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THE WESTERN KENTUCKY SPEOLOGICAL SURVEY—A PROGRESS REVIEW*

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The western Kentucky karst region is part of the Interior Low Plateaus Province. It is developed on massive Ste. Geneviève and St. Louis limestones (Mississippian) and has a local relief of about 35 m. Caves beneath the Pennyrile sinkhole plain typically are large, meandering, tubular passages containing streams; the commonest passage cross-section is that of a phreatic tube several times wider than high, half-filled with silt and/or water. Caves in the geologically more complex uplands bordering the sinkhole plain on the north and west are relatively dry and are more often joint-controlled mazes.

Principal caves known in the region, today, are Indian Cave (Warren Co.) with 2.7 km surveyed, the Savage System (Logan Co.) with 4.3 km surveyed, Lovell Cave (Muhlenberg Co.) with 1 km surveyed, Glover's Cave (Christian Co.) with 3.2 km surveyed, Cool Spring Cave (Trigg Co.) with 5.3 km surveyed, Lisanby Cave (Caldwell Co.) with 11.3 km surveyed, Kinnin Cave (Crittenden Co.) with 1.4 km surveyed, and Moodys Cave (Livingston Co.) with 1.7 km surveyed.

Wet suits are virtually mandatory in caves of the sinkhole plain, and most caves there are likely to flood during rains. There are few speleothems, and there are few vertical drops greater than 5 m.

REGIONAL SETTING

Western Kentucky (Figure 1) may be viewed as a series of cuestas, the escarpments defining uplands and lowlands of distinct geologic and geographic character. Middle Mississippian limestones in the region have an average dip of 0.5° north-northwest (Ulrich and Klemic, 1966). Karst pavement has been found in only a few locations, due to extensive soil development. Stream valleys are well alluviated with sand, clay, and chert gravel. Sticky red clays and chert cobbles mantle the ridgetops and plains.

The upper limestone, the Ste. Geneviève, is about 70 m thick. It is light- to medium-gray and varies from finely crystalline with dolomitic beds to coarse-grained bioclastic with oölitic beds (Ulrich and Klemic, 1966). The underlying St. Louis limestone is similar to the Ste. Geneviève, but contains thin, argillaceous beds as well as beds of chert (Figure 2).

The limestones appear to be well jointed, with sets trending least-west (Klemic, 1966). Faults trend roughly north-south; although numerous, they show little apparent movement. While joint control of cave passages, and inferentially groundwater movement, is common in the region, the effect that faults may have on groundwater movement is largely unknown.

The Western Kentucky Karst Region is part of the Interior Low Plateaus Province of eastern North America, which also includes much of central and east-central Kentucky, southern Indiana, southern Illinois, and southeastern Missouri. It lies immediately west of the renowned Mammoth Cave Plateau, often referred to as the 'Central Kentucky Karst' (Hess et al., 1974, pp. 1-2). There is no distinct boundary between the Central and the Western Kentucky Karst regions, although the Barren River has been suggested as an arbitrary dividing line. A significant difference between the two is that most of western Kentucky lacks the broad, clastic-capped ridges with underground drainage which are characteristic of the Mammoth Cave area.

From the Barren River and Bowling Green, a virtually unbroken sinkhole plain extends westward for approximately 125 km. It averages 30 km in width. Locally called the 'Pennyrile' (or 'Pennyroyal') after a kind of mint herb, the sinkhole plain in Kentucky encompasses western Warren County; all of Simpson County; the southern parts of Logan, Todd, and Christian counties; and eastern Trigg County. Portions of Robertson and Montgomery counties, Tennessee, are also included.

The karst plain is gently rolling to nearly level. Average local relief usually does not exceed 40 m, although occasional sandstone-capped knobs rise slightly higher. The plain is pocked with thousands of depressions, ranging from shallow sinks to karst windows often with vertical sides, and blind valleys. Drainage on the sinkhole plain is almost entirely underground; most of it is developed in the Ste. Geneviève. The principal 'base-level' streams which entrench the plain are Drake's Creek (a northward-flowing tributary of Barren River), several forks of the Red River, and the Little River and its Sinking and Muddy forks (southward- and westward-flowing tributaries of the Cumberland River).

*A short article describing the origin of the Western Kentucky Speleological Survey (WKSS) and the accomplishments of its first 3 years appeared in the July, 1978 *NSS NEWS* (Dyas, 1978). This paper summarizes WKSS progress from 1978 through 1984.

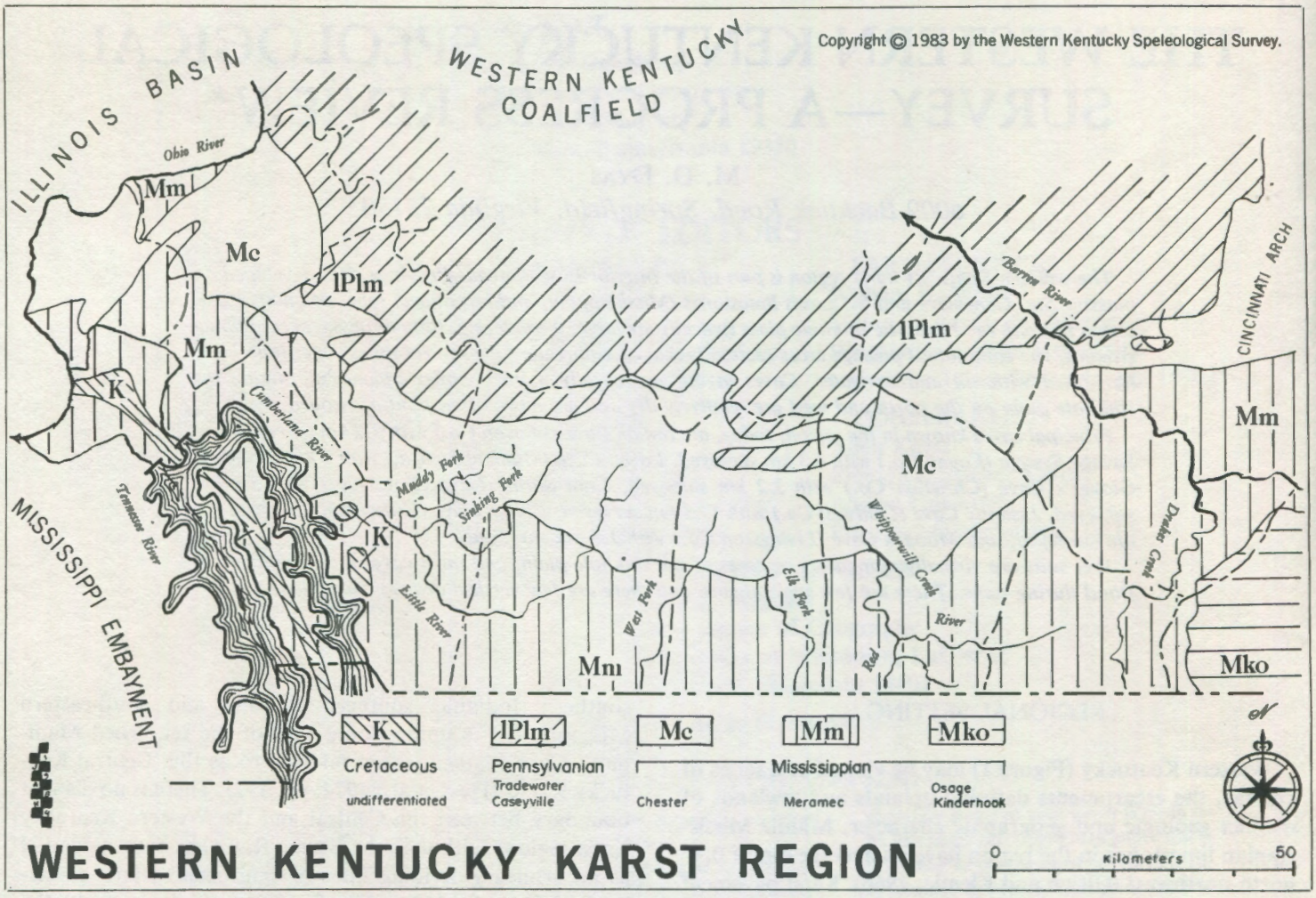

Figure 1. **Geologic relations of the western Kentucky karst belt. Data from American Association of Petroleum Geologists, Geological Highway Map 'Mid-Atlantic Region.' The Dripping Springs escarpment follows the southern edge of the Chesterian rocks (Mc).**

The Pennyrile Sinkhole Plain extends nearly to the confluence of the Ohio and Cumberland rivers, north and west of Trigg County, but it is not so broad or unbroken there as it is further east. It is interrupted by uplands and geologically complex fault zones in southern and western Caldwell County, in most of Lyon County, and in portions of Crittenden and Livingston counties. Both areas of the sinkhole plain, together, include 3750 km².

On the north, the Pennyrile adjoins a band of relatively rugged land, about 25 km in width, developed in late-Mississippian sandstones, shales, and limestones. This upland separates the sinkhole plain from the Pennsylvanian formations of the 'western Kentucky coalfields.' It is an extension of the Chester (Dripping Springs) Cuesta, in which many of the large caves of central Kentucky occur. However, the western Kentucky extension does not have as pronounced an escarpment as does the portion around Mammoth Cave.

Many of the limestones exposed in the region (notably, the Renault, Paint Creek, Kincaid, and Glen Dean) apparently are too impure, thin-bedded, or discontinuous to allow the development of large caves. Underground drainage is very localized or entirely absent. There are a large number of faults, as shown on U.S. Geological Survey geological quadrangle maps. Included in the upland are northern Logan, Todd, Christian, and Caldwell counties, plus adjacent small portions of Muhlenberg and Butler counties.

Cave Development

The majority of western Kentucky caves, and all of the larger caves known today, are found beneath the Pennyrile Sinkhole Plain. Many have entrances along or near the entrenched rivers. These caves are typically sinuous, tubular trunks containing large streams bordered by high silt banks.

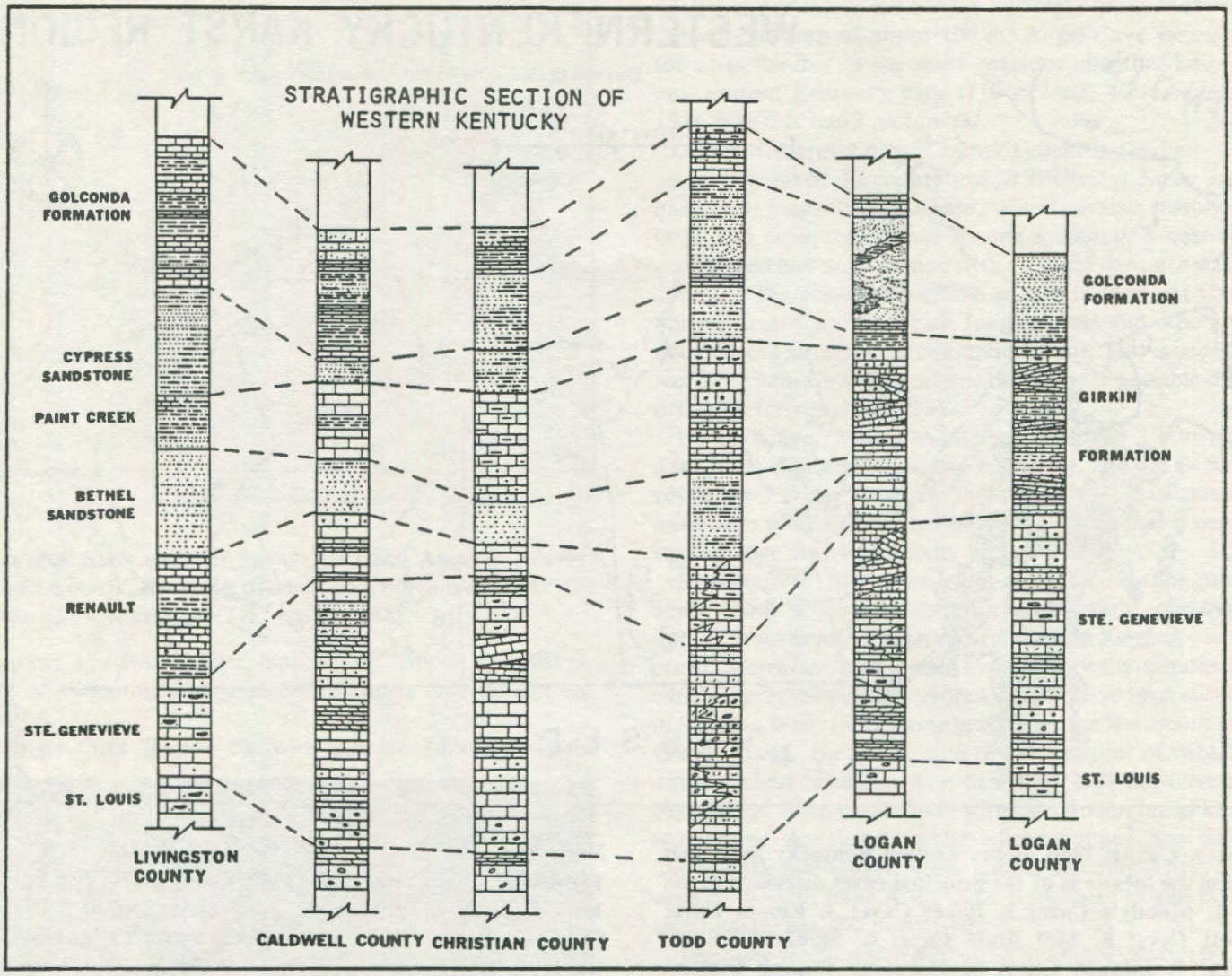

Figure 2. **Equivalent Mississippian stratigraphic units, passing from west to east (left to right) across the western Kentucky karst belt (from Mylroie, 1978.**

banks. Complication of this basic pattern by upper level developments is fairly common; less typical are maze caves and caves with modest vertical development.

The caves of the geologically more complex uplands bordering the sinkhole plain tend to be more-or-less dry. Joint-influenced mazes, even three-dimensional mazes, are more common.

The following county-by-county overview of the more significant western Kentucky caves known today begins in the Barren River area and progresses westward and northward to the Ohio River counties. Figure 3 shows the locations of the principal caves discussed in the text.

Warren County

Although roughly half of this county is west of the Barren River and, thus, is within the prospective study area of the Western Kentucky Speleological Survey (WKSS), most work has been done and probably will continue to be done by 'central Kentucky' groups. WKSS interest has so far been limited mostly to Indian Cave, which is just east of the Logan County line, near the community of South Union. Some 2.7 km have been mapped to date, including a rather lengthy deep-water section, a variety of stream crawls, and somewhat drier flood routes. This is definitely a 'wetsuit cave.' Drab Cave, with 607 m surveyed thus far, is a truncated upstream segment of Indian Cave almost entirely within Logan County. Three hundred and twenty-eight meters have been surveyed in Lemastus Cave, a flood route in the uvala between Indian and Drab Caves; a physical connection between the caves does not appear probable.

Simpson County

This area also overlaps the domain of 'central Kentucky' groups, and the WKSS has done almost no field work here.

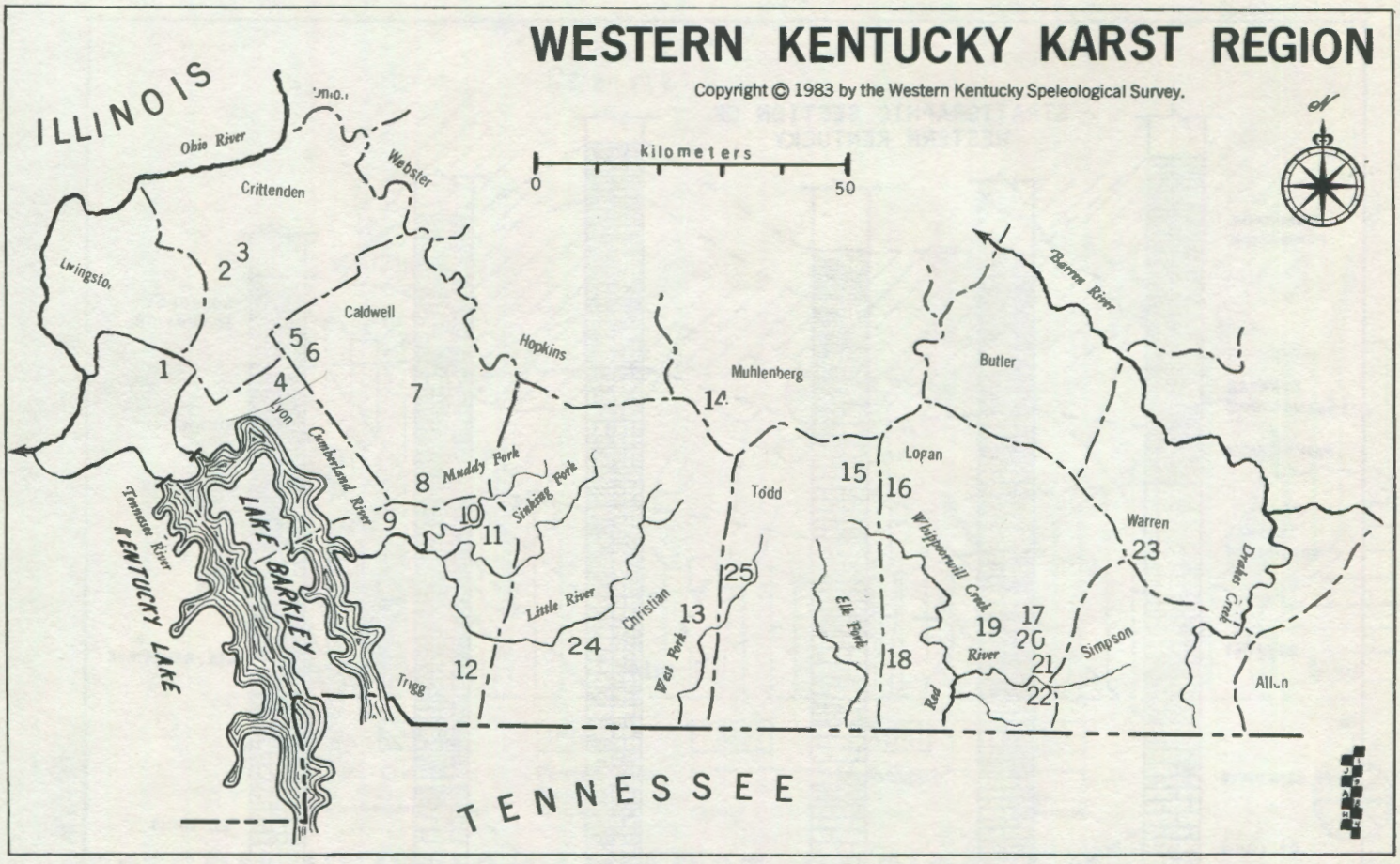

Figure 3. **County map of the western Kentucky karst belt showing the locations of the principal caves discussed in the text. 1. Moody's Cave; 2. Baker Cave; 3. Kinnin Cave; 4. Scott Cave; 5. Mill Bluff Cave; 6. Skinframe Sinks System; 7. Lisanby Cave; 8. Harmony Church System; 9. Kenady Spring; 10. Husk Cave; 11. Cool Spring, Decibel Cave, Boatwright Cave; 12. Big Sulphur Cave, Rimstone Runway Cave, Hurricane Cave, Corinth Church Cave; 13. Glover's Cave, Buzzard's Folly Cave, Twin Level Cave; 14. Lovell Cave; 15. Sharon Grove Caves, Antioch Creek Cave; 16. Potato Cave; 17. Gorham Cave; 18. Beaumont Cave; 19. Roaring Well; 20. Oakville Cave; 21. Kelly Cave; 22. Savage Cave, Angel Cave; 23. Indian Cave, Drab Cave; 24. Reeves Cave; 25. Dickenson Cave.**

Several significant caves are being studied by the Green River Grotto, based in Bowling Green.

Butler County

Another county on the eastern fringe of the WKSS study area, Butler is for the most part a coal-producing area. Until recently, it was thought to have little potential for caves. Of possible interest, however, is a 'haunted cave' in northeastern Butler County which was reported by a Louisville newspaper columnist. Limestone exposures in the extreme southern and northern ends of the county need to be checked. A cave believed to be of some size has been reported in southeastern Butler; however, the owner currently does not permit access.

Logan County

Logan County rivals Caldwell and Trigg counties for containing the largest number of known caves in western Kentucky. Most caves are beneath the broad sinkhole plain of southern Logan. Several small caves have been reported from hilly northern Logan County, and more work needs to be done there.

Pre-eminent and largest-known among Logan County caves is the Savage (Cook) System (Figure 4), with 4.3 km surveyed. It is part of a very interesting karst complex developed along a prominent local fault or fracture zone east of the village of Adairville and just north of the Tennessee border. The gaping main entrance to Savage Cave is an extremely significant archaeological site and recently was donated by the Archaeological Conservancy to Murray State University, after purchase from the late Mrs. Genevieve Savage. Carstens (1980) recently described the archaeology of Savage Cave. Beyond its entrance, Savage Cave consists largely of a sinuous, normally dry trunk passage with breakdown zones. It also has an active stream

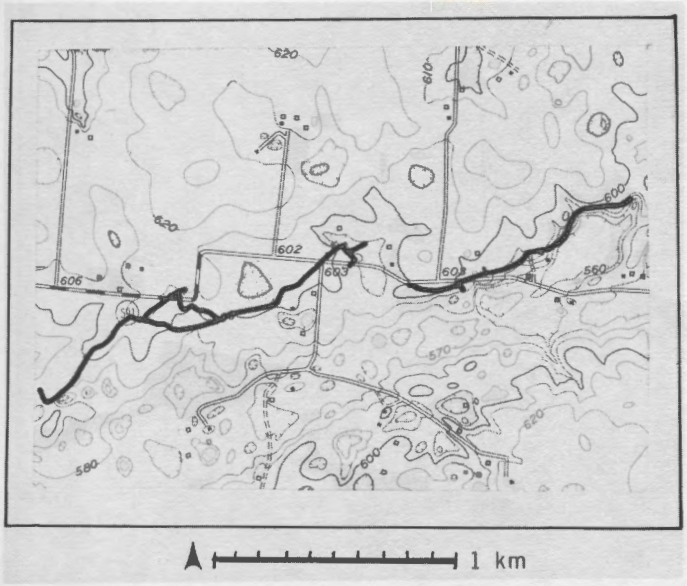

Figure 4. **Stick maps of Savage (W) and Angel (E) caves, Logan County, Kentucky overlaid on a portion of the USGS Adairville Quadrangle (7½' series, 1951).**

segment and two smaller, upper level canyon complexes, one of which includes a second entrance (the Edison entrance).

Angel Cave (Figure 5), with 1.5 km surveyed, is an upstream portion of the Savage System, separated from the latter by a sump of about 100 m. Angel Cave varies from tortuous fissures to the most spacious chamber known in any western Kentucky cave (110 m long, 40 m wide, and 10 m high). It has 3 entrances.

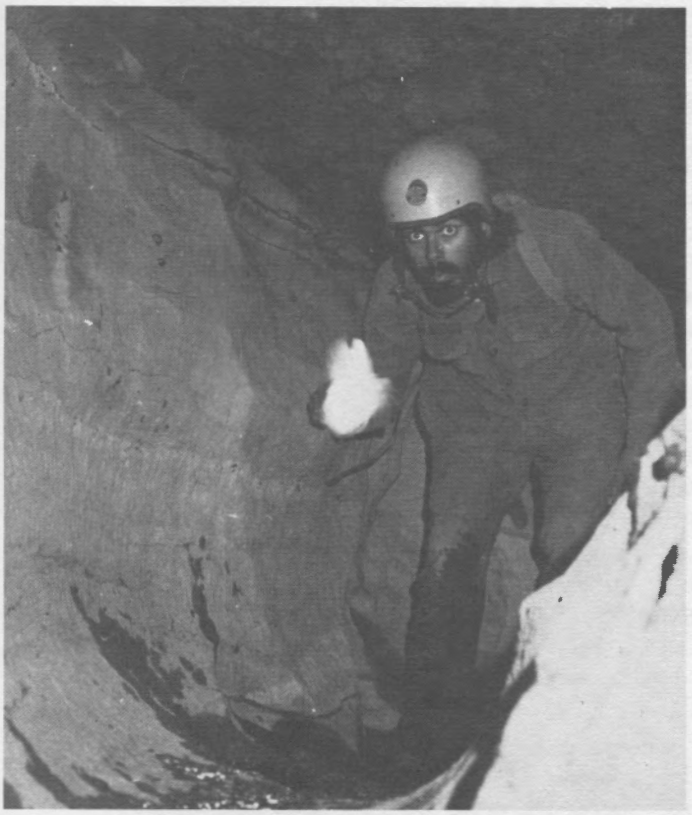

Figure 5. **Preston Forsythe probes flood route in Angel Cave, Logan County (Mark Colman photo).**

Another major Logan County system is Gorham Cave, east-southeast of the county seat (Russellville). Some 3.2 km have been mapped in Gorham, which consists mainly of a large and enjoyable trunk. During mapping, a near-sump was pushed and an extension with a second entrance was discovered. The resurgence of the stream in Gorham Cave is Spring Acres Cave, in which Joe Saunders and others have mapped 433 m (personal communication). This is separated from Gorham Cave by a sump, said to be negotiable during droughts for roughly 100 m.

Potato Cave, in northwest-central Logan County, has joint-maze characteristics, two entrances, and has been surveyed for 750 m. There are indications that this cave may have been mined for saltpeter. Potato Cave and a nearby, smaller cave may be partially in Todd County.

