguilla Cave, New Mexico, *NSS Bulletin*, Vol. 52, pp. 70-86.
- Hill, C. A. (1987). Geology of Carlsbad Cavern and other caves in the Guadalupe Mountains, New Mexico and Texas. *New Mexico Bureau of Mines and Mineral Resources, Bull.* 117, pp. 1-150.
- Jones, B. and MacDonald, R. W. (1989). Micro-organisms and crystal fabrics in cave pisoliths from Grand Cayman, British West Indies. *Journal of Sedimentary Petrology*, Vol. 59, pp. 387-396.
- Jones, B. and Motyka, A. (1987). Biogenic structures and micrite in stalactites from Grand Cayman Island, British West Indies. *Canadian Journal of Earth Science*, Vol. 24, pp. 1402-1411.
- Norton, R. A., Bonamo, P. M., Grierson, J. D., and Shear, W. A. (1988). Oribatid mite fossils from a terrestrial Devonian deposit near Gilboa, New York. *Journal of Paleontology*, Vol. 62, pp. 259-269.
- Petrunkovitch, A. (1945). *Calcitro fisheri*, a new fossil arachnid. *American Journal of Science*, Vol. 243, pp. 320-329.
- Pierce, W. D. (1950). Fossil arthropods from onyx marble. *Southern California Academy of Sciences, Bull.* 49, pp. 101-104.
- Pierce, W. D. (1951). Fossil arthropods from onyx-marble. *Southern California Academy of Sciences, Bull.* 50, pp. 34-49.
- Rowland, J. M. and Sissom, W. D. (1980). Report on a fossil paligrade from the Tertiary of Arizona, and a review of the morphology and systematics of the order (Arachnida, Paligradida). *Journal of Arachnology*, Vol. 8, pp. 69-86.
- Smith, D. (1987). "The Genesis of Speleothemic Calcite Deposits on Grand Cayman Island, British West Indies." Unpublished M.S. Thesis, The University of Alberta.
- Traverse, A. (1988). "Paleopalynology." Allen and Unwin, Inc., Boston.
- U.S. Congress. (1988). Federal cave resources protection act of 1988. Public Law 100-691. *U.S. Statutes at Large*, Vol. 102, No. 5, pp. 102 STAT. 4546-102 STAT. 4551.



# MINERALOGY OF CLAY SEDIMENTS IN THREE PHREATIC CAVES OF THE SUWANNEE RIVER BASIN

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*Bottom surface clay was sampled from two cave systems in Ocala Limestone draining into the Suwannee River (Peacock and Telford Springs Caves) in Suwannee County, Florida and one cave system in Suwannee Limestone draining into the Withlacoochee River (Madison Blue Spring Cave) in Madison County, FL. In all three cave systems, the predominant clay mineral observed was kaolinite. Kaolinite is also the predominant clay mineral found in most Florida and south Georgia soils in the Suwannee River basin. Quartz was found in the clay- or silt-sized fractions from Peacock and Madison Blue Caves. The fine clay fraction from Madison Blue Cave contained a small concentration of smectite. Gray-colored sediments from Telford and Madison Blue Caves contained some crystalline pyrite. The dominance of kaolinite may be evidence for the depositional (allochthonous) rather than in situ (autochthonous) origin of these materials.*

## INTRODUCTION

Most of what is known of cave sediment mineralogy is based on study of vadose caves. Little is known of the mineralogy of sediments in phreatic caves (Horne, 1990), where geochemical and sedimentation processes may differ from those in vadose caves. No data exist on clay mineralogy of sediments of phreatic North Florida caves.

The objective of this study was to characterize clay sediments found in selected phreatic caves of the Suwannee River basin. Both the predominance of either calcium carbonate or phyllosilicate clays and the type of phyllosilicate clay minerals may give some indication of the source of these clay sediments.

## GEOLOGY AND SOILS OF STUDY AREA

The Suwannee River Basin karst is bare or thinly covered limestone with high water table levels and substantial solution activity (Sinclair and Stewart, 1985). The Suwannee, Santa Fe, and Withlacoochee Rivers are entrenched in limestone channels (Rupert, 1988a). On or near the rivers, artesian springs issue from extensive networks of underwater limestone caves.

Caves of the Suwannee River basin form largely in the Ocala (middle Eocene) and Suwannee (Oligocene) limestones (Rosenau et al., 1977). Caves on the section of the Suwannee River occupied by Telford and Peacock Springs are found in the Crystal River (upper) formation of the Ocala Group, since this formation is at the surface in that area (Arthur, 1991). Caves along the lower Withlacoochee

River, where Madison Blue Spring is found, form in the Suwannee Limestone. The latter has been inferred from surface strata observed in nearby U.S. Geological Survey (U.S.G.S.) well cores drilled just east of the Withlacoochee River about 10 km upstream and 5 km downstream from Madison Blue Spring (Ceryak et al., 1983) and from a well core just west of the river about 8 km downstream from the spring (Hoenstine and Spencer, 1986; Hoenstine et al., 1990).

Ocala Group limestones found in the Suwannee River Valley approach 95% (Rupert, 1988a) to 100%  $\text{CaCO}_3$  (Calver, 1957) and contain very little clay or quartz sand impurities (Calver, 1957). However, cherty concretions and boulders can be found locally. West of the Suwannee River, Ocala Group limestones include dolomites and dolomitic limestone facies (Calver, 1957). In the area near the Suwannee River, the Ocala Limestone is covered with a thin veneer of post-Miocene undifferentiated clayey sands (Arthur, 1991) from which the local soils have developed.

The Suwannee Limestone is a partially re-crystallized calcerenite. It is pale orange, finely crystalline, highly fossiliferous, porous, and generally well indurated. It is nearly 97%  $\text{CaCO}_3$ , but dolomitization of the limestone has occurred in the subsurface at different depths (Hoenstine and Spencer, 1986). The limestone varies in character from hard and resonant to soft and granular with clay and sand (Calver, 1957). The Wakulla Spring cave system to the west is in Suwannee Limestone. At that location, the Suwannee Limestone was found to contain no recoverable insoluble



residues (Rupert, 1988b). In the area near the Withlacoochee River, the Suwannee Limestone is covered with a thin veneer of Pleistocene sand (Hoenstine and Spencer, 1986) from which the local soils have developed.

Impurities in both the Ocala and Suwannee limestones may include magnesium as  $\text{MgCO}_3$ , iron as one of several ferric or ferrous carbonates or sulfides, and sulphur as iron sulfide ( $\text{FeS}$ ), pyrite ( $\text{FeS}_2$ ), gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ), or anhydrite ( $\text{CaSO}_4$ ).

In the vicinity of caves, springs, and sinkholes in the Suwannee River basin, the authors have observed that sandy soils of the Alfisol and Ultisol orders tend to predominate. These landscapes are characterized by hardwood hammock (dense hardwood forest) and mixed hardwood-pine vegetation with limestone, clay, and water close to the surface. The clay fraction of these soils tends to be dominated by kaolinite with some montmorillonite and lesser quantities of quartz and hydroxy-interlayered vermiculite (HIV).

#### MECHANISMS FOR SEDIMENT TRANSPORT INTO UNDERWATER CAVES

In Florida karst, the interface between limestone and the overlying subsoil is extremely irregular (Puckett et al., 1990; Puri et al., 1967) due to subsoil solutional sculpture (Jennings, 1985). In the well developed karst west of the central Florida Ridge, limestone bedrock is so close to the surface in some places that normal subsoil layers have been truncated and transported by gravity, drained into subterranean air- or water-filled cavities through partially plugged solution pipes. White (1988) refers to this type of clastic sediment as "infiltrates" which are surface soils washed, piped, or slumped into open air-filled crevices or down dry sinkholes. This would provide a mechanism for the vertical transport of subsoil clay and sand into vadose caves. The mechanism for such transport into phreatic caves is not, however, well understood. Some sediment is transported vertically into phreatic conduits as indicated by the commonly observed debris cones in these caves. One of the authors has observed an apparently recent debris cone in the Peacock III section of the Peacock Springs cave system. This debris cone was composed of subsoil clay and sand containing largely undecomposed plant roots. The same author has observed the formation of a debris cone in Thunder Hole cave system (Madison Co., FL). Sandy debris was seen falling from the ceiling through the water column and piling up in a cone on the cave floor. Both of these observations were made during extended periods of drought with associated lowered water table levels.

During long periods of time during the glacial ice maxima, sea level was much lower but little is known of how much lower water table levels were in the area of these caves. No vadose-type speleothems are present in these caves. Vadose-type speleothems are very rare in this karst area of

Florida (Williams et al., 1977). No evidence has been presented in the literature or observed by the authors to indicate that these underwater caves have ever been vadose (air-filled) for a geologically significant period of time. Thus these caves cannot be called "submerged." Cave genesis and sediment deposition may have occurred primarily subaqueously.

A poorly understood and only recently examined possible source of clays and other minerals in phreatic caves is the downward transport of suspended colloidal mineral particles to the aquifer. This type of colloidal transport may be responsible for some of the easily disturbed, only partially settled sediments commonly observed by one of the authors in the crevices of underwater caves. Such colloidal transport may be differential with respect to clay mineralogy (Kaplan et al., unpublished data).

Within some solution shafts on the surfaces of limestones of the Suwannee River basin there is re-worked Hawthorn Group material deposited by erosional weathering (Williams et al., 1977). This material is a complex mixture of limestone and phosphatic apatite pebbles in a matrix of quartz sand and clay (montmorillonite, polygorskite, and kaolinite), and small amounts of trace substances such as uranium (0.006% in North Florida) (Sweeney and Windham, 1979).

Some cave tunnel segments and sinkholes may have formed in these easily erodible Hawthorn Group in-fills and inclusions in the limestone bedrock (Locascio, personal communication). Weathered and eroded Hawthorn Formation material, as well as more recent undifferentiated sandy material, have likely slumped into karst depressions and washed down the river bottoms into underwater caves during periods of back-flooding (reverse flow).

Clay and sand sediments may enter some phreatic caves by back-flooding when spring flows are reversed during floods of the Suwannee River and its tributaries. Bull (1981) described this type of process as "weather events injecting pulses of sediment-rich water by a translatory flow (shunting) mechanism into standing water in the caves" (Jennings, 1985). Clays brought into North Florida caves by this mechanism are likely to consist primarily of kaolinite since this is the most common clay mineral found in soils of the Suwannee River basin. Once inside phreatic conduits, clay sediments can be re-distributed, sorted, and weathered. They can also be chemically altered by changes in water chemistry.

#### MATERIALS AND METHODS

Spring water from Telford, Peacock, and Madison Blue Springs are of the calcium-magnesium bicarbonate type (Slack and Rosenau, 1979). Water chemistry data from Rosenau et al. (1977) are shown in Table 1. An understanding of water chemistry in underwater cave systems may be



useful in interpreting sediment mineralogy and geochemical processes.

Clay was sampled from the floors of two cave systems draining into the Suwannee River (Peacock and Telford Springs Caves) in Suwannee County, Florida and one cave system draining into the Withlacoochee River (Madison Blue Spring Cave) in Madison County, FL (Fig. 1, Table 2). Samples were collected far enough from cave entrances to avoid sampling the entrance facies. This required the use of cave certified scuba divers. These caves were selected for study because they are accessible to certified cave divers, shallower than 32 m (105 ft), and previously mapped.

In Telford Spring cave system (Fig. 2), sediment was sampled at the upstream end of Rolands Road, adjacent to Beulahland. The sample was taken from a clayey gray cave floor sediment with inclusions of semi-crystalline iron oxyhydroxide concretions. These iron oxyhydroxide formations, described by Martin (1990) may provide information

Table 1. Spring water chemistry data from Rosenau et al. (1977). Water samples taken at spring vent.

	Telford Spring	Peacock Spring	Madison Blue Spring
Sampled	11-21-73	11-20-73	mean of 7-23-46, 11-15-60, & 11-6-73
	mg L <sup>-1</sup>		
CO <sub>2</sub>	8.3	4.7	4.6
Ca	52	44	40
Mg	24	21	8.6
Na	2.3	2.2	2.6
K	0.4	0.5	0.6
Si as SiO <sub>2</sub>	6.9	5.9	9.2
HCO <sub>3</sub>	210	190	147
CO <sub>3</sub>	0	0	0
SO <sub>4</sub>	42	19	10.2
Cl	4.0	3.5	3.9
F	0.0	0.0	0.2
Sr	0.000	0.000	0.000
Total organic C	—	—	0.0
Total inorganic C	—	—	29
Organic N	—	—	0.04
NH <sub>4</sub> <sup>+</sup> -N	—	—	1.2
NO <sub>3</sub> -N	—	—	0.00
Ortho P (PO <sub>4</sub> as P)	—	—	0.52
Total P	—	—	0.03
Dissolved O <sub>2</sub>	3.0	3.0	2.5
Dissolved solids			
Calculated	233	187	148
Residue on evaporation at 180° C	244	191	159
Hardness as CaCO <sub>3</sub>	230	190	133
Noncarbonate hardness as CaCO <sub>3</sub>	60	40	17
Alkalinity as CaCO <sub>3</sub>	170	150	120
Specific conductance μmhos cm <sup>-1</sup> at 25° C	423	346	260
Color (platinum cobalt units)	5	5	2
pH	7.4	7.4	7.7
Temperature (°C)	21.0	22.0	21.2

Table 2. Clay sediment sample sources.

	Cave		
	Telford Spring	Peacock Spring	Madison Blue Spring
County	Suwannee	Suwannee	Madison
River receiving spring flow	Suwannee	Suwannee via Peacock Slough	Withlacoochee (North)
Tunnel/section in cave tunnel	Downstream from Beulahland	Peanut tunnel downstream from Waterhole Exposed clay bank	Main tunnel near Godzilla split Sand underlaid with clay
Type of Bottom	Soft clay		
Limestone formed in	Ocala	Ocala	Suwannee
Has upstream sinkholes?	yes	yes	yes
Reverse flow in flood?	yes	yes	yes
Color of deposit	grey	rust-red	grey
Flow velocity at sampling site†	medium	slow	medium
Total spring discharge‡ (L s <sup>-1</sup> )	1125	419	3261
Date(s) measured	mean of 5 1927-73	11-20-73	mean of 6 1932-73

†Flow described according to Wilson (1991).

‡From Rosenau et al., 1977.

on the geochemical history of these caves. In Peacock Springs cave system (Fig. 3), sampling was conducted in the deeper phreatic section of the Peanut Tunnel. This sample was taken from the exposed erosional face of a stratified bed of red clay. Large iron oxyhydroxide deposits were observed within a few meters of the sampling site. In Madison Blue Spring cave system (Fig. 4), sampling was conducted in the main tunnel near the Godzilla section offshoot. This sample was taken from a clayey gray cave floor sediment partially covered with white quartz sand.

Cave floor clay sediment "surface" samples were collected in 75 ml plastic cylinders by divers and stored at room temperature. For this preliminary study, controlled core samples were not collected, thus no inferences can be made about stratification of these cave sediments. Sub-samples were separated by particle size diameter into clay (less than 2 μm), silt (2-50 μm), and sand (50 μm to 2 mm diameter) fractions by means of differential settling and sieving. The clay fraction was subdivided into "fine" clay (less than about 1 μm) and "coarse" clay (1-2 μm). Clay plus silt-sized fractions and fine clay-sized fractions were suspended in de-ionized water, deposited on ceramic tiles, and saturated with Mg<sup>2+</sup> and glycerol in preparation for x-ray diffraction



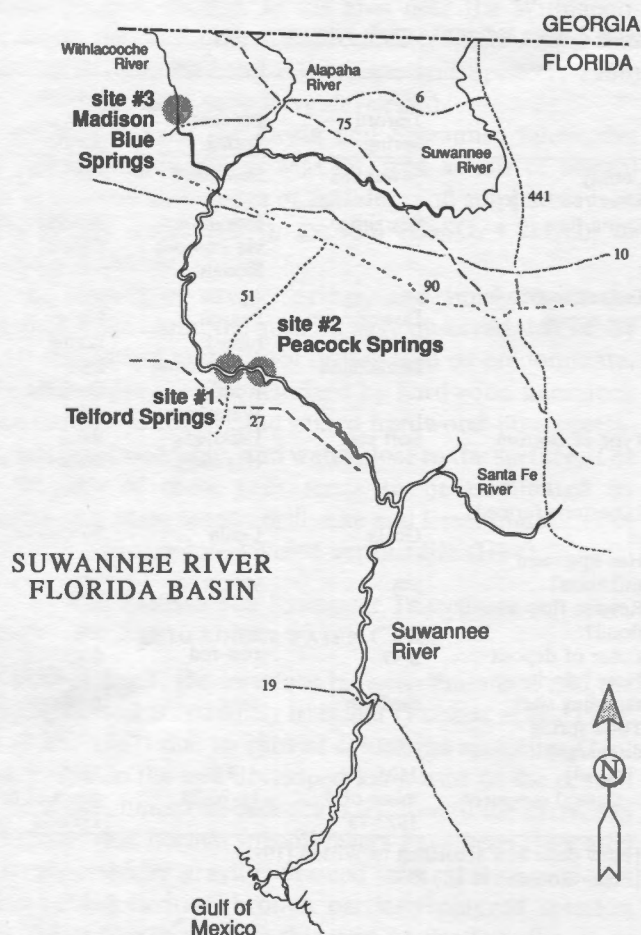


Figure 1. Suwannee River basin in North Florida spring country. Telford and Peacock Springs cave systems are on the Suwannee at Luraville. Madison Blue Spring cave system is on the Withlacoochee River (north) where it crosses State Road 6 between Madison and Jasper.

