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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 palaeomonid shrimp, 2 mysidaceans, 4 amphipods, 1 terrestrial isopod, 1 interstitial Anthurid isopod, 2 collemboles, 1 cockroach, 2 cixiid bugs, and 2 carabid beetles. The invertebrate 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, gypsiferous 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.


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 Standford Ltd., 12-14 Long Street, Kingston, or Edward Standford Ltd., 12-14 Long Street, Kingston.
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.

JAMAICA CAVE FAUNA

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. gracilis) 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 (=brotuld), 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 Cave 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.

<table>
<thead>
<tr>
<th>Cave name</th>
<th>Map grid location</th>
<th>Elevation (m)</th>
<th>Length (m)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clarendon Parish</strong></td>
<td></td>
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<tr>
<td>1. Jackson Bay Great Cave</td>
<td>H 472 303</td>
<td>0</td>
<td>3300</td>
<td>complex</td>
</tr>
<tr>
<td>2. Pedro Great Cave</td>
<td>G 476 468</td>
<td>500</td>
<td>520</td>
<td>moist</td>
</tr>
<tr>
<td>3. Portland Ridge Caves</td>
<td>H 495 310</td>
<td>13</td>
<td>500</td>
<td>dry</td>
</tr>
<tr>
<td><strong>Hanover Parish</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Cousins Cave no. 1</td>
<td>A 119 554</td>
<td>15</td>
<td>300</td>
<td>labyrinth</td>
</tr>
<tr>
<td>5. Cousins Cave no. 2</td>
<td>A 119 553</td>
<td>50</td>
<td>100</td>
<td>complex</td>
</tr>
<tr>
<td><strong>Manchester Parish</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Abbey Cave</td>
<td>D 364 406</td>
<td>44</td>
<td>700</td>
<td>moist</td>
</tr>
<tr>
<td>7. Coffee River Cave</td>
<td>D 333 476</td>
<td>275</td>
<td>2800</td>
<td>river</td>
</tr>
<tr>
<td>8. Oxford Cave</td>
<td>D 332 475</td>
<td>290</td>
<td>760</td>
<td>moist</td>
</tr>
<tr>
<td>9. Wyslip Water Cave</td>
<td>E 378 345</td>
<td>0</td>
<td>25</td>
<td>marine pool</td>
</tr>
<tr>
<td><strong>Portland Parish</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>10. Nonsuch Caves</td>
<td>M 750 455</td>
<td>182</td>
<td>76</td>
<td>moist</td>
</tr>
<tr>
<td>11. Brambribo Cave</td>
<td>G 454 478</td>
<td>610</td>
<td>335</td>
<td>moist</td>
</tr>
<tr>
<td>12. Cave River Cave</td>
<td>G 409 483</td>
<td>550</td>
<td>700</td>
<td>river</td>
</tr>
<tr>
<td>13. Chesterfield Cave</td>
<td>F 475 535</td>
<td>550</td>
<td>240</td>
<td>moist</td>
</tr>
<tr>
<td>14. Cricket Cave</td>
<td>G 456 475</td>
<td>680</td>
<td>100</td>
<td>stream</td>
</tr>
<tr>
<td>15. Dairy Bull Cave</td>
<td>F 415 569</td>
<td>3</td>
<td>100</td>
<td>marine pool</td>
</tr>
<tr>
<td>16. Douglas Castle Cave</td>
<td>G 456 477</td>
<td>685</td>
<td>40</td>
<td>moist</td>
</tr>
<tr>
<td>17. Falling Cave</td>
<td>G 456 475</td>
<td>685</td>
<td>100</td>
<td>moist</td>
</tr>
<tr>
<td>18. Green Grotto</td>
<td>(of Runaway Caves)</td>
<td>F 420 566</td>
<td>0</td>
<td>500</td>
</tr>
<tr>
<td>19. Ken Connell Hole</td>
<td>F 476 491</td>
<td>530</td>
<td>300</td>
<td>moist</td>
</tr>
<tr>
<td>20. Moseley Hall Cave</td>
<td>F 539 493</td>
<td>533</td>
<td>243</td>
<td>moist</td>
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<tr>
<td>21. Mount Plenty Cave</td>
<td>F 529 521</td>
<td>335</td>
<td>160</td>
<td>moist</td>
</tr>
<tr>
<td>22. Norwood Rat Bat Hole</td>
<td>G 410 487</td>
<td>530</td>
<td>134</td>
<td>moist</td>
</tr>
<tr>
<td>23. Runaway Bay Caves</td>
<td>F 420 566</td>
<td>10</td>
<td>1000</td>
<td>labyrinth</td>
</tr>
<tr>
<td>24. Thatchfield Great Cave</td>
<td>(= Thatchfield Light Hole)</td>
<td>F 444 548</td>
<td>414</td>
<td>1400</td>
</tr>
<tr>
<td>25. Thunder Cave</td>
<td>F 400 540</td>
<td>380</td>
<td>50</td>
<td>moist</td>
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<tr>
<td><strong>St. Catherine Parish</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26. St. Claire Cave</td>
<td>G 518 454</td>
<td>235</td>
<td>2900</td>
<td>river</td>
</tr>
<tr>
<td>27. Swansea Caves</td>
<td>G 497 464</td>
<td>460</td>
<td>1170</td>
<td>moist</td>
</tr>
<tr>
<td>28. Worthy Park Cave (no. 2)</td>
<td>G 504 453</td>
<td>380</td>
<td>716</td>
<td>stream</td>
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<tr>
<td><strong>St. Elizabeth Parish</strong></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>29. Duanwarie Cave (no. 1)</td>
<td>D 256 476</td>
<td>260</td>
<td>90</td>
<td>moist</td>
</tr>
<tr>
<td>30. Peru Cave</td>
<td>D 332 428</td>
<td>80</td>
<td>213</td>
<td>moist</td>
</tr>
<tr>
<td>31. Wallingford Cave</td>
<td>D 326 466</td>
<td>228</td>
<td>64</td>
<td>moist</td>
</tr>
<tr>
<td>32. Wallingford Sink Cave</td>
<td>D 326 465</td>
<td>213</td>
<td>413</td>
<td>river</td>
</tr>
<tr>
<td><strong>St. James Parish</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33. Brandon Hill Cave</td>
<td>(= Sewell Cave)</td>
<td>C 233 527</td>
<td>69</td>
<td>127</td>
</tr>
<tr>
<td>34. Maldon School Cave</td>
<td>C 270 526</td>
<td>579</td>
<td>152</td>
<td>stream</td>
</tr>
<tr>
<td>35. Mocho Cave</td>
<td>C 239 549</td>
<td>344</td>
<td>130</td>
<td>moist</td>
</tr>
<tr>
<td>36. Peterkin Cave</td>
<td>C 270 227</td>
<td>344</td>
<td>419</td>
<td>stream</td>
</tr>
<tr>
<td>37. Rota Cave</td>
<td>C 272 228</td>
<td>335</td>
<td>975</td>
<td>moist</td>
</tr>
<tr>
<td>38. Spring Vale Cave</td>
<td>(= South Rising Cave)</td>
<td>C 284 536</td>
<td>158</td>
<td>38</td>
</tr>
<tr>
<td><strong>St. Mary Parish</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39. Lucky Hill Farm Cave</td>
<td>F 538 519</td>
<td>260</td>
<td>150</td>
<td>stream</td>
</tr>
<tr>
<td>40. Idlewild Caves</td>
<td>K 582 547</td>
<td>15</td>
<td>30</td>
<td>dry</td>
</tr>
<tr>
<td>41. Rock Springs Cavern</td>
<td>K 574 489</td>
<td>290</td>
<td>2590</td>
<td>river</td>
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<tr>
<td><strong>Trelawny Parish</strong></td>
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<tr>
<td>42. Burnt Hill Cave</td>
<td>C 354 515</td>
<td>396</td>
<td>26</td>
<td>moist</td>
</tr>
<tr>
<td>43. Carambie Cave</td>
<td>C 354 511</td>
<td>503</td>
<td>335</td>
<td>labyrinth</td>
</tr>
<tr>
<td>44. Deeside River Cave</td>
<td>C 290 541</td>
<td>182</td>
<td>335</td>
<td>moist</td>
</tr>
<tr>
<td>45. Drip Cave</td>
<td>F 392 331</td>
<td>390</td>
<td>300</td>
<td>moist</td>
</tr>
<tr>
<td>46. Dromilly Cave</td>
<td>C 302 337</td>
<td>118</td>
<td>100</td>
<td>moist</td>
</tr>
<tr>
<td>47. Harries Caves (no. 1 and no. 2)</td>
<td>C 351 510</td>
<td>533</td>
<td>1313</td>
<td>complex</td>
</tr>
<tr>
<td>48. Hope Gate Cave</td>
<td>C 337 573</td>
<td>6</td>
<td>213</td>
<td>labyrinth</td>
</tr>
<tr>
<td>49. Printed Circuit Cave</td>
<td>C 352 510</td>
<td>533</td>
<td>3220</td>
<td>labyrinth</td>
</tr>
<tr>
<td>50. Windsor Great Cave</td>
<td>C 326 528</td>
<td>114</td>
<td>2977</td>
<td>complex</td>
</tr>
<tr>
<td><strong>Westmorland Parish</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>51. Monarva Cave</td>
<td>B 103 486</td>
<td>60</td>
<td>300</td>
<td>moist</td>
</tr>
<tr>
<td>52. Roaring River Cave</td>
<td>B 184 503</td>
<td>82</td>
<td>152</td>
<td>stream</td>
</tr>
</tbody>
</table>
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 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, trogloxene, 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, troglobite  
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 Molusca