Roaring Well, in the southwest-central part of the county, begins with a vertical entrance and several picturesque domes. It turns into a more typical western Kentucky stream crawl, thereafter, and trends toward a locally-famous cave which is presently closed. About 1.3 km have been surveyed in Roaring Well. In the same general area is Beaumont (Alex Cross) Cave, the most interesting feature of which is unusual chert bridging. Approximately 1.34 km have been surveyed in Beaumont Cave, with one stream crawl known to continue. Another 394 m have been mapped in an adjoining cave (Beaumont II), which almost certainly is hydrologically connected. Babe Allen Cave, a southern Logan County quasi-maze, has 400 m plotted.

The most recent noteworthy find in Logan County is Oakville Cave, in the south-central part of the county. It consists largely of normally-dry passages in a random maze configuration of surprising complexity. Discoveries in late 1982 and early 1983 suggest that there are considerably more passages than the 1.66 km charted so far.

Three caves of some size are presently explored in the uplands of northeastern Logan County: Chick Cave (978 m), Epley Cave (406 m), and Ode Britt Cave (unsurveyed). These caves are all developed in the limestone. Carr Cave, near Auburn in east-central Logan County, is an unsurveyed portion of what appears to be a very extensive underground drainage system.

Several other potentially important Logan County caves are known or rumoured. Among these is Kelly Cave, a part of the Sinking Creek complex in southeastern Logan County. About 1 km is understood to have been mapped by Jim Cubbage in conjunction with his studies at Western Kentucky University (unpublished); the cave is being re-mapped by the WKSS.

Todd County

Until recently, the WKSS had done little checking for caves in Todd County. It has extensive sinkhole plain and other cavernous territory, and it is sandwiched between portions of Logan and Christian counties where several significant caves are known. The only mapped cave in Todd County prior to 1982 was Ned's Swallow Hole. A small one, located near Glover's Cave (Christian County), it was examined by the Evansville Metropolitan Grotto (Shofstall, 1984).

Two fair-sized stream caves have now been surveyed by the WKSS in the Sharon Grove neighborhood of northeast-central Todd County. Sharon Grove Cave (864 m) has front and rear entrances, permitting a 'through trip' via canyon and crawl passages. Nearby Antioch Creek Cave begins as a nice walkway, but diminishes to a lengthy cobble crawl. In Antioch Creek Cave, 1340 m have been surveyed, including a back entrance complex; some stream crawl is still unsurveyed. Antioch Creek Cave is aligned very strongly with a local fault; it trends due west almost its entire length and may be called the 'straightest cave' in western Kentucky. Potter (Hadden) Cave, also in the Sharon Grove vicinity, is a dry, locally historic, joint-controlled cave in which 768 m have been surveyed. The Sharon Grove caves are developed in the Haney limestone.

The entrance of Merriweather Cave is just south of the state line (in Montgomery County, Tennessee), but the cave extends into Todd County, Kentucky; 390 m have been mapped.

The eastern portions of Glover's Cave and of Twin Level Cave, the two largest caves in Christian County, extend into Todd County. Dickenson Cave, in the same general vicinity (near Trenton), is the largest known cave entirely within Todd County, at 2.53 km surveyed. Dickenson has a lengthy segment of downstream 'borehole,' an upstream flood route complex, and an entrance zone which is one of a number of western Kentucky cave sites known to have been excavated for Indian artifacts.

Muhlenberg County

Muhlenberg County, the largest coal-producing county in western Kentucky, consists mainly of non-cavernous Pennsylvanian strata. The southwestern corner of the county has limestone and a few caves. Lovell Cave, in which about 1 km of semi-maze passage has been mapped by Mark Sumner et al. of Murray State University, is probably the most significant.

Christian County

This is, geographically, the largest county in the western Kentucky karst and has several important caves. Not much attention has been devoted to Christian County so far, but work by the Evansville Metropolitan Grotto is increasing our knowledge of the area.

Southeast of the county seat of Hopkinsville is a concentration of caves on the West Fork of the Red River, including the most famous cave in the area, Glover's Cave (Figure 6). Most of this cave was mapped *ca.* 1971 by the former Southwestern Kentucky Student Grotto of Murray; the Evansville Metropolitan Grotto recently increased the cave's official length to about 3.2 km. Glover's has a large and lengthy trunk, as well as less-inviting side passages. Adjoining Dry Cave, 1.2 km long, by all appearances originally was a part of Glover's (Shofstall, 1984). About 2 km downstream from Glover's is Twin (Double) Level Cave, in which the Evansville Metropolitan Grotto is presently working. Recent discoveries have extended this flood-prone cave to about 5 km. A connection was recently made between Twin Level and Watt (Carneal) caves. There are indications that Glover's and Twin Level caves at times have been the route of the same drainage, although Twin Level now carries most of the flow. Roughly opposite, across the river from Glover's, is Buzzard's Folly Cave, a joint-controlled maze with almost 1 km surveyed. Dry Ford Cave, also in the same neighborhood, is an unmapped cave related to a meander cut-off of the West Fork. A summary of the geology and hydrology of the West Fork caves has been published by the Evansville Metropolitan Grotto (Mason, 1982; Mason et al., 1984).

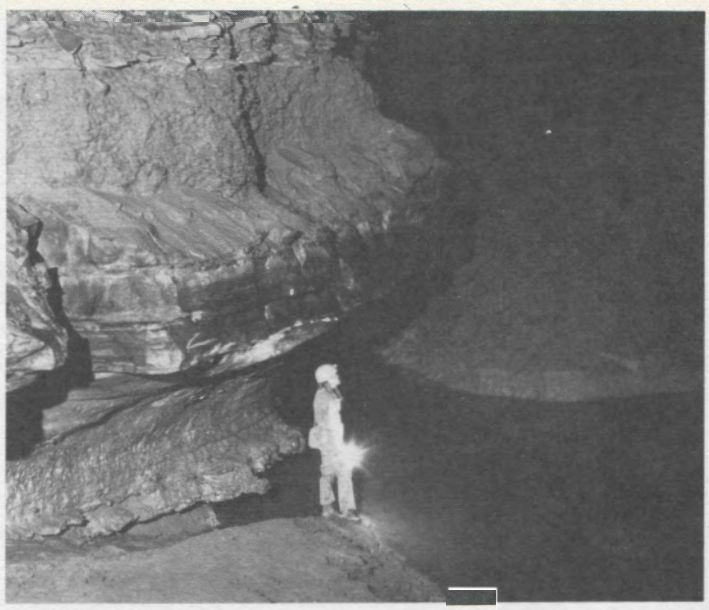

Figure 6. **Maryanne Speed in the main trunk of Glover's Cave, Christian County. Note typical, ponded stream and large silt banks (Mark Colman photo).**

Aside from the West Fork cave complex, the largest known cave in Christian County is Reeves (Thomas) Cave, southwest of Hopkinsville, near Herndon. Recently, 1480 m were mapped in this cave, which is a maze of flood routes and one of the more complex caves in western Kentucky. Although no permanent streams drain Reeves Cave, an impressive amount of flood debris has been deposited in it.

Outside the Glover's Cave neighborhood and Reeves Cave, not much is known about the sinkhole plain in southern Christian County, although it must have many caves. Much of the area is occupied by the Fort Campbell Military Reservation which limits access. Likewise, there are reports of caves in northern Christian County which have not been verified by the WKSS. These caves would probably be relatively small and dry, as is typical of the uplands.

Trigg County

At this time, there are more surveyed caves (49), with a greater combined length (over 23 km), in Trigg County than there are in any other western Kentucky county. This is due, in part, to work by the Murray State University students of

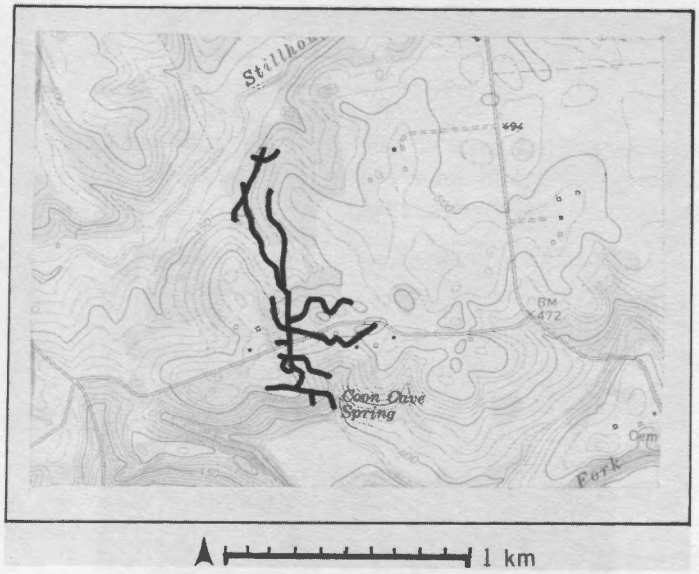

Figure 7. **Stick map of Cool Spring Cave, Trigg County, Kentucky, overlaid on a portion of the USGS Caledonia Quadrangle (7½' series, 1974).**

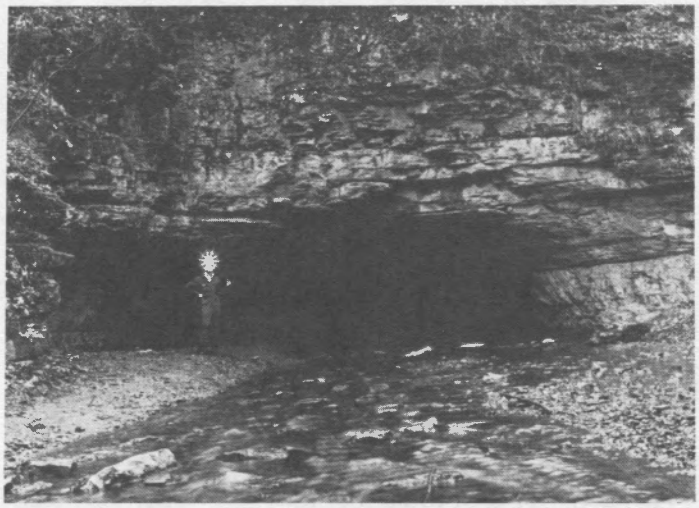

Figure 8. **Mark Colman at the main entrance to Cool Spring Cave, Trigg County (Mark Colman photo).**

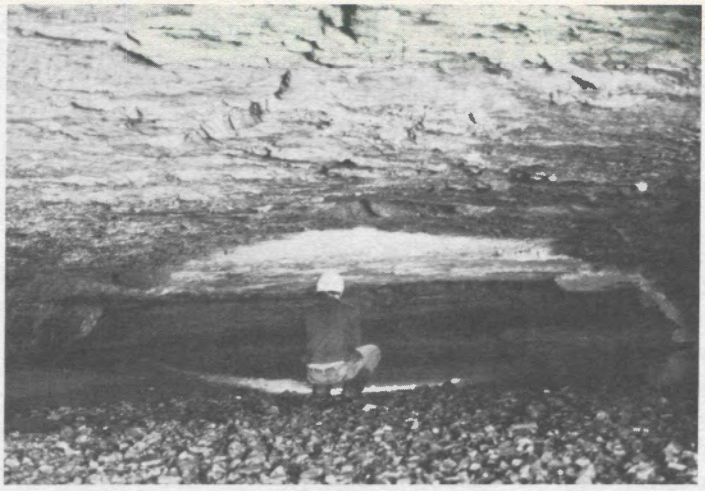

Figure 9. **John Mylroie examining cross-section of 'storm sewer' conduit, Cool Spring Cave, Trigg County (John Mylroie photo).**

John Mylroie, who have concentrated their attention on the entrenched Little River and its Sinking Fork in eastern Trigg County.

Cool Spring Cave (Figures 7, 8, and 9), a resurgence along Sinking Fork with three entrances, was considered to be the largest cave in western Kentucky prior to the 1980 discoveries in Lisanby Cave (Caldwell County). The old Southwestern Kentucky Student Grotto mapped much of Cool Spring in the late 1960's; a follow-up by Murray State University students a decade later raised the official length to approximately 5.3 km. The cave probably originated from an attempted subterranean piracy of Stillhouse Branch by Sinking Fork (Moore and Mylroie, 1979). Due to the substantial amount of known but unsurveyed passage (and potential for more) and to deficiencies in the existing map, a complete resurvey of Cool Spring has been undertaken jointly by Paducah's Black Hole Grotto and by Murray State University students. Cool Spring is a combination of streamways and upper levels of surprising complexity. Unfortunately, traffic to this cave is heavy, and vandalism is considerable. Also of concern is the fact that Cool Spring supports a sizeable summer colony of the endangered Gray Bat (*Myotis grisescens*).

Ladd Cave, with an estimated kilometer of muddy, multilevel passage, lies a short way northeast of Cool Spring. It is thought to be part of the same system.

Murray State cavers have investigated a variety of other caves in the Cool Spring neighborhood, including several associated with active or abandoned meander cut-offs of Sinking Fork. Of special interest is Decibel Cave, a 1.7 km joint maze. A second major underground drainage complex tributary to Sinking Fork resurges a short way upstream at Mill Spring (not enterable). This system carries most of the normal flow of Sinking Fork for a distance of several kilometers, but only small fragments of the system can be ex-

plored, due to sumps and, possibly, faulting. The largest piece, Boatwright Hole (412 m), is entered via a twin vertical 5 m drop in what is probably the deepest and most picturesque sinkhole in the region.

Cave resources on the main Little River, south of Sinking Fork, are comparable. The most important is Big Sulphur (Peedee) Cave (Figure 10), which currently is the fourth-largest in western Kentucky, with about 4.5 km surveyed. Like other major western Kentucky caves, Big Sulphur owes much of its extent to slightly higher, dry, offset levels. It also features a complex of large breakdown rooms. Big Sulphur has a considerable population of *M. grisescens* in the summer and should not be visited at that season. A map and detailed description of Big Sulphur Cave have recently been published by the WKSS (Mylroie et al., 1984).

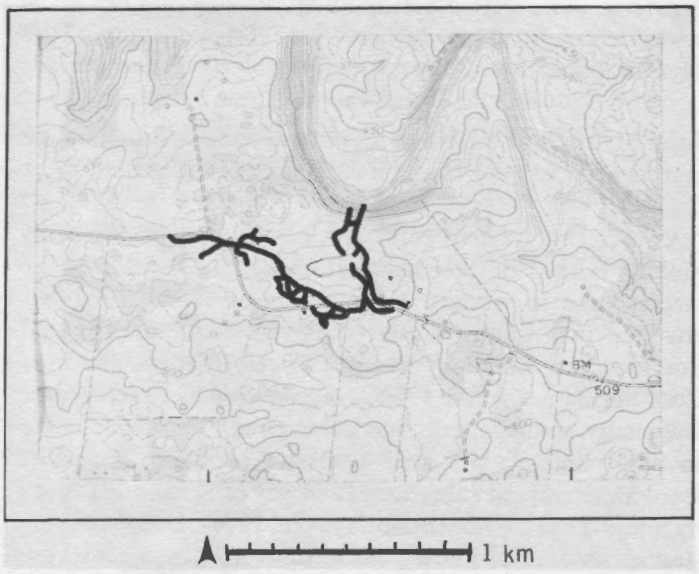

Figure 10. **Stick map of Big Sulphur Cave, Trigg County, Kentucky overlaid on a portion of the USGS Caledonia Quadrangle (7½' series, 1974).**

Downstream from Big Sulphur are several other significant caves. These include Rimstone Runway (1.2 km), Hurricane Cave (780 m, incompletely explored), Corinth Church Cave (1.40 km, with much water and many breakdown rooms), Hardy Cave (460 m), Taylor Bluff Cave (295 m), and the Belford Spring group, a probable archaeological site.

Several sizeable caves are known or conjectured to occur in the Muddy Fork watershed of northern Trigg County. Husk (Lawrence) Cave, with at least 1.1 km of meandering stream trunk and particularly large silt banks, is a portion of one extensive sinkhole plain drainage net. Kenady (Nichols) Spring Cave, with 2.11 km mapped to date, is the resurgence of another large drainage net near the Wallonia community. A surprisingly large breakdown room was among recent discoveries in Kenady Spring Cave.

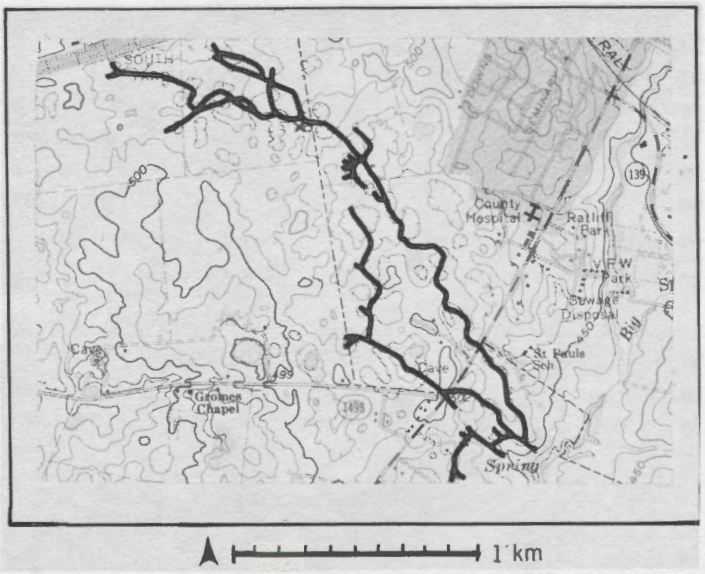

Figure 11. **Stick map of Lisanby Cave, Caldwell County, Kentucky, overlaid on a portion of the USGS Princeton Quadrangle (7½' series, 1967).**

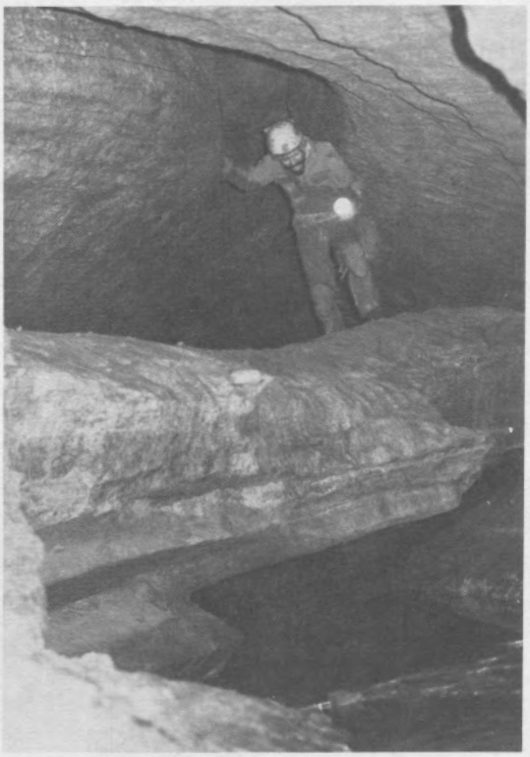

Figure 12. **Preston Forsythe negotiating the 'Waterfall Trail' in Lisanby Cave, Caldwell County (Mark Colman photo).**

Caldwell County

On the outskirts of Princeton, the county seat, is Lisanby Cave, the largest in western Kentucky (Figures 11 and 12). Some 11.3 km have been surveyed by the WKSS in the

course of more than 30 work trips since 1977, giving Lisanby nearly double the verified extent of any other Kentucky cave west of Bowling Green. The entrance portion of Lisanby is a dry complex of overlapping levels, reportedly worked for saltpeter and used as a refuge by deserters during the war between the States. This section is heavily vandalized by local amateur cavers; fortunately, two tight, wet 'keyholes' limit access to the remainder of the cave, including a stream trunk which can be followed continuously for about 3 km—the longest known single passage in western Kentucky.

Figure 13. **Preston Forsythe in small stream passage leading to the 'Paducah Extension' of Lisanby Cave, Caldwell County (Mark Colman photo).**

Almost half of the presently known extent of Lisanby Cave was discovered in 1980–81, following a breakthrough by Jay Grace and Mark Colman of the Black Hole Grotto. This 'Paducah Extension' (Figure 13) includes a network of inter-twined levels quite remarkable for this low-relief region. In early 1983, an almost-missed lead was found to connect with Farless Cave, a smaller, neighboring cave, thus adding nearly another kilometer of virgin passage to the system. As of this writing, exploration is again thought to be complete, although a few leads remain. Progress in Lisanby Cave has been limited by the cave's less pleasant aspects, particularly the 'bad air' which periodically recurs (due to industrial pollution, presumably). A detailed report and map of Lisanby Cave were recently published by the WKSS (Mylroie et al., 1984).

Big Spring Cave is a system of appreciable size developed under downtown Princeton. It does not connect with Lisanby Cave, rumors notwithstanding. It is very wet going, with at least one back entrance. About 800 m have been surveyed so far by Ray Taylor and the Princeton Mudcrawlers, a local caving group.

Exploration is considered finished, or nearly so, in several other noteworthy Caldwell County sinkhole plain caves. Mill Bluff Cave (2.5 km) is the resurgence of a major underground drainage net in the Fredonia Valley area of western Caldwell County. The yawning triple entrance to Mill Bluff, in an overhanging cliff, is one of the most striking scenes in the western Kentucky karst. The cave has a trunk with several 'lakes,' flood routes, and a limited upper level.

Several kilometers southeast of Mill Bluff Cave, in the heart of Fredonia Valley, is Skinframe Sinks (Rice) Cave, with 3 km mapped. The sizeable stream in this particularly flood-prone cave may flow either to Mill Bluff or southwest to Scott Cave in Lyon County; there are large 'missing pieces' in both directions. Skinframe Sinks consists of deep-water, 'backbreaker,' and, most of all, cobble crawlway. The 1.7 km route, mostly crawling, from the entrance to the eastern end of the cave is perhaps the most strenuous in western Kentucky. Adjoining this part of the cave is a flood-water sink complex which 'ought to connect' but which so far hasn't. The suspected sink point of the stream in Skinframe Sinks Cave is several kilometers further east. Several small (?) caves on the northern periphery of Fredonia Valley may feed water to Skinframe. One of these, not totally explored, is McElroy (Annie Dean) Cave, 215 m mapped. It contains a 20 m waterfall pit, the deepest and most 'sporting' drop known in western Kentucky.

Hayes Spring is a karst window between the Lisanby and Fredonia systems. The stream here is undoubtedly part of a large drainage net, but only small pieces of this complex have been physically explored.

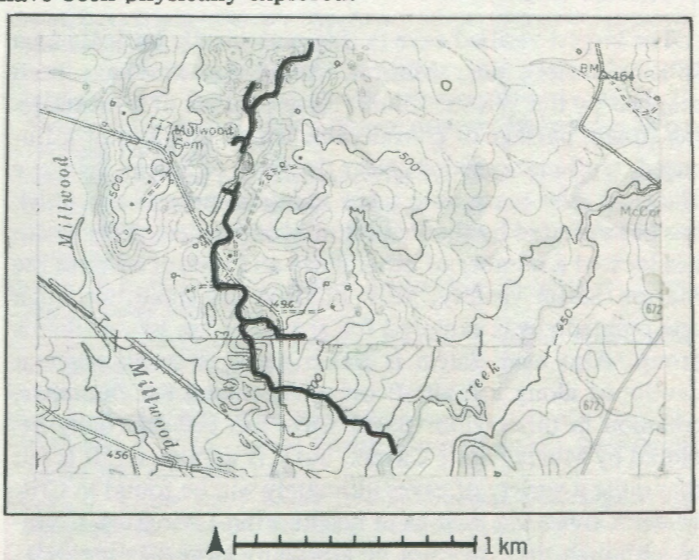

Figure 14. **Stick maps of Harmony Spring (N) and Harmony Church (S) caves, Caldwell County, Kentucky, overlaid on portions of the USGS Princeton East (N) and Cobb (S) quadrangles (7½' series, both 1967).**

Harmony Church Cave (Figure 14), 2.6 km mapped, is the largest-known portion of another important drainage system, this one in the Cobb neighborhood of southeastern

Caldwell County and adjoining Trigg County. This cave has two entrances, a trunk with considerable deep water, and a normally dry flood route several hundred meters long. A short distance upvalley from Harmony Church is Harmony Spring Cave, a truncated portion of the same system. This cave has four entrances and a good deal of deep water; a little over a km has been surveyed. A well serving an elaborate irrigation system on an adjoining farm was sunk to Harmony Spring Cave in 1982. Downstream of Harmony Church is a third significant segment of the same underground stream, Perkins Spring Cave. It has much deep water and 494 m surveyed.

The northern half of Caldwell County includes the fault-riddled Dripping Springs Escarpment. One prominent, sandstone-capped ridge here superficially resembles those in the Mammoth Cave region. The Princeton Mudcrawlers are investigating leads on this ridge; one cave having several climbable waterfalls and a few hundred meters of passage.

Lyon County

This small jurisdiction near the confluence of the Cumberland and Tennessee rivers has a sizeable piece of sinkhole plain, but, so far, only one cave of any significance has been located. Scott Cave No. 3, with 602 m surveyed, is predominantly a dry, upper-level remnant of an apparently large subterranean drainage system in the lower Skinframe Creek neighborhood. The master stream can be seen at two points, but it is not negotiable because of sumps.

Crittenden County

The largest verified cave in this geologically intricate area is Kinnin Cave near Marion. About 1.4 km have been mapped by the WKSS. Kinnin Cave consists of a meandering stream passage of considerable length and a joint-influenced, semi-maze section. Near the town of Salem, on Cave Hill, is a joint-maze cave a few hundred meters long which has been plotted by the Princeton Mudcrawlers. This group has located a number of other maze and stream caves in the Marion/Salem vicinity. Most of these are small, although one reputedly was explored for around a km by an Illinois group. Also near Salem is Baker Cave, a trunk segment developed along a fault. It once was mined for fluorspar, common in this region. Baker Cave has been partially explored by Murray State Cavers, but it is unmapped. It is felt that quite a variety of caves ultimately will be found in Crittenden County, as well as in neighboring Livingston County, although they may not be especially large.