Table 3. Results of mineralogical analysis of clay sediments in caves of the Suwannee River valley.

	Cave		
	Telford Spring	Peacock Spring	Madison Blue Spring
Effervescence with 0.1 M HCl?	no	slight	no
Effervescence with 1 M HCl?	trace	moderate	slight
Color of sand fraction	various	rust-red	white
Primary clay mineral	Kaolinite	Kaolinite	Kaolinite
Lesser minerals in clay or silt fraction	Pyrite	Quartz	Quartz, Pyrite, Smectite
Comments	Pyrite in sand fraction. Gypsum crystals formed when sand fraction was dried.	—	—

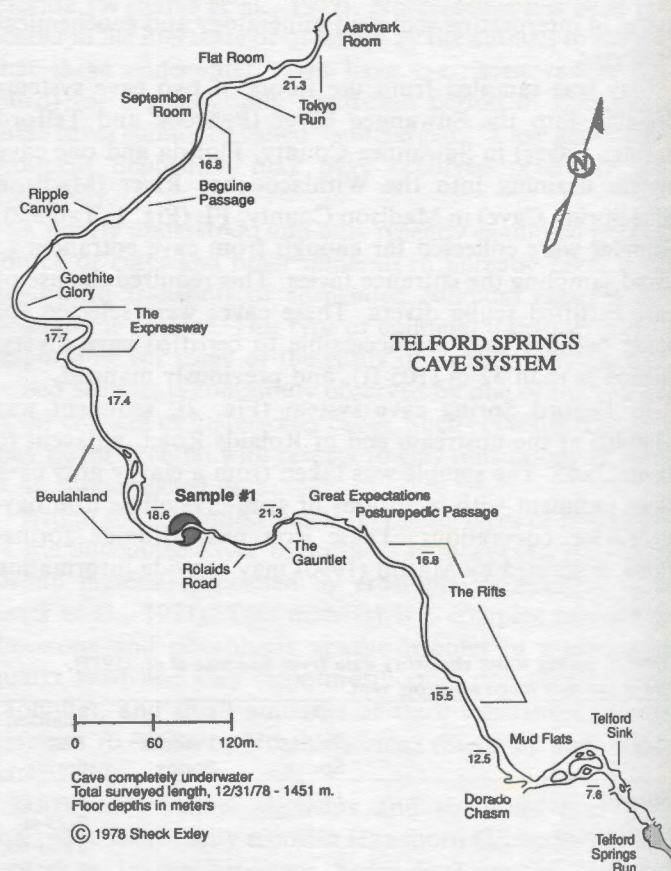
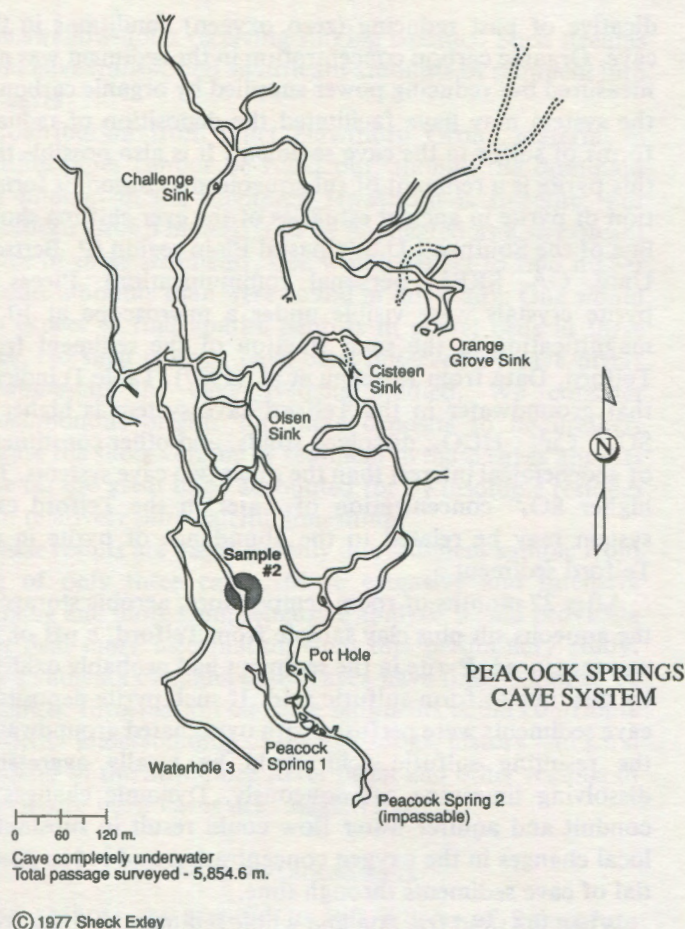


Figure 2. Telford Spring cave system, Suwannee Co., FL. Cave completely underwater. Sampling location was at upstream end of Roloids Road adjacent to Beulahland. (After Exley, 1978, with modifications).

analysis. Saturation with  $Mg^{2+}$  and glycerol was performed to provide a standard means for differentiating among expansible phyllosilicates (Whittig and Allardice, 1986). Samples were scanned at  $2^\circ 2\theta$  per minute using  $Cu K\alpha$  radiation and analyzed with a scintillation counter. For one sample (Madison Blue) which was subsequently determined to contain an expansible phyllosilicate (smectite),  $K^+$  saturation and heat treatments were also conducted to aid in identification.

Whole sediment samples were treated with drops of 0.1 and 1 M hydrochloric acid to test qualitatively for the presence of high concentrations of calcium carbonate. Calcium carbonate concentrations were not sufficient to justify measurement of weight loss for determination of percent soluble calcium carbonate.



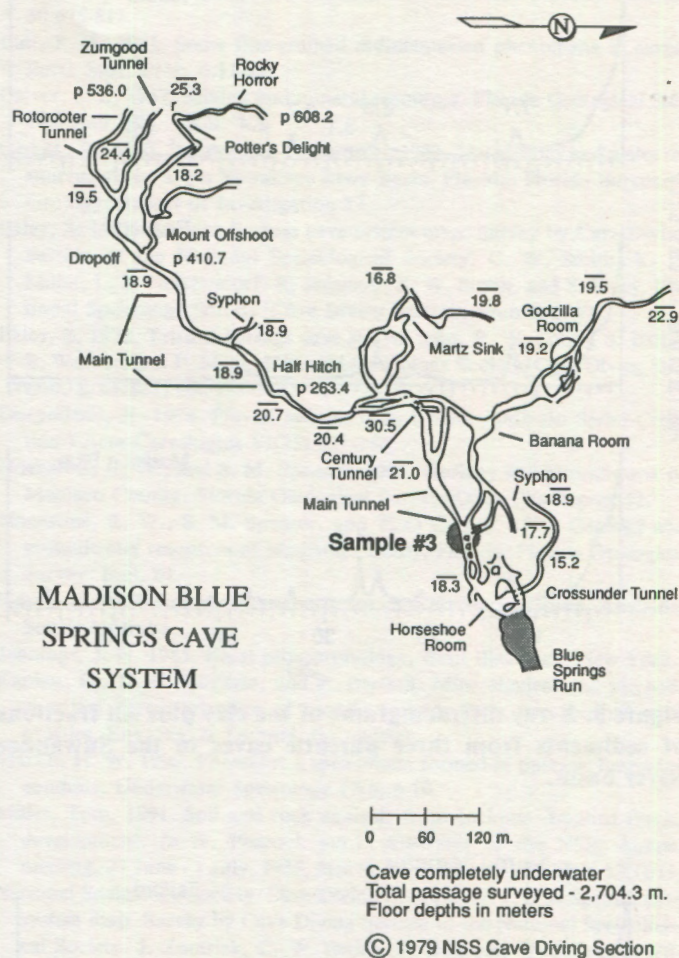


**Figure 3. Peacock Springs cave system, Suwannee Co., FL.** Cave completely underwater. Approximate sampling location is shown in the deeper Phreatic section of the Peanut Tunnel. (After Exley, 1977, with modifications).

#### RESULTS AND DISCUSSION

Results of analysis of the fine-clay and clay plus silt-sized fractions by x-ray diffraction are shown in Figures 5 and 6. Results of mineralogical analysis are summarized in Table 3. Effervescence of samples in 0.1 N HCl was minimal or undetectable (Table 3). No calcium carbonate minerals were detected with x-ray diffraction (Figs. 5 and 6). Thus, these clay sediments are not composed of significant quantities of clay-like calcilutite as were sediments in the Wakulla Spring cave entrance (Rupert, 1991; Rupert and Wilson, 1989).

In all three cave systems studied, the predominant clay mineral was kaolinite as indicated by 7.2 and 3.5 Å peaks (Figs. 5 and 6). Kaolinite is also the predominant clay mineral found in most Florida and south Georgia soils in the Suwannee River basin. Quartz was found in the clay- or silt-sized fractions from Peacock and Madison Blue and was especially common in Madison Blue, as indicated by the 3.3



**Figure 4. Madison Blue Spring cave system, Madison Co., FL.** Cave completely underwater. Approximate sampling location is shown in the main tunnel near the Godzilla section offshoot. (After NSS/CDS, 1979, with modifications).

Å peaks (Figs. 5 and 6). This is also the case with most Florida soils.

The fine clay fraction from Madison Blue contained a small concentration of smectite as indicated by the 19.6 Å shoulder in Figure 6. Smectite is also a constituent of the clay fraction of some Florida soils. Smectite often dominates the clay fraction of minimally-leached or alkaline soils, such as those developing on shallow limestone bedrock.

Both of the gray-colored sediments from Telford and Madison Blue contained crystalline pyrite ( $\text{FeS}_2$ ) in the coarser fractions. The 3.1, 2.7, 2.4, 2.2, 1.9, and 1.6 Å peaks in Figure 5 are all diagnostic for pyrite. The 3.1 Å pyrite peak can be seen in Figure 6 as well. This may be in-



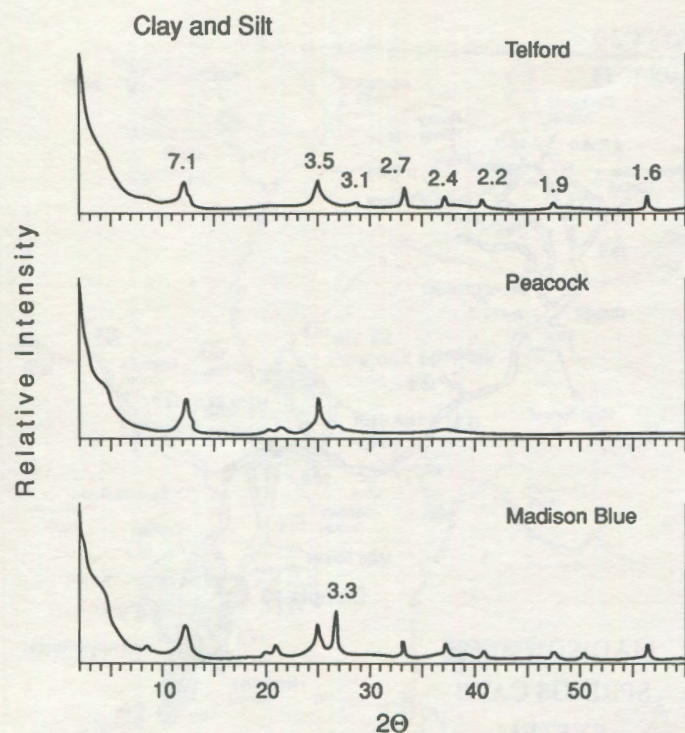


Figure 5. X-ray diffractograms of the clay plus silt fractions of sediments from three phreatic caves in the Suwannee River basin.

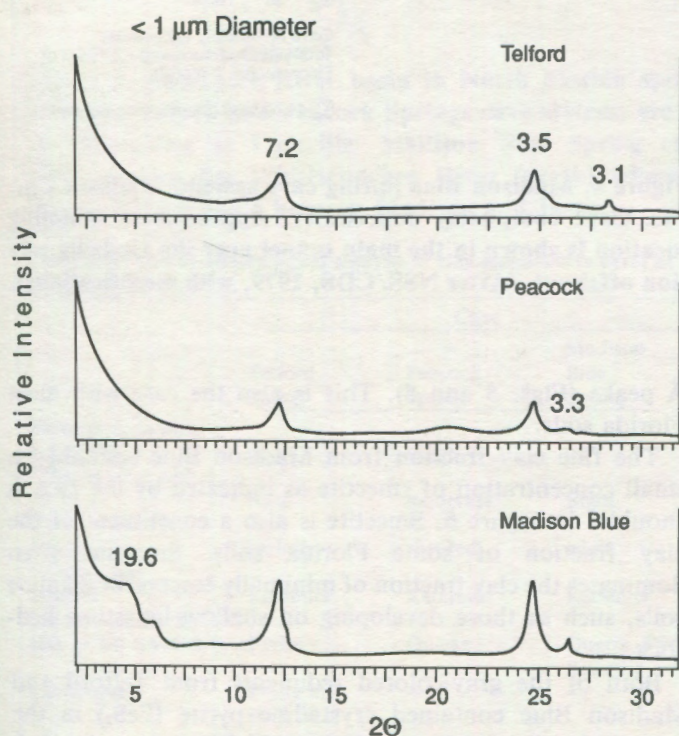


Figure 6. X-ray diffractograms of the < 1  $\mu\text{m}$  diam. clay fractions of sediments from three phreatic caves in the Suwannee River basin.

dicative of past reducing (zero oxygen) conditions in the cave. Organic carbon concentration in the sediment was not measured but reducing power supplied by organic carbon in the system may have facilitated the deposition of reduced forms of sulfur in the cave sediment. It is also possible that this pyrite is a remnant of subaqueous deposition or formation of pyrite in ancient estuaries of the ever-shifting shoreline of the Southeast U.S. Coastal Plain region (P. Bertsch, Univ. GA, SREL, personal communication). Pieces of pyrite crystals were visible under a microscope at 10  $\times$  magnification in the sand fraction of the sediment from Telford. Data from Rosenau et al. (1977) (Table 1) indicate that groundwater in the Telford cave system is higher in  $\text{SO}_4^{2-}$ ,  $\text{Ca}^{2+}$ ,  $\text{HCO}_3^-$ , dissolved solids, and other constituents of geochemical interest than the other two cave systems. The higher  $\text{SO}_4^{2-}$  concentration of water in the Telford cave system may be related to the abundance of pyrite in the Telford sediment.

After 27 months of room-temperature, aerobic storage of the aqueous silt plus clay sample from Telford, a pH of 2.1 was measured. Pyrite in the sediment had probably oxidized by this time to form sulfuric acid. If such pyrite deposits in cave sediments were perfused with oxygenated groundwater, the resulting sulfuric acid could be locally aggressive, dissolving limestone sub-aqueously. Dynamic changes in conduit and aquifer water flow could result in substantial local changes in the oxygen concentration and redox potential of cave sediments through time.

When the sand fraction and whole sediment samples from Telford were dried, clear platy crystals of gypsum were observed. These crystals apparently formed from the union of  $\text{Ca}^{2+}$  and  $\text{SO}_4^{2-}$  derived from calcite and weathered pyrite, respectively.

#### CONCLUSIONS

Preliminary data indicate that the mineralogy of clays found in the three caves studied is similar to that in overlying soils. The dominance of kaolinite may be evidence for the depositional (allochthonous) rather than *in situ* (autochthonous) origin of these materials, since neoformation (formation in place) of kaolinite may not be favored in the present geochemical setting of these caves. Water pH of 7.4 to 7.7 in these caves (Rosenau et al., 1977) constitutes thermodynamically unfavorable conditions for formation of kaolinite under most geochemical conditions. These results are similar to some of those from vadose caves (Bretz, 1942; Bögli, 1961; Bull, 1981; Gospodarić, 1974; Miller, 1991; Reams, 1968; Wolfe, 1972; Worthinton, 1991). Kaolinite and other constituents could be derived from proximal soils breached by limestone solution processes, or from river sediments transported into the system by back-flooding. During the last ice age, water table elevations in the area may have been lower. At that time these springs may not have functioned as springs, but rather may have



been swallow-holes receiving sinking streams. Such streams could have transported significant amounts of sediment into the caves.