Large accumulations of snail shells, most commonly of *Pleurodonte acuta*, *P. jamaicensis*, *Thelidomus acuta*, *Annularia pulchrum*, *Sagda* sp. (all Sagdidae) and *Dentalaria* 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.

*Subulina octona* Bracquiere, 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

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 Onychopora

Family Peripatidae

*Plicatoperipatus jamaicensis* (Grabham and Cockerell), accidental
- St. Ann: Moseley Hall Cave (Arnett, 1961). This species is more commonly known from Jamaican epigean localities.

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

**Figure 5.** *Speleoperipatus spelaeus from Pedro Great Cave.*

Troglolitic onycophorans ("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

*Schizomus* (Chamberlin), troglobite
Manchester: Oxford 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. Trelawney: Drip Cave, Windsor Great Cave. This endemic species is also known from Jamaican forests.

*Schizomus portoricensis* (Chamberlin), troglobite
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. Westmorland: 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

*Phrynus levi* Quintero, troglobite
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), troglobite

*Masteria pecki* Gertsch 1982a, troglobe
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. troglobile

Family Scytodidae

**Loxosceles caribbaea** Gertsch, troglobile

**Scytodes** sp. troglobile

**Scytodes longipes** Lucas, troglobile
Westmorland: Roaring River Cave, 5.

Family Oonopidae

**Triaeris stenaspis** Simon, troglobile
Hanover: Cousins Cave Cave no. 2. St. Ann: Worthy Park Cave no. 2. Westmorland: Roaring River Cave.

**Oonops castellus** Chickering, troglobile
Clarendon: Jackson Bay Cave.

**Oonops** sp., accidental

Family Dysderidae

**Ariadna arthuri** Petrunkevitch, troglobile
Hanover: Cousins Cave Cave no. 1. St. James: Rota Cave. Westmorland: Monarva Cave.

Family Ochyroceratidae

**Theotima** sp., troglobile
St. Catherine: St. Claire Cave. This species is eyeless and undescribed.

**Theotima minutissima** (Petrunkevitch), troglobile

**Ochyrocer a** sp., troglobile

Family Pholcidae

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

**Metagonia jamaica** Gertsch 1986, troglobile
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 quatoculus** Gertsch, troglobile
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, troglobile
St. Elizabeth: Duanwarie Cave. This essentially eyeless and long legged species is known only from this cave (Gertsch, 1982b).

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

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

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

**Anopsicus clarus** Gertsch, troglobile
Clarendon: Jackson Bay Cave. Portland Caves. This species is eyeless.

**Anopsicus nortoni** Gertsch, troglobile
Hanover: Cousins Cave Cave.

**Anopsicus zimmermani** Gertsch, troglobile
Trelawny: Carambie Cave, Printed Circuit Cave.

**Anopsicus undetermined**, troglobile

**Modisimus** sp., troglobile
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

Family Prodidomidae

*Zimiris* sp., troglobite

Family Nesticidae

*Gauce/mus cavernico/a* (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, Drink 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 cavernicola*. It was previously recorded from Peru Cave and Oxford Cave (Petrunkevitch, 1928).

*Eidmannella suggerens* (Chamberlin), troglophile
Hanover: Cousins Cove Cave no. 1.

Family Araneidae

*Pseudometa* sp., troglophile
St. Ann: Mt. Plenty Cave. Trelawny: Drip Cave.

Family Tetragnathidae

*Tetragnatha* sp., troglophile?

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

*Phrurolithus* sp., accidental?
Hanover: Cousins Cave Cave, 4. Trelawny: Harties Cave, 1.

Family Ctenidae

*Ctenus* sp., troglophile

*Ctenus* sp. troglophile

Family Gnaphosidae

*Lygromma gerschi* 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
Cynortina pecki Rambla (1969) troglobite

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.