Livingston County

The most significant known cave in Livingston County is Moody's (Sweet Potato, Owens) Cave. It was investigated *ca.* 1968 by the old Southwestern Kentucky Student Grotto and, more recently, it was mapped by Mark Caldwell et al., of Paducah. Moody's is a joint-controlled maze, predominantly of low passages, totalling at least 1.7 km. It may connect with a lower cave on the Cumberland River ('Jimsonweed' Cave), currently being surveyed by the Black Hole Grotto. Near the community of Lola is a so-far unmapped, three-dimensional maze cave located by Ray Taylor and the Princeton Mudcrawlers. It is of unusual interest because it is the largest in the area.

Generalizations About Western Kentucky Caves

Readers of this article will sense one overall fact about western Kentucky caves—Most aren't much fun. Many caves carry streams of substantial volume and to varying degrees, are prone to flash flooding and can be explored with peace of mind only if there is essentially zero chance of heavy rain. Most of the caves have such low gradients that extensive bodies of ponded water—deep in places—may be expected. Entrances are often at springs, karst windows, and floodwater ponors. Frequent immersion is the norm, and wetsuits are virtually mandatory. Likewise, since most of western Kentucky is a heavily cultivated region, decades of erosion have resulted in the deposition of large quantities of silt and flood debris in many of the caves, by all appearances clogging numerous entrances and passages. Many caves are interrupted by sumps, only one of which (to this writer's knowledge) has so-far been dived. Easy walking passageways and good-sized rooms are fairly common, but long crawls and stoopways are more typical.

The most common passage cross-section is that of a phreatic tube several times wider than high, half-filled with silt and/or water. Upper levels, generally only a few meters above stream level, are quite frequent; they sometimes have a modified canyon cross-section. Speleothems are occasionally encountered in these geologically immature caves, but they are certainly more the exception than the rule. Few drops exceed 5 m. Although several caves in the multi-kilometer range have been documented, there is little likelihood that 'world class' caves such as those in the Mammoth Cave Region will be discovered in western Kentucky.

Future Prospects

It can be said, after eight years of effort, that the WKSS now has at least preliminary knowledge of most of the more-obvious and/or better-known caves in this part of Kentucky, plus information about a fair number of the more obscure ones. As of the end of 1984, some 135 caves totalling more than 93 km have been mapped. It might also be assumed that continued progress will require more emphasis on ridge-walking, pushing small leads or near-sumps, digging, and so forth.

An analysis of topographic maps, especially those covering the Pennyrile Sinkhole Plain, strongly suggests that only a small fraction of western Kentucky's cave systems have been identified so far (of course, some caves can be expected

to have no obvious or humanly negotiable entrances.) Many areas have yet to be investigated in detail, particularly Christian, Todd, and Simpson counties.

A major deficiency, as of this writing, is an almost complete lack of stream-tracing studies, such as those being conducted in the Central Kentucky Karst. In low-gradient, sinkhole plain caves, sumps and floodwater routes are common, and full understanding of the caves requires a thorough water tracing program. It is hoped that one or more researchers will take up this challenge in the near future. Plenty of work in such disciplines as geology and biology also needs to be accomplished.

In comparison with more popular caving areas, conservation is not a particularly serious problem in western Kentucky. Large populations of cavers, such as exist in Ohio, Indiana, Missouri, and Tennessee, are closer to more attractive caving areas and, generally, have bypassed western Kentucky. Gross vandalism is largely limited to the few better-known caves (e.g., the 'main' sections of Lisanby and Cool Spring). The biggest concerns are pollution and sedimentation caused by unwise agricultural and/or industrial practices. Landowner relations are generally very good compared with those in more famous karst areas.

One matter which needs to be addressed is protection of the endangered Gray Bats which use Cool Spring and Big Sulphur caves in the warm months. Since Cool Spring has an absentee owner, a large main entrance, and is quite popular, it is doubtful that much could be done to limit traffic there. By contrast, Big Sulphur is less well known, has a single rather small entrance, and has an owner who lives on the property. Conceivably, this cave could be fenced to control access.

While there is no particular season for caving in western Kentucky, late summer and fall are usually the most predictable times for low water levels. Much of the survey's work has been accomplished during 5- to 10-day 'mini-expeditions' fielded several times a year. Cavers interested in western Kentucky are welcome to participate in these projects.

Acknowledgments

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NATURAL TEMPORAL EVOLUTION OF THE CO_2 CONTENT IN THE AIR OF THE "PAINTINGS CHAMBER" AT ALTAMIRA CAVE

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Results obtained from the measurement of the CO_2 content in the air of the "Paintings Chamber" at Altamira Cave (Santander, Spain) under natural conditions, that is in the absence of visitors, over a period of a year and a half, reveal that the content of this gas in the air of this chamber is closely linked to the thermal conditions inside the cave and shows a well-characterised annual variation, increasing during the spring and autumn months and decreasing during the summer and winter periods. Furthermore, chemical analysis of the water that flows into the "Paintings Chamber" of the cave shows that the CO_2 dissolved in this water presents values very close to those corresponding to the equilibrium at the partial pressure of this gas in the atmosphere of this chamber.

Introduction

The Altamira Cave lies within the area covered by the west flank of the syncline of Santillana del Mar (Santander, Spain) and is set in a subhorizontally stratified rocky stretch that is basically made up of compact calcarenite layers separated by clayey or limolytic levels and, sometimes, by fine marly-sandy intercalations (Cendrero et al., 1976).

The cave is located within the upper zone of the karst of Santillana del Mar, in the so-called senile area of the karst, in which the processes of destruction outweigh the processes of sedimentation and lithochemical reconstruction (Hoyos et al., 1981). The hydrological dynamics of this hypogeum system is due exclusively to the rainwater that seeps directly into the cave through the different calcareous strata of the ceiling.

As Figure 1 shows, the cave is of the static type, with a single entrance from the outside. It is slightly sloping, with a length of some 270 m and with a height and width that vary quite substantially from one point to another. Although the cave possesses a remarkable collection of painted and engraved prehistoric figures throughout the different chambers and galleries of which it is made up, the interest in the cave is mainly centered around the world-famous set of magnificent polychrome figures that occupy the ceiling of the so-called "Paintings Chamber," a relatively small space with an average floor area of 18 x 8 m^2 and an average height of 2.5 m. Given the extraordinary importance of this set of pictures, the study and monitoring of its state of preservation has always been, by far, the principal focal point for the attentions of the Altamira Research Centre, the body responsible for coordinating and consolidating the various research projects being conducted within the cave.

Within this context, the carbon dioxide content in the air of the Paintings Chamber at the Altamira Cave is a variable of the greatest importance, inasmuch as it is one of the principal parameters that determine the degree of aggressiveness or incrustability of the waters that impregnate the polychromed surface and is, therefore, closely related to the leaching and carbonate precipitation processes which obviously entail a degree of risk for the total or partial preservation of not only the paintings themselves but also their underlying rocky support.

The CO_2 gas content, which amounts to approximately 0.03% by volume in the free atmospheric air, reaches considerably higher values in underground limestone caves such as the one at Altamira, even in the absence of visitors, where CO_2 concentrations of up to 1% by volume (Brunet et al., 1980) or even higher (Delecour, 1968), (Renault, 1971) have been measured.

The source of the elevated levels lies in the metabolic processes of the microbial flora present in the chamber and, more fundamentally, in the dissolution of this gas by the water that seeps into the cave through the overlying soil before flowing over its internal rock surfaces. This carbon dioxide gas in solution in the seepage water comes, in turn, from the dissolution of airborne carbon dioxide in rainwater and surface waters and from the dissolution of this same gas, due to the action of vegetal roots and the decomposi-

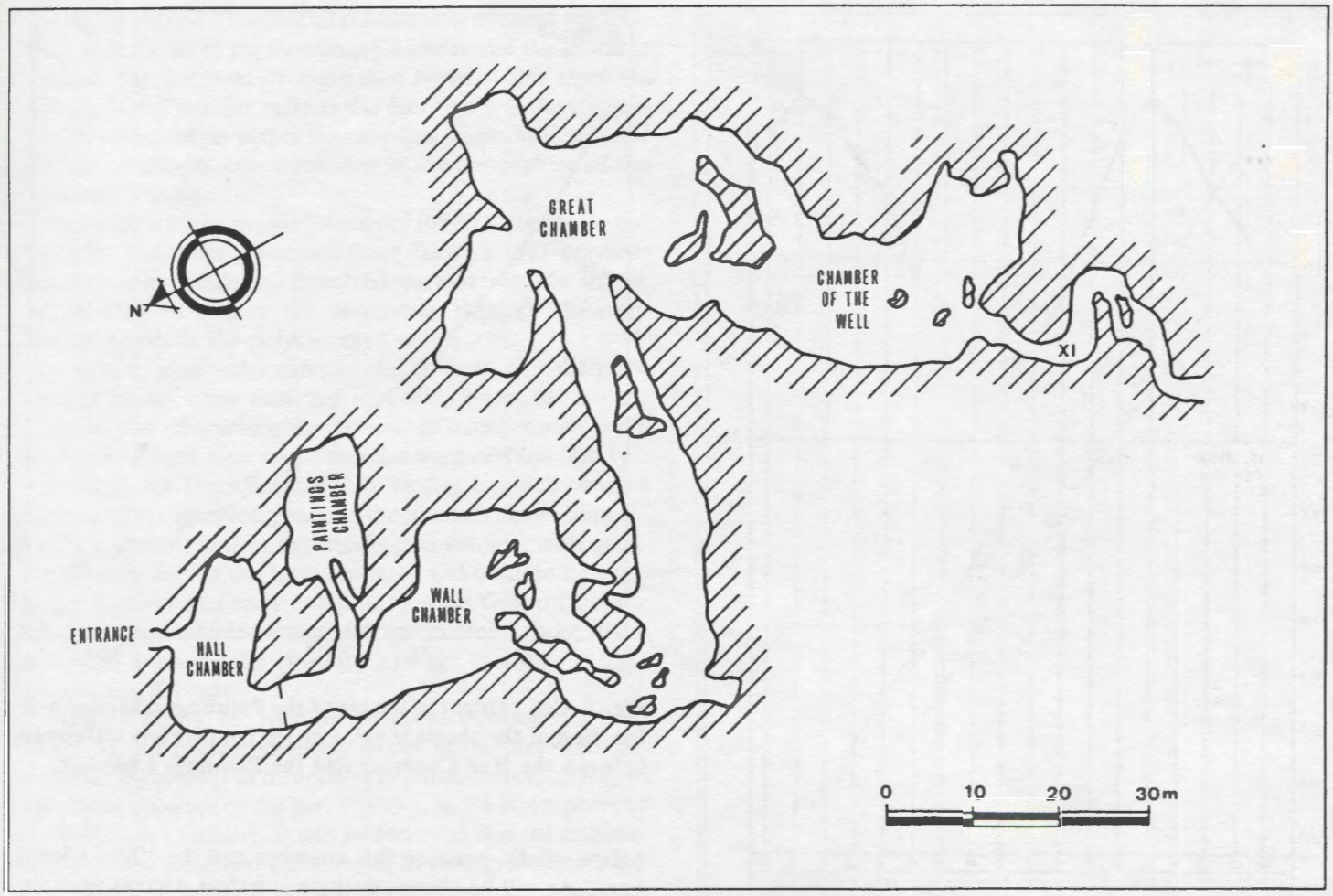

Figure 1. **Map of Altamira Cave.**

tion of organic matter, that takes place within the soil (Brunet and Vidal, 1981).

When the natural waters that have dissolved carbon dioxide within the soil seep through the internal surfaces of the cave, some of this gas is released upon the reduction of its partial pressure in the ambient air. This loss of dissolved carbon dioxide enhances the incrustation properties of the seepage water, inducing the precipitation of carbonates by this water.

Experimental Results

Measurements of CO_2 concentrations in the air of the Paintings Chamber at the Altamira Cave were taken under natural conditions (in the absence of visitors) using a CO_2 infrared analyzer connected to a data logging system by Monitor Labs including a strip printer, which provided measurements of gas concentration with an error of $\pm$ 0.01% by volume.

Data were obtained over the year and a half period between May 1980 and October 1981. In general, the carbon dioxide concentration within the Paintings Chamber remains practically constant throughout the day with the greatest fluctuations, always less than 18% of the average daily level, being recorded during the summer and winter months. These are, in fact, the seasons in which the lowest levels of CO_2 are to be found in the air of the Paintings Chamber and, also, it is at these times of the year that, in general, the greatest daily fluctuations in the outside temperature are recorded, these being logically translated into an increase in the fluctuations of the magnitude of the convective air interchanges between the outside atmosphere and that inside of the cave. On the other hand, these daily fluctuations of CO_2 levels in the air of the Paintings Chamber are fairly slow (normally taking place over periods of 7 to 8 hours) and the concentration of this gas always tends to recover its initial value once the original external thermal conditions are re-established.

On the basis of the data obtained throughout the whole measurement period, mean monthly values for the CO_2 content in the air of the Paintings Chamber were determined as an average of the corresponding mean daily values. Figure 2 shows the variations recorded in the mean monthly concentrations of carbon dioxide in the Paintings Chamber

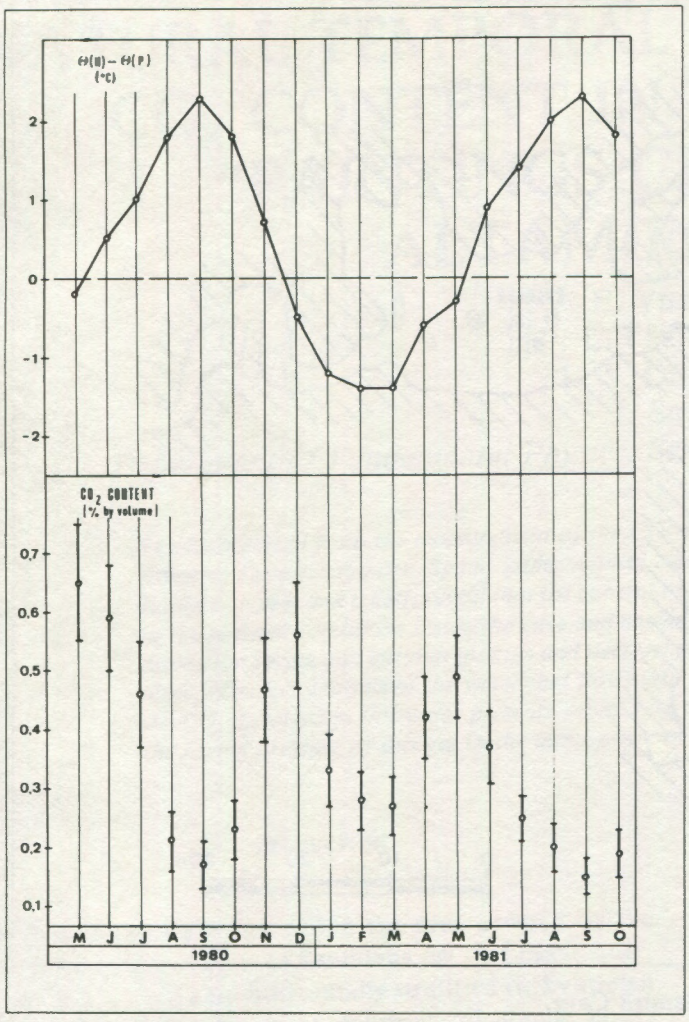

Fig. 2. **Annual variations of the average monthly CO_2 content in the Paintings Chamber and of the temperature difference between the Hall Chamber and the Paintings Chamber.**

throughout the measurement period. It will be observed that the CO_2 concentration increases in spring and in autumn until two distinct peaks are reached on the last months of these two seasons. In the same way, a reduction in the CO_2 content can be observed during the summer and winter months, with the minimum values being obtained at the end of these seasons. Figure 2 also shows the temporal variations in the temperature differences between the air of the Hall Chamber, located at the entrance to the cave, and the air of the Paintings Chamber (Villar et al., 1984). A clear correspondence can be observed between these variations and the variations recorded in the CO_2 content in the air of the Paintings Chamber.

To enable this relationship to be studied in more detail, Figure 3 shows the average monthly values for CO_2 levels in the Paintings Chamber set against the corresponding monthly values for the temperature differences, taken as absolute values, between this chamber and the "Hall Chamber." As will be observed, there is a clear decreasing exponential dependence between these two variables. Through linear regressions analysis, the experimental data have been adjusted to the following function:

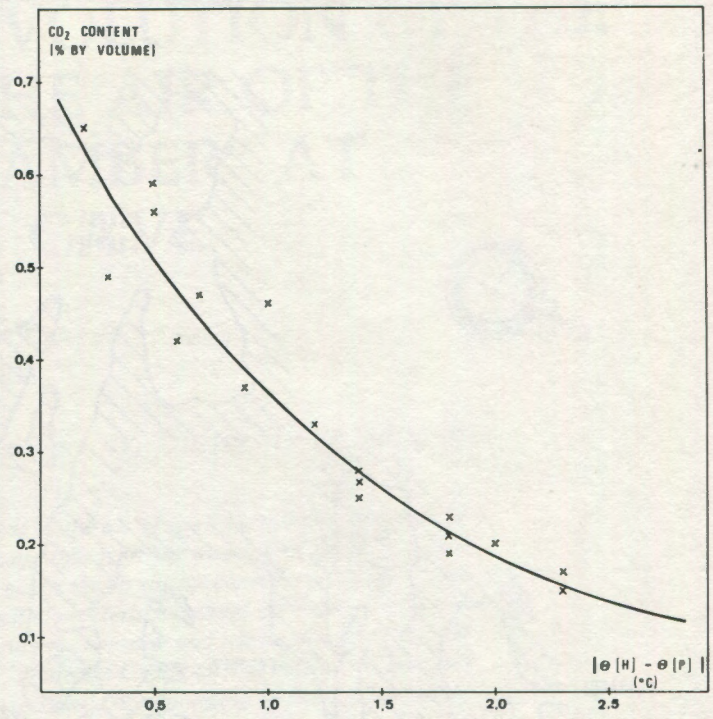

Fig. 3. **CO_2 content in the air of the Paintings Chamber as a function of the absolute value of the temperature difference between the Hall Chamber and the Paintings Chamber.**

$$C = C_0 + K_1 \cdot \exp(-K_2 - |\Delta\Theta|) \qquad (1)$$

where K_1 and K_2 are parameters to be determined, $|\Delta\Theta|$ is the modulus of the temperature difference in °C between the Paintings Chamber and the Hall Chamber, C is the concentration of carbon dioxide in the air of the Paintings Chamber expressed as a percentage by volume, and C_0 is the CO_2 content in the outside atmosphere which should, in principle, be the minimum value that could be possessed by the CO_2 concentration in the Paintings Chamber, in the hypothetical case of this chamber being extensively ventilated.

Assigning a value of 0.03% by volume to C_0, the values found for K_1 and K_2 and for the correlation coefficient of the adjustment follow:

$$K_1 = (0.70 \pm 0.08) \text{ volume percent}$$
$$K_2 = (0.74 \pm 0.11)\ °C^{-1} \qquad (2)$$
$$\text{Correlation coefficient} = 0.97$$

This decreasing exponential relationship between the CO_2 content in the air of the Paintings Chamber and the *absolute value* of the temperature difference between this chamber and the Hall Chamber reflects the fact that it is the convective air interchanges within the cave that basically determine the carbon dioxide concentrations in the atmosphere of the Paintings Chamber.

In addition to the measurements of the CO_2 content in the air of the Paintings Chamber, from January 1981 onwards analyses were made of dissolved carbon dioxide in the waters that flow into the ecosystem through different seepage points in the polychromed ceiling.

A total of nine water samples, taken from nine different seepage points, were analyzed at weekly intervals. On the basis of the characteristics of the different water seeps monitored, these nine water samples were divided into two general groups (Fernández, 1983): Group I, which consists of three of the samples, contains those which showed appreciable variations in time in the collected volume, with maximum values during the spring months and minimum values in late summer and early autumn, whereas Group II, made up of the six remaining water samples, contains those which presented a practically constant average monthly volume throughout the year.

Figure 4 shows, for each of the above-mentioned groups of waters, the average monthly values of the dissolved carbon dioxide content as a function of those corresponding to the partial pressure of the gas, P (CO_2), in the atmosphere of the Paintings Chamber. It will be observed that the relationship between these two variables is, in both groups, a linear one. Through the application of a linear regression analysis to these two sets of pairs of data, the values obtained for the slope are $(5.07 \pm 0.27).10^{-2}$ mol.at^{-1}.l^{-1} for Group I and $(5.05 \pm 0.26).10^{-2}$ mol.at^{-1}.l^{-1}for Group II, with correlation coefficients of 0.994 and 0.991, respectively. These slope values agree very acceptably with the value of $(4.70 \pm 0.02).10^{-2}$ mol.at^{-1}.l^{-1}, supplied by the tables (Bögli, 1980) for the Henry's constant corresponding to the CO_2 at a temperature of 14°C, which is precisely the average annual temperature of the air in the Paintings Chamber.

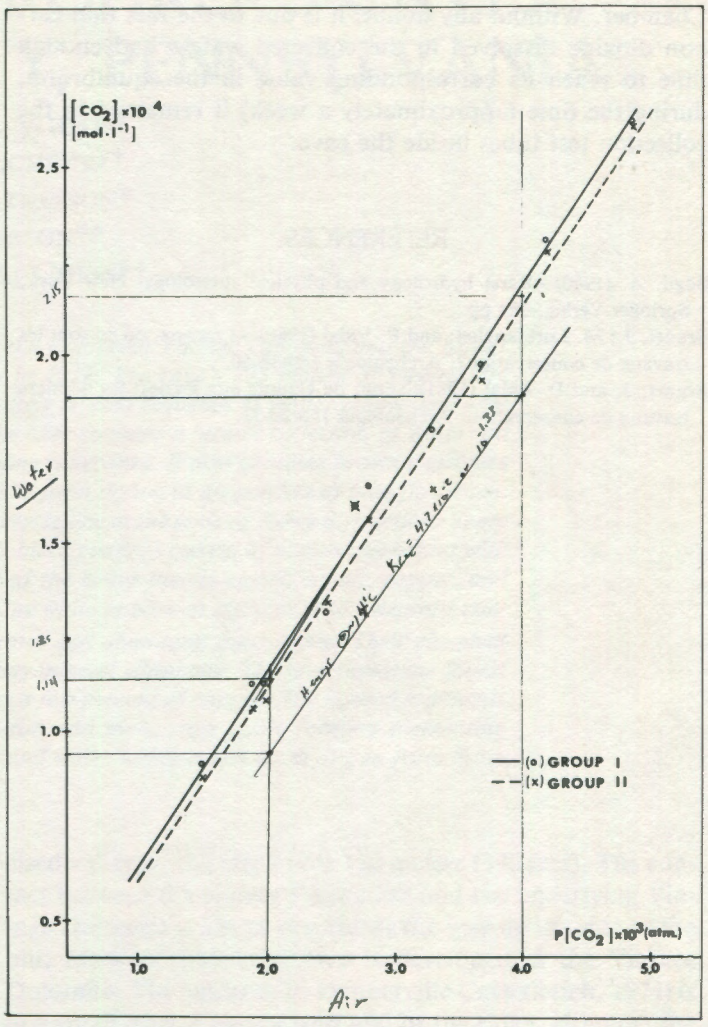

Fig. 4. **CO_2 content dissolved in the waters flowing to the Paintings Chamber as a function of its partial pressure in the air.**

Conclusions

Over a period of one year and a half, from May 1980 to October 1981, measurements were taken of the CO_2 content in the air of the Paintings Chamber at the Altamira Cave, under natural conditions (in the absence of visitors). The results obtained reveal that the concentration of this gas presents an annual variation characterized by an increase during the spring and the autumn, reaching maximum values in the final months of each of these seasons, and by a decrease during the summer and winter, with the minimum values being obtained at the end of each of these seasons. The average annual value of the carbon dioxide content in the air of the Paintings Chamber was 0.35% by volume and the maximum and minimum average monthly values were 0.65% and 0.15% by volume, respectively.

It was possible to establish the existence of a decreasing exponential relationship between the concentration of carbon dioxide in the Paintings Chamber and the absolute value of the temperature difference between the air in this chamber and the air in the Hall Chamber, located at the entrance to the cave. This relationship suggests a close dependence between the CO_2 content in the air of the Paintings Chamber and the magnitude of the convective air interchanges that take place within the cave.

Finally, the analyses carried out on the waters that flow into the Paintings Chamber make it possible to conclude that the concentration of dissolved carbon dioxide presents values that agree, within a good degree of approximation, with those corresponding to the equilibrium at the partial pressure of this gas in the atmosphere of the Paintings

Chamber. Without any doubt, it is due to the fact that carbon dioxide dissolved in the collected waters had enough time to reach its corresponding value in the equilibrium, during the time (approximately a week) it remained in the collection test tubes inside the cave.

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MINERALOGY OF ROHRER'S CAVE, LANCASTER COUNTY, PENNSYLVANIA

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SCOTT D. ATKINSON*
DALE IBBERSON**
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Rohrer's Cave, developed along the contact between the Cambrian Vintage Dolomite and the Kinzer shaley limestone, was opened by a sinkhole collapse in 1979. The cave's 275 meters of passage are floored in places with a brown mud overlying an intricately layered sequence of white, yellow, and gray sediment. In place of the usual calcite speleothems, the cave contains a bizarre collection of white and black soft mushy coatings and hanging forms resembling pinecones. It also contains brown stalactites and stalagmites of hydrated iron oxides. A boxwork-like form occurs as do patches of blue flowstone. The iron oxide speleothems are relatively pure but noncrystalline at the scale of X-ray diffraction. There is no evidence for other heavy metals with the iron. The black coatings consist of manganese oxides with exceptional concentrations (about 20 weight percent) of the heavy metals nickel, cobalt, copper, and zinc in various but approximately equal proportions. The white opaline or moonmilk-like deposits consist in part of noncrystalline hydrated aluminum silicates and aluminum phosphates. Their chemical composition and microstructure identify them as the clay mineral allophane. The blue flowstone found in a few patches in the cave is also allophane containing a few percent of copper. The layered sediments consist mainly of allophane with small amounts of iron and manganese oxide forming pigmenting layers. All deposits contain large proportions of unbound water which is lost on drying to form loose fine-grained powders or thin flakes.