Contribution from relict Hawthorn Group material in solution pipes cannot be ruled out, though the dominant clay mineral in the unaltered Hawthorn is smectite. For Hawthorn Group materials to be implicated as a significant source of these sediments, one would expect to find higher smectite amounts than were found in this study. One would also expect to find apatite pebbles in gravel beds in these caves. No such pebbles have been observed by cave divers anywhere in the cave systems studied. We consider autochthonous origins for these deposits to be unlikely because the sheer volume of sediment in these caves appears to be far too great to be accounted for by insoluble residues from relatively pure calcitic limestones.

These results are based on only one sediment sample from each of only three caves. More extensive and intensive sampling and more comprehensive analysis would provide a great deal more information than this preliminary study. Clay sediments of underwater caves have only begun to be examined. Information on these sediments could contribute to a better understanding of the hydrologic history and karst processes of the Suwannee River basin and other regions of karst where most caves are under water.

#### ACKNOWLEDGEMENTS

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#### REFERENCES

- Arthur, J. D. 1991. The geomorphology, geology and hydrogeology of Lafayette County, Florida. Florida Geological Survey. Open File Report 46.
- Bögli. 1961. Der Höhlenlehm. Mem. Rass. Spel. Ital. 5:11-29.
- Bretz. 1942. Vadose and phreatic features of limestone caverns. J. Geol. 50:675-811.
- Bull, P. A. 1981. Some fine-grained sedimentation phenomena in caves. Earth Surf. Proc. 6:11-22.
- Calver, J. L. 1957. Mining and mineral resources. Florida Geological Survey. Bull. 39.
- Ceryak, R., M. S. Knapp, and T. Burnson. 1983. The geology and water resources of the upper Suwannee River Basin, Florida. Florida Bureau of Geology. Report of Investigation 87.
- Exley, S. 1977. Peacock Springs cave system map. Survey by Cave Diving Section of the National Speleological Society. C. W. Smith, K. E. Miller, L. S. Holtzendorf, R. Johnson, R. W. Smith, and S. Exley. National Speleology Society/Cave Diving Section, Branford, FL.
- Exley, S. 1978. Telford Springs cave system map. P. W. Smith, S. Exley, B. Warner, and P. Meng. National Speleology Society/Cave Diving Section, Branford, FL.
- Gospodarić, R. 1974. Fluvial sediments in Krizna Jama (In Serbo-Croatian.) Acta Carsologica VI(25):327-366.
- Hoenstine, R. W., and S. M. Spencer. 1986. Geology and groundwater of Madison County. Florida Geological Survey. Open File Report 12.
- Hoenstine, R. W., S. M. Spencer, and T. O'Carroll. 1990. Geology and groundwater resources of Madison County, Florida. Florida Geological Survey. Bull. 61.
- Horne, P. 1990. Research handbook for cave divers. P. Horne, Adelaide, South Australia.
- Jennings, J. N. 1985. Karst geomorphology. Basil Blackwell, New York.
- Kaplan, D., D. C. Adriano, and P. Bertsch. Mineralogical and physico-chemical characterization of mobile colloids from two reconstructed profiles. Env. Sci. & Technol. (in review).
- Martin, H. W. 1990. Phreatite: a speleothem formed in phreatic limestone conduits. Underwater Speleology 17(6):6-10.
- Miller, Tom. 1991. Soil and rock analysis from cockpits: Implied fluvial development. In N. Peacock (ed.). Abstracts of the NSS. Annual meeting, 27 June - 1 July, 1988, Hot Springs, SD. NSS Bulletin 53(1):19.
- National Speleology Society/Cave Diving Section. 1979. Blue Springs cave system map. Survey by Cave Diving Section of the National Speleological Society. J. Zumrick, C. W. Smith, P. Deloach, W. Skiles, C. Pitcairn, C. Stevens, R. Rodgers, J. Townes, B. Stevens, T. Allen, K. Millier, P. Smith, P. Meng, B. Warner, B. Saunders, J. Stone, J. Lockwood, P. Prust, J. Hall, S. Exley, and T. Leitheuser. NSS/CDS, Branford, FL.
- Puckett, W. E., M. E. Collins, and G. W. Schellentrager. 1990. Design of soil map units on a karst area in west central Florida. Soil Sci. Soc. Am. J. 54:1069-1073.
- Puri, H. S., J. W. Yon, Jr., and W. R. Oglesby. 1967. Geology of Dixie and Gilchrist Counties, Florida. Florida Division of Geology. Bull. 49.
- Reams, M. W. 1968. Cave sediments and the geomorphic history of the Ozarks. Ph.D. dissertation, Washington University, St. Louis, MO.
- Rosenau, J. C., G. L. Faulkner, C. W. Hendry, Jr., and R. W. Hull. 1977. Springs of Florida. U.S. Geological Survey, Florida Bureau of Geology, and Florida Bureau of Water Resources Management. Fla. Bur. Geol. Bull. No. 31 (revised).
- Rupert, F. R. 1988a. The geology and geomorphology of Gilchrist County, Florida. Florida Geological Survey. Open File Report 18.
- Rupert, F. R. 1988b. The geology of Wakulla Springs. Florida Geological Survey. Open File Report 22.
- Rupert, F. R. 1991. Lithology and palynology of cave floor sediment cores from Wakulla Spring, Wakulla County, Florida. Florida Geological Survey. Open File Report 47.
- Rupert, F. R., and W. W. Wilson. 1989. The geology and hydrology of Wakulla Spring. p. 163-174. In William C. Stone (ed.), The Wakulla Springs project. U.S. Deep Caving Team, Derwood, MD.
- Sinclair, W. C., and J. W. Stewart. 1985. Sinkhole type, development, and



- distribution in Florida. U.S. Geological Survey. Florida Bureau of Geology. Map Series 110.
- Slack, L. J., and J. C. Rosenau. 1979. Water quality of Florida springs. U.S. Geology Survey. Florida Bureau of Geology. Map Series 96.
- Sweeney, J. W., and S. R. Windham. 1979. Florida: The new uranium producer. Florida Bureau of Geology. Special Publ. 22.
- White, W. B. 1988. Geomorphology and hydrology of karst terrains. Oxford Univ. Press, New York.
- Whittig, L. D., and W. R. Allardice. 1986. X-ray diffraction techniques. In A. Klute (ed.), Methods of soil analysis. Part 1. 2nd ed. Agronomy 9:331-362.
- Williams, K. E., D. Nicol, and A. F. Randazzo. 1977. The geology of the western part of Alachua County, Florida. Florida Geological Survey. Report of Investigations 85.
- Wilson, W. L. 1991. Water velocities in underwater caves of Florida. Underwater Speleol. 18(2):7-8.
- Wolfe, T. E. 1972. Fluvial cave sediments: A description and interpretation. International Geography 1:74-76.
- Worthington, S. R. H. 1991. Cave sediment fluxes in an allogenic karst. In N. Peacock (ed.), Abstracts of the NSS. Annual meeting, 27 June - 1 July, 1988, Hot Springs, SD. NSS Bulletin 53(1):19.



# FIRST RECORD OF THE COLONIAL CNIDARIAN CORDYLOPHORA LACUSTRIS WITHIN A FLOODED CAVE SYSTEM

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*Fourteen colonies of the freshwater colonial cnidarian Cordylophora lacustris were found in the fully-flooded cave system at Little River Spring, Suwannee County, Florida. This is the first record of colonial cnidarians from caves. A plankton sample collected from the cave contained epigeal species. Flow-reversal is suggested as a mechanism by which epigeal fauna enters fully-flooded caves.*

## INTRODUCTION

Ecological relationships among organisms living in the water-filled cave systems associated with Florida's springs are poorly understood. Past work on Florida's aquatic cave communities has focused primarily on troglobitic (cave obligate) forms, especially crayfishes. Franz and Lee (1982) discussed the distribution and evolution of Florida's troglobitic crayfishes, while Caine (1978) compared adaptive traits of epigeal and troglobitic crayfishes in Florida. In addition to troglobitic forms, numerous epigeal forms, including the American eel *Anguilla rostrata* and the yellow bullhead *Ictalurus natalis*, are known to inhabit Florida's aquatic caves (Relyea and Sutton, 1973), with *A. rostrata* apparently following a diel migration pattern to and from caves (Helfman, 1986). The redeye chub *Notropis harperi* and the pirate perch *Aphredoderus sayanus* have been reported from spring-caves and from pools in partially flooded caves (Marshall, 1947; Brockman and Bortone, 1977). Recently, colonization of aquatic caves by the exotic Asiatic clam *Corbicula fluminea* (Streever, 1992a) and tubificid worms (Streever, 1992b) has been reported. Information regarding competition and predation relationships between troglobites and epigeal forms that temporarily or irregularly inhabit caves is scarce. Zooplankton populations from Florida's caves have not been investigated.

Little River Spring cave system, located on the north bank of the Suwannee River in Suwannee County, Florida (lat. 29°59'47"N., long. 82°57'59"W.), consists of over 3000 m of known passage, all of which is submerged. The spring normally discharges water from the Floridan aquifer. The rate of discharge on 27 November 1973 was 84.4 m<sup>3</sup>/s, but this rate may change as a function of hydrostatic head (Rosenau et al., 1977). Following heavy rains, rising water levels in the Suwannee River can stop and occasionally

reverse the spring's flow, subsequently allowing river water to enter the cave. The last observed flow-reversal prior to this study occurred in November 1991.

This paper reports the colonization of the Little River Spring cave system by *Cordylophora lacustris* (Allman), an epigeal colonial cnidarian similar to *Obelia* spp. in appearance (Pennak, 1989). The colonization appears to have occurred following flow-reversal and mixing of the cave's spring water with Suwannee River flood water. A zooplankton sample from the cave was examined in an attempt to assess *C. lacustris* prey availability.

## METHODS

Divers equipped with 50 watt submersible lights visually censused *C. lacustris* colonies between 14 December 1991 and 24 January 1992. Census dives were completed to a distance of approximately 800 m from the cave's entrance at depths of 10-34 m. To insure against counting a single colony twice, the position of colonies was temporarily marked on the cave's permanent guideline. When conditions (cave configuration and current) allowed, dimensions of colonies were measured. Divers collected portions of colonies for examination in the laboratory. A single plankton sample was collected adjacent to a *C. lacustris* colony at a depth of 15 m by allowing water to flow through a Wisconsin plankton net for four minutes. A second census was conducted on 26 August 1992 in order to determine the status of colonies following six months of normal water flow. No attempt was made to measure colony dimensions or to collect plankton during this second census.

## RESULTS AND DISCUSSION

During 11 dives prior to the flow-reversal of November



1991, no colonies of *C. lacustris* were seen within the Little River Spring cave system. On dives following the flow-reversal, a total of 14 *C. lacustris* colonies was found within 400 m of the cave's entrance. No additional colonies were found beyond 400 m from the entrance. This census probably underestimated the true number of colonies since numerous passages which are too restricted for divers may contain colonies. Areal cover by colonies ranged from 0.1 m<sup>2</sup> to 4 m<sup>2</sup>, with a mean of 0.8 m<sup>2</sup> ( $n = 8$ , S.D. = 1.34 m<sup>2</sup>). Colony heights did not exceed 0.04 m. Colonies were generally anchored to limestone, although in some instances they had overgrown patches of clay and sand surrounded by limestone. Microscopic examination revealed that both gastrozooids (feeding polyps) and gonozooids (reproductive polyps) were present.

Ten colonies were located on the 26 August 1992 census. Three markers that had been left in the cave following the initial census were still present, and in all three cases the adjacent colonies appeared to be thriving. At least one new colony was located growing on the cave's permanent guideline. Because the majority of the markers had been removed from the guideline, it was impossible to know with certainty that the 6 additional colonies were the same as those which had been counted during the initial census. Also, the reduction from 14 colonies in January to 10 colonies in August 1992 may reflect a true reduction in the number of colonies or merely a less intensive censusing effort. Because of logistical and safety concerns, and because the goal in re-censusing the colonies focused primarily on establishing their ability to survive during periods of normal water flow, more intensive censusing could not be justified.

Previous reports of *C. lacustris* indicate a cosmopolitan distribution in brackish inlets, estuaries, and rivers (Pennak, 1989). *C. lacustris* dispersal is by means of a free-swimming planula larva; no medusa stage occurs (Pennak, 1989). Although *Hydra spp.* have been reported from caves (Vandel, 1965), the appearance of *C. lacustris* in the Little River cave system represents the first reported occurrence of colonial cnidarians in cave systems.

Cursory examination of the plankton sample revealed the presence of 16 individuals of a single unidentified species of calanoid copepod, 5 unidentified copepod nauplii, 8 individuals of *Eubosmina spp.*, a single *Leydigi quadrangularis*, and 4 unidentified rotifers. *Eubosmina spp.* and *L. quadrangularis* are typically found in surface water samples (Pennak, 1989).

Introduction of *C. lacustris* to the cave system probably occurred when planula larva were flushed into the cave dur-

ing the period of reversed water flow in November 1991. The appearance of tubificid worms in the aquatic cave system at Peacock Springs, Suwannee County, Florida also occurred following river water inundation of the cave (Streever, 1992b). Thus, flow-reversal events may be periods of population introduction for Florida's aquatic cave systems. A similar pattern of population introduction following hydrologic events has been reported in terrestrial caves of West Virginia (Culver, 1970). Also, introductions of *N. harperi* and *A. sayanus* to pools of a terrestrial cave in Jackson County, Florida appear to follow flooding of the Chipola River (Brockman and Bortone, 1977). In the Little River Spring cave system, zooplankton introduction may have occurred during the flow-reversal, but since no plankton samples were collected prior to the flow-reversal the possibility remains that a zooplankton population typically inhabits the cave.

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#### Literature Cited

- Brockman, K. A. and S. A. Bortone. 1977. Cave dwelling fishes in panhandle Florida. *Florida Scient.* 40 (4):406-407.
- Caine, E. A. 1978. Comparative ecology of epigean and hypogean crayfish (Crustacea: Cambaridae) from Northwestern Florida. *Am. Midl. Nat.* 99:315-329.
- Culver, D. C. 1970. Analysis of simple cave communities. I. Caves as islands. *Evolution.* 24:463-474.
- Franz, R. and D. S. Lee. 1982. Distribution and evolution of Florida's troglobitic crayfishes. *Bull. Florida State Mus., Biol. Sci.* 28 (3):53-78.
- Helfman, G. S. 1986. Diel distribution and activity of American eels (*Anguilla rostrata*) in a cave-spring. *Can. J. Fish. Aquat. Sci.* 43:1595-1605.
- Marshall, N. 1947. The spring run and cave habitats of *Erimystax harperi* (Fowler). *Ecology.* 28 (1):68-75.
- Pennak, R. W. 1989. Fresh-water invertebrates of the United States. John Wiley and Sons. Ronald Press, New York. 628 p.
- Relyea, K. and B. Sutton. 1973. Cave dwelling yellow bullheads in Florida. *Florida Scient.* 36 (1):31-34.
- Rosenau, J. C., G. L. Faulkner, C. W. Hendry, Jr., and R. W. Hull. 1977. Springs of Florida. Florida Bureau of Geology, Bulletin No. 31 (Revised). 461 p.
- Streever, W. J. 1992a. First record of *Corbicula* clams within flooded cave systems. *Florida Scient.* 55 (1):35-37.
- Streever, W. J. 1992b. Report of a cave fauna kill at Peacock Springs cave system, Suwannee County, Florida. *Florida Scient.* 55 (2):125-128.
- Vandel, A. 1965. Biospeleology, the biology of cavernicolous animals. Pergamon Press, Oxford. 524 p.



# HOW MANY SPECIES OF TROGLOBITES ARE THERE?

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The growing interest in biodiversity has prompted us to consider the question of the number of cave species there are likely to be. With the possible exception of birds and perhaps mammals, there is no group of organisms for which the total number of species is known directly. There is certainly no group of invertebrates for which even a majority of species are known, let alone described. Indeed, most arguments about global diversity (see Erwin, 1982; 1988) depend on a series of assumptions about the connection between local species diversity, e.g. the insects on a tree, and regional diversity. We describe below our estimate of the number of species of cave-limited species on a world-wide basis in the hopes of provoking further consideration of questions of biodiversity of cave organisms.

We start with a list of the described species of obligate cave animals in the Virginias, a region that has one of the best known cave faunas, at least in the U.S.A. Based on our two monographs of this fauna (Holsinger et al., 1976; Holsinger and Culver, 1988) we list the known species in Table 1. A total of 160 species is known and described in the litera-

ture. Additional species are known but not described (e.g. Ferguson, 1981) and still others are undiscovered. Among the groups listed in Table 1, one of the most studied is the amphipods. We estimate that the total number of cave-limited amphipod species, including described, collected but not described, and uncollected is 43. This includes 29 described species, 5 undescribed species of *Gammarus*, 6 undescribed species of *Stygobromus*, and 3 uncollected species. Since we have collected from over 500 caves in the two states, the number of uncollected species is likely to be small.