Family Chthoniidae
Lagynochthonius cavicolus Muchmore 1991, troglobite
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, troglobilphile
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 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
Trichouropoda sp. 1, troglobilphile
St. Catherine: St. Claire Cave.
Trichouropoda sp. 2, troglobilphile
St. Ann: Moseley Hall Cave.

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**Uroactinia** sp., troglobiphile  
St. Elizabeth: Peru Cave.

**Uroobovella** sp. 1, troglobiphile  
St. Ann: Moseley Hall Cave.

**Uroobovella** sp. 2, troglobiphile  
St. Catherine: St. Claire Cave.

**Uropoda (Phaulodinychus)** sp., troglobiphile  
St. Ann: Thatchfield Great Cave.

Order Acariformes  
Suborder Actinedida (Prostigmata)

Family Pygmeophoridae  
**Bakerdania** sp., troglobiphile  
St. Ann: Moseley Hall Cave. This is probably a fungivore; phoretic as adult females on insects.

Family Stigmaeidae  
**Stigmaeus** sp., troglobiphile  
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., troglobiphile  
St. Ann: Moseley Hall Cave. This is probably fungivorous.

Family Xenillidae  
**Xenillus** sp., troglobiphile  
St. Ann: Moseley Hall Cave. This is a fungivorous genus.

Family Oppiidae  
**Oppia** sp., troglobiphile  
St. Ann: Moseley Hall Cave. This genus is fungivorous.

**Multioppia** sp. ?, troglobiphile  
St. Catherine: St. Claire Cave.

Family Scheloribatidae  
**Scheloribates** sp., troglobiphile  
St. Ann: Moseley Hall Cave. Members of this genus are saprophagous and fungivorous.

Family Mochlozetidae  
**Unguizetes** sp. ?, troglobiphile  
St. Ann: Moseley Hall Cave. This is probably saprophagous.

Family Galumnidae  
**Galumna** sp., troglobiphile  
St. Ann: Moseley Hall Cave. This may be saprophagous or a predator on nematodes.

Genus undetermined, troglobiphile  
St. Ann: Moseley Hall Cave.

Suborder Astigmata (Acarida)

Family Histiotomatidae (= Anoetidae)  
**Histiotoma** sp., troglobiphile  
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, troglobiphile  

Class Maxillopoda  
Order Harpacticoida

Family Harpacticidae  
**Elaphoidella sewelli** Chappuis, troglobiphile  
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, troglobene  
Gecarcinus rurico/a (Linn.), troglobene  

Family Grapsidae  
Sesarma bidentatum Benedict, troglobite (Fig. 7)  
St. Ann: Cave River Cave, Lucky Hill Farm Cave. St. Elizabeth: Wallingford Sink Cave. Trelawny: Printed Circuit Cave. Mentioned by Hartknoll (1963) in stream flowing through unnamed cave on 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, troglobite  
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, troglobite  
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), troglobite  
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), troglobite  
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 troglobites (Botosaneanu and Holthuis, 1970).  
Macrobrachium carcinum (Linnaeus), troglobite  
Macrobrachium faustinum lucifugum Holthuis (1974), troglobite

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

Lucky Hill Cooperative Farm (Chace and Hobbs, 1969).  
Sesarma verleyi Rathbun, troglobite (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.
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, troglophilic

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

Order Amphipoda

Family Talitridae

*Hyalella azteca* group, troglophilic

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 freshwater 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

*Stygioymysis 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, troglophilic

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

Family Armadillidae

*Cubaris* sp., troglophilic

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., troglophilic or trogloxene

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, troglobiophiles

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 of 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

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.

Family Geophilomorpha

Family Schendylidae

*Tanophilus* sp. (?) troglophile
St. James: Brandon Hill Cave. St. Mary: Nonsuch Cave.

Genus undet.

Family Chilenophilidae

Genus undet., troglophile (?)

Class Diplopoda
Order Polyxenida

Family Polyxenidae

Genus and species undetermined, troglophile

Order Glomeridesmida

Family Glomeridesmidae

*Glomeridesmus* sp., troglophile
St. Catherine: Worthy Park Cave.

Family Comodesmidae

*Inodesmus jamaicensis* Cook, troglophile

Class Diplopoda
Order Polydesmida

Family Polydesmidae

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

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, 1975).

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 keaarti* (Humbert), troglobite
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.

Family Rhinocricidae

*Rhinocricus* sp., troglobite

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., troglobite
Clarendon: Jackson Bay Cave. An eyeless, white species with long antennae. This genus has not previously been reported from Jamaica.

*Pseudosinella violenta* group, troglobite?
Hanover: Cousins Cove Cave no. 2. Trelawny: Drip Cave, poor condition specimen. Westmorland: Monarva Cave. *P. violenta* (Falsom) has been reported from Jamaica, Mexico, and the United States.

Family Paronellidae

*Troglopedetes jamaicanus* Palacios-Vargas et al. 1985, troglobite (?)
Clarendon: Jackson Bay Cave, Pedro Great Cave. Hanover: Cousins Cove Cave no. 2. Trelawny: Drip 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., troglobite?

Family Hypogastruridae

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

Family Isotomidae

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

Family Cyphoderidae

*Cyphoderus similis* Folsom, troglobite
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, troglobite?

Order Thysanura

Family Nicoletiidae

*Nicoletia meinerti* Silvestri, troglobite
St. Catherine: Swansea Cave. This species is tropicopolitan and most populations are parthenogenetic.

*Grassieila* sp., troglobite
Westmorland: Roaring River Cave. These silverfish are subterranean and often myrmecophilous.

Order Blattodea

Family Blaberidae

*Pycnoscelus surinamensis* (Linnaeus), trogloxene

*Epilampra* sp., accidental
Trelawny: Printed Circuit Cave, 1 nymph.

*Panchlora* sp., troglobe.

Family Blattellidae

*Ischnoptera* sp. (probably), trogloxene
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 troglobitic Nelipophygus cockroach is found in many Jamaican caves, in wet and food-poor areas. Another species, a troglobile 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.*

*Family Blattidae*

*Nelipophygus* sp. 2, troglobile
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 Gryllidae*

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

*Order Dermaptera*

*Family Carcinophoridae*

*Euborellia annulipes* (Lucas), troglobile St. Ann: Mt. Plenty Cave.
*Carcinophora americana* (P. de Beauvois), troglobile St. James: Mt. Plenty Cave, Rota Cave.

*Family Labiidae*

*Marava jamaicana* (Rehn and Hebbard), troglobile St. Ann: Cave River Cave, Mt. Plenty Cave, Thatchfield Light Hole Cave.