INTRODUCTION

Rohrer's Cave contains a suite of noncrystalline silicate, phosphate, and hydroxide 'minerals' quite unlike any mineral suites previously described from solution caves (Hill, 1976; White, 1976). These deposits are all the more unusual because the cave is almost completely devoid of the usual carbonate minerals. The only similar deposit described in the literature is in the Mbobo Mkulu Cave, South Africa (Martini, 1980).

This paper describes the deposits and presents some details of their chemistry and microstructure. We deal first with the wall and ceiling deposits that at least have the superficial appearance of ordinary speleothems. The second part of the paper describes unique banded sediments on the floor that are chemically similar to the speleothems.

PHYSIOGRAPHIC AND GEOLOGIC SETTING

Rohrer's Cave lies about two kilometers east of Mountville in Lancaster County. The cave is beneath an east-west trending low ridge capped by the lower Cambrian Kinzer Formation. The cave is under a point of the ridge where it is cut by the west branch of Little Conastoga Creek. The ridge top is at an elevation of about 130 meters (430 feet); the incised valley of the creek is at 120 meters (390 feet). The contact between the Kinzer Formation and the underlying Vintage Dolomite is about two-thirds the way up the side of the hill. Most of Rohrer's Cave is developed in the Vintage Dolomite. The entrance to Donnerville Cave (Reich, 1974) is in a small quarry on the west end of the ridge, although the two caves do not connect. The Kinzer/Vintage contact is clearly visible at the top of the quarry wall.

The Kinzer Formation is described by Jonas and Stose (1930) as a hackly blue shale with thin earthy dolomite which weathers into a spotted 'leopard rock' in surface exposures. At the base of the unit are thin beds of impure dolomite which weathers into a fossiliferous yellow earth consisting mostly of silica and is known as 'tripoli.' The Kinzer Formation is somewhat metamorphosed and unlike most shales is resistant to erosion and thus supports minor uplands in the Lancaster area.

The Vintage Dolomite is the lowest of the Cambrian carbonate units. It lies directly above the Antietam Quartzite. It is a hard, coarsely crystalline massive blue dolomite that seems to have been partially metamorphosed into a dolomite marble.

Rohrer's Cave has no natural entrance. In 1979, the owner excavated to enlarge the parking lot of his hardware store. Some 3 to 4 meters of the weathered Kinzer Formation were removed as the cut was extended back into the ridge. A collapse occurred in the floor of the excavation, exposing the entrance chamber. The collapse sink has since

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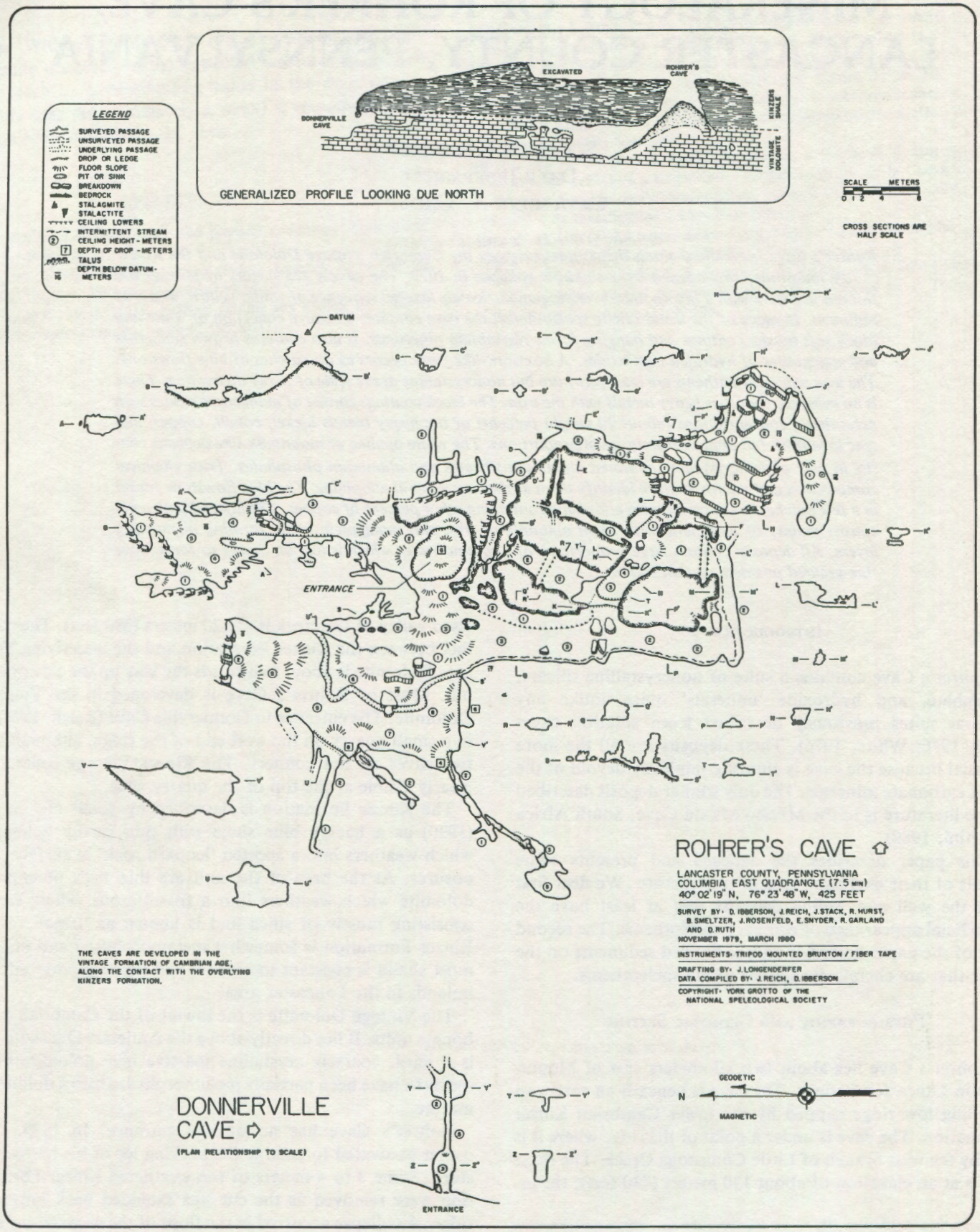

Figure 1. **Map of Rohrer's Cave.**

been roofed over and the present entrance to the cave is made through a trapdoor in the floor of the building that serves as Mr. Rohrer's lawn and garden department.

The cave was surveyed by members of York Grotto of the National Speleological Society in 1979-1980 (Fig. 1). For purposes of discussion, the cave is divided into five sections: the Entrance Chamber Complex, the North Passage, the Big Room, the South Passage Complex, and the Breakdown Room.

The present form of the Entrance Chamber is apparently due to the entrance collapse. The walls are rough fracture surfaces in shale, and the floor is composed of loose rubble. One descends this rubble slope to reach other parts of the cave. The contact between the Kinzer Formation and the Vintage Dolomite occurs at the ceiling level of the other passages where the rubble slope plunges under the walls of the Entrance Chamber. To the southeast of the Entrance Chamber is a passage near the top of the dolomite, walled by breakdown, that may be a remnant of the pre-collapse chamber.

The North Passage extends from the Entrance Chamber some 100 meters to a terminal breakdown. The passage contains some elaborate solutional sculpturing such as spongework and pendants. The bedrock of this passage is cut by boxwork-like insoluble joint fillings which may be minor insertions of diabase dikes that are common in the region.

The Big Room is a large room west of the Entrance Chamber and which may have been continuous with it before the entrance collapse. Several short passages open high on the west wall of the room. On the north side of the room, a floor of loose rubble slopes upward to a terminal breakdown. The cave is very shallow at this point and this breakdown, like that at the end of the North Passage, cannot be far below the land surface. It may result from the intersection of the cave with the hillside. The channel of a small wet-weather stream crosses the floor of the Big Room.

The South Complex is a group of passages in the Vintage Dolomite that extend southward from the Big Room at the level of its floor. For most part, these are tubular passages with smooth, sculptured walls. The passage shapes are highly irregular and there is no evidence for high-velocity flow on the bedrock walls. The entire pattern and passage shape of the cave is characteristic of dissolution by slowly moving groundwater under completely water-filled conditions.

The Breakdown Room is at the southeastern corner of the cave. It is reached by climbing up from the passages of the South Complex into a wide low chamber in the Kinzer Formation that seems to be entirely of collapse origin. A passage just below the Kinzer/Vintage contact extends north to the Entrance Complex.

Mineral Deposits

The reference to Rohrer's Cave 'minerals' is in quotes because the 'minerals' are all noncrystalline or at best very poorly crystalline. The formal definition of 'mineral' specifies a crystalline substance of specific chemical composition. Whether or not they are formally minerals, the bizarre deposits in Rohrer's Cave are certainly speleothems in that they are secondary deposits formed in the cave by

Table 1. Chemical Analyses of Rohrer's Cave Specimens

Element[a]	79RC004	79RC005	79RC006	79RC008	79RC010[b]	79RC015-3	82RC003	82RC004	82RC005	82RC006
Al	0.36	0.21	13.8	28.3	10.9	18.2	12.2	12.5	20.8	7.9
B	0.40	0.22	0.47	0.88	1.10	0.24	0.26	0.11	0.18	0.15
Ba	<0.01	<0.01	<0.01	<0.01	0.21	0.04	<0.01	<0.01	<0.01	<0.01
Ca	0.07	0.01	0.97	0.22	1.16	0.11	0.40	0.14	0.59	0.43
Co	<0.01	<0.01	<0.01	0.01	1.60	0.07	0.01	<0.01	0.01	<0.01
Cu	0.01	0.01	0.03	0.18	0.45	0.12	0.05	0.02	0.02	0.01
Fe	43	50	0.21	0.11	3.50	0.12	0.15	1.07	3.04	1.20
K	0.06	<0.01	0.05	0.05	0.64	0.07	0.05	0.01	0.07	0.11
Mg	0.06	0.01	0.19	0.18	0.67	0.05	0.12	0.09	0.24	0.11
Mn	0.01	<0.01	0.08	0.15	12.4	0.44	0.12	0.03	0.04	0.02
Na	0.27	0.14	0.33	0.60	0.85	0.19	0.20	0.08	0.16	0.11
Ni	<0.01	<0.01	0.01	0.05	1.57	0.04	0.04	0.02	0.04	0.01
P	3.34	1.53	0.35	0.32	0.30	7.75	0.10	0.05	0.13	0.07
Si	4.22	2.48	15.8	12.1	24.7	5.51	6.46	3.10	10.0	5.97
Zn	0.01	0.01	0.05	0.18	1.52	0.05	0.04	0.04	0.08	0.03
H_2O	3.0	9.4	18.1	2.89	5.7	24.7	39	53	10.7	60

(a) All results in weight percent of element. Elements not detected: Cd, Cr, Sr.

(b) Also contains 0.02% Pb and 0.06% Ti. These elements not found in other specimens.

Descriptions of Specimens:

79RC004 Small limonite stalactite from Breakdown Room.
79RC005 Limonite stalagmite from Breakdown Room.
79RC006 Layered sediment.
79RC008 Layered sediment from side passage.
79RC010 Black "button" from boxwork area in North Passage.
79RC015-3 "Pinecone Speleothem." See Figure 16.
82RC003, 82RC004, 82RC005, 82RC006 Sequence of banded sediments from South Complex. See Figure 20.

chemical precipitation long after the cave passage themselves were excavated. The deposits may be subdivided as:

i. The limonite speleothems
ii. Black and white flowstone and wall coatings
iii. The 'pinecones'
iv. The blue deposits

Each in turn will be described in the sections that follow and characterized to the extent possible.

The sample numbers (e.g. 79RC015) refer to a master catalog of cave material. The specimens remain in a collection at The Pennsylvania State University where they are available for further analysis. The first two digits are the year of collection: 'RC' refers to Rohrer's Cave, and the remaining three digits are a sequential numbering.

Because the Rohrer's Cave deposits do not diffract X-rays, identification of the materials by their characteristic X-ray diffraction patterns is not possible. Instead, chemical composition was determined by chemical analysis and from secondary X-ray emission spectra obtained using the energy dispersive detector (EDX) on a scanning electron microscope (SEM). The SEM itself was used to provide microstructural information. Structure on an atomic scale was deduced from infrared spectra which, unlike X-ray diffraction, does not require coherent crystal structures. Additional information on the identification of iron- and copper-containing materials was obtained from the visible and near-infrared absorption spectra measured by diffuse reflectance spectroscopy.

Specific instruments used were: ISI Instruments DS 130 dual scanning electron microscope with Kevex energy-dispersive X-ray analyser; IBM Model 98A fourier transform infrared spectrometer; Beckman DK-2A UV-vis-near IR spectrophotometer. Chemical analysis of selected specimens was obtained by dissolving the materials in a mixture of hydrochloric and hydrofluoric acids and analysing the resulting solutions by atomic emission spectroscopy using a DC arc source (Table 1). Figures 2-5, 8, 15, 18, 19, 21, & 22 are found on the color centerfold.

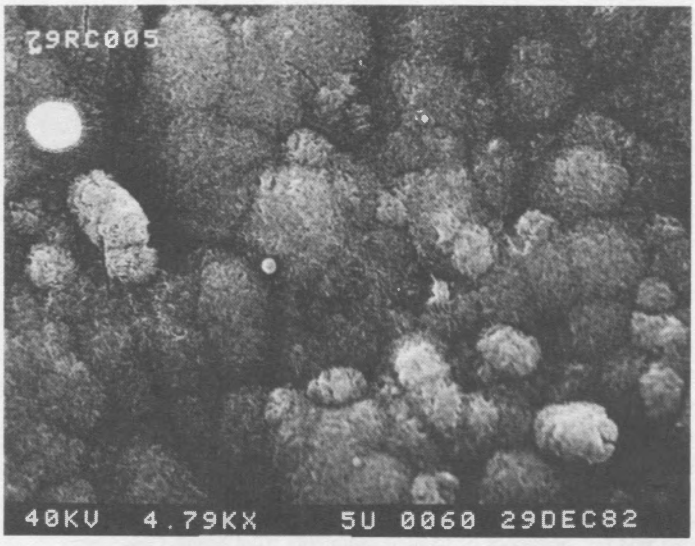

Figure 6. **Scanning electron microscope image of limonite stalactite 79RC005 showing nodular and fine platy structure. Image width 22 micrometers.**

Limonite Speleothems

Limonite speleothems occur only in the Breakdown Room. Seepage through cracks in the fractured Kinzer Formation has produced well-formed stalactites (Fig. 2), stalagmites (Fig. 3), and columns (Fig. 4). The speleothems range in color from orange-brown to almost black. In some parts of the Breakdown Room the speleothems form in direct contact with fresh fracture surfaces in the bedrock. In other parts of the room, the ceiling is coated with a yellow to red layer (Fig. 5). Although there is a great profusion of limonite speleothems in the Breakdown Room, they occur nowhere else in the cave. They are also restricted to the Kinzer Formation.

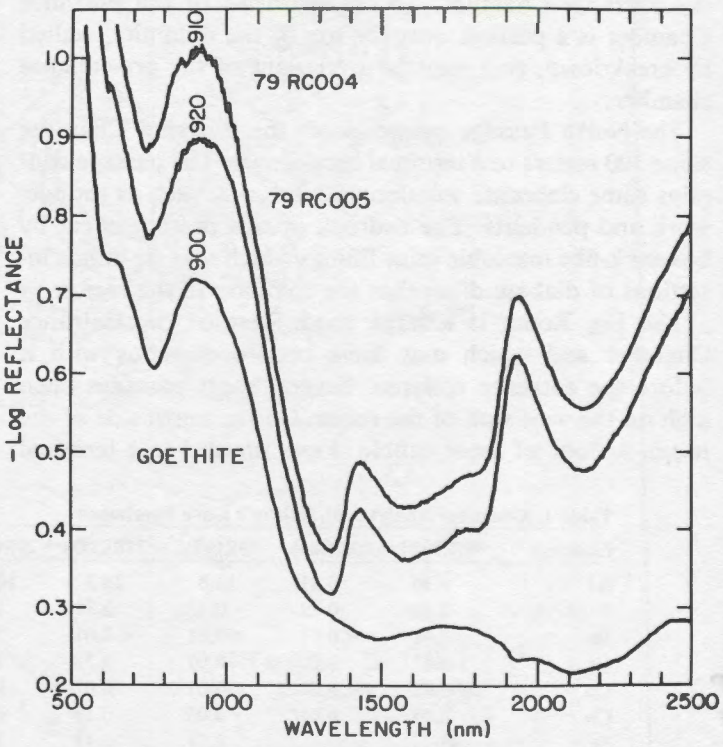

Figure 7. **Diffuse reflectance spectra of limonite speleothems in comparison with crystalline goethite. 79RC004 is an orange stalactite. 79RC005 is a nearly black stalagmite similar to those in Figures 2 and 3.**

The limonite speleothems contain a great deal of water. When they dry, they crumble into a pile of platy fragments. The light microscope reveals an intricate banding with individual layers only 50 to 100 micrometers thick. On a smaller scale, the scanning electron microscope reveals a nodular texture (Fig. 6) with nodules 2-5 μm in diameter. On a still smaller scale, just visible in the SEM range of Figure 6, is a

platy texture at a scale of 1000-3000Å. Since SEM images are obtained from samples mounted in vacuum chambers, it is possible that some of the small-scale textures developed when the sample is dried.

Reflectance spectra in the visible and near-infrared regions of the spectrum are very similar to those of goethite (Fig. 7). However, all specimens examined are amorphous to X-rays. These materials are described as 'limonite,' defined as a 'poorly crystalline to noncrystalline iron hydroxide or oxyhydroxide.' The large amount of included water in the speleothems shows up clearly as the 1450 and 1950 nm bands in Figure 7. Reflectance spectra of the red and yellow patches seen on the ceiling also indicate a limonite-like material, although the amount of included water is much less. Likewise an ocherous soil found near the Breakdown Room is limonite.

Chemical analysis of the limonite speleothems with the energy-dispersive secondary X-ray (EDX) attachment on the scanning electron microscope shows iron to be the only heavy metal. The limonite speleothems seem to be remarkably pure on an individual grain basis. Wet chemical analysis (Table 1) averages a large volume of sample and gives a representative bulk composition. In addition to iron, substantial concentrations of phosphorus and silica were found. The elemental compositions given in Table 1 can be recalculated as the oxides. The sum of these including the loss on drying (assumed to be unbound water) does not add up to 100 percent. If the mass deficit is assumed to be bound water, an estimate can be made of the major constituents of the limonite speleothems (Table 2). The phosphorus is almost certainly present as the phosphate anion, and because iron is the only cation present in large concentration, a ferric phosphate is assumed. Silicon is listed as SiO_2 although the possibility of an iron silicate cannot be excluded. The bound water is found to be more than sufficient to form FeOOH but not sufficient to form $Fe(OH)_3$. The proportions of iron hydroxides and oxyhydroxide cannot be calculated because of the unknown amount of water tied up with hydrated silica and with the iron phosphate. The composition given in Table 2, therefore, is only suggestive of the composition of the limonite speleothems. The presence of phosphate is especially interesting as it has not been previously reported in iron oxide speleothems.

The exact mineralogical character of the limonite speleothems awaits more detailed characterization. Finlayson and Webb (1985) argued that many 'limonite' speleothems belong to the hisingerite—ferrihydrite series of amorphous or poorly crystalline iron silicate—iron oxide hydrate minerals. Because the minerals in the cave contain such large quantities of water, it is very difficult to demonstrate that the structures and compositions found in the laboratory are representative of the original cave material. For the moment, the identification is only as limonite.

Table 2. Recalculated Composition of Limonite Speleothems in Weight Percent.

Compound	79RC004	79RC005
FeOOH + $Fe(OH)_3$	66.5	79.0
$FePO_4$	16.3	7.5
SiO_2	9.0	5.3
Unbound water	8.0	9.4

Black and White Flowstone

Flowstone and dripstone-like speleothems occur in isolated patches in the Big Room, in the South Passage Complex, and in passages north of the Breakdown Room. Some of these are pure white, some are jet black, and some are mottled mixture of the two. Figure 8 shows one such patch.

These speleothems are soft, almost mushy, and contain large quantities of water. Fresh fracture surfaces glisten with large clear grains embedded in a pasty white mass. When the material dries, it collapses into a loose white (or black) powder. Samples examined include the following:

79RC001 Thin white coating on breakdown
79RC002 Black and white coating
79RC003 White powder scraped off Vintage Dolomite
79RC010 Black 'button' from North Passage

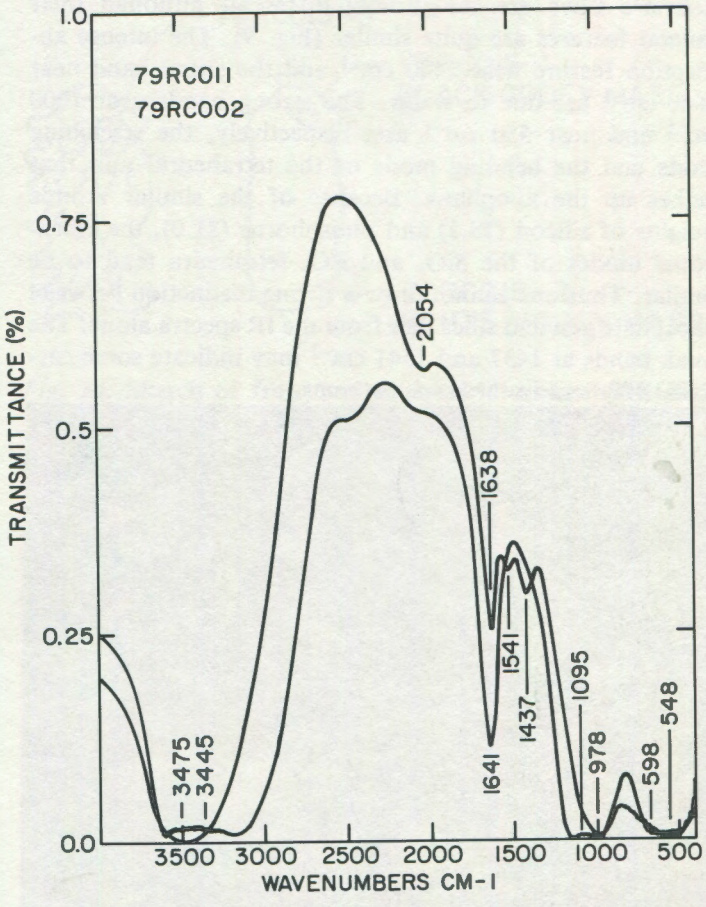

Fig. 9. **Infrared spectra for alumino-phosphate white material (79RC002—upper curve) and alumino-silicate white material (79RC011—lower curve).**

79RC102 Wall nodule with black coating
80RC009 Loose black soil

Analysis of the white wall coatings (79RC001, 79RC002, and 79RC003) by EDX shows that most of the material is an alumino-silicate, usually with more aluminum than silica, although the ratio varies considerably from specimen to specimen. All specimens examined were noncrystalline by X-ray diffraction. The composition, combined with the white gel-like physical appearance satisfies the definition of allophane (Grim, 1953; Wada, 1978), an amorphous alumino-silicate found in soils and as a weathering product of volcanic glasses. However, many of the Rohrer's Cave samples also contain measurable concentrations of phosphorus, and specimen 79RC002 is mainly aluminum phosphate.

Webb and Finlayson (1984) and Finlayson and Webb (1985) describe allophane speleothems from various granite caves. They suggest that the infrared spectrum is a diagnostic signature. However, the spectra shown in their papers are fairly typical of many noncrystalline silicates with layer-like atomic arrangements. The spectra of the alumino-silicate material and the alumino-phosphate material from Rohrer's Cave are measurably different, although their general features are quite similar (Fig. 9). The intense absorption feature near 3400 cm^{-1} and the sharp band near 1640 cm^{-1} are due to water. The strong bands near 1000 cm^{-1} and near 550 cm^{-1} are, respectively, the stretching mode and the bending mode of the tetrahedral unit that makes up the allophane. Because of the similar atomic weights of silicon (28.1) and phosphorus (31.0), the vibrational modes of the SiO_4 and PO_4 tetrahedra tend to be similar. Thus one cannot draw a strong distinction between phosphate gels and silica gels from the IR spectra alone. The weak bands at 1437 and 1541 cm^{-1} may indicate some carbonate content in these speleothems.

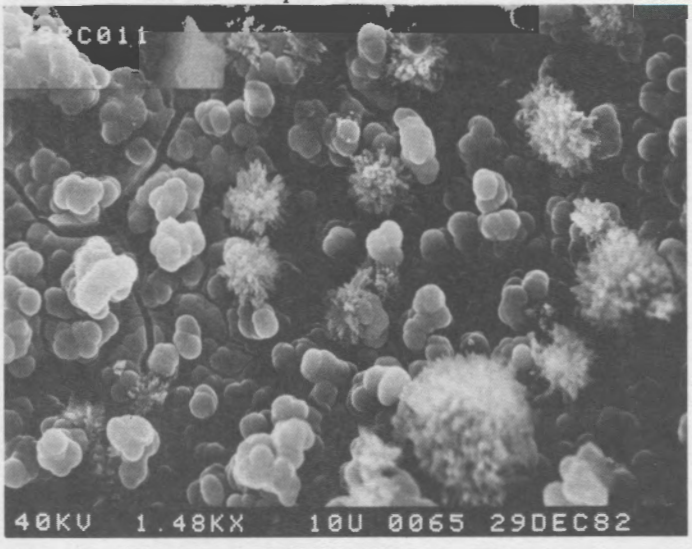

Fig. 10. **SEM image of white stalactite 79RC011 showing nodular masses with interspersed 'flowers.' Image width 77 µm.**

Specimen 79RC011 was a stalactite about 8 cm long and 2 cm in diameter growing from the ceiling of a passage in the Vintage Dolomite. It has an irregular surface and a loose porous internal texture very similar to the photograph of an allophane stalactite from a lava cave published by Finlayson. and Webb (1985). The stalactite was predominantly the white material with a tinge of green color.