The second step is to estimate the total number of aquatic cave limited species in the Virginias. In the recent compilation of Botosaneanu (1986), a total of 1444 subterranean karstic species is listed (Table 2). This includes groups little studied in the Virginias such as the Ostracoda and Copepoda. We assume the proportions listed in Table 2 represent the relative proportions of species in Virginia and West Virginia caves, if the fauna were completely known. Since 20.6% of the species listed by Botosaneanu are amphipods, we estimate that the total number of aquatic species in the Virginias is 209 ( $= 43/.206$ ).

The third step is to estimate the total number of terrestrial and aquatic cave-limited species in the Virginias. Of the

Table 1. Number of cave-limited species (troglobites = TB), the number of single cave endemics, and the number of regional endemics (i.e., endemic to the Virginias) in Virginia and West Virginia. Data are from Holsinger et al. (1976), Holsinger and Culver (1988) and unpublished compilations.

Taxonomic Group	TB	Single	
		Cave Endemics	Regional Endemics
Flatworms	9	4	7
Oligochaetes	4	3	4
Snails	4	2	4
Amphipods	29	7	23
Isopods	17	3	13
Crayfishes	1	0	1
Pseudoscorpions	18	13	18
Mites	5	1	5
Spiders	9	2	4
Centipedes	1	0	1
Millipeds	10	0	10
Springtails	8	2	7
Bristletails	2	0	2
Beetles	42	17	40
Salamanders	1	1	1
TOTAL	160	55	140

Table 2. Number and frequencies of aquatic species in different taxonomic groups described from caves and associated karst features, compiled from Botosaneanu (1986). Only groups with 10 or more species are listed.

Group	Number	Per Cent
Platyhelminthes	69	4.8
Nematoda	12	0.9
Mollusca	238	16.5
Annelida	38	2.6
Crustacea		
Copepoda	252	17.5
Ostracoda	59	4.1
Isopoda	241	16.7
Amphipoda	298	20.6
Decapoda	117	8.1
Other	55	3.8
Chordata		
Pisces	35	2.4
Caudata	14	1.0



species listed in Table 1, 38.1% are aquatic. If this is the true proportion of aquatic species, then the total number of troglobites in the Virginias is 549 (=  $209/.381$ ).

The fourth step is to estimate the total number of species in the Appalachians. Over 85% of the species are endemic to the region and over one-third are known from a single cave (Table 1). Furthermore, those few species known from a broad area are likely to be a series of sibling species that are morphologically indistinguishable and but genetically distinct (see Laing et al., 1976). We assume that the number of species increases linearly with area. The actual relationship may be more complex and better described by log or semi-log relationships, but we use as a first estimate a simple linear relationship. Roughly half of the Appalachian karst areas south of the glacial maximum are in the Virginias, so the total estimate of troglobites in the Appalachians is 1000.

The fifth step is to estimate the total number of species in the continental U.S.A. There are six karst regions with a diverse cave fauna (see also Barr, 1967): Florida limestone areas, Appalachians, Cumberland Plateau, Interior Low Plateaus, Ozark Plateau, and Edwards Aquifer. If the faunas in each region are roughly equivalent, there should be 6000 troglobites in the U.S. Note that we have ignored regions with at least some cave invertebrates such as Guadalupe Mountains, Sierra Mountains, Columbia Plateaus, etc. More importantly, we have not included the highly diverse fauna of lava tubes in Hawaii (Howarth, 1972; 1981). Thus, this estimate is likely to be an underestimate.

The final step is to estimate the total number of species on a global basis. If the U.S. has roughly 10% of the karst that was not covered by glaciers, then the total number of worldwide species should be about 60,000. The fauna of lava tubes are likely to have 1000 to 10,000 additional species. More generally, we expect that the number of troglobites worldwide is between 50,000 and 100,000.

#### References Cited

- Barr, T. C. 1967. Observations on the ecology of caves. *Amer. Natur.* 101:475-492.
- Botosaneanu, L. [ed.] 1886. *Stygofauna mundi*. E. J. Brill, Amsterdam.
- Erwin, T. L. 1982. Tropical forests: their richness in Coleoptera and other arthropod species. *Coleopterists Bull.* 36:74-75.
- Erwin, T. L. 1988. The tropical forest canopy: the heart of biotic diversity, pp. 123-129. In E. O. Wilson [ed.], *Biodiversity*. National Acad. Press, Washington, D.C.
- Ferguson, L. M. 1981. Cave Diplura of the United States. *Proc. Eighth Int. Congr. Speleology*, Bowling Green, Ky. 1:11-12.
- Holsinger, J. R., R. A. Baroody, and D. C. Culver. 1976. The invertebrate cave fauna of West Virginia. *Bull. W. Va. Speleological Survey*, No. 7, 82 p.
- Holsinger, J. R., and D. C. Culver. 1988. The invertebrate cave fauna of Virginia and a part of east Tennessee: zoogeography and ecology. *Brimleyana* No. 14:1-162.
- Howarth, F. G. 1972. Cavernicoles in lava tubes on the island of Hawaii. *Science* 175:326-326.
- Howarth, F. G. 1981. Non-relictual terrestrial troglobites in the tropical Hawaiian caves. *Proc. Eighth Int. Congress Speleology*, Bowling Green, Ky. 2:539-541.
- Laing, C. D., G. R. Carmody, and W. B. Peck. 1976. How common are sibling species of cave-inhabiting invertebrates. *Amer. Natur.* 110:184-189.



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ARCHAEOLOGY AND ANTHROPOLOGY

BIG MANHOLE CAVE, EDDY COUNTY

Pat Jablonsky - Department of Earth Science, Denver  
Museum of Natural History

Big Manhole Cave is located on Federal (BLM) lands less than a quarter mile from Carlsbad Caverns National Park and approximately one mile east of Lechuguilla Cave. Big Manhole Cave is not a recent discovery but was explored as far back as Jim White's era of exploration in the early years of the century. In 1988, when exploration at Lechuguilla Cave was at a fevered pitch and trips into the cave were beginning to exceed a few days, exploring for a possible second entrance was considered. It was at this time that cavers remembered that Big Manhole Cave had been reported as having blowing air. Because of its close proximity to Lechuguilla Cave, renewed interest opened exploration at Big Manhole.

The cave has not produced significant cave nor proven to be the "back door" to Lechuguilla but it has proven to be important for paleontological and sedimentological studies. Dr. Art Harris of University of Texas at El Paso and Dr. Tom Stafford of the Institute for Arctic and Alpine Research, Boulder, Colorado, have been provided a veritable gold mine of bones and sedimentological deposits. Species of extinct and extant mammals have been identified and the sediments are providing invaluable data for climatological and other related studies.

ARE YOU SOMEWHERE BETWEEN BEING A GONZO  
CAVER AND THE ARMCHAIR VARIETY? LOOKING FOR  
A NICHE TO FILL? STAY TUNED FOR SOME EXCITING  
IDEAS

Pat Jablonsky - Department of Earth Science, Denver  
Museum of Natural History

Cavers can get involved in some exciting and worthwhile caving activities by assisting researchers and scientists with a variety of activities—anything from being sherpas to conducting actual research experiments. In recent years more and more opportunities have arisen for cavers to assist researchers and complete research in caves. Carlsbad Caverns National Park and its numerous caves and

various research projects being completed by scientists is the subject of this presentation.

HANGING YUCCA SHELTER CAVE: NEGATIVE HAND  
PRINTS IN THE MIDDLE PECOS VALLEY OF NEW  
MEXICO

Carol Belski - White Sands Grotto, GYPKAP, Southwestern  
Region

Since the early 1980s this shelter cave has received occasional attention from Southwestern Region personnel because of its archaeological manifestations. The ceiling of the shelter has several negative hand prints, painted in ochre color. The alluvial fill in the cave has produced several finds of potsherds. Most recently, possible teepee rings, shelter walls, fire pits, and hearth rings have been noted in the immediate area of the shelter cave. Research has shown that this area was inhabited intermittently since Pale-Indian times, at least since 8000 B.C. The hostile environment discouraged any permanent settlements until modern technology came forth. The questions of "Who?" and "Why?" are explored in this continuing research project.

LECHUGUILLA CAVE, CARLSBAD CAVERNS NATIONAL  
PARK CHIROPTERAN STUDIES

Pat Jablonsky - Department of Earth Science, Denver  
Museum of Natural History

The purpose of this study was to collect, identify, and compare the chiropteran faunas found in the cave with other such faunas of Carlsbad Caverns National Park. The first aspect of this project utilized cavers from the 1990-1991 Lechuguilla Cave Project Christmas Expedition. Cavers participating received a collections kit with simple instructions on how to collect the delicate specimens and bring them safely to the surface for study. Results included the recovery of 15 skulls or partial skulls. Ten other specimens were left in the cave due to either the fragility of the skeletons or their cementation to formations. Four species belonging to three genera were collected; all are members of the family, Vespertilionidae.



## CASS CAVE MASTODON *MAMMUT AMERICANUM* SETS RANGE AND ELEVATION RECORDS FOR WEST VIRGINIA

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The recent find of a well preserved juvenile mastodon tooth *Mammot americanum* in Cass Cave, Pocahontas County, West Virginia marks the 17th mastodon discovery for West Virginia. Including nine mastodon discoveries there have been a total of 26 "elephants" found in the state. Eight mastodons but no mammoths have been found in West Virginia caves. Other mastodon finds include Organ, Rapps, and McFerrin Caves in Greenbrier County; two from Scott Hollow Cave in Monroe County; Bowden Cave, Randolph County; and Big Springs Cave, Tucker County. This discovery is made even more significant because it extends the range of the mastodon into Pocahontas County. In addition, this discovery extends the elevation range for mastodon in West Virginia to 2,975 feet. Mastodons and Mammoths became extinct at the end of the Pleistocene thus the discovery is assigned a minimum age of 10,000 years.

## A PATHOLOGICAL PECCARY CANINE FROM A WEST VIRGINIA CAVE

Frederick Grady - 1201 South Scott Street, Apartment 123,  
Arlington, Virginia 22204

A pathologically deformed lower canine of *Platygonus compressus* has been identified from Maiden Run Cave #1, Monongalia County, West Virginia. The tooth is from a mature individual and the crown is well worn. The root is peculiar in that it shows a tendency toward doubling on the fore to aft plane. Heavily grooved canines of *Platygonus compressus* have been previously described; the grooves being attributed to feeding on abrasive roots or leaves.

## CERRO RABON ARCHAEOLOGICAL SURVEY 1992 (MEXICO): PRELIMINARY RESULTS

Roman Hapka

During the past ten years of speleological survey on the Cerro Rabon plateau in the southeast corner of the Sierra Mazateca (Oaxaca), cavers have encountered different kinds of cave and rock shelter occupations.

After nine weeks of archaeological research in 25 newly discovered sites near the villages of San Martin Caballero and Altamira, the first results show a high density of human use of caves in the past. Different kinds of tombs and water tanks constituted the built structures discovered; no settlements were found.

The artifacts, like ceramics, stone axes, and obsidian blades permitted us to date the first occupation of this area in the Postclassic period (900-1550 AD). The geographical limit of the Postclassic habitations seems to correspond to the modern one. This limit seems also to be the furthest point where the indigenous people penetrated in the thrilling pristine cloud forest that is still covering a part of the Cerro Rabon plateau.

## BIOLOGY

### PALEOBIOLOGICAL RESOURCES FROM THE INDIANA KARST: EXTINCT AND EXTRALIMITAL VERTEBRATE REMAINS

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Twenty-seven extinct and extralimital vertebrate taxa have been recovered from Quaternary-aged cave and karst features in southern Indiana. Extinct taxa include the giant land tortoise, beautiful armadillo, dire wolf, Leidy's peccary, flatheaded peccary, long-nosed peccary, and Harlan's musk-ox. Extralimital species that no longer occur in Indiana include the hairy-tailed mole, arctic shrew, longtail shrew, smoky shrew (large variant), marsh rice rat, southern red-backed vole, heather vole, yellow-cheeked vole, southern bog lemming, and snowshoe hare. Remains of the western ophisaur, smooth green snake, plains pocket gopher, thirteen-lined ground squirrel, and eastern woodrat record distributional changes of taxa currently inhabiting the state. <2>The Indiana remains range in age from the last (Sangamonian) interglacial into late Holocene times. Several middle- and late-Wisconsinan radiocarbon dates have been determined from bone collagen.

As is the pattern on many Late Pleistocene localities throughout much of North America, several Indiana cave deposits record the co-occurrence with extinct taxa of northern and temperate species that today have segregated ranges. This lends support to the Climatic Equability Model which suggests that late Pleistocene climates had less seasonal temperature extremes with more evenly distributed moisture, resulting in a relaxing of



environmental barriers that currently segregate the distribution of many species.

The snowshoe hare, pygmy shrew, and smoky shrew currently display geographical variation in size. The Indiana fossils indicate larger individuals than those currently inhabiting the state, suggesting affinities with more northern populations of snowshoe hare, pygmy shrew, and perhaps also smoky shrew.

Some fossils demonstrate biological change of species through time. Late Pleistocene black bear (*Ursus americanus amplidens*) fossils are larger than those of the later (Holocene) sub-species *Ursus a. americanus*. *Platygonus vetus* (Illinoian or Sangamonian aged) appears to have evolved into the smaller *P. compressus* of later, Wisconsinan times.

The diversity and abundance of terrestrial vertebrate remains recovered from the cave and karst features of southern Indiana have not been preserved in the other major depositional environments (kettle lake and bog, glacial sluiceway, and floodplain deposits) of Indiana. The caves preserve a unique and sometimes long biological and environmental history. Preservation and management of these resources is important if those histories are to be understood.

#### THE MICROBIAL WORLD OF CAVES

Larry Mallory, Professor, Environmental Sciences Program, Department of Plant and Soil Science University of Massachusetts, Amhurst, Massachusetts 01003

Carbonates represent the largest single reservoir of carbon on earth. Many organisms, procaryotic and eucaryotic, are capable of both direct and indirect solubilization and deposition of carbonate minerals. The White Cliffs of Dover, England, are striking evidence that biota are capable of large scale geochemical activities involving carbonate. It is, therefore, not surprising that limestone caves support a large, highly diverse bacterial community. Bacteria are most often found at interfaces, especially those in which one phase is water. Our laboratory group has completed extensive characterization of microbial communities found in the Ten-Mile Creek cave system in Tennessee and the Mammoth Cave system in Kentucky. We examined moist, drained sands and clays, as well as saturated materials for bacterial density, respiratory activity, and phenetic and metabolic diversity. We have studied the presence and density of human pathogens, and examined the bacterial community response to the addition of trace amounts of toxic organic chemicals.

The density of bacterial cells varied from  $8.6 \times 10^3$  to  $5.1 \times 10^7$  cells per wet gram. The lowest estimates were obtained from moist, fine-grained material that had not

received additional water for at least 11 months. The highest estimates were made from saturated sand and gravel that received a constant addition of flowing water. The dissolved oxygen concentration in the latter sample was 9.6 mg per liter. In many samples actively respiring cells, determined using an *in situ* staining technique, accounted for over 50% of total cells. This is somewhat surprising given that total organic carbon in these samples ranged from 37  $\mu$ g to 41  $\mu$ g per liter. A total of 846 strains isolated from 4 sites have been examined for 117 to 195 morphological, physiological, and biochemical characteristics. Both oligotrophs and copiotrophs were recovered for study. Numerical taxonomic techniques were used to cluster the resulting strain x test matrices. All sites exhibited a high degree of phenetic diversity and very few defined groups could be identified to species level with any confidence. A typical cave bacterium was found to be a short, nonmotile rod which formed small, raised off-white colonies on peptone-containing agar medium. The strain does not form spores and is not acid fast. The typical cell grew at 12C, was capable of growth in the presence of 2% (w/v) NaCl, or at pH 9.0, and possessed the enzyme catalase. As a group, cave bacteria were found to be more capable of utilizing recalcitrant organic compounds as sources of carbon and energy in comparison to surface microbial communities. Over 10% of tested strains were capable of cellulose digestion and two-thirds utilized cellobiose, an intermediate of cellulose metabolism. Approximately 25% of tested strains were capable of using benzoate as a sole carbon and energy source. The bacterial community found in limestone caves was metabolically active, and possessed both oligotrophic and copiotrophic members. The community was typified by a high amount of phenetic and metabolic diversity.

#### THE IMPORTED RED FIRE ANT IN TEXAS CAVES

William R. Elliot - Research Associate, Texas Memorial Museum and Contract Biologist  
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The imported red fire ant *Solenopsis invicta* Buren invaded the United States in the 1930s through the port of Mobile, Alabama. The species moved into Texas by 1956. In 1989 the ant began colonizing karst areas in central Texas and cavers began reporting infestations in cave entrances. By 1991 about 40% of the known endangered species caves in Travis and Williamson Counties had fire ants foraging inside. The 18 to 24°Celsius temperature of Texas caves is nearly optimal for foraging ants but not for reproduction. The ants have been observed preying on



young cave crickets, millipeds, pseudoscorpions, earthworms, and other fauna. Eleven endangered species cave areas were compared regarding treatments of ant mounds with hot water and the commercial ant baits, Logic and Amdro, while another area received no treatment. Hot water with detergent was the most effective treatment but was too costly in time and labor for large areas. Hot water or steam is recommended for its immediate benefits and for its minimal impact on other fauna. Control of fire ants will be a long-term task on endangered species preserves that are being established in the Austin area. This study was supported by the Texas Parks and Wildlife Department, U. S. Fish and Wildlife Service, and the Ciba-Geigy Company.