*Order Orthoptera*

*Family Gryllidae*

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

*Order Dermaptera*

*Family Carcinophoridae*

*Euborellia annulipes* (Lucas), troglobile St. Ann: Mt. Plenty Cave.
*Carcinophora americana* (P. de Beauvois), troglobile St. James: Mt. Plenty Cave, Rota Cave.

*Family Labiidae*

*Marava jamaicana* (Rehn and Hebbard), troglobile St. Ann: Cave River Cave, Mt. Plenty Cave, Thatchfield Light Hole Cave.

*Order Orthoptera*

*Family Gryllidae*

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

**Family Cydnidae**

*Amnestus trimaculatus* Froeschner, troglophilic

*Rhytidoporus indentatus* Uhler, troglophilic
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, troglophilic
Trelawny: Harties Cave.

*Microvelia cubana* Drake, troglophilic

*Microvelia albonotata* Champion, troglophilic

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

**Family Reduviidae, Subfamily Esmesinae**

*Ploiaria umbrarum* McA. y Maldonado, troglophilic

**Order Coleoptera**

**Family Carabidae**

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

*Ardistomis* sp. 2, troglobite

*Colpodes cavicola* Darlington, troglophilic
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.
Family Dytiscidae
Genus and species undetermined, troglophile
St. Elizabeth: St. Claire Cave, 10 from cave stream-pools.

Family Hydrophilidae
**Omicrus lateralis** Smetana, troglophile

**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

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

**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 Ptiliidae
Genus and species undetermined.

Family Nitidulidae

Family Histeridae
**Saprinus** sp., troglophile

Family Staphylinidae
**Aleochara** sp., accidental
Manchester: Oxford Cave, 4 specimens, cave entrance zone.

**Athea** 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 gogates** Erichson, troglophile
St. Ann: Mt. Plenty Cave, common on guano piles.

**Medon** sp., troglophile
St. James: Brandon Hill Cave, many in guano piles.

**Gyrophaena** 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.
JAMAICA CAVE FAUNA

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

Family Anobiidae

Genus and species undetermined, accidental

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 seminolella* (Beautenmuller) 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.

*Cypomyrmex rimosus* (Spinola), troglophile

*Dorymyrmex* sp., troglophile
St. Ann: Lucky Hill Farm Cave.

*Gnamptogenys continua* Mayr, troglophile

*Hypoponera opaciceps* (Forel), troglophile
St. Ann: Hutchinson Hole Cave, Mt. Plenty Cave. St. James: Rota Cave. St. Mary: Rock Spring Cave. This is a tramp species.

*Hypoponera* sp. 2, troglophile
Hanover: Cousins Cove 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  
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

Probaryconus sp., troglophile  

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

Macromesus 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. Ann: Brandon Hill Cave, Mt. Plenty Cave, Runaway Bay Caves. St. James: Brandon Hill Cave. This ant was introduced from West Africa and is now widespread in the West Indies.

Genus and species undetermined  

Family Mycetophilidae

Neoditomyia sp., troglophile  
Manchester: Abbey Cave; Oxford Cave, larva and pupae in hanging web. St. Ann: Brambrilio 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 Orfelia (Jackson, 1974).

Family Sciariidae

Sciara ? sp., troglophile  

Family Psychodidae

Tribe Pericominii, undet. genus, troglophile  

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Family Scatopsidae

*Reichertella* sp., troglophile  
*Scatops* sp., troglophile  
St. Ann: Brambibo Cave.

Family Ceratopogonidae

*Dasyhelea* sp. 1, troglophile  
*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 epigean 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

*Peloropeodes* sp., troglophile  

Family Phoridae

*Pholeomyia* sp., troglophile  

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 troglobiophiles 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 km², 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 km² has only eight troglobites (Peck, 1974; 1981; Peck and Kuvalova-Peck, 1981). Cuba is a much larger island, with an area of 105,000 km². 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-
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 2. Summary of freshwater, groundwater, and anchialine troglobites of Jamaica and cave locality (from Table 1).