SEM images of the white material (Figs. 10 and 11) show a nodular or botryoidal structure with a particle size of 2-5

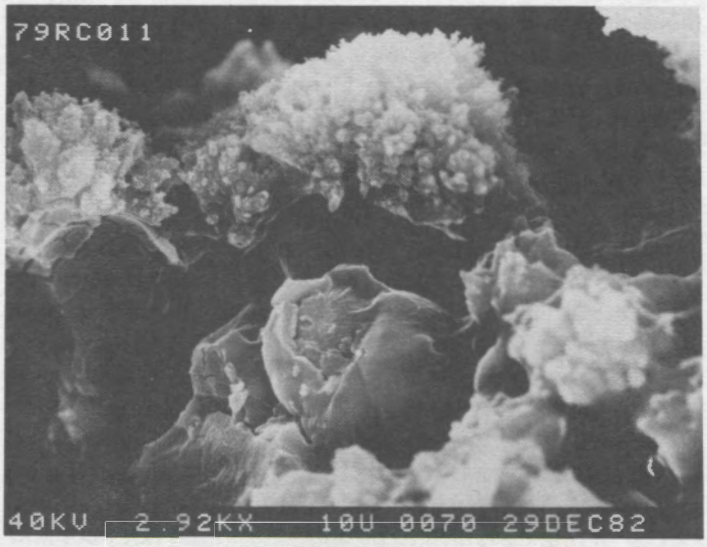

Fig. 11. **Close-up of 79RC011. Image width 38 µm.**

µm. Interspersed with the nodules are tufts of radiating 'flowers.' EDX analysis shown both 'flowers' and nodule to have similar chemical compositions (Fig. 12). The material is dominantly aluminum with some silicon and minor amounts of calcium. The EDX spectrum does not determine whether the material is a single compound or a mixture. The

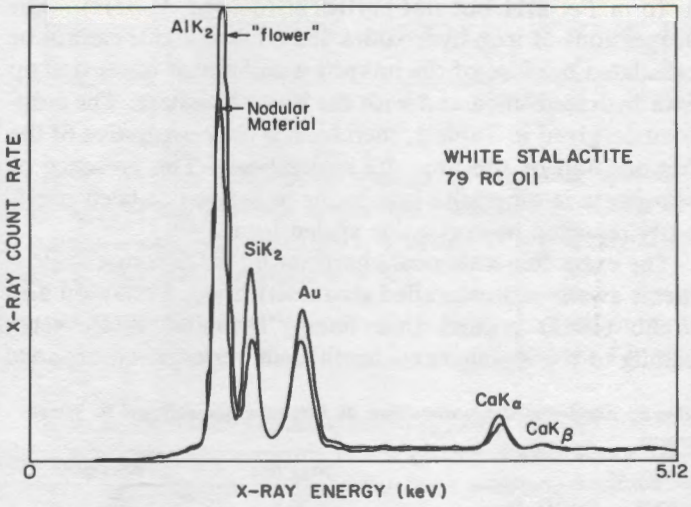

Fig. 12. **Energy dispersive X-ray (EDX) spectrum of white stalactite 79RC011. The peak marked 'Au' is an artifact from the gold coating evaporated onto the sample to prevent charging in the electron beam.**

ratio of Al/Si peak intensity varies somewhat from sample to sample. X-ray diffraction patterns contain two weak peaks at 4.80 and 4.31Å which tentatively identify the presence of poorly crystallized gibbsite, $Al(OH)_3$.

The black material is mainly an oxide of manganese. It likewise is amorphous to X-rays. Specimen 79RC012 has a nodular structure with a well-developed layering (Fig. 13).

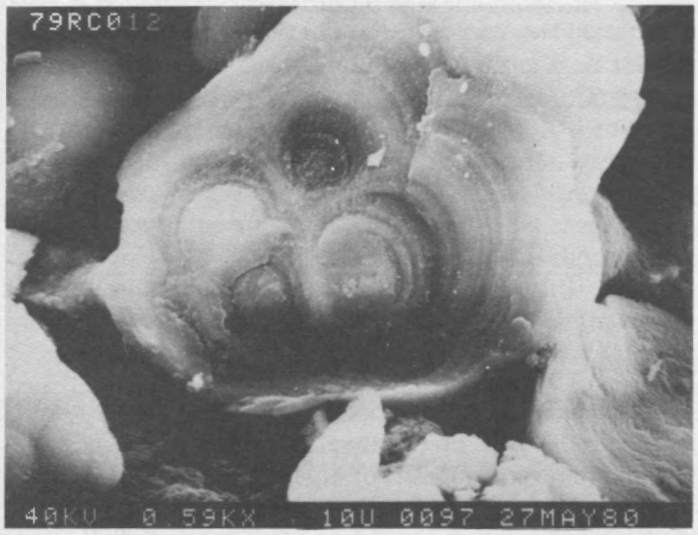

Figure 13. **SEM image of cross section of manganese-rich nodule (79RC012) showing layered structure.**

EDX spectra of the black oxides show that about 80% of the material is manganese oxide and that the remaining 20% is a mixture of cobalt, nickel, copper, and zinc (Fig. 14). The relative proportions of these metals varies from sample to sample. Iron is conspicuous by its absence. The black deposits are essentially iron-free just as the iron speleothems are free of manganese and other heavy metals.

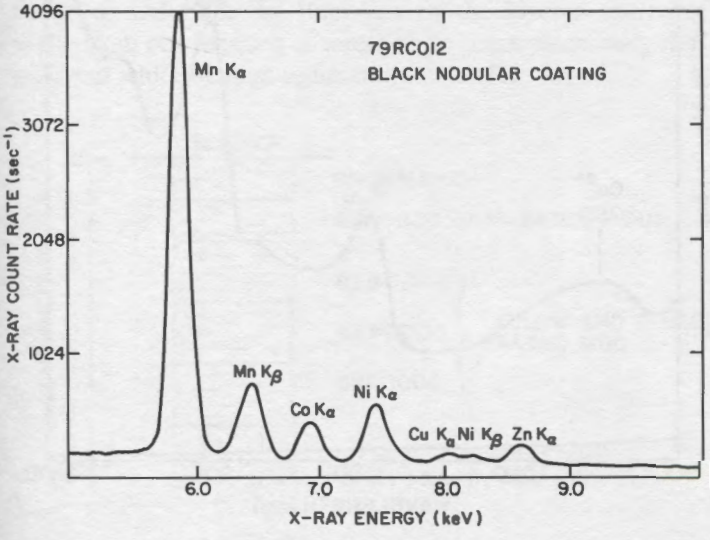

Fig. 14. **EDX spectrum of black manganese-rich nodule showing mixture of transition metals present. Concentrations are roughly proportional to peak count rates.**

The EDX analyses are generally supported by the bulk chemical analysis (Table 1). Specimen 79RC010 is a black 'button' which almost certainly has other material mixed with it as suggested by the high aluminum and silicon content. It also contains some iron. This particular sample is less pure in bulk analysis than were several other specimens under EDX analysis.

The 'Pinecones'

The most remarkable speleothems in Rohrer's Cave are the 'pinecones' that are found in the passage north of the Breakdown Room (Fig. 15). These are knobby masses of soft black and white material hanging from the ceiling by a much smaller stalk. Although having the appearance of rather bizarre stalactites, the 'pinecones' lack a central canal. These speleothems are extremely delicate as the material is soft and only loosely consolidated like the other black and white speleothems. One specimen (79RC015) had fallen under its own weight. It was borrowed for examination and sampling (Fig. 16) after which it was returned to the owner.

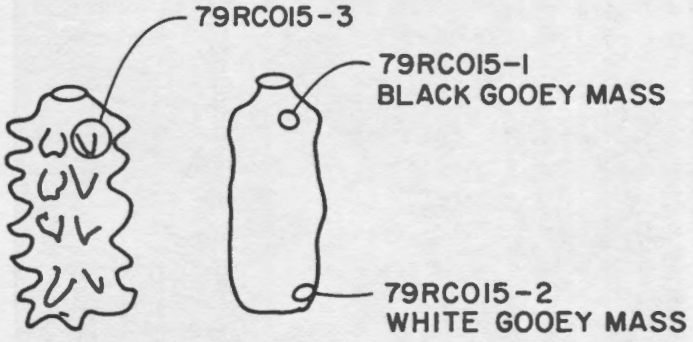

Fig. 16. **Sketch of front and back of 'pinecone' 79RC015 showing location and number of extracted samples.**

The 'pinecones' are delicately layered like most of the other speleothems. One side of the typical 'pinecone' is rough and knobbly giving the speleothem the pinecone appearance. The other side is smooth and exposes a white mass with black material speckled through it. The black material, according to EDX analysis, is the same manganese oxide with other heavy metals that makes up the other black deposits in the cave. The white material is either an alumina-silica-calcia compound or an aluminum phosphate compound. Split 1 from sample 79RC015 is a silicate with black pigmenting material. Split 2 is a phosphate. There is no obvious difference in the physical appearance to distinguish white mushy silica from white mushy phosphate. The chemistry shows up clearly on EDX spectra and some differences are also seen in the infrared spectra (Fig. 17).

Three chips of split 79RC015-3 were analysed by a precision EDX technique which gives quantitative concentration.

The results in which oxygen is by difference from 100% follow:

	Chip 1	Chip 2	Chip 3
Al	32.44	30.88	30.61
P	16.89	18.18	18.40
O	50.67	50.94	50.99

Chips 2 and 3 correspond to Al:P atomic ratios of almost 2:1. The crystalline material that most nearly corresponds to this composition is augelite, $Al_2PO_4(OH)_3$, which can also be written $AlPO_4 \bullet Al(OH)_3$. The excess aluminum hydroxide phase is consistent with the gibbsite found in some of the white speleothems.

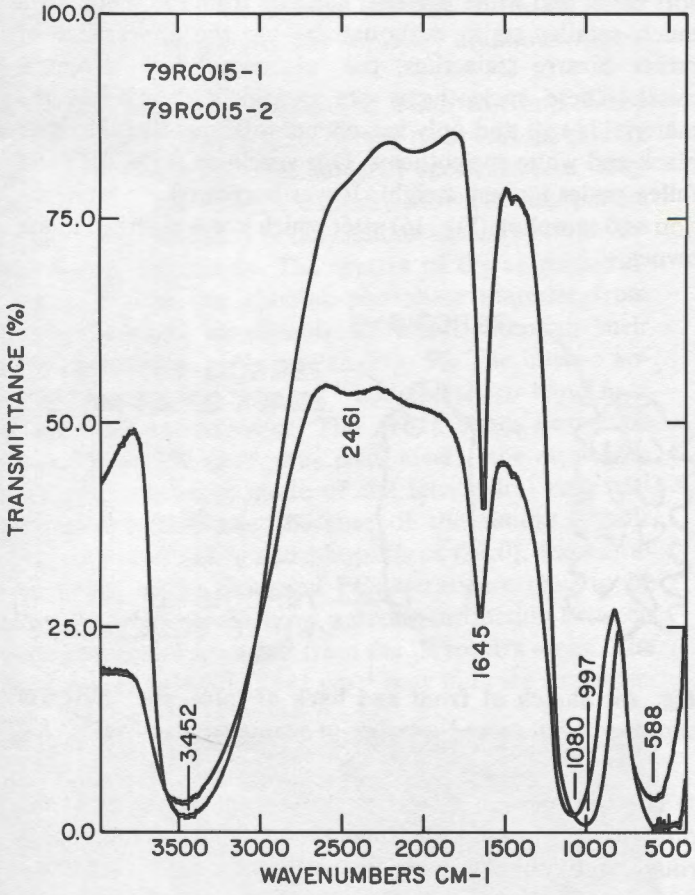

Fig. 17. **Infrared spectra of 'pinecone' 79RC015. Split 1 is black material which turns out to be mainly alumina-silica material with some manganese oxide as pigment. Split 2 is alumino-phosphate material.**

The chemical analysis of sample 79RC015-3 (Table 1) averages over a larger volume than does the EDX analysis and shows that both silicate and phosphate material occur in nearby regions in the speleothem. The principal components were recalculated as the oxides (Table 3) and as the mole fraction of oxide components. The bound water was determined by difference after accounting for the oxygen needed to form the oxides from the elements and deducting the loss on drying which was tabulated as 'unbound water.' The sum of silica and P_2O_5 mole fractions just about balances the alumina mole fraction suggesting a formula $Al_2O_3 \bullet (SiO_2 + P_2O_5) \bullet nH_2O$. Because the speleothems are noncrystalline and of variable composition little more can be said about mineralogy.

Table 3. Recalculated Chemical Analysis of Pinecone Speleothem (79RC015-3). Mole fraction includes only bound water normalized to dry weight.

Component	Weight Percent	Mole Fraction
Al_2O_3	34.4	0.268
MnO_2	0.7	0.006
P_2O_5	17.8	0.099
SiO_2	11.8	0.156
Bound H_2O	10.7	0.471
Unbound H_2O	24.7	—

The Blue Deposits

In a small side passage north of the Breakdown Room, and near the part of the cave where the 'pinecones' are found, are several deposits of blue flowstone (Fig. 18). The solutions depositing the material descend through cracks in the Kinzer Formation and spread along the walls and under ledges to produce forms similar to calcite flowstone. There are black coatings in the side passage in addition to the blue material.

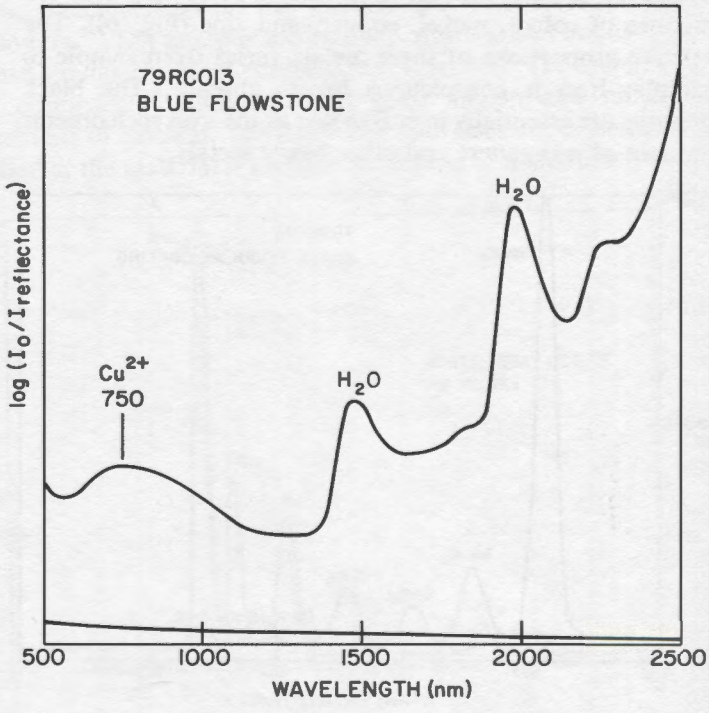

Fig. 19. **Diffuse reflectance spectrum of blue flowstone showing characteristic absorption band of Cu^{2+}.**

The blue flowstone is amorphous to X-rays. Energy dispersive X-ray spectroscopy shows the material to contain mainly aluminum with some silicon and a small amount of calcium in proportions similar to the other white deposits. The infrared spectrum is also very similar to the spectra of the alumina-silica materials in the black and white speleothems. In addition, the specimen examined, 79RC013, contains a few percent copper plus a trace of iron. A diffuse reflectance spectrum (Fig. 19) confirms that the blue color is due to copper. The broad band near 750 nm is at the expected position for Cu^{2+} coordinated by six oxygens, hydroxyls, or water molecules (see White, 1981, for further discussion of the origin of color from transition-metal ions in speleothems). The other bands in the near-infrared spectrum are due to the molecular vibrations of water molecules in this highly hydrated material. The copper is dispersed as Cu^{2+} in solution in the alumino-silicate host. It is not concentrated in specks of black oxide. Thus the blue flowstone seems to be a Cupric-doped allophane possibly similar to the blue flowstone described by Martini (1980).

Banded Sediments

The floor of the Big Room and the South Passage Complex consists of sticky brown clay that on the surface seems to be typical Pennsylvania cave mud. Beneath the brown mud layer is a layer of intricately banded orange, gray, and white sediments. Below the banded sediments is coarse sand and gravel rather similar to stream-deposited clastic sediments found in other caves. Figure 20 shows a 'stratigraphic column' for the sediments. The thickest part of the sequence has an orange and white banding, but the upper few centimeters have a gray and white banding (Fig. 21). The banded sediments underlie the brown surface sediments in the Big Room as well, but the thickness of the layered material varies from one location to another. In some places only the gray and white banded sediments occur (Fig. 22).

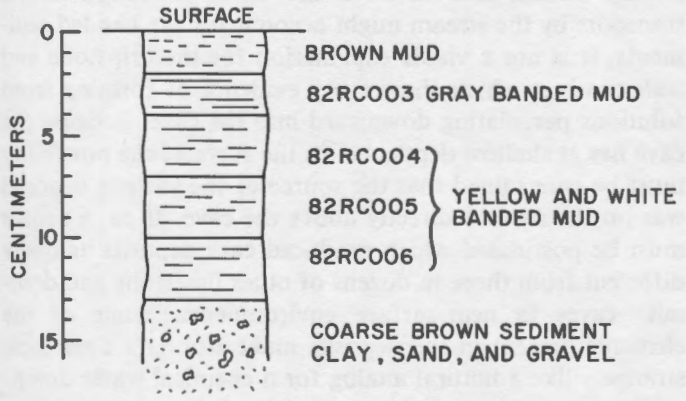

Fig. 20. **Section through banded sediments in South Complex showing sample numbers.**

The individual layers of sediment are extremely thin. Specimen 79RC006 was originally a massive block of wet gray mud. After drying slowly for a year, it broke down into a mass of white and gray flakes, each only a few hundred micrometers thick. The sediments contain large quantities of water. Air-drying for one week produces the following weight losses:

Top layer of fine-grained brown mud	34%
Gray-white layer	68%
Orange-white layer	69%
Lower coarse-grained brown layer	31%

The layered sediments contain twice as much water as typical clastic cave sediments.

The bulk of the layered sediment seems to be allophane. EDX analysis of 79RC008 shows mostly aluminum with some silicon and calcium. The nodular microstructure (Fig. 23) is also characteristic of allophane. EDX analysis shows that the dark bands that occur in the gray and white banded sediments are manganese oxide with nickel, cobalt, copper, and zinc as was found for the black component of the speleothems.

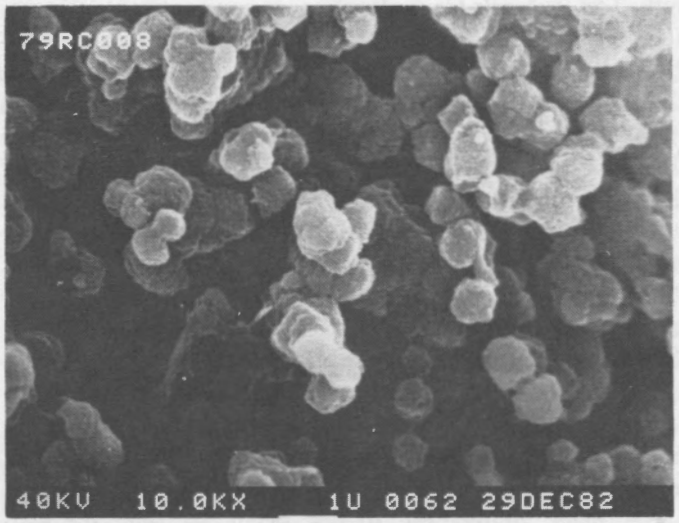

Fig. 23. **SEM image of white layers in the gray-white banded sediment 79RC008. Image width 12 μm.**

The chemical analyses of the different segments of the stratigraphic section sketched in Figure 20 are averages over many layers. Individual layers of the dried sediment are paper thin, 100-200 μm. The layered sediments are mainly alumina and silica; little phosophorus was found in the chemical analyses. A larger quantity of iron occurs than in the allophane speleothems, and iron seems to be responsible for the yellow-orange color banding. Sample 82RC003 is from the upper gray and white banded layer, and it contains much less iron than the lower three layers and a slightly larger manganese concentration. Calculated Al/Si atomic ratios range from 1.38 to 4.2 for the four samples listed in Table 1.

Samples 80RC008 and 80RC009 are soils from the high passage on the west side of the Big Room. Sample 80RC008 is a loose brown soil, rather sandy in appearance, that forms the exposed surface of the fill. Sample 80RC009 was found under the brown soil. It is a loose, absolutely black powder of about 10 μm particle size. EDX results show that about 10% of the material is an alumino-silicate much like the white speleothems elsewhere in the cave. Ninety percent of the powder is a manganese oxide of which some 20 percent is a mixture of iron and nickel with a trace of cobalt. The composition of this black soil thus differs from that of the black speleothems in that zinc and copper are below limits of detection and that iron is at a measurable level.

Discussion and Conclusions

Mineralogically, Rohrer's Cave contains three kinds of materials, all amorphous on the scale of X-ray diffraction:

i. Allophane
ii. Black mixed manganese and other heavy-metal oxides
iii. Limonite

Allophane is the most important constituent in terms of bulk. The Rohrer's Cave allophane is commonly aluminum-rich and some specimens contain excess aluminum as gibbsite, $Al(OH)_3$. Stalactitic speleothems, wall coatings, the blue flowstone, and the banded sediments on the cave floors are all composed mainly of allophane. The Rohrer's Cave allophane is also unusual in that it contains quantities of phosphate and that some speleothems seem to be nearly pure aluminum phosphate. Allophane is described as sometimes containing phosphate, but the nearly pure aluminum phosphate would be a precursor for other minerals and probably should not be called allophane. Because of the abundance of aluminum, opal-like silica deposits are not found. Likewise, the concentration of alkali elements, particularly sodium, is small. The alumina-silica phosphate materials contain a great excess of water and could best be described as gels.

The black manganese oxides occur as separate wall coatings, as blebs of material mixed with allophane, and as thin pigmenting layers in the gray/white banded sediments. All occurrences are similar, consisting mainly of manganese dioxide with various quantities of nickel, cobalt, copper, and zinc. Manganese oxide is known to act as a scavenger for other transition metals, but the concentration of these metals found in the Rohrer's Cave deposits is unusually high. A further peculiarity is the near absence of iron in the manganese oxide deposits.

The term 'limonite' is used in the absence of data that would provide a more precise description of the hydrated oxides of ferric iron. Limonite occurs principally in dripstone form in one chamber of the cave and is physically isolated from the various allophane deposits. Likewise, the limonite deposits contain only minor concentrations of other heavy metals.

The Rohrer's Cave deposits are very unusual compared with the speleothems commonly found in solution caves in carbonate rock. The allophane found in caves in granite and other silicate rocks quite likely originates with the dissolution, alkali metal extraction, and reprecipitation of feldspar minerals. The allophane found in the eastern Transvaal was said to be related to ore deposits (Martini, 1980). The mechanism of deposition poses questions that cannot be answered with the data presently available. The solutional transport of aluminum, silica, and phosphate requires much higher pH than is normally found in carbonate groundwaters. Some of the floor sediments were slurried into water which was then found to have a pH in the range of 8-9. Rough calculations suggest pH values of 11-12 in the sediment pore waters. Not only must one postulate a source for the allophane and associated compounds but one must devise a source for extremely alkaline solutions.

Limonite, on the other hand, is usually associated with acidic groundwaters. Limonite and goethite stalactites occur in caves where the cavernous limestone underlies coal-bearing rocks. Oxidation of pyrite in the coal horizons produces acidic solutions which can retain the iron in solution. When these solutions are neutralized after they have percolated downward into the cavernous limestones, the iron is precipitated. Limonite or goethite can be transported in suspension as colloids or as very fine-grained particles until the material accumulates in dripstone deposits. Such a mechanism cannot be applied easily to Rohrer's Cave. Not only are the pyrite-rich horizons not present above the cave, but one has the very odd situation of the limonite dripstone requiring an extremely acid percolation water in one chamber of the cave while the allophane deposits only a few meters away appear to have highly alkaline pore water.

The age relations of the deposits also raise some contradictory suggestions. The layered sediments lie between what seems to be steam-transported gravel at the base and brown fine-grained cave mud at the top. The sediments may, therefore, be rather old and date from a time when the nearby stream had invaded the cave. Although lateral transport by the stream might account for the banded sediments, it is not a viable explanation for the dripstone and wall coatings which show every evidence of forming from solutions percolating downward into the cave. Because the cave lies at shallow depths below the surface, the possibility must be entertained that the source of the various deposits was on the surface directly above the cave. If so, a source must be postulated which produced cave deposits uniquely different from those in dozens of other limestone and dolomite caves in near-surface environments. Some of the elements present in the deposits make Rohrer's Cave look strangely like a natural analog for a chemical waste dump.

The present investigation was intended as a description and identification of the deposits. Further work on these materials is required to answer questions of origin and depositional mechanism.

Acknowledgments

We thank members of York Grotto for assisting with field work on the cave and Jay Longenderfer for drafting the map. Appreciation is extended to Mr. Rohrer for his cooperation and permission to enter the cave.