#### LUMINOUS CAVE MOSS: EMERALD OF THE PLANT KINGDOM

Nancy E. Holler - PO Box 100, Old Fort, NC 28762

Through the ages, speleologists have always been intrigued by any natural phenomena which penetrates the subterranean darkness. Perhaps the least known but most fascinating of these oddities is the luminous cave moss, *Shistostega pennata*. While most cavers have heard of the famous glowworms in the Waitomo caves, or the mysterious calcite afterglow, the luminous cave moss is equally beautiful and impressive.

In July 1991, in a little-known sea cave in New England, Dad and I had a rare opportunity to observe and photographically document this exquisite plant first hand. The moss is able to grow in relatively dark, moist areas by concentrating what small amount of light is available. The tiny lens-like structures of the plant reflect part of the light from the cave's twilight zone, giving a spectacular emerald-green cat-eye effect.

#### SOME OBSERVATIONS ON THE DISTRIBUTION AND MICROHABITAT OF *CAECIDOTEA CAROLINENSIS*

Dr. Cato Holler, Jr. - PO Box 100, Old Fort, NC 28762

The Ascid crustacean, *Caecidotea carolinensis*, has of this date, been collected from only two locations. The first site is a small seep flowing through a non-carbonate tectonic cave in the western Piedmont Province of North Carolina. The second location is over 170 airline miles away in a limestone solution cave in coastal South Carolina. The latter specimens were found residing beneath pine cone bracts in backwater areas of an active underground stream.

#### INVERTEBRATES AND MICROORGANISMS OF LECHUGUILLA CAVE

Deborah L. Carr, M. Tad Crocker, Lavrairie K. Hawkins, Patricia Leonard, W. Calvin Welbourn

A biological inventory of Lechuguilla Cave, Carlsbad Caverns National Park, Eddy County, New Mexico, was conducted from July 1989 through December 1991. Studies concentrated on the identification of invertebrates, fungi, and bacteria inhabiting the Entrance Pit and the Dark Zones of the cave. invertebrates found in the Entrance Pit included a variety of accidental species (beetles, flies, ants, and grasshoppers) and several troglonec, troglophilic and troglotic species (camel crickets, rhadine beetles, mites, collembolans, and millipedes). A variety of spider species was found, many of which probably inhabit the entrance area. Dark Zone invertebrates were limited to two species of camel crickets, rhadine beetles, one species of collembolan, one species of dipluran, and one species of centipede. Thirty-seven different species of fungi in 13 different genera were cultured from a variety of habitats in the cave. Seven different species of bacteria were identified to genera.

#### SYSTEMATICS AND POPULATION GENETICS OF HELEOMYZID FLIES IN CAVES

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Several species of heleomyzid flies commonly occur in caves. Despite their abundance, their significance in cave ecosystems has been overlooked. I made several collections of heleomyzid adults from caves in southern Illinois, central Indiana, and central Kentucky. An analysis of preliminary data suggested differences in the seasonal and spatial distributions of five species. *Aecothea specus* (Aldrich) was common in both entrance and total-darkness areas in all seasons except winter. *Aecothea fenestralis* (Falln) was not found; confusion of it with the previous species may have caused erroneous literature records of it in caves. I commonly found *Amoebaleria defessa* (Osten Sacken) during the warmer months and *Amoebaleria sackeni* Garrett during the winter months. Both *Amoebaleria* species were more common in deep cave areas. *Heleomyza brachyptera* (Loew) was more common near entrance areas and common all year. *Heleomyza serrata* (Linnaeus) was rare and only found near entrances. All five species were limited to damp and muddy areas of caves.



The classification of four species remains unresolved. Shape of male genitalia is the only character that distinguishes *Ae. fenestralis* from *Ae. specus* and *Am. defessa* from *Am. sackeni*. Some taxonomists treat the congeners as two species and others treat them as a single variable species.

Using starch gel electrophoresis of enzymes of adult flies, I found allozyme differences that distinguish *Am. defessa* and *Am. sackeni*, indicating that they are reproductively isolated. I also gathered allozyme data for *Ae. specus*, *H. brachyptera* and *H. serrata*. I assessed with these data genetic variability within populations of the five species and related it to environmental variability. I analyzed the genetic differentiation of populations from different caves with Wright's F-statistics and calculated genetic distance estimates for all pairwise comparisons of populations and species.

#### A UNIQUE CHEMOAUTOTROPHICALLY BASED CAVE ECOSYSTEM

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A unique subterranean ecosystem associated with thermomineral - sulfurous waters has recently been discovered in Southern Dobrogea, Romania. Twenty five unknown species of terrestrial and aquatic troglobites have been discovered in the Movile Cave so far. Their advanced troglomorphy suggests that they are evolutionary quite old, having origins perhaps in the Miocene (5.5 to 5.2 million years ago). The entire energy base of the biological community appears to be supplied by autochthonous chemolithoautotrophic carbon fixation by sulfide-oxidizing microorganisms. The sulfideoxidizing bacteria present in the water of the Movile Cave may have an active role in the process of karstogenesis in this region.

#### THE SOURCE OF SULPHUR RIVER IN PARKER CAVE, KENTUCKY: A CASE OF OIL WELL POLLUTION OR A RISE OF NATURAL BRINE

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When Sulphur River was discovered in 1974, the sulfurous brine entering Parker Cave was interpreted by Jim Quinlan (then at Mammoth Cave National Park) as originating from abandoned, uncased oil wells that abound

in the area. However, there was another possibility based on three lines of evidence. If brine could rise up old oil wells then it could also rise up natural fractures, and Parker Cave is developed within a structural monocline where a higher fracture density would be expected.

A lineament analysis of the area by Angelo George (George Consultants) identified an open triangular intersection in the southwestern part of the cave; sites where lineaments cross have been considered zones of enhanced vertical hydraulic conductivity. Finally, data on the growth rate of the Phantom Flowstone (a poorly consolidated mass deposited by Sulphur River) indicated that far more time than the 60 years since oil exploration began would be needed to account for the present accumulation. Recent tests with a steel probe revealed that whereas the entire lower mass is two meters high, the poorly consolidated portion is at most half a meter thick. These observations support the original interpretation that Sulphur River rises from an abandoned oil well.

Flow from unplugged wells is thought to affect water quality in other streams in Parker Cave as well and the effects are expressed in the subterranean aquatic biological community. For example, massive crayfish die-offs have been observed in Parker River. Plugging leaky wells is good for the aquifer and that's good for everybody, including cave life. But to plug them you've got to find them, and this is very difficult because locations (if even recorded) are often inaccurate. Visual clues over Parker Cave are scant because the drilling sites have been rehabilitated to pasture and casings were often pulled to save money.

Cultural clues in concert with sensing technology may provide a way to find obscure abandoned wells. Henry Holman (Mammoth Cave National Park) has made extensive observations on where oil wells have been sited in relation to property lines and land use practices. These and observations on where the well would have been located relative to cuttings and other debris from the drilling operation can narrow the search. Although most casings were pulled, a magnetometer survey would detect buried bits of cable and other ferrous debris. Ground penetrating radar would be an alternative except that clay is virtually opaque to this wavelength. Bill Wilson (Subsurface Evaluations Incorporated) has suggested using a low-level gamma scintillation detector to locate shale cuttings left from the drilling, and possibly even radon gas rising through the well.

If a strategy for finding old wells is worked out, and these are plugged, then Parker Cave provides an excellent opportunity to measure any success in aquifer remediation. Joe Meiman (Mammoth Cave National Park) has monitored water quality in and downstream of Parker Cave for the past decade. If Sulphur River or any of the less anomalous



stream chemistries improve after plugging a well, then we will receive feedback on our efforts. This is important not only for the Central Kentucky Karst, but for all karst areas where hydrocarbon exploration has occurred. Any suggestions from interested readers will be welcome.

#### SULFIDE-CONTAINING CAVES AS ANALOGS OF SUBMARINE HYDROTHERMAL VENT ECOSYSTEMS

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It has become evident over the past decade that sulfide-driven ecosystems can achieve very high primary productivity. The most spectacular examples of such ecosystems are in association with submarine hydrothermal vents along the Mid-Ocean Ridge on the ocean floor. There, millimolar concentrations of sulfide emitted in hydrothermal fluids fuel dense microbial communities. In turn, animal communities are supported through grazing and the establishment of symbiotic relationships with sulfideoxidizing bacteria. In contrast to the best-known forms of life, which rely ultimately on light as an energy source, submarine hydrothermal vent communities are dependent only upon chemical energy, mostly metabolism of sulfide. Such ecosystems raise many interesting biological and biochemical questions. Although novel, such ecosystems are little-studied because of their remoteness, usually 2 kilometers in depth on the ocean floor. Access is only by advanced submersibles.

Ecosystems associated with terrestrial sulfide-containing springs have long been studied by microbiologists, although progress has been limited by a general inability to cultivate community constituents for laboratory studies. Such communities generally are not applicable to the submarine situation, because sulfide also can serve in bacterial photosynthesis, so the basis of the food chain is not exclusively chemical and the organismal composition differs in the presence and absence of light (photo synthesis). In the cavern environment, light is not available and so the sulfide-based communities truly are similar to at least low-temperature hydrothermal vents. (Most hydrothermal discharge is 30° Celsius.) Inspection of some sulfide-containing communities of microorganisms and invertebrates presumably supported by the sulfur-oxidizing microorganisms. Such caves offer excellent and accessible models for sea floor communities.

#### CONSERVATION AND MANAGEMENT

##### LINT ACCUMULATIONS IN CAVES ARE BECOMING MORE PREVELANT

Pat Jablonsky - Department of Earth Science, Denver  
Museum of Natural History

Until recently, lint accumulations in caves was thought to be little more than a nuisance and only minor efforts had been done to abate or control its impact. Lint accumulations are now recognized as a serious concern and the abatement of lint is being realized in numerous commercial caves.

Observations in Carlsbad Cavern indicate that lint is not just a benign aesthetic problem but under some conditions is an active medium for erosion of formations. Lint may provide a nutrient base for a microbial ecological system as well. What is being done to slow down accumulations of lint and to prevent its negative impact on caves is the subject of this presentation.

##### CAVE FAUNA CONSERVATION IN TEXAS

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This paper discusses the numerous threats, past and present, to the cave and ground water fauna of Texas. A review is presented of cave fauna conservation in Texas including controlling biologic, geologic, historic, and economic factors.

Texas has many caves and a high species diversity owing to its geologic complexity and location. New cavernicole species are still being discovered at the same time that caves are being degraded or found. The major threats to cave fauna are land development, ground water over pumping, fire ants, human disturbance, and pollution. The special problems associated with the conservation of bats, salamanders, invertebrates, and ground water are discussed. Cave preserves are being created under the auspices of at least two habitat conservation plans, Texas Parks and Wildlife Department, Texas Nature Conservancy, Texas Cave Management Association, and other organizations.



## DEVILS ICEBOX WATER QUALITY STUDY JUNE 1982 TO JULY 1984

Scott Schulte

For many years it has been suspected that Devils Icebox Cave has had a water quality problem from possible contamination by domestic and livestock sewage or by toxins from sinkhole dumps, chemically treated agricultural land, and/or bats. In 1981 a population of cave organisms was lost due to an unknown cause that illustrated the vulnerability of the Devils Icebox Cave system. Of particular interest to the Missouri Division of Parks, Recreation, and Historic Preservation is the preservation of habitat required by two organisms listed by State and Federal agencies as rare and endangered species. It is the policy of the Department of Natural Resources to take whatever reasonable steps are available to protect the Devils Icebox Cave from any kind of environmental degradation. Therefore, a two-year monitoring program was designed to determine if a problem exists. The study would also provide background water quality information for further studies.

Four stations were chosen for monitoring. Site 0001 was the stream at the cave entrance. This site was monitored weekly and, as the downstream extent of the cave, represented the average water quality of the cave. A second site, Site 2200, monitored the main stream at 2,200 meters upstream from the entrance. Two other sites, Site 2200L and site 1810R, monitored significant feeder streams from side passages, the drainage of which was most likely from beyond the park's boundary.

While measurable chemical and biological contamination was found, the level of contamination is not generally a threat to aquatic organisms within the cave. Certain relationships between the sample sites and the recharge area were observable. The data obtained establishes a base line for future studies and measurement of pollution in the future.

Further studies are indicated that would define the recharge areas (dye tracing) and examine some of the questions that have emerged as a result of the study.

## THE SLOANS VALLEY CAVE SYSTEM AND THE PULASKI COUNTY LANDFILL

Wm. Duke Hopper and Dr. Hillary Lambert Renwick

In 1980 the Pulaski County Landfill was issued a permit to operate a "sanitary landfill" in Pulaski County, Kentucky. The landfill is located on a strip mine site. The

valleys surrounding the landfill are floored with karsted Mississippian limestone. Of particular interest and concern is the Sloans Valley Cave System. The Sloans Valley Cave System was surveyed to over 24 miles during the 1970s by Lou Simpson and associates from several Ohio and Kentucky grottos. Surface runoff from the permitted landfill is known to sink and enter the Sloans Valley Cave System at two locations.

Today the Pulaski County Landfill is nearing its permitted capacity and is attempting to comply with stricter revised regulatory requirements that go into effect in July 1992. In order to extend the life of this facility, the operators are pursuing a variety of regulatory options, including the vertical expansion of the existing sanitary landfill and the permitting of additional acreage on the adjacent strip mine bench for the construction of a "contained landfill." Over the past 12 years the local citizens' awareness and opposition to the landfill has grown, and the caving community has continued to speculate as to the effects of the landfill on the Sloans Valley Cave System and surrounding area.

Accompanying the rumor and fear has been a profound paucity of facts. In late 1991 it was decided to establish a Miami Valley Grotto/Ohio Valley Region (NSS) subcommittee to examine the effects of the Pulaski County Landfill on the Sloans Valley Cave System, adjacent private and public land, and on Lake Cumberland. The first stages have been completed in what is evolving into a comprehensive, long-term environmental impact study with a set of short- and long-range goals. Research results and political developments to date will be discussed.

## AN UPDATE ON CAVE MANAGEMENT GOALS WITHIN THE TEXAS STATE PARK SYSTEM

Ron Ralph and Robert Burnett - Texas Parks and Wildlife  
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A number of karst properties have been acquired by the State of Texas over the last 7 years including the Devil's Sinkhole and Kickapoo Caverns. The caves contain a number of significant archeological, paleontological and biological resources now under investigation.

There are new developments in legal requirements, carrying capacity and volunteer inventory projects. An experimental high density visitation is proposed.



## CAVE RESOURCE MANAGEMNT PROJECTS AT TIMPANOGOS CAVE NATIONAL MONUMENT, UTAH

Rodney D. Horrocks - Timpanogos Cave National  
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Timpanogos Cave National Monument is in the second year of an aggressive three year resource management plan. The resource management office at the monument is currently staffed with three workers who are directing a number of cave restoration and management projects. A long history of public tours through the caves have supplied current managers with plenty of restoration and management projects. Presently, seven areas of resource management are being concentrated upon, including: A comprehensive resource management plan, cave resurvey, cave inventory, cave restoration, geographic information, system utilization, environmental monitoring, and hydrologic studies. A host of volunteer groups are being utilized, including; cavers from the Timpanogos, Wasatch, and Salt Lake Grottos, interested adults from nearby cities, and boy and girl scout troops.

## BUREAU OF LAND MANAGEMENT CAVE MANAGEMENT ACTIVITIES IN 1992

James Goodbar

The Bureau of Land Management (BLM) is responsible for the stewardship of our public lands. It is committed to manage, protect and improve these lands in a manner to serve the needs of the American people for all times. Management is based on the principle of multiple-use and sustained yield of our nation's resources. Caves are one of the natural resources the BLM is responsible for managing. During 1992 the BLM Carlsbad Resource Area has engaged in several cave management activities for the purpose of protecting and learning more about our cave resources.

The BLM has completed the withdrawal application and environmental assessment for nearly 4,000 acres of land containing more than thirty significant caves in ten areas.

Cooperative agreements for two cave inventory projects have been completed, one for \$4,000 with the Southwest Region NSS and the second for \$1,000 with the Cave Research Foundation. Two more cooperative agreements have been initiated, one with the Lubbock Flats at \$1,000, and the second with Ohio State University for a one year cave biology inventory at \$3,800.

A Cave/Karst Drilling Guide has been written to provide the oil and gas industry with a set of procedures to follow when operating in cave and karst lands. The procedures were developed by a BLM Cave/Karst Task Force. The Task force was formed in 1991 and composed of representatives from four federal agencies, two State of New Mexico agencies, five companies from the oil and gas industry, the NSS, and the Lechuguilla Cave Project, Inc. The drilling guide adopted the approach of the task force to detect and avoid caves and karst features prior to drilling site locations and apply specific drilling, casing and cementing procedures to reduce impact to karst lands being drilled.