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Cave localities (from Table 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platyhelminthes, Tripladonta, Turbellaria</td>
<td>43</td>
</tr>
<tr>
<td>1. Family, genus undetermined</td>
<td>1</td>
</tr>
<tr>
<td>Crustacea, Mysidae, Stygiomysisidae</td>
<td>2</td>
</tr>
<tr>
<td>2. Stygiomysis major Bowman (1976)</td>
<td>1</td>
</tr>
<tr>
<td>Crustacea, Mysidae, Mysisidae</td>
<td>3</td>
</tr>
<tr>
<td>3. Antarctophyllum peckorum Bowman (1977)</td>
<td>1</td>
</tr>
<tr>
<td>Crustacea, Amphipoda, Gammaridae</td>
<td>5</td>
</tr>
<tr>
<td>4. Metariphargus jamaicensis (Holsinger)</td>
<td>1, Springfield (0m)</td>
</tr>
<tr>
<td>Stock (1983)</td>
<td>2</td>
</tr>
<tr>
<td>5. Metariphargus craterensis Stock (1983)</td>
<td>Crater Lake (1m)</td>
</tr>
<tr>
<td>Stock (1983)</td>
<td>3</td>
</tr>
<tr>
<td>6. Metariphargus hyporheicus Stock (1983)</td>
<td>Rio Seco (0m)</td>
</tr>
<tr>
<td>Stock (1983)</td>
<td>7</td>
</tr>
<tr>
<td>7. Metaniphargus anchihalinus Stock (1983)</td>
<td>Discovery Bay (0m)</td>
</tr>
<tr>
<td>Crustacea, Isopoda, Amphipoda</td>
<td>8</td>
</tr>
<tr>
<td>8. Cyathura parapatamica Botosaneanu and Stock (1982)</td>
<td>Buff Bay River (80m)</td>
</tr>
<tr>
<td>Crustacea, Decapoda, Grapsidae</td>
<td>9</td>
</tr>
<tr>
<td>9. Sesarma verleyi Hartmann (1984)</td>
<td>7, 12, 14, 26, 28, 36, 47, 49</td>
</tr>
<tr>
<td>Crustacea, Decapoda, Palamolidae</td>
<td>10</td>
</tr>
<tr>
<td>10. Troglocubanus jamaicensis Holthuis (1963)</td>
<td>38</td>
</tr>
<tr>
<td>Vertebrata, Pisces, Bythitidae</td>
<td>11</td>
</tr>
<tr>
<td>(= Brotulidae)</td>
<td>Lucifuga sp? 1</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Cave localities (from Table 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onychophora, Peripatidae</td>
<td>1</td>
</tr>
<tr>
<td>1. Speleoherpetes spelaeus Peck (1975a)</td>
<td>2</td>
</tr>
<tr>
<td>Araneae, Dipluridae</td>
<td>2</td>
</tr>
<tr>
<td>2. Masteria pecki Gertsch (1982a)</td>
<td>17</td>
</tr>
<tr>
<td>Araneae, Ochyroceratidae</td>
<td>3</td>
</tr>
<tr>
<td>3. Theotima sp.</td>
<td>26</td>
</tr>
<tr>
<td>Araneae, Pholcidae</td>
<td>4</td>
</tr>
<tr>
<td>4. Metagonia jamaica Gertsch (1986)</td>
<td>1</td>
</tr>
<tr>
<td>Araneae, Gnaphosidae</td>
<td>5</td>
</tr>
<tr>
<td>5. Anopsicus clarus Gertsch (1982b)</td>
<td>1</td>
</tr>
<tr>
<td>Araneae, Dipluridae</td>
<td>6</td>
</tr>
<tr>
<td>6. Anopsicus jarmila Gertsch (1982b)</td>
<td>28</td>
</tr>
<tr>
<td>Araneae, Dipluridae</td>
<td>7</td>
</tr>
<tr>
<td>7. Anopsicus limpidus Gertsch (1982b)</td>
<td>14</td>
</tr>
<tr>
<td>Araneae, Phalangididae</td>
<td>8</td>
</tr>
<tr>
<td>8. Anopsicus nebulosus Gertsch (1982b)</td>
<td>29</td>
</tr>
<tr>
<td>Araneae, Opiliones, Phalangididae</td>
<td>9</td>
</tr>
<tr>
<td>9. Anopsicus pecki Gertsch (1982b)</td>
<td>3</td>
</tr>
<tr>
<td>Araneae, Gaaphosidae</td>
<td>10</td>
</tr>
<tr>
<td>10. Lygromma gertschi Platnick and Shadab (1976)</td>
<td>17, 28, 45</td>
</tr>
<tr>
<td>Opilionidae, Phalangididae</td>
<td>11</td>
</tr>
<tr>
<td>11. Cynorina pecki Rambla (1969)</td>
<td>2, 8, 14, 17, 28, 43</td>
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<tr>
<td>Opilionidae, Phalangididae</td>
<td>12</td>
</tr>
<tr>
<td>12. Stygnomma fiskeni Rambla (1969)</td>
<td>1, 7, 8</td>
</tr>
<tr>
<td>Pseudoscorpionida, Bochicidae</td>
<td>13</td>
</tr>
<tr>
<td>13. Troglobochica jamaicensis Muchmore (1984)</td>
<td>1</td>
</tr>
<tr>
<td>Pseudoscorpionida, Chthoniidae</td>
<td>14</td>
</tr>
<tr>
<td>Pseudoscorpionida, Chthoniidae</td>
<td>15</td>
</tr>
<tr>
<td>15. Tyrranochthonius hoffi Muchmore (1991)</td>
<td>5, 32, 43</td>
</tr>
<tr>
<td>Pseudoscorpionida, Chthoniidae</td>
<td>16</td>
</tr>
<tr>
<td>16. Lagynochthonius typhus Muchmore (1991)</td>
<td>34</td>
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<tr>
<td>Schizomida, Schizomidae</td>
<td>17</td>
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<tr>
<td>17. Schizomus troglobius Rowland and Reddell (1981)</td>
<td>1</td>
</tr>
<tr>
<td>Crustacea, Isopoda, Styloniscidae</td>
<td>18</td>
</tr>
<tr>
<td>18. Clavigeronsiscus sp.</td>
<td>27, 28</td>
</tr>
<tr>
<td>Hexapoda, Collembola, Entomobryidae</td>
<td>19</td>
</tr>
<tr>
<td>19. Metaschizomyia sp.</td>
<td>1</td>
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<tr>
<td>Hexapoda, Collembola, Paronellidae</td>
<td>20</td>
</tr>
<tr>
<td>20. Troglopedetes jamaicensis Palacios-Vargas (1985)</td>
<td>1, 2, 5, 6, 7, 8, 11, 14, 20, 26, 28, 30, 39</td>
</tr>
<tr>
<td>Insecta, Blattodea, Blattellidae</td>
<td>21</td>
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<tr>
<td>21. Nelidophygalys sp.</td>
<td>8, 11, 14, 17, 26, 27, 28, 29, 46, 47, 52</td>
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<tr>
<td>Insecta, Hemiptera, Kinnaridae</td>
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<tr>
<td>22. Oecidius antricola Fennah (1980)</td>
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<tr>
<td>Oecidius minax Fennah (1980)</td>
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<td>Insecta, Coleoptera, Carabidae</td>
<td>24</td>
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<td>24. Ardistomis sp. 1</td>
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<tr>
<td>Ardistomis sp. 2</td>
<td>17</td>
</tr>
</tbody>
</table>

ACKNOWLEDGEMENTS

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JAMAICA CAVE FAUNA


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

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Division of Natural Sciences, Mobile College, Mobile, AL 36663-0220 (SDC)

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 entrance 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).