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THE DEFLECTED STALACTITES OF DAN-YR-OGOF: A HYPOTHESIS

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The direction of deflected segments of 27 soda straw stalactites and columns was measured in the areas of Monk Hall in Dan-yr-Ogof, a cave in South Wales. The direction of deflection in many cases is parallel to the direction of the passage, suggesting air movement as a causative factor in the deflections.

INTRODUCTION

Dan-yr-Ogof is a major show cave in the Upper Swansea (or Tawe) Valley of South Wales. Discovered in 1912, it has been extensively explored; its known length exceeds 15 km. Most of the work on the cave has been described by Coase and Judson (1977), and exploration is continuing. During the source of an expedition whose major purpose was exploration, the author was able to measure segments of 27 deflected soda straw stalactites in the areas known as the Cloud Chamber, Monk Hall, and Grand Canyon. An example of a deflected straw is shown in Figure 1.

Crystalline minerals in caves can exhibit strange forms, and these have stimulated the curiosity of scientific and lay observers for a long time (see Hill, 1976, and White, 1976). Deflected stalactites, (stalactites that do not hang vertically), are one such class. In some cases deflections from the vertical can be explained in terms of breakdown shifting, in which entire stalactites are moved from their original vertical orientation. Carroll (1978) extended this explanation by proposing that catastrophic polar shifts can account for deflected stalactites growing from solid roofs. A previous analysis of the Dan-yr-Ogof data (Sevenair, 1978) and other non-cave evidence has shown this catastrophic explanation to be very unlikely. The growth mechanisms of normal soda straws and stalactites are fairly well understood (Moore, 1962; Curl, 1972), but the published work on the mechanism of the origin of deflected stalactites may be summarized by the comment of Hill (1976, p. 34): "origin is unknown."

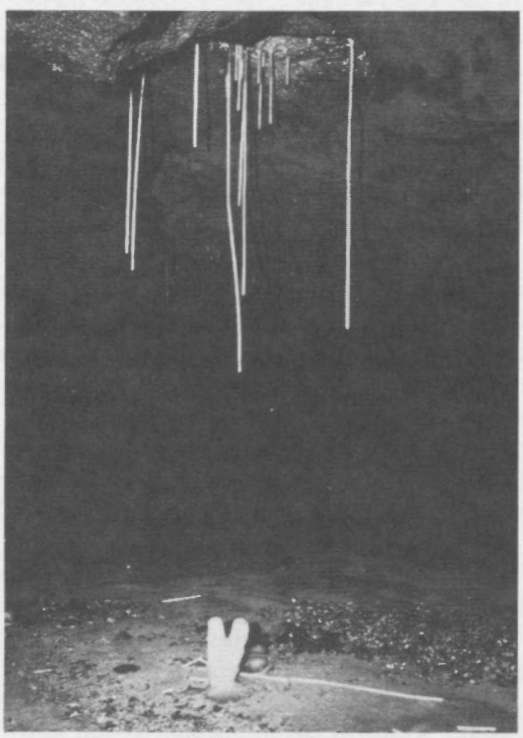

Figure 1. **Deflected soda straw with associated stalagmite, Dan-yr-Ogof, South Wales. This is straw #6 in Table 1.**

METHODS AND RESULTS

Deflected stalactites were selected for examination based on accessibility. No attempt was made to perform a complete statistical study on the entire stalactite population; the majority of soda straws had little or no deflection, and so were not measured. Compass direction of deflection was measured using a Suunto compass, and the deflection from the vertical was measured using a Suunto clinometer. The location of each stalactite was noted on a tracing of that portion of the Coase and Judson (1977) map which covers the study area.

Of the 27 soda straws examined, three were segmented and had more than one compass direction of deflection. The compass direction of deflection of the 31 segments is shown in the third column of Table 1. When the direction of deflection is tabulated against the compass direction, there appears to be no clustering (Sevenair, 1978).

Two of the straws were on a high ceiling, and the angle of deflection from the vertical could not be measured. Of the 25 remaining, seven had two measured deflected segments; in five of these cases the two segments had the same compass

Table 1. Passage orientation, compass direction of deflection, and the difference between the two for 31 deflected straw segments.

Straw No.	Passage Direction (a)	Direction of Deflection (b)	Difference (c)	Comments from the Survey Notes (d)
1	57	20	37	two deflected segments
2	57	55	2	parallel to passage
3A	86	300	34	1 cm from #3B at base
3B	86	115	29	1 cm from #3A at base
4	70	285	35	1 cm from #5 at base
5	70	25	45	1 cm from #4 at base
6	23	245	42	
7	354	350	4	parallel to passage; two deflected segments
8	348	170	2	parallel to passage
9	348	350	2	parallel to passage
10	348	350	2	20 cm from #9
11	348	230	62	not parallel to passage
12	19	350	29	two deflected segments
13	70	260	10	
14	70	170	80	turns after exiting a ceiling crack; two deflected segments
15	85	165	80	originates at wall
	85	240	25	close to wall
16	70	70	0	
17	0	240	60	turns after exiting a ceiling crack
	0	5	5	
	0	240	60	
18	0	180	0	
	0	250	70	
19	64	65	1	
20	40	80	40	
21	348	350	2	between #9 and #10; two deflected segments
22	348	30	42	near #21
23	350	355	5	between #7 and #22
24	332	130	22	2 deflected segments
25	70	95	25	3 deflected segments; 2.5 cm from #26
26	70	30	40	2.5 cm from#25

Notes: (a) Measured from the map in Coase and Judson (1978). (b) Compass direction to the tip from the root. (c) Difference between the passage direction and the compass direction of deflection expressed as an acute angle. (d) When "two (or three) deflected segments" is indicated here, all segments have the same compass angle of deflection. When two or more sets of data are given under the same straw number, not all segments have the same angle.

direction of deflection. Two of the straws had three such segments; in one of these cases all three segments had the same compass deflection. The amount of deflection from the vertical for each of these 37 segments has been published previously (Sevenair, 1978). Again, no clustering was apparent.

Air movements are widely believed to be involved in the formation of deflected stalactites, and the Dan-yr-Ogof data were considered from two viewpoints in considering this hypothesis. First, the passage direction was measured at each stalactite location from the map of Coase and Judson (1977). The difference between the passage direction and the direction of deflection was then calculated by subtraction.

Table 2. Summary of Differences Between Compass Direction of Deflection and Compass Direction of Passage.

Difference interval degrees (1)	Number of straws with difference in this interval	Number of straws within 3 cm. of an obstacle (2)
0 - 10	12	0
11 - 20	0	—
21 - 30	5	3
31 - 40	5	3
41 - 50	3	1
51 - 60	2	1
61 - 70	2	0
71 - 80	2	2
81 - 90	0	—

(1) The difference is measured as the acute angle between the extended center line of the passage and the compass direction of deflection of the straw or segment. (2) Deflection of these straws begins within 3 cm. of a wall, the roof, or another straw.

The data for each straw is given in Table 1, and the results are summarized in the first two columns of Table 2. The most frequent direction of deflection is within 10° of the axis of the passage; 12 segments have this orientation, though more than half of the segments are deflected in other directions.

Further, the survey notes indicate that ten of the segments whose compass direction of deflection is not parallel with the passage direction are located within 3 cm. of the wall, the roof, or another stalactite. This is true of none of the twelve parallel-deflected segments (this is shown in the third column of Table 2). In such locations local eddies or turbulence may cause the wind direction to vary from the passage direction.

Hill (1985) has suggested a second mode of examination of the data. In this, only the 19 straws measured completely were considered. For these, the amount of deflection from the vertical vs. the distance along the straw was determined (Table 3). These results indicate that the amount of deflection increases steadily along the straws until they are about 1 m long; then the deflection decreases somewhat. The initial low values can be explained by a slowing of the wind near passage surfaces and other stalactites by friction; toward the center of the passage, where the wind velocity would be greater, deflection is greater. The lower deflection at the end of the longest straws may indicate that very long,

Table 3. Average Amount of Segment Deflection vs. Distance Along the Straw.

Distance along straw, cm.	No. of segments in this interval	Average deflection from vertical, degrees
0 - 15	24	1.13
15 - 30	21	1.76
30 - 45	20	2.40
45 - 60	22	4.05
60 - 75	22	4.82
75 - 90	13	5.38
90 - 105	7	4.0
105 - 120	4	4.0
120 - 135	5	4.6
135 - 150	2	3.5

radically deflected straws break under their own weight. It appears, at least, that the Dan-yr-Ogof data is consistent with the wind deflection hypothesis.

The Mechanism of Deflection

Before a hypothesis concerning deflection is proposed, the mechanism of normal, non-deflected soda straw growth may need clarification. The most obvious explanation, perhaps, is that soda straws grow downward under the direct influence of the force of gravity. This is unlikely; when the forces operating on an ion being deposited on a calcite crystal are compared, the force of gravity is very weak in comparison with the electrostatic forces involved in solution and crystallization.

Crystal growth occurs most rapidly from existing nuclei (Holden and Singer, 1960; Pavia et al., 1982), and calcite crystals will grow fastest along the c-axis, all other factors being equal. In Figure 2A, consider three calcite nuclei (a, b,

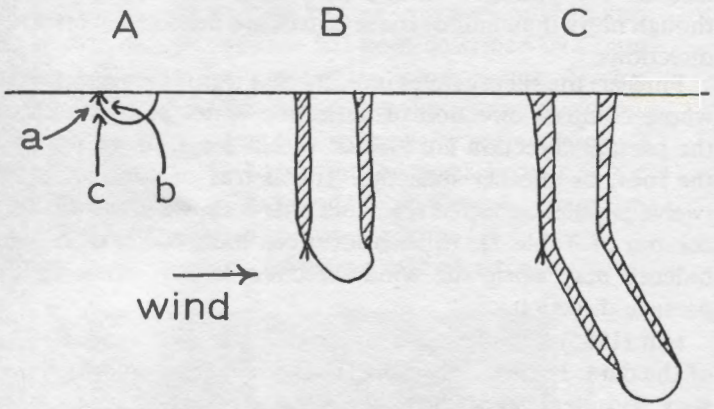

Figure 2. **A. Crystal growth from different nuclei in a new soda straw. Orientation (c) is favored because its c-axis is in the region of greatest supersaturation.**

B. Crystal growth from different nuclei in a soda straw in which the drop of water is deformed by air movement. Deflected orientation (b) is favored.

C. Growth of long straight deflected segment from origin in B above. Other crystal nuclei have been left behind.

and c) at the edge of a water droplet on the roof of a cave. If a soda straw is to grow, the droplet will be losing carbon dioxide and becoming supersaturated with respect to calcite. Any crystal whose c-axis is aimed outside the droplet will be expected to grow slowly from lack of raw material (a). Any crystal whose c-axis is aimed into the drop (b) is growing into a region in which the dissolved carbon dioxide concentration is relatively high and supersaturation is low; crystal growth will therefore be slow. A crystal oriented along the surface of the droplet (c) will remain in the area of carbon dioxide loss and high supersaturation; it will grow more rapidly. This crystal will be oriented downward. Continued growth of such crystals will lead to the normal soda straw form, as described by Moore (1962).

The proposed mechanism for deflected soda straw formation is illustrated in Figures 2B and 2C. In 2B, the original crystals of the straw have ceased to grow, perhaps because of a temporary cessation of water flow. With a resumption of water flow, new crystal nuclei have formed at the tip of the straw. The droplet at the end of the straw may be slightly deformed by air movement. If this occurs, the crystals whose growth is favored by the nearness of their c-axis to the surface will no longer be vertical. If water flow and calcite deposition continue without interruption, these nonvertical crystals may become the only ones present at the tip of the straw and the only ones able to grow. If no new nuclei to begin crystals of other orientations are formed, long, deflected segments can grow even in the absence of steady air movement (Figure 2C). Other implications of soda straw growth along the surface of water droplets have been described by Curl (1972).

The Dan-yr-Ogof straws of this study seem to require that deflection be a rare event here. The sample includes a straw containing a 0.9 m straight segment with a deflection of 3°, and a 0.4 m segment having a deflection of 10°. A large majority of the straws are not deflected at all. In these cases, growth may have begun vertically in the still air near the ceiling, and continued downward on vertically-oriented crystal tips despite any wind.

Acknowledgments

The author would like to thank the other members of the expedition: Peter Hambledon, Anthony Hodge, John Wood, Steve Weston, Roger Martin, Alastair Kidd, Terry Worthington, and especially Gareth Davies and John Bowden. I would also like to thank the management of the Dan-yr-Ogof Showcaves, without whose support this work would not have been possible.

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CONFERENCE REPORT

On Meetings of the British Cave Research Association

B.C.R.A. National Caving Conference— Lancaster University, September 29–30, 1984

B.C.R.A. Cave Science Symposium— Sheffield University, November 10–11, 1984

The annual conference of the B.C.R.A. at Lancaster University was attended by several hundred cavers and, as usual, was devoted primarily to the sporting side of caving. Over 40 papers were read covering recent discoveries in the British Isles (in Yorkshire, Mendip, Wales and Southwest Ireland, and on overseas expeditions (to Austria, Canada, France, Greece, Java, Mexico, Norway, Sarawak and Spain!) By way of contrast, the symposium at Sheffield was a new venture aimed at complementing the Annual Conference and providing a forum for British cave scientists. In any event, it attracted an enthusiastic audience of about 50 which included Professor *Yuan Daoxian* from China. The day started with Cave Physics as *Stephen Gale* discussed 'Dissolution bedforms in karst conduits' while *Pete Smithson* described 'Cave temperature investigations' at Cresswell Crags using thermistors. His data indicates a rapid attenuation of temperature fluctuations with distance into the cave and suggested that countercurrent draughts flowed over the floor and roof. The day's only hydrological paper was given by *John Gunn* who summarised the results of earlier 'Karst hydrological studies in Derbyshire' and described the methods of and early results from his own research on the Castleton area. The next 4 papers were all devoted to age-dating techniques. *Tim Atkinson* and *Peter Rowe* gave a detailed review of the current state of the art in 'Speleothem dating' while *Barnaby Smith* provided a glimpse of the hopefully not-too-distant future when 'Electron Spin Resonance dating of cave calcite' may become routine, greatly extending the value of caves for environmental reconstruction. This would also be assisted if U-series dating could be applied to faunal remains in caves, and *Angela Rae* described 'A feasibility study for Uranium series disequilibrium dating of bone' in which some progress had been made. A more conventional approach was adopted by *Tom Lord* who used speleothems in known stratigraphic relation to bone fragments to produce 'Uranium series dated mammalian faunas from northwest Yorkshire Caves.' Attention then switched to the hole itself as *Pete Smart* outlined 'Cave development in Ogof Fynnon Ddu,' a complex system in South Wales. From caves we progressed (?) to the muck therein as *Mark Noel* explained how 'Palaeomagnetic studies of cave sediments' are undertaken while *Richard Shaw* in his paper on 'Cave sediments and their bearing on the evolution of Peak District Caves' showed how studies of microscopic features on sediment grains could be used to infer surface palaeoclimates. Another side to muck was explained by *Chris Hunt* and *Geraint Coles* whose 'Palynological and Palaeoecological investigations in a Creswell Cave' were used to chart the history of vegetational changes in and around the cave. The formal part of the symposium was rounded off in classic style by *Tony Waltham* with a slide show on Chinese karst. However, for those keen to get underground, two fieldtrips had been arranged for the Sunday. The "wets" accompanied *John Gunn* on a trip to the Castleton karst and Peak Cavern while the less agile enjoyed a pleasant stroll around the Cresswell Crags Visitor Centre and associated archaeological investigations.

All participants voted the Symposium a resounding success and it is hoped that it will become an annual event. Full marks to *Mark Noel* who ably organised the show.

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(Reprinted from GEO², Volume 12, No. 2, Spring, 1985)

The Legacy of Groundwater in Karst Areas: Iowa, Minnesota, and Wisconsin, April, 1985, LaCrosse, WI

On Tuesday and Wednesday April 16–17, 1985, some 160 scientists, health officials, educators, environmentalists, lawyers, and interested citizens met in LaCrosse, Wisconsin, to learn about and discuss karst groundwater and problems associated with it. The large turnout demonstrates the rapidly increasing awareness of the environmental difficulties inherent with carbonate groundwater systems.

The meeting was arranged by The Minnesota Project: A Center for Public Policy Study and Community Development. Sponsoring agencies were the geological surveys of Iowa, Minnesota and Wisconsin.

After welcoming remarks were made, the general topic of karst and karstification was explained by Calvin Alexander (Geology Department, University of Minnesota). George Hallberg (Iowa Geological Survey) then discussed the far-reaching extent of karst groundwater pollution. The health implications of groundwater contamination were presented by Michael Kamrin (Center for Environmental Toxicology, Michigan State University). Robert Hilton (Chief, Groundwater Division, EPA) wrapped up this general session with a discussion on the federal government's role in protecting groundwater.

With the introductory sessions over, the participants had the rest of the day to select from four workshops to attend.

The workshops were held twice in order for each participant to have the opportunity to attend two. The Tuesday afternoon workshops were as follows: 1. Groundwater Contamination Due to Agricultural Chemicals and Fertilizers, 2. Soil Conservation Practices: Which One Helps in Karst, 3. Geologic Mapping in Karst, and 4. Technical Aspects of Karst Research. Each workshop was comprised of three or four papers, and considerable time was devoted to discussion, which was plentiful and lively.

Tuesday evening a social hour and conference dinner were arranged for us. The dinner speaker was Ray Krueger, a lawyer from Milwaukee, who gave an amusing and worrisome presentation on the 'Legal Remedies for Groundwater Problems.'

Wednesday morning presented us with another general session which was of a more specific nature than the previous morning's session. Topics were oriented to the role of local and state governments and their approaches to the problem of protecting groundwater and mitigating damage.

That afternoon four more workshops were held, each with two or three discussion papers. The general topics were as follows: 1. Public Education, 2. Well Testing, 3. Regulating Septic Systems and Private Water Wells, and 4. Local Government Tools to Protect Groundwater. As on Tuesday, these workshops were repeated to allow maximum participation. The conference ended with a wrap-up session where the moderators summarized their various workshops.

This was a well-planned conference, and one of the more informative that I have ever attended. Many thanks and much praise to Loni Kemp and her staff at The Minnesota Project for organizing it. There was general agreement among the participants that another similar conference should be held in the future.

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Association of American Geographers
April, 1985, Detroit, Michigan

After a flurry of cave and karst activity at the 1984 AAG Convention in Washington, D.C., where there were several paper sessions, a weekend fieldtrip, exploration session, and cartography exhibition, there was no organized session at this year's convention. Caves and karst were nonetheless represented by four presentations.

Joyce A. Quinn presented a paper on "Radon compared in three Nevada caves," in which she showed the correlation between radon concentrations and micrometeorology. Percy H. Dougherty gave a presentation on "Stream capture in a Kentucky karst," in which a model of polje formation was presented. A study of carbonate and noncarbonate terrains entitled "Relationships of valley form to lithological characteristics of selected meander valley segments in central Tennessee," was given by Hsiang-te Kung. In a presentation entitled "Preliminary numerical analysis of forest vegetation of Cockpits Country, Jamaica," Frank Davis investigated the impact of environmental factors on the type and density of vegetation in the karst region.

Although the 1985 convention did not have much cave and karst material, several NSS and AAG members got together and plans were made to organize another karst symposium at the 1986 meeting to be held May 4–7, 1986, in Minneapolis, MN. The local arrangements are being handled by George Huppert of the University of Wisconsin-LaCrosse.

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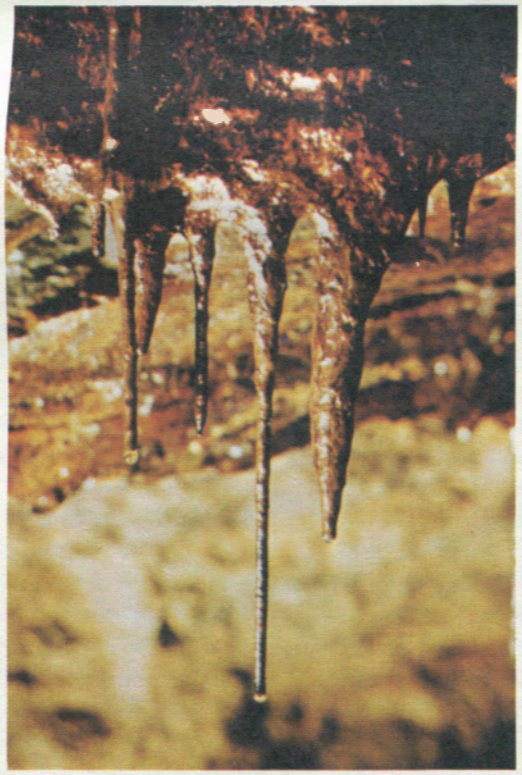

Figure 2. **Limonite stalactites on ceiling of Breakdown Room. Photo by Keith Arnold.**

Figure 3. **Limonite stalagmite in Breakdown Room. Photo by R. Reich.**

Figure 4. **Black limonite columns in Breakdown Room. The ceiling is a fracture surface in the Kinzer Formation. Photo by Bernard L. Smeltzer.**

Figure 5. **Section of Breakdown Room ceiling showing nearly pure black patches of massive limonite interspersed with yellow and orange coatings. Photo by author.**

Fig. 8. **Black and white flowstone and stalactites. Photo by Toni Williams.**

Fig. 15. **'Pinecone' hanging from ceiling of passage just north of Breakdown Room. Photo by Bernard L. Smeltzer.**

Fig. 18. **Blue flowstone in ceiling crack in Kinzer Formation. Photo by Dale Ibberson.**

Fig. 21. **Exposed section of yellow and white banded sediments in South Complex. The overlying brown clay layer and underlying gravel and pebble layer can be seen. Thin gray layer occurs at the top. Photo by author.**

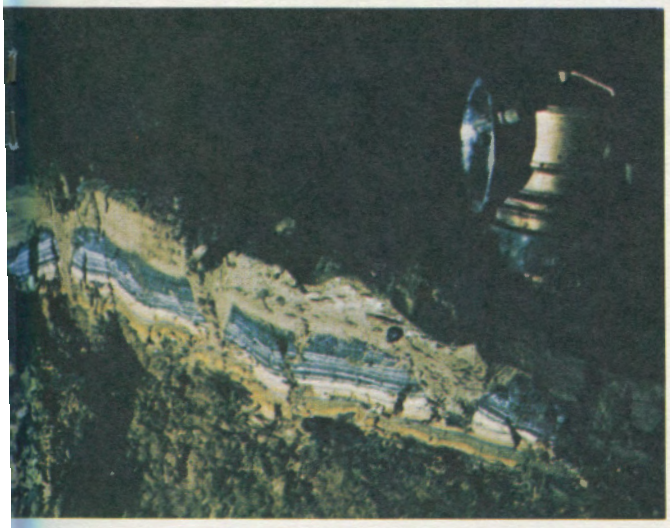

Fig. 22. **Gray and white banded sediments. Photo by Dale Ibberson.**

BOOK REVIEWS

The Creative Explosion: An Inquiry into the Origins of Art and Religion. John E. Pfeiffer. Ithaca: Cornell University Press, 1985. xvii & 270 pp. $12.95 paperback.

John E. Pfeiffer is a distinguished science writer who is best known for two works in anthropology and archeology, *The Emergence of Man* and *The Emergence of Society*, which have been popular textbooks. *The Creative Explosion* fits between those two books in subject matter. In this most recent book in the series, Pfeiffer tells the story of the discovery of the earliest known art and provides an interpretation of its meaning in ritual and religion. The book is beautifully illustrated and clearly written. It will be of interest to anyone who cares about caves, and cavers will discern that Pfeiffer himself is one of the tribe.

The art is there, most spectacularly in polychrome paintings in many caves in Europe. It can be appreciated aesthetically, but what does it mean? How does one go about figuring out what it means? And once you have a hypothesis, how do you test it, given that the artists have been dead for tens of thousands of years?

The most straightforward way is through ethnographic analogy. These people were our ancestors, and many of their basic needs and emotions must have been like ours. Thus the basic assumption has to be that there are some constants in human nature, a specification of the more general assumption that in very basic ways things and events of the past were like things and events of the present.

Given this, Pfeiffer details the ways of life, and particularly the use and meaning of the art forms, of Australian aborigines and other contemporary groups of hunters and gatherers. We know that art and symbolic forms play key roles in ceremonies of passage and in rituals where important bodies of religious and other knowledge are passed on. Pfeiffer compares such ritual ordeals to brainwashing. If someone were taken into an alien environment—a cave, for example—and made to crawl through tight passages in the dark until that person were completely disoriented, and then exposed to flashing lights, to processions of painted animals high on walls and ceilings . . . it would be an impressive experience. One would probably remember it rather well. Even today on lighted tourist tours that cave art is absolutely spectacular.

Pfeiffer combines speculation about this way of impressing knowledge and its importance on people with a discussion of medieval memory techniques to present an interpretation of what cave art was all about. A very old technique for remembering anything at all (e.g., random lists, numbers, verses, things) is first to memorize a place with lots of niches in which you can put things. The medievals used to memorize every nook and cranny in a cathedral. Then when they had to remember something, they would walk through the cathedral in their minds and put one item in each nook or cranny. When they had to remember the lot, they would just walk through their minds and look in those places, and there they would find what they had to remember.

Caves provide lots of nooks and crannies, and when these places are enhanced with paintings and engravings, the caves become even more potent memory palaces. Pfeiffer thinks this is probably a main purpose of the art caves.

What did they have to remember? Pfeiffer uses another analogy to hypothesize about this. When a species of animal is confined or pressured by climatic change, then knowledge about how to survive in extreme conditions becomes very important. In Europe during glacial times life was tough. The inability to survive harsh winters may have wiped out the Neanderthals. (Another theory is that the Cro-Magnons wiped them out; genocide, the past is like the present, remember.)