The Big Manhole Cave Dig Project has been reorganized such that all participants will be signed up as BLM volunteers. BLM will provide, to the extent available, all digging equipment, survey supplies (books, flagging tape, pens, etc.), and all ropes or hardware available. All trips will be coordinated through the BLM. Key personnel involved in past digs shall be present during all digging trips to insure continuity in the project. Survey data will belong to the BLM with copies made available. A written proposal for the excavation of paleontological resources will be required prior to the continuation of the dig. If the proposal is approved the BLM will provide assistance of the paleontological research.

## DIGGING

### THE CURRENT STATUS OF THE BIG MANHOLE DIG

Jeffrey K. Lory

This presentation will commence with a brief review of what happened with the dig at Big Manhole Cave as reported at last year's convention. The remainder of this report, as outlined below, will be a summary of events up to the point of this year's convention.

The dig was restarted on the last weekend of July 1991 after a ten-month administrative shut down. Three more dig sessions occurred during the first week of August, one weekend in September, and the Thanksgiving Holliday. Prior to the dig over the Thanksgiving weekend, a meeting was held to discuss the plan of action to be taken once breakthrough occurred. This meeting involved key representatives from the Bureau of Land Management, the dig coordinators, and Lechuguilla Cave Project, Inc. As a result of that meeting, the dig once again stalled; this time a political rift developed between caver factions. Hopefully, by the time of convention, we can report on a resolution of the problem and another restart of digging activity.



## THE DEVELOPMENT OF A FORMAL PROPOSAL FOR A DIG ON PUBLIC LANDS

Steve Peerman - 1757 Defiance Road, Las Cruces, New  
Mexico 88001

This presentation will outline the process of making a formal proposal for a dig in a cave on public lands. Although each dig may be somewhat different, the discussion will include issues common to all digs, especially those where a public entity is involved in cave management. Those issues include safety, planning, archaeological and paleontological support, techniques, personnel, and restoration.

An outline of an appropriate dig proposal will be provided.

### THE COMPLETE DIGGER'S KIT

Bill Yett - 2930 East Fourteenth Avenue, Denver, Colorado  
80206

This presentation will be a demonstration (show and tell) of the digging equipment carried by an experienced digger. The author will invite discussion of additional and/or alternative equipment. Feel free to bring some of your own for comparison purposes.

## GEOLOGY AND HYDROLOGY

### STRUCTURAL CONTROLS ON THE DEVELOPMENT OF CUEVA CHEVE: A RECONNAISSANCE REPORT

Louise D. Hose - Department of Geology, University of  
Colorado, Colorado Springs, Colorado 80933-7150

The dominant structural feature near the Cueva Cheve system in the Sierra Juarez, Oaxaca, Mexico is a thrust fault trending  $\sim$ N20°W 60°W. Most of the cave parallels the fault immediately east of and under the hanging wall, which is composed of insoluble cataclastic rocks. Open, broad hinge folds in the cave walls verge to the east and plunge  $\sim$ 15°N27°W. Conjugate joint sets trend  $\sim$ N19°W 50°E and  $\sim$ N27°W 62°W.

Localized beds of foliated limestone with mylonitic textures are exposed north of Camp II. Foliation readings cluster around N21°W 55°E and are consistently parallel or sub-parallel to bedding.

A second major, north-northwest trending thrust fault crops out on the surface about three kilometers east of the cave. Insoluble rocks form the footwall.

Another prominent structural trend includes east-northeast striking faults. The upper part of the cave mostly trends parallel and just south of a right-lateral separation fault that strikes  $\sim$ N75°E and dips to the north. A passage near the terminal sump has formed along another fault oriented N81°E 40°N. They may be tear faults associated with thrusting or they may be younger faults. Conjugate joint sets oriented  $\sim$ N89°E 60°N and  $\sim$ N81°E 76°S are prominent, particularly near the terminal breakdown pile.

The cave north of Camp II is within mostly east-northeast-dipping beds. The linear development of this part of the cave may be because water in the cave is: (1) Trapped between insoluble rocks above the junction of the two north-northwest-trending thrust faults; (2) Flowing near the trough of a syncline; (3) Following fractures in heavily fractured rocks near the western thrust fault.

### LIMITATIONS ON REGIONAL CORRELATION OF CAVE LEVELS, INDIANA AND KENTUCKY

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Cave levels and surface landforms (planation surfaces and river terraces) have previously been correlated in the Chester Upland and its northern extension (the Crawford Upland) in southern Indiana with some success. In Mammoth Cave (Kentucky) and Wyandotte Cave (Indiana) the local control on base level is provided by tributaries of the Ohio River and the Green and Blue Rivers respectively. A polarity reversal in the sediment fill at ca. 168 meters in both caves provides the basis for a correlation between level "C" in Mammoth Cave and the upper (Old Cave) level in Wyandotte Cave.

Attempts have also been made to correlate levels in Mammoth Cave with caves in the northern part of the Mitchell Plain in central Indiana. However studies of two caves, Doghill-Donnehue and Buddha-Christian Caves, suggest that the processes governing cave level development in the sinkhole plain are different from the simple base level control operating in Mammoth and Wyandotte Caves. Different levels in Doghill-Donnehue and Buddha-Christian Caves, which are elevated above the local base level provided by the East Fork White River, appear to be a product of a progressive lowering of the water table accompanying retreat of tributary valley headwalls through sapping.



Regional correlations of cave levels in Indiana and Kentucky karst are likely only to be possible between caves that directly respond to changes in the regional base levels, and, in consequence, the validity of such correlations is likely to depend, in large part, on the nature of the base level control operating in individual cave systems.

#### CONDUIT AND NON-CONDUIT KARST AQUIFER DEVELOPMENT IN THE TRANS-PECOS REGION OF TEXAS

George Veni - George Veni and Associates,  
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The Diamond Y and Comanche spring systems are formed in the Cretaceous Fredericksburg Group carbonates near Fort Stockton, Texas. The Comanche Springs drainage basin contains several caves, sinkholes, and swallets. The springs discharge from an extensive cave. Hydrograph and dye tracing data also indicate the aquifer has a significant conduit component. In contrast, no caves are known in the Diamond Y drainage basin and the surface karst is poorly developed. Hydrograph and geochemical data suggest a largely diffuse flow aquifer system. These differences in adjacent drainage basins are the result of deep-seated brines leaking up into the Diamond Y basin and increasing the groundwater's degree of calcite saturation. The brines, which are rising along the trend of the buried Permian Capitan Reef Limestone, may have partially dolomitized or prevented the dedolomitization of the Fredericksburg Group in that locale.

#### SPELEOGENESIS OF CAVE OF THE WINDS, MANITOU SPRINGS, COLORADO: MIXING OF HIGHLY CARBONATED MINERAL WATER AND NORMAL METEORIC SURFACE WATER

Fred G. Luiszer - Geological Sciences, University of  
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Cave of the Winds is located about two kilometers north of Manitou Springs, which is eight kilometers west of Colorado Springs, Colorado. The chemistry of 20 springs, 3 streams and a cave water were analyzed. These springs occur where Fountain Creek, the local base level, intersects the Ordovician Manitou Limestone, a major aquifer.  $87\text{Sr}/86\text{Sr}$  ratios of the mineral spring waters suggest that they percolated through a deep granitic source.

The  $\delta^{13}\text{C}$  of  $\text{CO}_2$  in the water suggests that the  $\text{CO}_2$  has a deep seated origin. The nearby Ute Pass Fault, a northwest trending reverse fault with up to 10 kilometers of offset, is the probable path for the mineral waters. The more mineralized springs have  $\text{CO}_2$  partial pressures [ $\text{PCO}_2$ ] up to 1.8 and are saturated with respect to calcite. Surface streams and an resurgence have  $\text{PCO}_2$ s of -0.0035 and are also saturated with respect to calcite. Several of the springs in Manitou Springs represent a mixture of these two waters; these, however, are very undersaturated with respect to calcite. There is evidence of a mixing zone that occurs beneath the city of Manitou Springs that leads to dissolution of calcite and the formation of cave passage. A paleospring-paleosinkhole next to and above Cave of the Winds indicates that Cave of the Winds was similarly formed 4.0 Ma. Since that time, with down cutting and lateral movement of Fountain Creek toward the south, the springs and mixing zone have moved southward to their present location at Manitou Springs.

#### STRATIGRAPHIC AND STRUCTURAL CONSTRAINTS ON THE DEVELOPMENT OF THE CAVE OF THE WINDS, COLORADO

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Cave of the Winds, near Manitou Springs, Colorado, is within the upper 15 meters of the Late Ordovician Manitou Dolomite and the entire eight-meter thick, Devonian(?) Williams Canyon Formation. The Manitou formation contains limestone and dolomite. The Williams Canyon Formation comprises limestone and dolomite interbedded with limy shale and sandstone. The Mississippian Leadville Limestone is a massive limestone that provided a ceiling for cave development.

Beds dip consistently between  $9^\circ$  and  $15^\circ$  to the east-southeast and southeast. The cave formed along intersections of bedding planes, joints, and microfaults that dominantly trend  $\text{N}0^\circ$  to  $10^\circ\text{W}$ . Passage development is rectilinear. Dome-ceiling rooms formed at joint crossings and boneyard speleogens throughout the cave represent a phreatic origin.

The world-famous beaded helictites and anthodite displays are restricted to the upper Manitou and lower Williams Canyon Formations. The speleothems are concentrated on up-dip sides of the passages.



## ASPECTS OF THE GEOMORPHOLOGY OF OAK RIDGE, TENNESSEE

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In the Oak Ridge, Tennessee, area Alleghanian deformation associated with the Southern Appalachian Foreland Fold-Thrust Belt (240 Mya) is responsible for a series of steeply dipping non-carbonate and carbonate strike-bands throughout the region. The interpretation of cave passage morphology and related sediment deposition provides one of the best means of unravelling the geomorphic history of the region. Due to the non-carbonate barriers, cave development here occurs preferentially along strike with local vadose components. Evidence of extensive Pliocene karstification includes typical karst features such as caves, sinkholes, sinking streams, springs, and grike and pinnacle topography.

Relict cave segments and alluvial terraces have been preserved within and on resistant carbonate ridges. A regional erosional-depositional interpretation may be drawn from these karst and relict alluvial features. Alluvial terraces have been mapped at elevations of 740 to 775 and 800 to 825 feet MSL, well above the Clinch River base level prior to damming. An abandoned Clinch River meander occurs at 800 to about 825 feet. At elevations of 840 to 850 feet MSL there is a widespread occurrence of terrace remnants in most tributaries to the Clinch River, suggesting a relatively long period of adjustment to a stable base level. At higher elevations of 875 to 900; 1,050 to 1,140; and 1,200 to 1,350 feet MSL old alluvium has been preserved on mostly karst landforms. Thick alluvial sediments (e.g. 1,200 to 1,350 feet MSL) may provide evidence for a rise in base level. Similarly, sediment infilling of canyons in Spring Hill Saltpeter Cave may provide evidence for a regional rise in base level. To date, relict phreatic (water table) conduits have been surveyed at 937, 945, and 973 feet MSL (Cherokee Caverns), up to 240 feet above today's stream flow (e.g., scallops), but have had their catchment basins beheaded (Copper Ridge Cave). Abandoned large diameter phreatic conduits portray very slow fluvial erosion (i.e. tens of thousands of years) to a stable base level, alternating with periods of comparatively rapid erosional dissection (vadose passages). Relict phreatic conduits have superposed solutional features typical of flood water origin

under alternating vadose and phreatic flow conditions. Paleomagnetic studies aimed at detecting magnetic polarity chrons recorded in oriented cave sediments and relict terrace soils are being used to assess the area's geomorphic chronology.

## ONYX MINING IN VIRGINIA CAVES

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Cave onyx has been mined from four Virginia sites in Botetourt, Rockbridge, and Rockingham Counties. Botetourt County's Perry Saltpetre Cave was mined for cave onyx during the 1920s. The use of blasting and the absence of scrap piles differentiate this site from the other deposits. Some of this onyx may have been utilized for a terrazzo stone in contrast to traditional uses as a dimension or decorative stone. In Rockbridge County, cave onyx from Marble Cave was cut at Rapps Mill according to local lore. Neither the dates of mining nor the market for this dimension stone product are known. The Onyx Hill deposit of Rockingham County was mined in the late 1800s by the Virginia Minerals and Mining Company according to the present land owner. Deed searches did not turn up any information on this company. However, they did reveal that the Virginia Onyx Company paid for property and onyx rights at this site in 1893. Although no actual mining can be documented in Onyx Cave, the main Onyx Hill deposit is an extension of Onyx Cave. The market for the dimension stone is not known. The Miller onyx deposit of Rockingham County was reportedly worked between 1870 and 1892 for tombstones. Cave onyx tombstones have been located in the Beaver Creek Church of the Brethren and the Green Wood Cemeteries of Rockingham County. In 1892, the Virginia Onyx Company was organized to mine and market onyx at the Miller site and is known to have shipped some onyx products to New York in 1897.

## PALEO-CAVITY FILLS FORMED BY UPWARD INJECTION OF CLASTIC SEDIMENTS DUE TO LITHOSTATIC LOAD: EXPOSURES IN CAVE OF THE WINDS, COLORADO

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Paleo-karst fills have traditionally been interpreted as the result of collapse and in-filling of overlying younger strata into cavities in older, soluble rock. Exposures of the Williams Canyon Formation in Cave of the Winds,



Colorado provide compelling evidence of upward injection of clastic sediments from older, underlying strata into paleo-cavities within overlying carbonate beds. All preserved bases of paleo-fills in Cave of the Winds end in laterally continuous clastic layers made up of sediments similar to the fills. The clastic layers are convex upward under the filled cavities. A three-step model is proposed to explain these exposures: (1) Deposition of the Devonian(?) Williams Canyon Formation comprising interbedded limestone, dolomite, sandstone, siltstone, and shale; (2) Caves formed in the carbonate layers. Either the clastic sediments were not yet lithified or their cement was dissolved. The clastic sediments, driven by lithostatic pressure, plastically flowed into the voids of the overlying carbonate rocks. The age of this event is unknown but it clearly predates the present cave. The event may have been associated with the Late Mississippian karst plain; (3) The present cave formed, probably in the Tertiary, and exposed the paleo-fills. Locally, mud from the clastic layers flowed into the present cave, probably under phreatic conditions.

#### CHEMOLITHOAUTOTROPIC IRON SEDIMENTS AT CAVE OF THE WINDS AND THE IRON SPRINGS OF MANITOU SPRINGS, COLORADO.

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Thiefs Canyon is a passage in the lower southeastern part of Cave of the Winds, which is two kilometers north of Manitou Springs, Colorado. At its southern end, a one-meter thick sequence of unusual sediment was encountered during excavation of a blowing lead. The lowest layers of this sequence, which is ~ 4 Ma, contain residue formed during initial formation of the passage. Above this are layers consisting of biologically precipitated hematite that contain large amounts of As and Pb. Next above is a bed of pyrolusite (MnO<sub>2</sub>) and above that, interbedded detrital silt and clay layers.

The mixing of mineral water and meteoric water formed very corrosive waters, which dissolved limestone and left the residue. This mixing zone progressively moved downward and southward in response to the southward migration of Fountain Creek. Soon after, iron oxide was precipitated in response to oxygenation by admixed meteoric water. Today, similar As and Pb rich iron oxides are being precipitated at Ouray Spring near Manitou Springs, by the activity of chemolithoautotrophic bacteria *Gallionella ferruginea*. The branching morphology of the iron oxide in Thiefs Canyon suggests that *Gallionella* was also responsible for its formation. With continued migration of the mixing zone southward, the groundwaters

were further mixed with oxygenated surface waters, leading to the precipitation of pyrolusite. The clay and silt that caps the chemical precipitates record detrital sedimentation in the cave after the mixing zone had moved even further to the south.

#### BAHAMIAN BLUE HOLES: DESCRIPTION AND DEFINITION

Bernice Burkeen and John Mylroie - Department of Geology and Geography, Mississippi State University, Mississippi State, Mississippi 39762

The term blue hole originated as a local expression in The Bahamas to describe deep water-filled pits. The term appears on early British navigation charts, for example Blue Hole Point. The term blue hole, along with the term ocean hole, was used by early workers in The Bahamas (Agassiz, 1893; Shattuck, 1905; Doran, 1913). The latter two investigators explained the term blue hole as derived from the deep blue color of the pits, in contrast to the turquoise of the shallow lagoons in which the blue holes were often found. Stoddard (1962) briefly compared the terms ocean hole and blue hole, preferring the latter term because of the striking visual impression the features make. The term blue hole became popular after publication of George Benjamin's classic paper on Bahama blue holes in National Geographic Magazine in 1970. Most publications thereafter, including a long series in the 1980s in the journal Cave Science, referred back to Benjamin's article.