<table>
<thead>
<tr>
<th>Cave</th>
<th>Date</th>
<th>Number and Kinds of Bats Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buzzard’s Den Cave, Clarke Co. (AL 2835)</td>
<td></td>
<td>12 November 1988 12 P. subflavus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 January 1989 2 P. rafinesquii</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24 February 1990 100 P. subflavus</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broadenax Cave, Clarke Co. (AL 128)</td>
<td></td>
<td>11 February 1989 0 bats</td>
</tr>
<tr>
<td>Broughton Cave, Monroe Co. (AL 2722)</td>
<td></td>
<td>12 February 1983 12 P. subflavus</td>
</tr>
<tr>
<td>February Cave, Monroe Co. (AL 2919)</td>
<td></td>
<td>25 February 1990 20 P. subflavus</td>
</tr>
<tr>
<td>Kimbrough Cave, Clarke Co. (AL 2920)</td>
<td></td>
<td>25 March 1990 3 P. subflavus</td>
</tr>
<tr>
<td>Lion’s Den Cave, Clarke Co. (AL 2806)</td>
<td></td>
<td>22 October 1988 10 P. subflavus</td>
</tr>
<tr>
<td>Locklin Cave, Monroe Co. (AL 2853)</td>
<td></td>
<td>29 July 1989 1 M. australis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24 February 1990 30 M. australis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 P. subflavus</td>
</tr>
<tr>
<td>Mclean’s Cave, Clarke Co. (AL 2738)</td>
<td></td>
<td>13 September 1986 1 P. subflavus</td>
</tr>
<tr>
<td>McVay Cave, Clarke Co. (AL 129)</td>
<td></td>
<td>21 April 1989 1 P. subflavus</td>
</tr>
<tr>
<td>Myrick’s Cave, Clarke Co.</td>
<td></td>
<td>18 March 1989 2 P. subflavus</td>
</tr>
<tr>
<td>Oscar Braun Cave, Washington Co.</td>
<td></td>
<td>12 June 1989 0 bats</td>
</tr>
<tr>
<td>Rabbit Creek Cave, Clarke Co. (AL 2267)</td>
<td></td>
<td>19 March 1983 3 P. subflavus</td>
</tr>
<tr>
<td>Randon’s Creek Cave, Monroe Co. (AL 2833)</td>
<td></td>
<td>13 February 1982 10 P. subflavus</td>
</tr>
<tr>
<td>Rock House Cave, Covington Co. (AL 1011)</td>
<td></td>
<td>5 March 1989 0 bats</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12 June 1989 0 bats</td>
</tr>
<tr>
<td>Rock Pit Cave, Monroe Co. (AL 1013)</td>
<td></td>
<td>11 May 1985 0 bats</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25 February 1990 several P. subflavus</td>
</tr>
<tr>
<td>Smith Cave, Clarke Co. (AL 2266)</td>
<td></td>
<td>19 March 1983 1 P. subflavus</td>
</tr>
<tr>
<td>Steve’s Solo Hole, Monroe Co. (AL 2918)</td>
<td></td>
<td>6 March 1990 3 P. subflavus</td>
</tr>
<tr>
<td>Stallworth Cave, Clarke Co. (AL 2832)</td>
<td></td>
<td>13 September 1986 0 bats</td>
</tr>
<tr>
<td>Upper Rabbit Creek Cave, Clarke Co.</td>
<td></td>
<td>18 March 1989 0 bats</td>
</tr>
<tr>
<td>Walker Cave, Clarke Co.</td>
<td></td>
<td>18 March 1989 0 bats</td>
</tr>
<tr>
<td>Whitehead Cave, Clarke Co. (AL 2834)</td>
<td></td>
<td>13 September 1986 0 bats</td>
</tr>
</tbody>
</table>
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 Conecu (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. griseascens have been reported from Sanders Cave (LaVal, 1967). M. griseascens has been reported from "the cave near Fort Deposit" (Howell, 1921:24), which could be B. C. Barganier Cave (B. Autry, the landowner, indicated he was unaware of previous visits by scientists). No M. lucifugus, M. septentrionalis, and M. griseascens 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 Autaugaaville, 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

---

### Table II


<table>
<thead>
<tr>
<th>Cave</th>
<th>Summer (June, July, and August 1990)</th>
<th>Winter (February and March 1991)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. C. Barganier Cave, Butler Co.</td>
<td>2 P. subflavus</td>
<td>45 P. subflavus</td>
</tr>
<tr>
<td>Buzzard’s Den Cave, Clarke Co. (AL 2835)</td>
<td>0 bats</td>
<td>185 P. subflavus</td>
</tr>
<tr>
<td>Cary Cave, Conecu Co. (AL 1424)</td>
<td>0 bats</td>
<td>105 P. subflavus</td>
</tr>
<tr>
<td>Chimney Cave, Covington Co.</td>
<td>0 bats</td>
<td>8 P. subflavus</td>
</tr>
<tr>
<td>Broadway Cave, Clarke Co. (AL 128)</td>
<td>0 bats</td>
<td>0 bats</td>
</tr>
<tr>
<td>Davis Hunting Club Cave, Monroe Co.</td>
<td>no data</td>
<td>9 M. austroriparius</td>
</tr>
<tr>
<td>February Cave, Monroe Co. (AL 2919)</td>
<td>0 bats</td>
<td>176 P. subflavus</td>
</tr>
<tr>
<td>Hodges Cave, Conecu Co.</td>
<td>0 bats</td>
<td>0 bats</td>
</tr>
<tr>
<td>Lion's Den Cave, Clarke Co. (AL 2806)</td>
<td>1 P. subflavus</td>
<td>517 P. subflavus</td>
</tr>
<tr>
<td>Locklin Cave, Monroe Co. (AL 2853)</td>
<td>3 M. austroriparius</td>
<td>40 M. austroriparius</td>
</tr>
<tr>
<td>Mt. Moriah Cave, Wilcox Co. (AL 134)</td>
<td>0 bats</td>
<td>83 P. subflavus</td>
</tr>
<tr>
<td>Myrock’s Cave, Clarke Co.</td>
<td>0 bats</td>
<td>25 P. subflavus</td>
</tr>
<tr>
<td>Rock House Cave, Covington Co. (AL 1011)</td>
<td>1 M. austroriparius</td>
<td>29 P. subflavus</td>
</tr>
<tr>
<td>Rock Pit Cave, Monroe Co. (AL 1013)</td>
<td>0 bats</td>
<td>8 M. austroriparius</td>
</tr>
<tr>
<td>Sanders Cave, Conecu Co. (AL 167)</td>
<td>ca. 8,000 M. austroriparius</td>
<td>21 P. subflavus</td>
</tr>
<tr>
<td>Sleaze Hole, Monroe Co. (AL 2921)</td>
<td>0 bats</td>
<td>19 P. subflavus</td>
</tr>
<tr>
<td>Stallworth Cave, Clarke Co. (AL 2832)</td>
<td>2 P. subflavus</td>
<td>47 M. austroriparius</td>
</tr>
<tr>
<td>Stone’s Cave, Wilcox Co. (AL 1110)</td>
<td>0 bats</td>
<td>314 P. subflavus</td>
</tr>
<tr>
<td>Walker Cave, Clarke Co.</td>
<td>0 bats</td>
<td>0 bats</td>
</tr>
<tr>
<td>Whitehead Cave, Clarke Co. (AL 2834)</td>
<td>0 bats</td>
<td>19 P. subflavus</td>
</tr>
</tbody>
</table>
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 (cohabiting 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. griseus, 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 woods, 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. griseus, 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.

ACKNOWLEDGMENTS

R. Chambers and B. Milam participated in most of the field trips. Other persons that provided information and assistance were B. Autry, C. Autry, M. Bailey, J. Bartig, K. Branson, J. Buchanan, S. Burt, R. Carter, B. Cary, C. Curren, A. Diamond, J. Dobe, D. Dumont, K. Edson, G. Folkerst, G. Gardner, K. Guyse, T. Henry, S. Hicks, C. Hilton, D. Holliman, S. Humphrey, J. Hunt, J. Jennings, R. Johnson, C. Jones, K. Kilburn, C. Madison, D. Miller, R. Mount, J. Myers, T. Nupp, B. Perryman, B. Simons, C. Smith, D. Speake, R. Stallworth, W. Stone, Jr., J. Walker, L. White, R. Whitehead, S. Yanoviak, G. Youngblood, and K. Youngblood. This project was funded by the Alabama Department of Conservation and Natural Resources, Game and Fish Division, Nongame Wildlife Program. F. S. Debson and R. S. Lishak critically evaluated an early draft of the manuscript. This is journal article no. 15-933430 of the Alabama Agricultural Experiment Station.