The Creative explosion of Pfeiffer documents and interprets is not just in art, but in technology as well. The people who painted the caves also invented almost every low-energy tool and device that we know of, including spindle whorls, bows and arrows, and hundreds of different kinds of bladed tools. They commanded their environment as human beings never had before, and they dominated it as thoroughly as is possible without farms and factories. It was only about 10,000 years ago that human beings invented agriculture and started on the road to civilization. And into the twentieth century, the Eskimos were better adapted to life as hunters and gatherers in the Arctic than any European products of the industrial revolution. To this day one could survive in the Arctic with self-contained independence only with Eskimo ways.

Pfeiffer says that there was stress on human beings to invent to survive, and also stress to remember because of the explosion of knowledge that was necessary for survival. Success often depended on cooperation among larger and larger groups (25 people being ideal for congeniality, more than that leading to more and more internal conflict), and success led to increases in population and to larger groups. Ritual art and ceremonies furthered both social cohesion and the preservation and transmission of knowledge and doctrine. This is Pfeiffer's reasonable thesis based on ethnographic analogy and great empathetic understanding of cave art and artists.

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Karsification on the Silurian Escarpment in Fayette County, Northeastern Iowa. Michael J. Bounk. Guidebook No. 40, Geological Society of Iowa, 1983, 27 p. (Available for $2.00 from the Iowa Geological Survey, 123 North Capitol Street, Iowa City, Iowa 52242)

It is gratifying to see a long-neglected and underrated karst area receive some necessary, although brief study. Over the last few years increasing attention has been focused on the karst of Northeast Iowa and Southwest Minnesota. These efforts have shown that karstification is far more extensive and significant than previously thought.

This fieldtrip guidebook is one of the more recent attempts at understanding and describing the regional geology. Most of Bounk's work is a discussion of the local geology of northeastern Iowa, specifically Fayette County. Some detail is given on the speleogenesis and hydrologic relationships among several caves. The last seven pages are devoted to a detailed 54-mile roadlog to many of the features mentioned in the text.

Dye tracing in 1981 showed the existence of an extensive karst drainage system through several strata and across surface drainage basins. Subsurface piracy has diverted a portion of the waters that once flowed to Soward's Cave now into Dutton's Cave. Directions to these caves and other karst features are given in the roadlog of the guidebook.

The concept and role of 'mechanical karst' is discussed. This process involves the gravity sliding of carbonate blocks on the underlying, incompetent shale at the edges of escarpments. The resulting crevasses produced by the sliding apparently precludes further solutional karstification by diverting water directly onto the lower, insoluble shale.

The Fayette County caves seem to be remnants of an earlier, more extensive system of post-glacial caves. The greater portion of these caves have been destroyed by valley-head erosion. An alternative possibility is offered as well, which suggests that differing lithologies are responsible for the presence of the caves.

This guidebook is specifically intended for geologists. Therefore, the terminology and concepts may be unfamiliar to those untrained in geology. The text is well documented and supported by the use of maps, geologic columns, and joint diagrams. However, a general areal key map showing the specific location of the large-scale maps would have been helpful. Two of the geologic columns need the geologic ages inserted, although the ages are obvious from the text. Some handlettering and hand-drawn symbols detract from the professionalism of several of the columns.

While this guidebook is somewhat narrow in its regional perspective, it is a brief, worthwhile introduction to the geology of a recently recognized, significant American karst region. Finally, the price should make the book attractive to the most meager of budgets.

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The Archaeology, Geology, and Paleobiology of Stanton's Cave, Grand Canyon National Park, Arizona. Robert C. Euler, ed. Grand Canyon Natural History Association Monograph No. 6, 1984. 141 pp. $11.00. Paperbound.

Caves in the Grand Canyon have been among the richest sources of evidence about the Canyon's prehistory and its changing climate and ecology. Stanton's Cave, near the Colorado River in the Marble Gorge section, is only a few hundred feet long, but is one of the most informative caves. This book is a multidisciplinary study of it and is the most ambitious work yet published on a single Grand Canyon cave. Fifteen authors are contributors.

The cave's archeology is covered by editor Euler, who presents photos and technical analysis of more than 100 ancient split-twig figurines excavated from the cave—the largest number described from any one site. These unique and enigmatic animal images were cached in a number of Southwestern caves, most of them in the Grand Canyon, about 3,000 to 4,000 years ago. Although many were found in context in Stanton's Cave, their cultural origins remain inconclusive due to lack of association with other artifacts.

Chapters by other authors cover unusually varied Pleistocene plant and animal remains and the climate/ecologic shifts they imply. Some of these are surprising—a robin species and an extinct turkey have affinities with species found in eastern Mexico.

An interesting and controversial feature of Stanton's Cave is a deposit of silt mingled with driftwood, C^{14}-dated at about 43,700 years old. This is 144 feet above present river level, raising the question of how the driftwood got into the cave. The book discusses two conflicting possibilities.

Paleoecologist Paul Martin (p. 135) speculates that the wood could have been washed in by exceptionally high Pleistocene river discharge, but also says "The greatest of the recorded pre-dam discharges, approximately 300,000 cfs at Lees Ferry, may have put the driftwood in the cave (see Hereford, this volume)." He does not clearly explain how a historic flood could account for deposits 40 millennia old. Furthermore, in citing Hereford, Martin seems to have his units confused; Hereford's chapter actually states that a flow of nearly 300,000 cubic *meters* per sec—35 times the historic record flow—would be required to overtop the cave mouth.

Richard Hereford's alternative hypothesis, more carefully supported than Martin's, proposes that the driftwood floated into the cave during ponding of the river by a massive rockfall. Hereford, of the USGS, has mapped remnants of such a rockfall at Nankoweap Creek 20 miles downcanyon.

Neither author has examined another cave, several miles downriver from Stanton's, in which I have seen a second example of high-level silt and driftwood deposits. Nor do they comment on the striking similarity of the silt in both caves to silt banks accumulated in the slack water at the head of Lake

Mead in recent decades. I consider this similarity strong evidence in favor of the cave silt and wood being left, as per Hereford, by the backwaters of rockslide damming. A superflood from upriver might have been expected to leave primarily coarser and more chaotic deposits.

The most disappointing aspect of the Stanton's Cave book is that there is scant reason for having the word "geology" in its title. There is a chapter on paleomagnetism of the silt (consistent with the driftwood radiocarbon age), but the basic geology and genetic history of the cave itself are almost totally neglected. This reflects the absence of a speleologically oriented investigator among the contributors.

The researchers did not map, and perhaps did not even visit, the uppermost chamber in the back of the cave, which was once accessible by a ladder left by a river party. I visited that room in 1965 and found a deposit very much older than any covered in the book—a remnant of consolidated siltstone that apparently had once filled the chamber, and possibly the entire cave. In a bedding plane in this I found a fossil trackway of a small animal. This was examined by William J. Breed of the Museum of Northern Arizona, and was further studied by Dr. Donald Baird of Princeton, who interpreted the tracks as made by a Paleozoic amphibian, tentatively *Batrachichnus delicatulus*. The find was published by Breed under the title "Arizona's Oldest Amphibian" (*Plateau,* 40:2, Fall 1967, pp. 68–71).

This may be the world's oldest reported fossil in cave fill, and should have been cited in a work intended as a comprehensive survey of Stanton's Cave deposits. It indicates that at least part of the cave is a re-excavated Paleozoic paleocave. Most cavities in the Grand Canyon Redwall cliffs seem to fall into this category, but no others have been reported to contain fossils from that era. I hope that future investigations of Stanton's Cave will include professional re-evaluation of these early deposits.

For purchasing information, inquire of the Visitor Center, Grand Canyon National Park, Grand Canyon, Arizona 86023.

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Groundwater as a Geomorphic Agent. R. G. LaFleur, (ed.). Boston: Allen & Unwin, Inc., 1984, 390 p., $50.00.

This book is a collection of fifteen papers which were presented at the 13th annual Binghamton Symposium on Geomorphology in the fall of 1982 at Troy, New York. Groundwater plays a role in the development of nonkarst terrains as well as karst terrains, and the first six papers of this text discuss the role of groundwater in nonkarst landscapes. These six papers discuss the role of groundwater as a soil-former (rates of formation), as a piping agent, as a controller of drainage networks, as an etching agent, and as a precipitor of duricrusts.

The remaining chapters discuss the role of groundwater in the development of karst landscapes. These chapters begin with a good introduction into a hydrologic classification of caves and karst by John Mylroie. The next paper, by Art Palmer, describes karst features which can be used to interpret the geomorphic history of an area. He then applies the theory to three areas: Bermuda, central Kentucky, and south-central Indiana. The next two papers, one by Drake and the other by White, discuss models of carbonate solution by groundwater. These two chapters illustrate different approaches to the problem. Drake suggests that the geomorphic effect of groundwater in karst terrains is dependent on temporal and spatial scales and that long-term rates of erosion are related mainly to runoff and are similar throughout the world. White on the other hand utilizes a combination of rate equations and mass transfer equations to develop models for specific landforms such as dolines, cutters, etc. Chapter 11, the next paper, by Cullen and LaFleur, investigates the theory needed to simulate carbonate aquifers through use of a computer. The authors found that finite-difference numerical methods applied to non-Darcian models were useful in modeling karst aquifers.

The remaining chapters (12–15) are case studies of specific karst areas. The areas are the eastern coast of the Yucatan Peninsula, the Cumberland Plateau, permafrost regions of Canada, and karsted plateaus (including the Helderberg, Mississippian, and Edwards). The chapter discussing the Yucatan, by Back, Hanshaw, and Van Driel, stresses the role of dissolution within the freshwater-saltwater mixing zone. Crawford, in the next chapter, believes that the role of karst in slope retreat along escarpments where limestone are overlain by less soluble rocks has been overlooked and is of utmost importance. The chapter on karst in permafrost regions, by Ford, addresses two questions. First, what is the extent of karst landforms and circulation of groundwater in permafrozen ground? Second, to what extent is karst developed beneath glaciers which will become permafrozen upon deglaciation? He concludes that karst circulation is limited to the present-day active zone and that much of the known karst has been inherited from pre-periglacial times. The last chapter in the book, by Kastning, compares and contrasts the structural settings of three carbonate plateaus, the Helderberg, the Mississippian, and the Edwards. He concludes that in these moderately deformed areas the fracturing in the rocks is related to the regional structures and is uniform and systematic.

In a society where the members complain that membership dues of $22.00 per year are excessive, I suspect that the $50.00 price tag of this book will keep many people from buying it. That is unfortunate; there is some good stuff here.

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Karst Hydrology and Physical Speleology. Alfred Bögli (translated by June C. Schmid): Berlin, New York, and Heidelberg: Springer-Verlag, 1980, 284 p.

There are few textbooks published in the English language that address the principles of physical speleology (Geomorphology and hydrogeology of karst and caves). The most notable recent volumes include *Karst* by J. N. Jennings (Australia, 1971), *Karst Landforms* by M. M. Sweeting (Great Britain, 1972), *Morphogenetics of Karst Regions* by L. Jakucs (Hungary, 1977), and *The Science of Speleology* by T. D. Ford and C. H. D. Cullingford (Great Britain, 1976). Professor Alfred Bögli's text, a translation from the German, is the most recent addition. Each book, taken alone, is an excellent synthesis of speleological science. However, it is unavoidable that the emphasis in each case is tempered by the author's personal research interests, geographic bias, and familiarity with the work and publications of his peers. Bögli's book is no exception. His expertise, as a Swiss scientist, is largely in the western European karst, particularly that of the Alps. Nonetheless, most of the text is a meticulous and comprehensive treatment of the chemical and physical processes of karstification.

As expected, Bögli devotes considerable space to the geochemistry of karst waters, including his singularly most significant and controversial contribution to speleology, *mischungskorrosion* (dissolution resulting from mixing of karst waters of differing chemical equilibria). Yet, the geochemical chapter is one of the most comprehensive of those published to date and summarizes many recent studies.

Coverage of surficial karstic landforms (e.g. pavements, dolines, karren, etc.) in Bögli's text is comparable to that in Jennings and Sweeting. Definitions and descriptions are clear and well organized.

One of the most significant contributions of Bögli's book is an extensive coverage of the physical behavior of karstic water. This includes a quantitative discourse on the hydrodynamics of flow in conduits and a comparative discussion of flow within the vadose, phreatic, and flood zones. Later chapters address the development of conduit levels, classification of karstic springs, and tracing of groundwater.

The second half of the book is devoted to physical speleology. Successive chapters discuss karstic collapse, morphology of cave passages and chambers, deposition of clastic and chemical sediments (including speleothems), cave minerals, speleogenesis, cave climates, ice caves, and the classification of caves. Selected recent advances in physical speleology are included.

Karst Hydrology and Physical Speleology is an important new text on karst and caves. It is an indispensable source for hydrologic and geomorphic studies in karstic terranes. However, the discriminating reader should be forewarned that there are disturbing omissions within the appropriate chapters. For example, some important recent contributions on speleogenesis and karst published during the last two decades are glaringly absent, including several North American benchmark papers by Arthur N. Palmer, William B. White, and others.

In summary, Bögli's text is a well-documented contribution to speleology. Because textbooks on speleology are still in a developmental stage, it is advisable that for completeness and for comparison researchers peruse all of the recently published texts. Bögli's is one of the first to successfully combine treatments of karstic groundwater and speleogenesis and as such it is a landmark contribution.

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LETTERS

Call for Reviews

Dear Readers:

As editor of the new Book Reviews Section of the *NSS Bulletin*, I am pleased to introduce myself. I am currently a geology graduate student at the University of Minnesota, with special interests and research pursuits in karst hydrogeology.

I am convinced that the addition of the Book Reviews Section to the *Bulletin* has been a valuable improvement to its format. I am sure this change is welcomed by all segments of the *Bulletin's* audience.

In keeping with the high standards that the *Bulletin* has maintained in the past, the Book Review Section will be devoted to reviews of books, monographs, and other significant documents of caves and karst research. As envisioned, it will be a regular reminder to the scientific community of the important contributions to speleology that have appeared in the recent past. My hope is that it will also serve the needs of the 'sport' caver who may have a more limited scientific background. For that person, the Book Review Section may help to expand one's interests in karst research through introduction to the cave and karst systems being investigated, the questions being asked, and the techniques being employed to answer those questions. Meeting the needs of both the scientific and the 'sport caving' audiences is a primary goal of the Book Review column. Any comments as to how well this goal is being achieved will be most welcome.

Of course, to maintain a steady input of review articles, reviews must be written. As Book Review Editor, I will maintain lists of books to be reviewed and persons interested in writing reviews. Occasionally I may also write a review, but I promise to not monopolize the reviewing process. If the editor were to write all of the reviews, the job would become overwhelming, and no doubt the audience would quickly tire of a single viewpoint. Therefore, I am asking for volunteers to write book reviews for this column in future issues. Suggestions for titles to be reviewed are also most welcome. Please contact me before you begin, however. For maximum efficiency, I think it is important that our efforts be coordinated so that we know what is being pursued and by whom.

I believe that a Book Review Section is a valuable addition to the *NSS Bulletin*. I hope the *Bulletin* readers are anticipating the forthcoming book reviews as eagerly as I am.

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Discontent with Abstracts

Dear Editor:

I am sending this letter to you rather than to one of the *Bulletin's* Board of Editors because the remarks contained herein are not directed to the editor of a particular field or type of paper, but are offered as a suggestion that might improve the Bulletin somewhat if passed on to all would-be contributors. The subject is abstracts and how to write one.

I enclose a photocopy of an abstract from Vol. 46 No. 1. I read the title of the paper "A Long-Nosed Peccary (*Mylohyus Nasutus*) From Knob Rock Cave, Indiana" and was mildly intrigued, having found some peccary bones in caves myself. But time did not permit or I was not sufficiently intrigued to read the entire article. So I read the abstract in order to learn the main points of the paper without having to wade through it. So what did I find in the abstract? Nothing! It reads like a menu or perhaps a concert program, telling me what I *will* learn *if* I read the paper. This is an absolutely worthless abstract, and altogether too commonly just what people write thinking they have written an abstract.

I would like to suggest that all contributors to the *Bulletin* be advised of the purpose of an abstract: to inform the reader who is short on time just what the main points and conclusions of the paper are; to allow the convention-goer who is faced with having to choose between two talks given at the same time a basis for determining which of the two is more important to him; to provide the convention-goer with the basics of the talk he had to miss; in short to inform , not to tease.

Perhaps all contributors to the *Bulletin* should be given a copy of Ken Landes' excellent little one-page article on how to write an abstract (Ed.—Landes, Kenneth K. "A scrutiny of the abstract; Bulletin of the American Association of Petroleum Geologists, Vol. 50 [1966], p. 1992.) See copy enclosed—his example of how *not* to write an abstract is just precisely what the author of the peccary abstract did.

Thank you for your consideration of this matter; if all authors can be made aware of the purpose of an abstract I am certain the *Bulletin* will be enhanced.

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REFERENCES

Landes, Kenneth K. (1966)—A scrutiny of the abstract: Am. Assoc. Petroleum Geologists Bull. 50:1992.

CAVE AND KARST ABSTRACTS

Biology

Morphometrics and evolution of *Speodesmus* in Central Texas caves (Diplopoda, Polydesmida), Elliott, William R., Ph.D., Texas Tech University, 1976. 155 pp.

Millipeds of the genus *Speodesmus* inhabit caves in Texas, New Mexico, and Tamaulipas, Mexico. Morphometric variation was studied in populations from 89 caves in Central Texas. Aspects of the study included geographic variation, divergence, temporal variation, and secondary sexual dimorphism.

Central Texas *Speodesmus* species are arranged in the *bicornourus* and *echinourus* species groups. The former contains four species, three of which are undescribed; the latter contains two species, one of which is undescribed. Morphometric data for each species group were ordinated by principal component analysis, from which groups were selected for further study with canonical variate analysis. The groups of the *bicornourus* species group are phenetically more divergent than those of the *echinourus* species group.

Although the full ranges of the two species groups are similar, the *bicornourus* species group is more concentrated in the presumably older caves of the Balcones Escarpment. The *echinourus* forms also inhabit some of the escarpment caves, but they inhabit younger caves as well and they occur in more caves. Canonical variate analyses were made of geologic and physiographic variables associated with the caves inhabited by each species group, both species groups, and *S. bicornourus*. The major difference in the distributions of the two species groups is the absence of *echinourus* forms from the northern Balcones Escarpment. It is hypothesized that the *echinourus* forms are latecomers to Central Texas, relative to the *bicornourus* species group, and that they invaded Texas from the south. Dissection of cavernous outcrops, or competition with *S. bicornourus* may have excluded the *echinourus* species group from the northern escarpment caves. It is hypothesized that the distribution of the various forms of *S. bicornourus* is the result of geologic isolation. The smaller forms are found on the periphery of the species' ranger. Since the time of geologic dissection of this range, large body size and loss of one secondary sexual character have originated in the central populations.

Analysis of variance of samples of several populations separated by a decade's time revealed some significant changes in body size. Because of small sample sizes, great confidence should not be placed in these results.

Secondary sexual dimorphism was studied with analysis of variance and canonical variate analysis. Sex dimorphism is similar in the two species groups, but the *echinourus* species group is more homogeneous in its dimorphism. This is another indication that the latter has not been isolated in caves as long as the *bicornourus* species group.

Ecomorphological Analysis of an Assemblage of Bats: Resource Partitioning and Competition
Freeman, Gerald Eugene, Ph.D.
University of Colorado at Boulder, 1984. 141 pp.

The importance of competition in the organization of assemblages of organisms is undergoing vigorous debate. Knowledge obtained from this debate has become increasingly important to ecologists and conservation biologists for the management of assemblages of organisms and design of nature reserves.

Multivariate analyses of morphological and ecological data were used to define niches of 11 species of bats from an assemblage in northwestern Colorado. Null models tested the hypothesis of random (non-competitive) co-occurrence of species. The niche variation model, which suggests that species on the borders of assemblage niche space should be more variable due to competitive release, was examined. The assumption that morphological characteristics can predict ecological interactions was tested.

Morphological data (22 characters) were analyzed by principal component analysis to define niches. Three components explained 84% of the variance and indicated "size," "foraging style-food capture," and "food hardness" as niche dimensions. Factor scores from these components were used to calculate Euclidean distances between species. The distribution of Euclidean distances among the 11 species was compared to 25 randomized distributions based on randomized factor scores; no significant differences were found. The randomization analysis was repeated using seven closely-clustered species. Significant differences from random were noted in 18 of 25 cases. No overdispersion of niches was found as the mean Euclidean distance between seven species in the actual assemblage was smaller than the mean Euclidean distance from the 18 randomized assemblages. Pairwise niche divergences were suggested between some pairs of non-congeners. However, the patterns of divergence were interpreted as due to differences in phylogeny. No significant correlation ($r_s = -0.2578$, $n = 11$, $p = 0.22$) was found between mean intraspecific Euclidean distances of a species and the mean distance of that species from other species in the assemblage.

Principal component analysis of food habit and foraging data defined food hardness and foraging style as important niche dimensions. Null models using ecological data (food habits) disclosed no evidence for assemblage-wide or pair-

wise competition for food resources. The distributions of Euclidean distances from assemblages with randomized food resource matrices were not significantly different from the distribution of Euclidean distances from the actual assemblage. No significant correlation was found (r_s = −0.3470, n = 11, p = 0.15) between species' nearest neighbor distance in food space and its dietary diversity . . . (Author's abstract exceeds stipulated maximum length. Discontinued here with permission of author.) UMI

Reproductive Ecology of *Agave Deserti* Engelm (Agavaceae) in the Absence of Coevolved Bat Pollinators

Fulton, Robert Edward, M. A., California State University, Fullerton, 1984. 122 pp.

Agave deserti Engelm (Agavaceae) is one of several species in the genus showing floral characteristics consistent with the syndrome of bat pollination (chiropterophily). Three populations of *A. deserti* were studied, one outside the range of pollinating bats in California, and two within the range of the nectar/pollen feeding bat *Choeronycetris mexicana,* in Mexico. Predictions are given concerning selection for floral characteristics conducive to pollination by insect visitors to the plants, in the absence of bats. Pollinating bats were not predictable at any of the sites, consistent with mounting evidence of declining activity of these bats in northern ranges. Insect visitors were not observed to be important pollinators of the chiropterophilous flowers at two sites, and therefore did not act as selective forces. The third population (subspecies *pringlei*) showed some selection for pollination by carpenter bees (*Xylocopa* sp.). Asexual reproduction in *Agave* is discussed as a "safety mechanism" ensuring survival.

Patterns of Feeding and Habitat Use By Little Brown Bats, *Myotis Lucifugus* (Chiroptera: Vespertilionidae), Over and Around Lake Opinicon, Ontario Canada

Harrison, Thomas Michael, M.SC., Carleton University (Canada), 1983

Bat activity and feeding were monitored under a range of meteorological conditions. Bat dispersal was studied using chemi-luminescent light tags. Insects and faeces were collected to analyze diet.

Bats were most active along shorelines and least inland. They fed mostly near the surface of the lake, showing wide variation in feeding bout times. Activity and feeding increased from mid-July to mid-August.

Bats dispersed to and then followed the nearest shoreline for at least 3.5 km from each colony. Feeding grounds of both colonies widely overlapped when the young were volant.

Bats shifted from eating largely dipterans in May to trichopterans in August. Insect activity and bat feeding declined below 12°C, during strong winds, and during increased moonlight.

Evidence is shown for reduction of intraspecific competition by expansion of feeding ranges into regions of overlap. Displacement of individual bats from home ranges could account for the geographic range of *Myotis lucifugus.*

Behavioral Basis of Foraging Flexibility in Three Species of Insectivorous Bats; an Experimental Study Using Captive *Antrozous pallidus, Eptesicus fuscus* and *Myotis lucifugus*

Gaudet, Connie Lee, M.SC. Carleton University(Canada) 1983

Captive *Antrozous pallidus, Eptesicus fuscus* and *Myotis lucifugus* all express a range of behavioral abilities that could enable them to cope with a patchy and unpredictable food resource. All species exhibit some degree of sensory modality in "prey" detection. Low-frequency sounds indicative of prey are used by each species to locate targets. All species use echolocation to locate small moving discs and *Antrozous pallidus* and to a lesser extent *E. fuscus* will rely on vision to locate these discs under certain conditions. Only *A. pallidus* will abandon echolocation and use vision when light permits. All species use memory to locate food sites and will remember some sites for long periods of time as well as incorporating new sites readily. The ability to learn a novel foraging behavior through observation of an experienced bat is expressed in each species. As well, *A. pallidus* and *E. fuscus* significantly reduce search time when locating a food patch in a group as opposed to individually. *Eptesicus fuscus* will reduce activity in response to food limitations dependent on weight of the bat and food availability.

The Effects of Urbanization on Habitat Use by the Big Brown Bat, *Eptesicus fuscus*

Geggie, Judith Frances, M.SC. Carleton University (Canada) 1983

Habitat use by populations of the Big Brown Bat, *Eptesicus fuscus*, was compared in urban and rural areas using ultrasonic sensors. Field work was conducted in eastern Ontario and western Quebec in the summer of 1981. Rural *E. fuscus* foraging activity was concentrated in residential zones, with high activity also occurring over water. Activity was low over rural parkland and farmland. Urban habitats did not show significant differences in levels of *E. fuscus* foraging activity, although the overall foraging rate was lower in the urban environment than in the rural.

The movements of individual Big Browns were monitored

using radio telemetry. Tagged *E. fuscus* from both urban and rural environments used more than one diurnal roost; the possible adaptive value of roost switching for *E. fuscus* is discussed.

The consequences of urbanization for an insectivorous temperate-zone bat species are considered, with emphasis on differential prey availability and roost availability in urban and rural areas.