Blue holes occur in lagoons, lakes, ponds, and land areas throughout the Bahamas. They may contain marine, brackish, or fresh water, or may penetrate from fresh or brackish water into marine water. They often lead into extensive cave systems at depth. Blue holes found in lakes and lagoons often show tidal flow and may play a significant role in island hydrology. The term blue hole has been poorly defined, and as a result the literature contains many references to blue holes that are difficult to compare. Some workers have called ponds over 100 meters across a blue hole because of a 2-meter diameter pit demonstrating tidal flow in one corner of the pond. The term is also confusing in that karst springs are sometimes called blue holes by locals in numerous settings in the Americas (in both Kentucky and Jamaica, for example). Other features, such as cenotes in Yucatan, are morphologically similar to blue holes.

We propose to define blue holes as: "pits developed in carbonate rock with a depth to width ratio greater than one that extend below sea level for a majority of their depth." We further subdivide the category of blue hole into



ocean hole and inland blue hole. An ocean hole "opens directly into a lagoon or the ocean, is usually tidally influenced, and contains marine water." An inland blue hole "opens directly onto the land surface, or into an isolated pond or lake, may be tidally influenced, and may contain a variety of water chemistries from fresh water to marine." Blue holes are extremely interesting speleological features, with importance to our understanding of cave development, global climatic change, and biological evolution. The term needs to be objectively defined.

#### OPEN VERTICAL VOLCANIC CONDUITS AND REFLUX CHAMBERS ASSOCIATED WITH XENOLITH BEDS, HUALALAI VOLCANO, HAWAII COUNTY, HAWAII: A PRELIMINARY REPORT

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Marlin Spike Werner - PO Box 11509, Hilo, Hawaii 96721

In January 1992 members of the Hawaii Speleological Survey and Hawaii Grotto of the National Speleological Society investigated reputed lava tubes or vents at the head of xenolith beds of the Kaupulehu lava flows of Hualalai Volcano, Hawaii. Several linear groups of open vertical volcanic conduits were found, some with unusual pahoehoe hoods and comparatively narrow vertical sills or septae separating them. Four reflux chambers were found at the bottom of one or more vertical conduits. One of these is sizeable and complex. Its ceiling is largely demarcated by a moderately dipping bed of dense lava which incorporates varying quantities and types of xenoliths, quite different from the xenolith beds previously known. These discoveries have implications on the theoretical genesis of the Hawaiian Islands.

#### GOVERNMENT REGULATIONS OVER SITING LANDFILLS AND THE MEANING OF KARST: A CASE HISTORY

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Many states have inadequate regulations pertaining to the siting of landfills in karst regions. Tennessee, for example, tends to emphasize surface features on site as sinkholes and often ignores the presence of caves, springs, and dolines close to the site boundary that are obviously hydrologically tied to the karst aquifer system. The regulations do not require dye-trace studies and falsely provide "protection" of the aquifer by placing a buffer zone around a karst feature on a disposal site.

At one site in eastern Tennessee a battle is in progress over permitting the expansion of an existing landfill to allow room for the disposal of medical and construction wastes. The landfill in the proposed expansion area is underlain by one of the most cavernous members of the Ordovician-age Knox Group. The rock is strongly folded and springs and caves ring the property boundary. Ground water flows along strike within solution conduits as evidenced by a long cave containing a stream that has been mapped to nearly the facility boundary. Yet, few karst surface features have been found on the site. Despite evidence from present monitoring wells demonstrating ground water contaminated from past practices and expert testimony stating the site is unrefutably underlain by karst, the permitting process continues. This case history is just one of many that demonstrates that the regulations must be changed to look at the broad picture for evaluating landfill sites in karst. Off site monitoring must be required and dye tracing must be included in evaluating the potential for contaminant transport and aquifer vulnerability.

#### PROJECT KARSTMAP: A STATUS REPORT

William B. White - Department of Geosciences, The Pennsylvania State University, University Park, Pennsylvania 16802

William K. Jones - Karst Waters Institute, PO Box 490, Charlestown, West Virginia 25414

Project KARSTMAP is an ambitious effort to produce a map, series of maps, or Atlas showing the karst regions of the United States. The reference document is the U. S. Geological Survey's "Engineering Aspects of Karst," a National Atlas sheet by W. E. Davies, et al. in 1984. This map shows outcrop areas of karstic and pseudokarstic rocks with color coding to indicate degree of karst development and structural setting. The scale is 1:7,500,000. To display more detail, the KARSTMAP project plans to develop individual state maps, probably on a scale of 1:1,000,000 or 1:2,000,000. Three classes of karst related features can be displayed: distribution of karstic rocks, distribution of closed depression features (sinkholes and blind valleys), and distribution of caves. The project is set up as a cooperative venture coordinated within the NSS Section of Cave Geology and Geography with individual committees assigned to the various States. The project also has the task of working cooperatively with several on-going efforts sponsored by State Geological Surveys and by other groups and individuals.



LITHOLOGIC FACTORS AFFECTING CAVERN  
DEVELOPMENT IN CAVE HILL, AGUSTA COUNTY,  
VIRGINIA

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The origin of caves in the central Valley and Ridge Province has been strongly controlled by the composition of the host rock (mainly limestone), structure of the bedrock, and development of the surrounding landscape. Variations in composition and porosity of vertical beds of the Conococheague Formation at Cave Hill, Augusta County, Virginia were previously studied by dissolving rock samples in diluted hydrochloric acid, analyzing samples through x-ray powder diffraction techniques, and saturating samples with water and weighing. The present investigation extended this work through petrographic examination of thin sections of samples collected in Grand Caverns and on the surface of the hill. This allowed precise determination of composition by point counting, measurement of grain size, and identification of microstructures.

Results show that the previous determinations made by the dissolving method were reasonably accurate. However, thin-section techniques allowed quartz and clay fractions of the insoluble material to be quantitatively determined. Microstructures, (e.g. clay laminations, stylolites, calcite veins, infilled vugs) were readily seen in thin-section but not in hand samples. Pores in the limestone and sandstone units were typically filled with precipitated calcite or silica. This occurred after the beds were deposited but well before the caves formed. During speleogenesis, dense, microcrystalline limestone beds were readily dissolved, whereas those consisting of sandstone, siltstone, or mudstone were not. Results indicate that beds of rock that are microcrystalline and purest in calcite are the least porous, and those that are low in calcite content and contain mostly insoluble material are the most porous. That the most soluble rocks are the least porous or permeable implies that the groundwater flow that dissolved them may have been carried through the rock sequence along adjacent highly porous and permeable beds of insoluble material, such as interbedded sandstones. This mechanism for speleogenesis in rocks of mixed lithologies is proposed as a new hypothesis that may have application in many other cave regions.

HISTORY

A WEEK IN THE FOOTSTEPS OF MARTEL--AND SOME  
EARLIER CAVERS

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In October 1991 I had a wonderful week in the cave country of southern France, seeing some of the world's most famous caves and speleological museums. As a result of the heartwarming help of Jacques Choppy (an outstanding old-timer of the SpeleoClub de Paris and a director of Grotte de Clamouse--an especially notable show cave) we were able to accomplish about twice as much as we could have done alone. But this report will give an idea of what is possible in a week, in case you are headed that way.

The venture began poorly, but that did not last long. We travelled by Eurail Pass from Paris to Brive where we picked up a Hertz car. From Brive, Lascaux II was only a short drive. This is the artificial replica of "the Sistine Chapel of prehistoric art." At first glance it appears impressively cavey. But it is disappointingly small, and most of the replicas of the famous paintings seemed dull and lifeless in comparison to published photos of the real things. Rather sadly we walked the short distance to the entrance building of the real Lascaux Cave, thinking about what we had not seen.

Shaking off our somber beginning, we veered through a network of back roads, heading generally toward the prehistory center of Les Eyzies. French roads are good, with signs at every little intersection. But usually the signs indicate only the next village. Even for Jacques a good map and constant navigation were necessary everywhere off the main roads.

Soon Jacques pointed us to the Abri de Cap Blanc, which I had never heard of. Abri means grotto or rockshelter, and this was a great one. It was closing time but Jacques was welcomed as a VIP (here and everywhere else we went, except Lascaux), and we received a special tour to view and admire prehistoric wall sculptures of horses, bison, and deer about 14,000 years old. I had not known that such sculptures existed.

Then on to Les Eyzies itself, where new and old buildings cling beneath overhanging cliffs of the Vézère River, home of man for perhaps 35,000 years. In the Abri Pataud we were welcomed in the middle of a lecture on the current excavations and exhibits. Adjacent to the diggings is a little archaeological museum, beautifully done. Our hotel was in an old mill nearby, really delightful. There are so many caves, archaeological sites, and archaeological and speleological museums in and around this tiny village



that we could have spent the entire week here. Make reservations far in advance in tourist season.

Next morning was the amazing Musee National de Prehistorie. I had expected all the portable wonders of Cro-Magnon art to be somewhere in Paris. Instead, world-famous carvings like the Venus of Brassempouy are here where they began, for anyone to study and photograph at leisure (as long as no flash is used).

#### HARRY FOX'S LOST CAVE ON MAUNA LOA VOLCANO, HAWAII

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The July 1950 issue of *Popular Mechanics* included a well illustrated article on a notable lava tube cave on Mauna Loa Volcano, Hawaii, discovered by a Harry Fox in 1935. Nothing was known of Mr. Fox nor his cave until 1991 when Mr. Fox appeared at Hawaii Volcanoes National Park, asking for assistance in locating his cave. It was quickly determined that the cave is on private property east of the national park but a search by local landowners and Mr. Fox was unsuccessful. In 1992 Mr. Fox again returned and one of the landowners believes that he has located the cave. Enlargements of 1949 photos of the cave will be displayed. It is in an area closed to all caving, hiking, and similar activities.

#### CHEROKEE CAVE IS STILL THERE

Joseph E. Walsh and Lois M. Walsh, - 660 Green Hedge  
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Cherokee Cave was discovered in 1841. In 1842, Adam Lemp purchased the cave and began building his brewing empire. This enterprise prospered until the advent of prohibition in 1920. At one time, as many as three breweries simultaneously used different, unconnected portions of the same cave. After prohibition, refrigeration made the use of caves obsolete in the brewing industry. Cherokee Cave lay deserted and forgotten. It became a trash dump and a target for vandals.

In 1946, Lee Hess purchased the cave, cleaned it up, and excavated a tunnel to connect two known (but separated) portions of it.

During the course of excavation, a large deposit of Pleistocene peccary bones was found. At the invitation of Mr. Hess, the American Museum of Natural History investigated this very important paleontological site in 1946. Mr. Hess successfully operated Cherokee Cave as a show cave from 1950 to 1961.

The Missouri Highway Department purchased part of the cave in 1961 and collapsed the commercial entrance prior to the construction of I-55 above that section of the cave.

Today, much of the cave still remains hidden beneath the modern city. The old tourist trails and a portion of the Peccary cemetery remain intact. Artifacts from the days of the breweries can still be seen. The cave literally abounds in history.

#### HUMAN SCIENCES

##### PUBLICITY, WHAT'S OUT THERE

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NSS policy on publicity does not take place in a vacuum; information about caves is available from many sources. A computer search of three databases abstracting print media (magazines and newspapers of widespread circulation) for articles referring to caves and caving found approximately 500 articles covering a 10+ year period. Articles were sorted into mutually exclusive categories based on their main theme. Most prevalent (each representing 15% of the sample) were articles reporting on cave exploration and paleontology/archeology. Also common (>10%) were articles on commercial caves and tourism (foreign and domestic), conservation and threats to caves and cave art. Reports on rescues made up only 8% of the total but were much more common when newspapers were considered separately.

#### INTERNATIONAL EXPLORATION

##### DOMINICAN REPUBLIC SPELEOLOGICAL EXPEDITION 1992

Jeff Uhl - RR 1 Box 620, Greenlane, Pennsylvania 18054

Columbus, on his first voyage, discovered La Isla Española (The Spanish Isle) now known as Hispaniola. The Dominican Republic occupies the eastern two-thirds of this island in the West Indies, which it shares with Haiti. The country has an area of 48,734 square kilometers, approximately the size of the state of West Virginia, and a population of 5.7 million people. The capital and largest city is Santo Domingo, with a population of 1.6 million. Santo Domingo is the oldest city in the new world, built soon after the island was discovered in 1492. The Dominican Republic has had a long and colorful history. Today the country is a democratic republic with free



elections and political stability. A glimpse of the rugged landscape from the air inevitably reminds one of a remark made by an English admiral to George III in answer to the question of how the Caribbean island could best be described. He reportedly crumpled up a piece of paper and said, "Your majesty, this is Hispaniola." Throughout the Dominican Republic the mountainsides are largely barren, the aftermath of extensive karstification and erosion, as well as centuries of slash and burn clearing, that decimated the primeval forests.

The activities of the 1992 Dominican Republic Speleological Expedition centered in the Catanamatias area. The Catanamatias Valley is a 30 square kilometer closed drainage basin located near the Haitian border at about 19 degrees latitude and 71 degrees 30 minutes longitude. It is surrounded by peaks over 1,700 meters high and is accessed only on horseback.

The major goal for the 1992 Dominican Republic Speleological Expedition was to explore the headwaters of the Rio San Juan and the Rio Yacahueque to look for resurgences from Catanamatias or El Fundita. El Fundita is a karst plateau at 1,450 meters adjacent to Catanamatias. On the 1991 Dominican Republic Speleological Expedition Fred Wefer led a team to this area and located a total of 83 pit/cave entrances.

#### EXPLORATION IN THE SIERRA JUAREZ, OAXACA, MEXICO

Matt Oliphant - 4105 Lowell Ave., La Crescenta, CA 91214

Louise D. Hose - Department of Geology, University of Colorado, Colorado Springs, CO 80933-7150

A team of thirteen American, two Swiss, and one Mexican cavers explored the karst and caves in the Sierra Juarez in Oaxaca, México this spring. Activities in the principal known cave of the region, Cueva Cheve, included two camps at Camp III and one camp at Camp II (-1006 m and -783 m respectively, below the Cheve entrance). Original exploration, surveying, can and rigging maintenance, and geologic observations and sampling were accomplished during the underground stays. The explored part of the system remains 1386 m deep and is now 22.5 km long.

Two other caves that may connect into the system were explored. Cueva del Rancho Palomora, in the "middle karst", was explored and mapped for 308 m. Exploration was stopped by a flowstone choke but air flow is good. Cueva Palomitas, near the Cueva Cheve entrance, was also explored. The survey stopped after 540 m at the top of a

100 m pit which had a lead at the bottom. Air flow in this cave is also good.

Three reconnaissance trips to new areas were made. Excellent relationships were established in the villages of La Hierbabuena and San Miguel Santa Flor in the middle karst. Several pits and sinkholes were visited near La Hierbabuena. The isolated village of Zautla, northeast of the presently explored system had previously turned cavers away on two occasions. A two-person team was well received and allowed to explore four small caves below the town and to visit the spectacular karst above the town.

#### CHIAPAS; REPORT ON THE 1992 EXPEDITION

Don Glasco - 12544 Kempston Lane, Woodbridge, VA 22192-5360

In February of 1992, six U.S. cavers conducted a two week exploration of the Arroyo Grande karst valley in the northern highlands of Chiapas in southern Mexico. A pleasant mountain climate, accessibility, comfortable accommodations and immediate proximity to mostly horizontal caves make this an ideal expedition area for cavers with limited time and who may not feel macho enough for the better known but more taxing Mexican cave expeditions.

The study area was the Arroyo Grande valley, a classic karst valley with a high density of sinkholes and larger dolines (approximately 50 per square kilometer). The valley is wedge shaped, about 7 km wide at the top and tapering to a few hundred meters wide at the bottom about 8 km away. The valley and strata dip have a near constant 15 degree dip. There is a 1300 m elevation difference from the top of the valley to the major resurgence draining the valley. Pits are numerous ranging from short 10 m drops to the 283 m deep Sotano del Arroyo Grande. Very few have been explored to date.

The focus of the expedition was to push the longest known cave, in the valley, C. del Arroyo Grande. The upper and lower entrance are 1.1 km apart (straight distance) with a 200 m elevation difference. Attempts to connect 590 m long Cueva de La Poza, which passes below C. del Arroyo Grande, and nearby 1892 m long C. de Queso Grande were unsuccessful. Connection with 212 m long C. del Tecalote was made and most known leads cleaned up. A very promising lead remains in the downstream section of the cave but a 1.5 m diameter siphon halted progress. It should be open in late April, the driest time of the year. Another 1231 m was added for a total of 8334 m, making it currently the 13th longest cave in Mexico.



Of biological interest, several small (4 cm diameter) white crabs were spotted in C. del Arroyo Grande and another cave. They are probably troglobitic and possibly a new species. Confirmation may come with next year's sampling.

Several other shorter caves (less than 200 m) were found and surveyed. Hundreds of sinkholes and dozens of cave entrances and pits remain to be checked.