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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 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% MgCO₃ 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.

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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 (Leiobumum 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.

Petrunkevitch (1945) reported fossil arthropods (arachnids) from a calcium carbonate deposit in northern Arizona referred to as onyx marble. According to Edwin D. McKee (in Petrunkevitch, 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 cavernicolous. 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 fossils. 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.

ACKNOWLEDGEMENTS

We thank the U.S.D.A. Forest Service for permits to collect the speleothems which are reported upon herein. Jennifer Milburn, Jerry Trout, and Ransom Turner (all from U.S.D.A. Forest Service), Lisa Spillers (Wembley Downs, West Australia), and Joli Lee (Alamogordo, New Mexico) are thanked for their help in collecting samples. James Barrick (Department of Geosciences, Texas Tech University) and Chris Durden and James R. Reddell (Texas Memorial Museum) are thanked for comments on the manuscript. Mike Gower (Department of Geosciences, Texas Tech University) kindly prepared the thin-sections. This study was partially funded by grants to VJP by the National Speleological Society.

REFERENCES


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% CaCO₃ (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 dolomitized 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 calcarenite. It is pale orange, finely crystalline, highly fossiliferous, porous, and generally well indurated. It is nearly 97% CaCO₃, 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 MgCO₃, iron as one of several ferric or ferrous carbonates or sulfides, and sulphur as iron sulfide (FeS₂), pyrite (FeS₃), gypsum (CaSO₄ • 2H₂O), or anhydrite (CaSO₄).

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 subaquously.

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 Rolais 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 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 deionized water, deposited on ceramic tiles, and saturated with Mg²⁺ and glycerol in preparation for x-ray diffraction

### Table 1. Spring water chemistry data from Rosenau et al. (1977).

<table>
<thead>
<tr>
<th>Telford Spring</th>
<th>Peacock Spring</th>
<th>Madison Blue Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date(s) measured</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mg L⁻¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>8.3</td>
<td>4.7</td>
</tr>
<tr>
<td>Ca</td>
<td>52</td>
<td>44</td>
</tr>
<tr>
<td>Mg</td>
<td>24</td>
<td>21</td>
</tr>
<tr>
<td>Na</td>
<td>2.3</td>
<td>2.2</td>
</tr>
<tr>
<td>K</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Si at SiO₂</td>
<td>6.9</td>
<td>5.9</td>
</tr>
<tr>
<td>HCO₃</td>
<td>210</td>
<td>190</td>
</tr>
<tr>
<td>H₂CO₃</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CO₂</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SO₄</td>
<td>42</td>
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<td>0.0</td>
</tr>
<tr>
<td>Sr</td>
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<td>0.000</td>
</tr>
<tr>
<td>Total organic C</td>
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<td>-</td>
</tr>
<tr>
<td>Total inorganic C</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Organic N</td>
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</tr>
<tr>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NO₃⁻-N</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ortho P (PO₄ as P)</td>
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<td>-</td>
</tr>
<tr>
<td>Total P</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dissolved O₂</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Dissolved solids</td>
<td>233</td>
<td>187</td>
</tr>
<tr>
<td>Calculated</td>
<td></td>
<td></td>
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<tr>
<td>Residue on evaporation at 180°C</td>
<td>244</td>
<td>191</td>
</tr>
<tr>
<td>Hardness as CaCO₃</td>
<td>230</td>
<td>190</td>
</tr>
<tr>
<td>Noncarbonate hardness as CaCO₃</td>
<td>60</td>
<td>40</td>
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<tr>
<td>Alkalinity as CaCO₃</td>
<td>170</td>
<td>150</td>
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<tr>
<td>Specific conductance 1/µmhos cm⁻¹ at 25°C</td>
<td>423</td>
<td>346</td>
</tr>
<tr>
<td>Color (platinum cobalt units)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>pH</td>
<td>7.4</td>
<td>7.4</td>
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<tr>
<td>Temperature (°C)</td>
<td>21.0</td>
<td>22.0</td>
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</table>

### Table 2. Clay sediment sample sources.

<table>
<thead>
<tr>
<th>Cave</th>
<th>Telford Spring</th>
<th>Peacock Spring</th>
<th>Madison Blue Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>County</td>
<td>Suwannee</td>
<td>Suwannee</td>
<td>Madison</td>
</tr>
<tr>
<td>River receiving spring flow</td>
<td>Suwannee</td>
<td>Suwannee via Peacock Slough</td>
<td>Withlacoochee (North)</td>
</tr>
<tr>
<td>Tunnel/section in cave tunnel</td>
<td>Downstream</td>
<td>Peanut tunnel</td>
<td>Main tunnel</td>
</tr>
<tr>
<td>From Beulahland downstream</td>
<td>Waterhole</td>
<td>Exposed</td>
<td>near Godzella</td>
</tr>
<tr>
<td>Type of Bottom</td>
<td>Soft clay</td>
<td>Rust-red clay</td>
<td>Sand</td>
</tr>
<tr>
<td>Limestone formed in</td>
<td>Ocala</td>
<td>Ocala</td>
<td>Suwannee</td>
</tr>
<tr>
<td>Has upstream sinkholes?</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Reverse flow in flood?</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Color of deposit</td>
<td>Grey</td>
<td>Rust-red</td>
<td>Grey</td>
</tr>
<tr>
<td>Flow velocity at sampling site</td>
<td>Medium</td>
<td>Slow</td>
<td>Medium</td>
</tr>
<tr>
<td>Total spring discharge (L s⁻¹)</td>
<td>1125</td>
<td>419</td>
<td>3361</td>
</tr>
<tr>
<td>Date(s) measured</td>
<td>mean of 5</td>
<td>11-20-73</td>
<td>mean of 6 1927-73</td>
</tr>
</tbody>
</table>
| **Flow described according to Wilson (1991).**
| **From Rosenau et al., 1977.**

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SUWANEE RIVER BASIN

GEORGIA

FLORIDA

SUWANEE RIVER

FLORIDA BASIN

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.