## **PHOTOGRAPHY**

### **PHOTOGRAPHIC TECHNIQUES FOR DOCUMENTING AND INTERPRETING THE GEOLOGY OF CAVES AND KARST**

Ernst H. Kastning and Karen M. Kastning Department of Geology, Radford University  
Radford, Virginia 24142

In order for scientific photography to be effective it should be both a tool and an art form. Each photograph is taken to illustrate a feature, to convey a concept, to interpret a geologic process, to present an example, or to serve as part of the supportive data. Many photographs appear in technical presentations in the scientific literature. Speleological photography poses challenges that differ drastically from those of other scientific endeavors. Caves are an alien and typically harsh environment that do not offer the relative comfort and ease of access found in the laboratory or in the field. Geologic features in caves are three-dimensional and in nearly all cases, photographs taken to illustrate or interpret geologic attributes need to accentuate the three-dimensionality of the subject. The same principles, such as side lighting and the taking of multiple flash exposures, that are employed in artistic cave photography, can be effectively used to create depth. Size and distance must be determinable in the photograph and this implores the use of a scale. The choice of a scale (e.g. ruler, person, pencil, etc.) must be appropriate and easily used, yet it should not dominate the picture.

Context is of considerable importance in geologic photography. In most situations, objects need to be shown *in situ* such that their relationship to their surroundings is clearly shown for interpretive purposes. The photographer should have the basic lenses to cover the subject at the right focal length. Many cave photographers use a moderately wide-angle lens (24- to 35-mm) for passage-size photography and a normal macro lens (50-mm) for close-up work.

Most pictures will be still-life, but in the case of hydrologic activity, it may be highly desirable to show running water or pools. Care should be taken to highlight

the water by catching the texture of the water surface. Where geologic changes occur over short periods of time (e.g. sedimentation, collapse), sequence photography may be accomplished by re-occupying camera positions and angles over the time interval.

### **HOW TO USE TRADITIONAL PORTRAIT LIGHTING FOR BETTER SPELEOTHEM PHOTOGRAPHS**

David and Janet McClurg - 1610 Live Oak Drive, Carlsbad, New Mexico 88220-4104

A good, and relatively easy, way to improve your pictures of cave formations is to adapt some of the basic principles of traditional portrait lighting to cave photography. Taking portraits in a studio may seem a long way from shooting speleothems in a damp, muddy cave, but there are some surprising similarities. This paper will discuss these subjects and show examples of how the techniques can be applied.

### **COAT YOUR BULBS**

Rick Day - RR 5 Box 318-19, Harrison, Arkansas 72601

Have you ever been frustrated by the relative lack of blue bulbs? Rick Day will demonstrate an easy and economical method of turning any flashbulb blue using a lacquer dip. Cave proven results! Bring up to a dozen of your clear ones for conversion.

### **CLOSE-UP PHOTOGRAPHY WITH MULTIPLE MINIATURE FLASH UNITS**

Roger V. Bartholomew - 910 Laurel St., Rome, NY 13440

Close-up electronic flashes from Porter Camera, Cedar Falls, Iowa employ two miniature flash heads supported on long bendable wires connected to a camera mounted power supply. Cave adapted units can be made from Fuji Disposable FA1011B camera parts (see Minotsu, in "Flash", v7, #2, p 30) or from Kodak disk camera parts (BNF Enterprises, Peabody, MA). Photos taken with a miniature flash head on each side of the camera to axis show that as 90 degrees is approached more of the surface topography of the formation is revealed. Beyond 90 degrees the edge of the formation is emphasized. Control of reflections is critical. A polarizer can be used to decrease unwanted reflections from water surfaces, wet formations or wet cave walls when the light hits the water 53 degrees from the normal (37 degrees from the surface).



## SURVEY AND CARTOGRAPHY

### PROGRESS WITH CAVE MAP LANGUAGE; SURVEY PROCESSING, MANAGEMENT, AND ARCHIVING OF THE MAMMOTH CAVE DATA

Mel Park, President, Cave Research Foundation

The raw survey data for the Mammoth Cave System is contained in slightly more than 3,000 field survey books and that number is increasing by 15 to 30 every month. With that amount of data, the transcription to machine-readable form had better be a one-time process; the task of retyping all of that information into some new computer format is simply too staggering. In addition, the day-to-day management of so complex a data set is, itself, a formidable task. Therefore, the computer programs that handle our data must meet needs not previously thought necessary for cave survey programs. We set out to develop a system suitable for data archiving and data management as well as performing the conventional processing expected of cave survey programs. The result, Cave Map Language, will be both explained and demonstrated.

Cave Map Language (CML) is a way of writing down all of the data that are collected by survey parties and doing it in a manner that is both easily read and maintained by humans and that can be read and processed by machines. As a format for data exchange, it is intended to be a tool by which underground survey data can be archived and transmitted. As a running system of computer programs that parse and otherwise manipulate CML data, it is intended to be a tool for the daily maintenance of survey data, the making of maps, and the extraction of sets of data that can be sent to other computer applications and uses.

An abiding principal has been to make the language, and computer, conform to the way that data have been collected rather than making data transcription conform to some perceived requirements of the computer. Thus, every survey and data convention that has been used in the 35 years of work at Mammoth Cave is, or can be, provided for. Data using those conventions do not have to be converted to other units or coordinate systems before being processed by language tools. Survey data are written in plain text (ASCII) in close to the same way that they are written down in the raw survey notes. The data format is free, both in the ways that data are permitted to be arranged on each line and in the way that groups of survey data can be arranged. The language specification requires that the programs that support it allow forward referencing of data, that is, a station or survey does not have to be defined before it is referenced in another survey. There are provisions for embedding comments (textual data intended to be read by

humans) and notes (textual data intended to be processed by machines) with the numerical survey data, just as one makes notes in a survey book.

CML is supported by a single large program and a growing number of smaller utilities for converting other data formats into CML. At its present state of development, the code is 12,000 lines of system-independent ANSI-C code. The program has been written to be platform independent and has been successfully compiled and used on Macintosh, MS/DOS, and IBM R6000 computers.

The program performs the conventional tasks of generating Cartesian coordinate data, doing loop closure, and generating graphics files. It serves as a data management tool in that it can produce a number of useful data summaries. For example, survey log sheets can be generated that show such things as the date, location, and personnel involved in a survey trip plus a schematic of the passages surveyed. CML interacts with SMAPS/GIS in ways that satisfy Park Service and CRF cartographic needs by producing Standard Exchange Format (SEF) files suitable for importing into SMAPS.

### THE USE OF AN ORIENTEERING COMPASS FOR SKETCHING

Dan Legnini - 120 North Huffman Street, Naperville,  
Illinois 60540

Application of a simple compass as a drafting aid for the sketcher will be demonstrated. An inexpensive, commonly available compass can be of great help when sketching to scale. Plotting of both plan and profile can be simplified with this one tool.

### FORMAL TRAINING FOR CAVE SURVEYORS

Angela Morgan - 222 Evalyn Street, Madison, Alabama  
35758

Tom Moss - 307 Bethune Way, Huntsville, Alabama 35806

The Fern Cave project was formed in 1991 with the goal of resurveying Fern Cave, Alabama. High standards for the survey were established. Because of the strict standards being followed, and also because it was realized that many potential project members might not have the experience and/or skills necessary to perform sketching or perform instrument-reading functions on survey trips, training and certification procedures were established to train sketchers and instrument readers.



A two-day training course was developed for sketching and instrument reading. The first day of the course consists of a classroom session and a practice session; the sketching and instrument classes are separate on this day. On the second day, all the students are together and survey in a cave for several hours.

At the time of this writing the survey class has been taught twice. Discussion will cover details of how the course is taught, what has been learned in the process of teaching it, student reaction to the course, the project's certification procedures, and how the training and certification process has benefitted the Fern Cave Project.

#### SMAPS/GIS—A CAVE-ORIENTED GEOGRAPHIC INFORMATION SYSTEM

Douglas P. Dotson, Assistant Professor  
Department of Computer Science, Frostburg State University, Frostburg, Maryland 21532-1099

SMAPS/GIS was developed in cooperation with the National Park Service beginning in June 1990. The purpose of the project is to develop a Geographical Information System which was particularly suited to the unique aspects of cave resource management. The resulting system has been adopted as the "standard" system for cave resource management in the NPS.

The presentation will begin by showing why traditional raster and vector based GIS packages fall short when dealing with cave related data. The remaining time will concentrate on the GIS related features available in the SMAPS Cave Management System and the SMAPS/GIS option. A hypothetical cave with many diverse resources will be used as an example of how data is managed and manipulated. A complete scenario will be presented which will show how the GIS may be used as a practical management tool.

#### BUILDING THE DATABASE FOR A CAVE-ORIENTED GEOGRAPHIC INFORMATION SYSTEM.

Douglas P. Dotson, Assistant Professor  
Department of Computer Science, Frostburg State University, Frostburg, Maryland 21532-1099

This paper will concentrate on the various methods for gathering data to build a database for a cave oriented Geographic Information System. A real world project will be used to illustrate, showing methods for gathering data from existing paper maps as well as gathering new data in

the cave itself. The current cave inventory project at Wind Cave National Park will be used as an example of the inventory process.

#### UNITED STATES EXPLORATION

##### SEA CAVE EXPLORATION IN THE CALIFORNIA CHANNEL ISLANDS

Dave Bunnell - 320 Brk Drive, Boulder Creek, California 95006

The Channel Islands lie off the coast of southern California, south of Santa Barbara and Ventura. Exploration since 1982 has yielded 100+ caves surveyed on Santa Cruz, 116 on Anacapa, and 45 on Santa Rosa. Work on Anacapa Island is nearly complete with a surprising density of caves found in its five-mile length. Many show a maze-like pattern.

The National Park Service has sponsored our survey work on Santa Rosa Island, providing transportation and lodging. The caves there are more diverse than on the other islands due to a greater variety of host rocks (sandstone, conglomerate, basalt) and the presence of several huge littoral collapses, creating pits 50 to 60 feet deep into former sea cave chambers. The rougher surf typical around this island has yielded caves of impressive volume, one containing passage widths in excess of 100 feet. Work has only just begun on this island, which may prove the most prolific in terms of both number and size of caves.

##### RECENT EXPLORATION IN WIND CAVE, SOUTH DAKOTA

Jim Nepstead - Wind Cave National Park

Exploration in Wind Cave, Custer County, South Dakota, has increased significantly in pace during the course of the past two years. More than ten miles of new passage has been mapped since January 1991. These new discoveries are the results of the efforts of many volunteer groups, most notably from Colorado. Much of the new passage is contained within the boundaries of previous exploration, but in September 1991 a major breakthrough in the remote Silent Expressway area occurred. As of April 1992, close to three miles of large, breezy cave have been explored beyond the breakthrough. In addition to a "survey as you go" philosophy, an "inventory as you go" policy has developed at Wind Cave. The data generated is already beginning to prove valuable to both cave managers and researchers alike.



## FORMAL ORGANIZATIONAL STRUCTURES IN USE BETWEEN EXPLORATION CAVERS AND UNITS OF THE NATIONAL PARK SYSTEM

Bill Yett - 2930 East Fourteenth Avenue, Denver, Colorado  
80206

Informal understandings, local improvisation, and permit systems have characterized past arrangements between exploration cavers and the National Park Service. Recently, more formal arrangements such as memorandums of understanding have also been widely used. The most recent development is use of volunteer status, known as "Volunteers in the Park" or "VIPs." This status can be extended to both individuals and members of organized groups. Volunteer status is analogous to that of an unpaid employee, and volunteers are considered as employees under the Federal Compensation Act and the Federal Tort Claims Act. As such they are entitled to medical and hospital care for work related injuries under the Compensation Act. The Tort Claims Act provides a means whereby damages may be awarded as a result of claims against the National Park Service and also provides protection from personal liability for acts within the scope of assigned volunteer duties. Housing, compensation for incidental expenses, and damage or loss of personal equipment is also allowed under prescribed circumstances.

Past and present arrangements between exploration cavers and Park System units are examined as illustrative of various arrangements.

## CONTINUED EXPLORATION IN OLAA CAVE, HAWAII

Dave Bunnell - 320 Brk Drive, Boulder Creek, California  
95006

On a 1987 trip to the Big Island of Hawaii, a group of us from Southern Cal Grotto had surveyed over six kilometers in Olaa Cave, located in heavily forested paleoflows near the town of Volcano. Exploration upflow had halted at an eight-meter high lava falls with a six-foot tall red drip spire at its base. In summer of 1991, three of us returned with a rented aluminum extension ladder and scaled this drop, followed 300 meters later by a six-meter high falls, that was also "laddered." Above, we found names and dates carved in rafted blocks and a survey line. Alas, shortly beyond we reached a collapse, apparently the result of road construction. This effectively terminated the cave, but with our new survey the cave stands at 258 meters deep and just under seven kilometers in length with 17 lava falls eight of which require rope.

## THE DISCOVERY, EXPLORATION, AND SURVEY OF PEACHERS CAVE SYSTEM, ORANGE COUNTY, INDIANA

Scott Fee - 5471 N Fenmore Road, Indianapolis, Indiana  
46208-2036

Peachers Cave was documented as early as the 1930s and formerly consisted of two small-chambered caves. During a routine survey trip in February 1991 by Scott Fee, Tom Hornaday, and Dave Seng, a previously overlooked crawl was pushed that has yielded over 1.5 miles of significant cave passages.

The entrance crawl led immediately to 3,000 feet of simplistic borehole with only two short crawlways slowing the explorer. These crawlways separate two of the most decorated chambers in Indiana. This upper level is so sensitive to caver traffic that the surveyors walked single-file in the same trails before marking them with flagging tape. The current foot paths have become a testimonial to the damage that occurs once the explorer leaves the trail. All the photography shown was taken while on the path.

Much concern arose when an Indiana State Senator and the Division of Natural Resources became involved. With the cave having no obstacles to prevent potential vandals and speleothem mining, the conservation effort went one step further when a gate was installed within the entrance crawlway at the landowner's request.

The lower level floods completely and has limited exploration to dry days. It is here that albino fish and crawfish are routinely seen. Three different sumps all occur within a few feet of being directly under the entrance; thus limiting the lower level to being pushed upstream in polypropylene and wetsuits. Mapping and exploration continues during dry months.

## RECENT ACTIVITIES IN CARLSBAD CAVERNS NATIONAL PARK, NEW MEXICO

Dale Pate

The past year has seen a lot of activity concerning caves of the park and there are a number of projects in the works. Several new small caves were discovered bringing the total to 80 caves in the park. Of these, ten remain open for cavers to obtain permits to.

Of critical concern is the proposed gas and oil drilling along the northern boundary of the park in the vicinity of Lechuguilla Cave. The Bureau of Land Management is now in the process of completing an Environmental Impact Statement for that area.



in the process of completing an Environmental Impact Statement for that area.

This year, the Cave Resources Office has been able to hire three seasonal employees, enabling the park to complete various projects such as replacing a wooden bridge in Carlsbad Caverns that has been deteriorating due to it being placed in water. Other projects have included work in many back-country caves as well as surveying and restoration in Carlsbad Caverns. We have also started an active program of inventorying the resources in all the caves in the park. Any new surveying will also include the inventory process at the same time. With the new SMAPS/GIS program recently developed by Doug Dotson, we should be able to identify trends and learn quite a bit about the various features found in the caves of the park.

A series of climbs above the Chocolate Drop in the New Mexico Room of Carlsbad Caverns by Don Doucette Art Wiggins, and others have led to a major discovery of more than one mile of surveyed and inventoried passages and a number of interesting leads. This new area has been named Chocolate High.

A new U.S. depth record was recently set by British diver Peter Bolt by diving in the Lake of the White Roses in Lechuguilla Cave. His dive was supported by British, Canadian, and American crews. The official depth of 1,593 feet (486 meters) is being released by the National Park Service for the depth of Lechuguilla Cave.



## Index to Volume 54 of the National Speleological Society Bulletin

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This index contains references to all articles and abstracts published in volume 54 parts 1 and 2. Abstracts for the 1992 NSS Annual Meeting are contained in this volume.

The index consists of three sections. The first of these is a **keyword index** which starts on **page 103**. Keywords include: unique words from the article title, cave names, geographic names, and descriptive terms. The second section is a **biologic names index** on **page 110**. These terms are Latin names of organisms discussed in articles. The third section is an alphabetical **author index** starting on **page 112**. Articles with multiple authors are indexed under each author.

Citations include only the name of the authors, followed by the page numbers of the article. Within an index group, such as "Archaeology", the earliest article is cited first, followed by consecutive articles.

Index data was input on an IBM-PC using the SDI-Soft front-end program designed by Keith Wheeland. The index was prepared on an IBM 4341 computer running a VM/CMS operating system. Indexing was performed by the IBM KWIC/KWOC program as modified by William H. Verity at The Pennsylvania State University Center for Academic Computing. Formatting was accomplished using the SCRIPT text formater, and Generalized Markup Language, with camera-ready copy produced on a Xerox 2700 laser printer.

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