<table>
<thead>
<tr>
<th>Cave</th>
<th>Effervescence with 0.1 M HCl?</th>
<th>Effervescence with 1 M HCl?</th>
<th>Color of sand fraction</th>
<th>Primary clay mineral</th>
<th>Lesser minerals in clay or silt fraction</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telford Spring</td>
<td>no</td>
<td>trace</td>
<td>various</td>
<td>Kaolinite</td>
<td>Pyrite</td>
<td></td>
</tr>
<tr>
<td>Peacock Spring</td>
<td>slight</td>
<td>moderate</td>
<td>rust-red</td>
<td>Kaolinite</td>
<td>Quartz (Pyrite)</td>
<td></td>
</tr>
<tr>
<td>Madison Blue Spring</td>
<td>no</td>
<td>slight</td>
<td>white</td>
<td>Kaolinite</td>
<td>Quartz, Pyrite, Smectite</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Telford Spring cave system, Suwannee Co., FL. Cave completely underwater. Sampling location was at upstream end of Rolaids 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° 2θ per minute using Cu Ka 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.
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 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 (FeS₂) 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-
Clay and Silt

Telford

7.1 3.5 2.7 2.4 2.2 1.9 1.6

Peacock

< 1 µm Diameter

Telford

7.2 3.5 3.1

Peacock

19.6

Madison Blue

3.3

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 µm 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 x 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 SO\text{4}^{2-}, Ca^{2+}, HCO\text{3}, dissolved solids, and other constituents of geochemical interest than the other two cave systems. The higher SO\text{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 Ca\text{2+} and SO\text{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 authochthonous 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

The authors are grateful to Bill Wilson of Subsurface Evaluations, Inc. and Dr. Paul Bertsch of the Savannah River Ecology Laboratory for their reviews of this paper. We thank Fred Hecker for assisting the senior author with sediment sample collection, Keith Hollien for running x-ray diffraction analyses, Alexandra Webber for preparation of figures, and the National Speleological Society/Cave Diving Section for permission to reprint modified cave maps. The authors acknowledge Frank Rupert of the Florida Geological Survey, Peter Horne of the South Australia Underwater Speleological Society, Dr. Guerry McClellan of the University of Florida Geology Dept., and cave divers Tom Morris, Don Landis, Lloyd Bailey, Steve Gerrard, and others for sharing their observations on karst geology and phreatic cave clay sediments. Preparation of this manuscript was supported in part by contract DE-AC09-76SR00-819 between the US Department of Energy and the University of Georgia's Savannah River Ecology Laboratory.

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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 epigean species. Flow-reversal is suggested as a mechanism by which epigean 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 epigean and troglobitic crayfishes in Florida. In addition to troglobitic forms, numerous epigean 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 reedy 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 epigean 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 m³/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 epigean 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 m² to 4 m², with a mean of 0.8 m² (n = 8, S.D. = 1.34 m²). 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 *Leydigia 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 during 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.

**Acknowledgments**

I thank Jason Hale and Randy Edelstein for their assistance with the underwater censusing and Richard Franz, Tom Crisman, and anonymous reviewers for their comments concerning this manuscript.

**Literature Cited**


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 literature. 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
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 semilog 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 world-wide 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.

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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 come forth. The questions of “Who?” and “Why?” are explored in this continuing research project.

LECHUGUILA 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.
The recent find of a well preserved juvenile mastodon tooth *Mammut 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**

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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 Martín 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
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 µg to 41 µg 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 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 12°C, 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 cellulbiose, 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

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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 caverns 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, millipedes, 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 famous 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 CAEIDOTEA CAROLINENSIS

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

The Aselid 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


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 troglobiotic, troglophilic and troglobitic 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 diplurum, 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 species (Aldrich) was common in both entrance and total-darkness areas in all seasons except winter. Aecothea fenestralis (Fall) 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. fenestratis from Ae. specus and Am. defessa from Am. sackeni. Some taxonomists treat the congeneries 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 sulfuric 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 autotrophic chemolithotrophic carbon fixation by sulfide-oxidizing microorganisms. The sulfide-oxidizing 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 sulfuric 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 section 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 PREVAILANT

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 baseline 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

Win. 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 grottoes. 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 Department, 4200 Smith School Rd., Austin, TX 78744

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, palentological 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 MANAGEMENT PROJECTS AT TIMPANOGOS CAVE NATIONAL MONUMENT, UTAH

Rodney D. Horrocks - Timpanogos Cave National Monument, 865 W. 160 N., #114, Provo, UT

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 Holiday. 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 Peeman - 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 ~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 ~15°N27°W. Conjugate joint sets trend ~N19°W 50°E and ~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 ~ 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 ~ N89°E 60°N and ~ 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.

THE NSS BULLETIN, DECEMBER 1992 • 89
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, 11304 Candle Park, San Antonio, Texas 78249

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 Colorado,P.O. Box 250, Boulder, Colorado 80309

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. The Sr ratios of the mineral spring waters suggest that they percolated through a deep granitic source.

The δ13C of CO2 in the water suggests that the CO2 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 CO2 partial pressures [PCO2] up to 1.8 and are saturated with respect to calcite. Surface streams and an insurgence have PCO2s 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 CONSTRAINS ON THE DEVELOPMENT OF THE CAVE OF THE WINDS, COLORADO

Curtis J. Esch, Timothy J. Dienst, Louise D. Hose, Department of Geology, University of Colorado,Colorado Springs, Colorado 80933-7150

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° and 15° to the east-southeast and southeast. The cave formed along intersections of bedding planes, joints, and microfaults that dominantly trend N0° to 10°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 Saltpetre 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 lave 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. Paleo-magnetic 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 Cemetery 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

Louise D. Hose and Curtis J. Esch - Department of Geology, University of Colorado,Colorado Springs, Colorado 80933-7150

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.

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

Fred G. Luiszer - Geological Sciences, University of Colorado, P.O. Box 250, Boulder, Colorado 80309

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 $\approx 4 \text{ Ma}$, 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 ($\text{MnO}_2$) 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

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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, HAWAI'I: A PRELIMINARY REPORT

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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

Albert E. Ogden - 1804 Canada Flatt Road, Cookville, Tennessee 38501

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

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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

Kass Kastning - PO Box 1048, Radford, Virginia 24141

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 powderdiffraction 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

William R. Halliday, M.D. - 6530 Cornwall Court, Nashville, Tennessee 37205

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 Vezere 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. Adjoining 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 speleological and archaeological 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

William R. Halliday, M.D. - 6530 Cornwall Court, Nashville, Tennessee 37205

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 Drive, Fenton, Missouri 63026-3465

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

Bernice Gottschalk - 6233 E. Mudmill Rd., Breverton, NY 13029

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

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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, Mexico this spring. Activities in the principal know 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 Palomitas, 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 Sozano 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 Quezo 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

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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 such a 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 (rawing data intended to be read by humans) and notes (extual 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

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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
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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 fail 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
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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 result 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 OLA'A 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 Ola'a 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 46208-2836

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, Tem 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 that 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 formatter, and Generalized Markup Language, with camera-ready copy produced on a Xerox 2700 laser printer.

The authors wish to thank William H. Verity for his assistance. Computer funds were provided by the College of Earth and Mineral Sciences, The Pennsylvania State University.
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