Geology and Geography

Types of Karst, With Emphasis on Cover Beds in Their Classification and Development

James Francis Quinlan, Jr., Ph.D.
The University of Texas at Austin, 1978

Karst can be usefully classified according to eight major attributes: cover, rock type, climate, geologic structure, physiography, hydrology, modifications during or after karstification, and dominant landforms. Each or several of eight subclassifications based on these attributes will accurately describe any karst terrain and its subsurface. Karst may develop in almost any type of rock but is most common in carbonate, sulfate, and halide rock and sediment that contains these minerals.

The most important attribute of a karst is the presence or absence of covering rock or sediment. Cover, or lack of it, influences almost all aspects of karst development: landforms prsent, rate of development, hydrology, and the formation and preservation of sedimentary deposits, some of which may be mineralized, others of which may uniquely preserve beds and fossils that can be used to interpret the age and development of ancient landscapes.

Although the major emphasis of the text is on the description and interpretation of karst landscapes rather than the types of karst landforms, it shows that six types of karst features—soil karren, geological organs, pocket deposits, near-surface rock-subsidence features, structural sinks, and vertical shafts—are end-members of a continuum of genetically related point-solution-subsidence features. There are numerous names for these common features in many countries and languages.

Interstratal karst, a type of karst that is covered by and developed beneath *pre-karst* rock or sediment, may or may not be part of the contemporary landscape. It is *younger* than its cover. It is formed by the solution of rock in the subsurface, most commonly beneath relatively insoluble rock such as sandstone and chert. The term refers to areal solution rather than to cave development. Interstratal karst is present in almost all karst areas but generally is not recognized or discussed in regional geologic literature. It is especially common in terrains underlain by salt and gypsum.

Many interstratal karsts are characterized by the occurrence of breccia pipes. The pipes may form in response to collapse into a cavity in evaporite or carbonate rock, and they may propagate upward by stopping toward the surface, as much as 1,500 m above. They occur in more than 50 areas in North America and Europe.

The hydration of anhydrite to gypsum takes place in the subsurface or at outcrop. A synthesis of chemical, thermodynamic, and petrographic literature shows that hydration is favored by low temperature and low salinity and that reaction kinetics are more important than relative solubilities. Expansion of anhydrite is limited by confining pressure; it occurs more readily at shallow depths. Gypsum may be emplaced by three types of deposition: weathering-front migration (analogous to uranium roll-front development), supergene enrichment (analogous to caliche development), and vein growth. Water movement during hydration is intergranular and very slow.

Geomorphic Analysis of Groundwater Outflow from Mountainous Watersheds Order No. DA8415331

Zecharias, Yemane Berhan, Ph.D.,
Cornell University, 1984. 291 pp.

The recession of groundwater outflow from unconfined aquifers and its relationship to basin-morphology are analyzed for 19 basins located in the Appalachian Plateaus. A method of determining the characteristic slope of a basin is developed based on a consideration of basin-geometry and fundamental geomorphic principles. The new method gave results that are in close agreement with those obtained from Soil Survey reports.

A principal component analysis (PCA) of 12 measured and derived morphologic parameters, and correlation tests of parameter-pairs show that drainage density, average basin-slope, and elongation ratio are the most important distinguishing geomorphic characteristics of the basins. In addition, the results of the PCA indicate that basins located in a section of a geomorphic province exhibit overall hydrogeomorphic similarities although each possesses an assemblage of morphologic attributes that makes it distinct from the others. Therefore, in as much as groundwater outflow is largely controlled by the geology and geomorphology of a basin, climatic and vegatational factors may be assumed uniform in baseflow studies of such areas.

A quasi-steady state approach is adopted to derive a groundwater outflow model that takes aquifer slope into account. Model-based analysis of long-term streamflow records of the basins gave average basin reaction-factors that are strongly correlated with basin slope values. Depending on their inclination, different parts of the same aquifer have different reaction-factors. As a result, the overall reaction-factor of a basin is time dependent, and a single value of the parameter is meaningful only in the sense of a time-average value for a recession period.

The spatial and temporal variations of the reaction factor

impart a dynamic behavior to the process of groundwater outflow. Both variations are the result of the magnitude and the non-uniform distribution of slope in a basin. The model and the results of the statistical analyses show that baseflow recession characteristics are strongly controlled by average basin-slope and drainage density.

WATER QUALITY IN THE FORESTVILLE CREEK KARST BASIN OF SOUTHEASTERN MINNESOTA

GROW, SHEILA R., M.S., *University of Minnesota,* 1985. 220pp.

This study documented the water chemistry of a karst basin in southeastern Minnesota from May 1983 to May 1984. The study site was in Fillmore County. Weekly samples were collected from two sinking streams, an unnamed stream in Fairview Blind Valley and the South Branch of the Root River, and two resurgent springs, Moth and Grabau. Moth and Grabau Springs head Forestville Creek. Water from the South Branch of the Root River sinks and resurges at Moth and Grabau Springs, flows down Forestville Creek, and the rejoins the Root River 3 km downstream from the Springs.

The most important indicator of change in the water chemistry was the level of discharge of Forestville Creek. Large fluctuations in discharge and complex reactions between the measured parameters occurred between sampling periods. Changes in the water chemistry due to seasonal effects were much more subtle. High discharge associated with a storm event in late June and early July increased nitrates, chlorides, sulfates, and atrazine concentrations. However, following a storm event in August the nitrate concentrations were diluted and the atrazine concentrations were less than one-third of the concentrations recorded in July. High discharge associated with spring melt diluted all the measured parameters except atrazine.

Nitrate concentrations, as well as the concentrations of the other measured parameters, decreased during the study period. Two possible explanations for this decrease in nitrates include: a) long term precipitation or climatic patterns and b) the implementation of the payment-in-kind (PIK) program. The study area received 25% more precipitation than normal during the study period and the PIK program reduced the amount of cultivated land in the watershed by 30%. The decrease in nitrate concentrations may be related to any combination of these factors or to some other yet unknown cause.

Mass transport budgets were calculated for nitrate-nitrogen, atrazine, calcium, and magnesium concentrations. The amount of nitrate-nitrogen removed from the Forestville karst basin through Moth and Grabau Springs was equivalent to a minimum of 46 lbs. per cultivated acre in 1983 or to a maximum of 67 lbs. per cultivated acre in 1983. The atrazine removed through Moth and Grabau Springs was equivalent to a minimum of 0.12% or a maximum of 0.18% of the atrazine applied to the Forestville karst basin. Assuming all the magnesium and calcium were derived from dissolution of bedrock within the study area, and environmental conditions remained the same as during the study period, the minimum was 5.4cm/1000 yrs. Obviously, the surficial lowering rate would not be uniform but would be concentrated along solution-enlarged passages such as sinkholes.

SYNTHESIS AND TRANSPORT STUDIES OF THE INTRASYNCYTIAL LAMINA, AN UNUSUAL PLACENTAL BASEMENT MEMBRANE OF THE LITTLE BROWN BAT *MYOTIS LUCIFUGUS*

CUKIERSKI, MARK ALAN, PH.D. *Cornell University,* 1985. 234pp.

The chorioallantoic placenta of *Myotis lucifugus* undergoes a transition from endothelialchorial to hemochorial. The original maternal endothelial basement membrane is incorporated into the apical portion of the syncytiotrophoblast where it persists until term. This intrasyncytial lamina is separated from the maternal blood by thin ectoplasmic projections of the syncytiotrophoblast which project through the lamina and spread over the surface completely engulfing it. While there appear to be direct channels, at junctions of the ectoplasmic processes, from the maternal blood to the intrasyncytial lamina, perfusion studies using the electron dense tracers alcian blue, ruthenium red and Thorotrast show that these channels were physiologically closed. In contrast lanthanum nitrate was able to gain access to the lamina via extracellular channels. The endocytic uptake of the tracers was similar. These studies suggest several pathways for substances to cross the ectoplasmic zone and the intrasyncytial lamina. Substances may gain direct access to the lamina via extracellular channels, reach the lamina by vesicular transport or bypass the lamina completely.

Further tracer studies with different molecular weight heme proteins and 3-3' diaminobenzidine (DAB) cytochemistry to detect uptake showed no evidence of endocytic uptake although positive DAB reactions were found in trophoblast lysosomes of both heme injected and control animals. The morphology and distribution of lysosomes was confirmed by demonstration of acid phosphatase activity. X-ray mapping and microanalysis showed heavy concentrations of iron with lysosomes. This along with the uptake of exogenous ferritin suggests that the chorioallantoic placenta of *Myotis* is active in iron transport and that iron passes through the lysosomal compartment. It is probable that endogenous heme or other iron compounds react with DAB peroxidase techniques.

Autoradiographic studies show that the syncytialtrophoblast synthesizes portions of the intrasyncytial lamina demonstrating its partial fetal origin. How long the original material components persist is unknown.

NATURAL IODINE-129 AS A GROUND-WATER TRACER

FABRYKA-MARTIN, JUNE TAYLOR, M.S. *The University of Arizona,* 1984. 163pp. Director: S. N. Davis

Iodine-129 ($t_{½}$, 16 My) is a naturally-occurring tracer which can be used to study hydrologic and geologic processes on time scales up to 100 My. Global modelling suggests that the pre-bomb atmospheric ratio $^{129}I/I$ should have been constant in time and space. This ratio is the starting value in ground-water recharge, and subsequent ratio changes are determined by isotope contributions from three sources: recharge water, iodine leached from the formation, and *in situ* uranium fission.

This expected behavior is compared to field study results. Ground-water samples from the Great Artesian Basin, Australia, provide an estimate of the atmospheric equilibrium ratio, 6×10^{-13}. Down-gradient changes in water up to 1 My old suggest that subsurface production can be significant. The usefulness of ^{129}I as an indicator of brine source and age is verified in brines collected in and around Louisiana salt domes. The method leads to ages of 7 and 9 My for two brine pockets trapped within Jurassic salt, and 32 to greater than 40 My for oil-field brines in Miocene sands adjacent to the domes.

Webb, John A. and Finlayson, Brian L. (1984)—Allophane flowstone from Newton Cave, western Washington State: *NSS Bulletin* 47: 45-48.

ALLOPHANE FLOWSTONE FROM NEWTON CAVE, WESTERN WASHINGTON STATE

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Yellow-orange flowstone collected from a marble cave in a small area of alpine karst is composed of allophane, an amorphous aluminosilicate clay mineral. This deposit of allophane is notable in that it has a very low molar Si/Al ration (0.06), and its infra-red absorption spectrum almost completely lacks peaks in the 350-500 cm^{-1} region. This is the first reported occurrence of allophane speleothems in limestone caves. The allophane is probably forming as a result of weathering of plagioclase and amphibole minerals in the hornfels layers within the marble sequence in which the cave has formed.

INTRODUCTION

Allophane is a naturally occurring amorphous clay mineral composed of silica, alumina and water in varying proportions. It commonly occurs as a major constituent of soils on volcanic ash, and is also widely distributed in podzols developed on a variety of parent materials (Wada, 1980; Young et al., 1980; Farmer, 1984). Allophane in soils is intimately mixed with the other soil components, and can only be effectively extracted in solution, preferably using acid oxalate (Farmer, 1985). Naturally-occurring pure allophane precipitates, e.g., spring deposits and speleothems, are much easier to study, but have been used relatively little in allophane investigations because of their rarity. Only a few such occurrences are known: spring deposits on the side of an andesitic volcano in New Zealand (Wells et al., 1977), flowstone on the limestone walls and roof of a mine in Derbyshire, England (Wilkinson, 1950), flowstone in a granite cave in southeast Queensland, Australia (Webb and Finlayson, 1984), and stalactites in a basalt cave in western Victoria, Australia (Finlayson and Webb, 1985). The recognition of new occurrences of allophane is thus of considerable interest.

When discussing the apparent rarity of allophane speleothems, Webb and Finlayson (1984) noted that in the literature there are descriptions of speleothems which might be allophane, although not identified as such. Halliday (1963, 1966) described a pasty red-orange flowstone from several caves on Cave Ridge, Washington State, and identified it as "cimolite," a hydrous aluminium silicate. However, cimolite is an invalid mineral name because the type material was shown to be a mixture of montmorillonite and alunite (Caillere and Henin, 1963). Webb and Finlayson (1984) speculated that the Cave Ridge flowstone was in fact allophane, and Dr. William Halliday kindly made available to the authors a small sample of yellow-orange flowstone from Newton Cave on Cave Ridge, in order for it to be analysed and identified.

REGIONAL SETTING

Cave Ridge is a small area of karst topography located immediately south of Mt. Snoqualmie, in western Washington State, approximately 40 miles east-southeast of Seattle. The ridge lies at an elevation of 4,750-5,200 feet, and contains many sinkholes and at least eight caves (Halliday, 1963). The area is irregularly covered by alpine forest, and shows many effects of Pleistocene glaciation, including hanging valleys and glacial striae.

The caves were formed within the Denny Formation, which consists of interbedded marble and hornfels of probable Palaeozoic age (Foster, 1960). This unit has been deformed and metamorphosed by the intrusion of the nearby Snoqualmie granodiorite and the average dip is about 30° north-northwest (Halliday, 1963). The caves have in general formed along the dip or strike, and tend to be narrow and contain large amounts of unstable breakdown derived from the hornfels interbeds.

Newton Cave is the longest in the area, with about 500 feet of explored passage and an estimated depth of 180 feet (Halliday, 1963). The cave is a complex of narrow passageways and small, mostly elongate chambers. The walls show

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abundant outcrops of noncalcareous material (hornfels) contained within the marble. Red or red-orange flowstone covers the walls in places, and other speleothems are restricted to rare small stalactites and coralloidal nodules.

Red yellow and brown terraced flowstone is present in at least three more caves on Cave Ridge; other speleothems are small and rare (Halliday, 1963).

Sample Identification and Analysis

The Newton Cave flowstone gave a strong positive result using the Fieldes and Perrott (1966) test for allophane. This test is based on the principle that aqueous solutions of fluorides at pH greater than 7 react at the hydroxy-alumina sites, release hydroxyl ions and cause a rise in pH with simultaneous formation of fluoaluminate. A small quantity (10mg) of sample is placed on dry filter paper (previously soaked with phenolphthalein indicator), and wetted with a drop of saturated NaF solution. If appreciable allophane is present, the filter paper will turn red. Although this test has been shown not to be specific for allophane in soils (Brydon and Day, 1970), the other materials for which it gives positive results are unlikely to occur as speleothems (Finlayson and Webb, 1985).

The flowstone is amorphous, as its X-ray diffraction pattern lacks well-defined peaks, although there is a very broad band between 3.4 and 3.9 A.

An X-ray fluorescence (XRF) analysis of the sample (Table 1) shows that it is composed largely of Al and Si, with a Si/Al ration of 0.06. There is also a minor Fe component and a very high loss on ignition, due to both water and CO_2.

The infra-red (IR) absorption spectrum shows a number of broad peaks (Fig. 1). The very strong peak at about 3400 cm^{-1} represents the O-H stretching vibrations of SiOH, AlOH and water (Moenke, 1974; Ryskin, 1974), and the strong 1620 cm^{-1} peak is due to the bending vibrations of unbonded pore water (Moenke, 1974).

The 1400 cm^{-1} peak may indicate the presence of organic carbon. A number of organic molecules (e.g., CH_2, CH_3) have absorption peaks in this region (Silverstein et al., 1981), and a previously described allophane with a strong 1400 cm^{-1} peak contained 6.5% organic carbon (Webb and Finlayson, 1984). The 1400 cm^{-1}peak could also represent carbonate, as the carbonate ion has a strong absorption band at about this wavenumber. However, carbonate has another strong peak at 800-880 cm^{-1} (Gadsden, 1975), and this is lacking in the present spectrum (Fig. 1). Furthermore, the allophane described in Webb and Finlayson (1984) contained only 0.5% carbonate but had a strong 1400 cm^{-1} peak. The uncertainty regarding this peak could be resolved by a carbonate/organic carbon determination on the Newton Cave allophane, but unfortunately the sample available was too small to allow this.

The broad peaks at about 970 cm^{-1} and 560 cm^{-1} are diagnostic of allophane (e.g., see Wada, 1980; Farmer et al., 1979; Parfitt et al., 1980). The absence of absorption at 800 cm^{-1} indicates that the silica in the sample is not a discrete phase, so the flowstone is a true aluminosilicate and not just a mixture of amorphous silica and amorphous alumina.

The 970 cm^{-1} peak is caused by Si-O stretching vibrations. Silicates in which the silica tetrahedra are linked into chains, sheets, or three-dimensional frameworks have a very strong Si-O stretching peak that varies in position between 1100 and 1000 cm^{-1}, decreasing in wavenumber as the percentage of tetrahedral Al in the mineral increases (Milkey, 1960). Silicates composed of independent silica tetrahedra (i.e. nesosilicates) have the Si-O stretching peak at 900-970 cm^{-1} (Parfitt and Henmi, 1980); the clay mineral imogolite, which also has independent silica tetrahedra, has a Si-O stretching peak at 940-950 cm^{-1} (Parfitt and Henmi, 1980). Thus in the Newton Cave allophane the silica tetrahedra are independent of each other, as might be expected from the very low Si/Al ratio of this sample (Table 1).

Table 1. XRF analysis (in wt.%) of allophane flowstone from Newton Cave (LOI = loss on ignition). Detection limits for all elements (including TiO_2 are 0.01% or less.

SiO_2	2.48
TiO_2	0.00
Al_2O_3	36.59
Fe_2O_3	0.36
MnO	0.11
MgO	0.09
CaO	0.10
Na_2O	0.10
K_2O	0.01
P_2O_5	0.08
SO_3	0.29
LOI	59.07
total	99.28
Si/Al (molar)	0.06

The very broad peak at around 560 cm^{-1} can be assigned to vibrations of octahedrally coordinated Al in gibbsite sheets (Farmer, 1985). Gibbsite has a strong absorption peak at 540-560 cm^{-1} (Gadsden, 1975), and phyllosilicates with gibbsite layers in their structures (e.g., imogolite, kaolinite, muscovite) have strong peaks between 540 and 600 cm^{-1} (Stubican and Roy, 1961; Wada, 1980). Synthetic alumina gels prepared by Farmer et al. (1979) are characterised by well developed peaks at about 550 cm^{-1}. The octahedral Al peak in the IR spectrum of the Newton Cave allophane is stronger than the 970 cm^{-1} Si peak, as expected from the very low Si/Al ratio of the sample.

Since natural allophane deposited by a spring in New Zealand was shown to contain both tetrahedral and octahedral Al (Farmer, 1985), it is possible that the present sample may also contain some tetrahedrally coordinated Al. However, octahedral Al is believed to be predominant in the New Zealand allophane, and this is likely to be the case for

the Newton Cave sample also.

All allophane IR spectra that have been previously published show a series of peaks between 350 and 500 cm^{-1}, with the most commonly occurring peaks being at 430-460 and about 350 cm^{-1} (Farmer et al., 1979; Parfitt et al., 1980; Wada, 1982). Of these, the Newton Cave allophane lacks the former and has only a very weak shoulder at about 340 cm^{-1} (Fig. 1). The 430-460 cm^{-1} peak may represent Si-O bending vibrations (Parfitt and Henmi, 1980). In pure silica the Si-O bending peak is at 460-470 cm^{-1} (Moenke, 1974), but the position of this peak is altered by the presence of octahedral cations (Farmer, 1974). In a series of synthetic allophanes prepared by Farmer et al. (1979), the intensity of this peak decreased as the percentage of silica in the samples decreased, until it was absent altogether in a pure aluminous gel. Thus the lack of this peak in the IR spectrum of the Newton Cave sample can be attributed to its very low silica content.

The allophane peak at about 350 cm^{-1} (specified as 348 cm^{-1} in many references) has been used extensively to recognise imogolite structures in allophanic clays (e.g., Farmer et al., 1977). The weakness of this peak in the present sample indicates that little, if any, imogolite structure is present.

Both Wada (1982) and Farmer (1985) have subdivided allophane into different types, and the present sample can be classified in either system. The Newton Cave allophane belongs to the "allophane-like constituents" of Wada's twofold classification, on the basis of its peak at 970 cm^{-1} (rather than approx. 1000 cm^{-1}) and its low Si/Al ratio. The sample largely dissolved in hot 5% Na_2CO_3, a diagnostic test used by Wada (1980) to identify allophane-like constituents. However, Farmer (1985) has questioned the use of solubility tests to distinguish types of allophane.

Within Farmer's (1985) threefold classification, the Newton Cave allophane is closest to his proto-imogolite group, based on the presence of the 970 cm^{-1} peak and the low Si/Al ratio. However, Farmer et al. (1979) regarded the 348 cm^{-1} peak as characteristic of proto-imogolite, and this peak is very weak in the Newton Cave sample. Nevertheless the present sample is best assigned to proto-imogolite, and this peak is very weak in the Newton Cave sample. Nevertheless the present sample is best assigned to proto-imogolite, as it is not sufficiently different to warrant creation of a new group.

It is not the intention of this study to compare the two classifications, or to indicate if one is more suitable than the other. However, it should be noted that Wada's allophane-like constituents appear to be approximately equivalent to Farmer's proto-imogolite.

Formation of Allophane Speleothems

Allophane spring deposits and speleothems are rare, and the processes involved in their formation are not well documented. Wells et al. (1977) found that allophane precipitation from a surface spring was influenced strongly by the rise in pH consequent on loss of excess CO_2 from the spring water. Similar processes are likely to be operative in caves (Finlayson and Webb, 1985).

Soil allophane is derived from the alteration of aluminosilicates (primary or secondary) or volcanic glass (Wada, 1977; Butt, 1983), and a similar source is likely for the allophane in spring precipitates and speleothems. In every instance where these deposits have been reported, aluminosilicate minerals occur nearby, in a variety of lithologies: basalt (Finlayson and Webb, 1985), andesite (Wells et al., 1977),

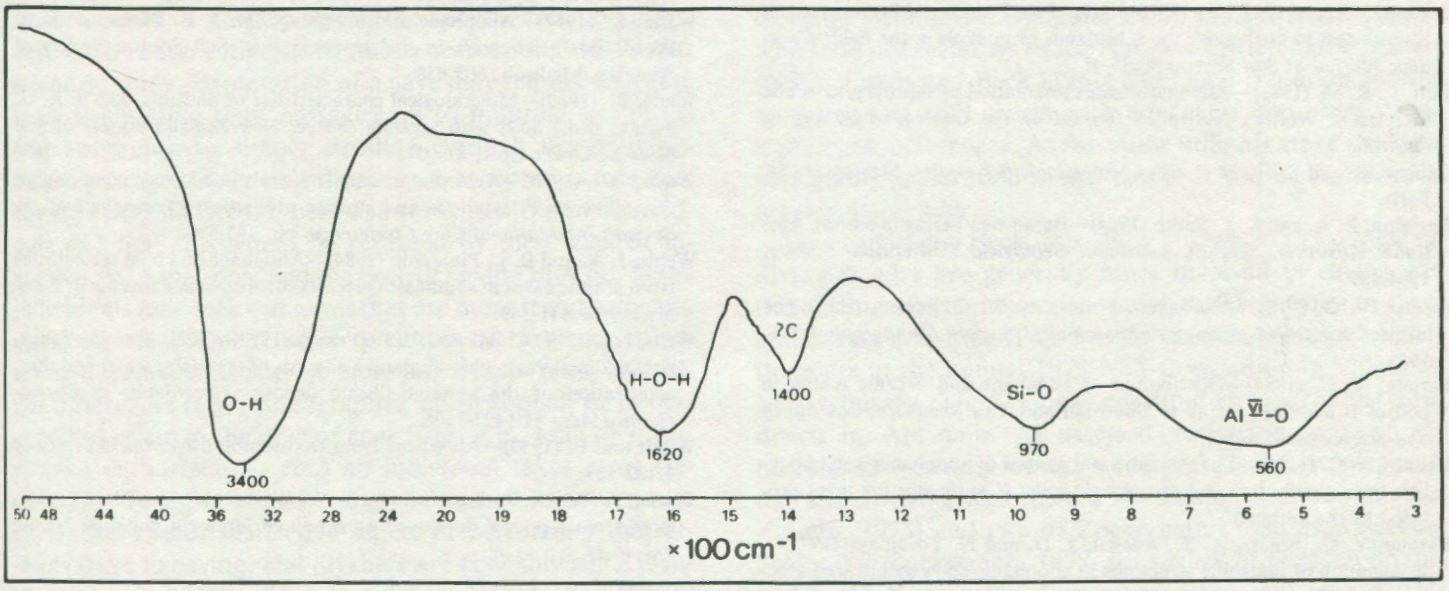

Figure 1. **IR absorption spectrum of allophane flowstone from Newton Cave, showing bond assignments for absorption bands.**

granite (Webb and Finlayson, 1984) and shale (Wilkinson, 1950). In the case of Newton Cave, aluminosilicate minerals (andesine, diopside, epidote and hornblende) are present in the hornfels layers within the marble sequence in which the cave has formed (Foster, 1960). Allophane has been recognized as the earliest weathering stage of amphiboles and plagioclase (Snetsinger, 1967; Eggleton and Smith, 1984; Banfield and Eggleton, 1984), so weathering of these minerals in the hornfels probably provided the sol from which the allophane flowstone has formed.

Newton Cave allophane represents the first occurrence of this mineral in limestone caves proper, although allophane flowstone has been recorded previously in a mine in limestone (Wilkinson, 1950). Allophane speleothems in limestone caves may have been misidentified or overlooked until now, but they are unlikely to be common, as suitable nearby occurrences of aluminosilicate minerals are not often present.

Acknowledgments

Thanks are due to Mark Sherman (Cascade Grotto, NSS) who collected the flowstone sample from Newton Cave, and to Dr. William Halliday who sent it to the authors. Maunu Haukka and Phil Hannaker of the Geology Department, Melbourne University and Max Beyer, Chemistry Department, Melbourne University, helped with the analyses of the sample.

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CAVING PRACTICES, INVOLVEMENT IN CAVING, AND PERSONALITY IN NSS CAVERS: A SURVEY STUDY

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In a survey conducted at the 1979 NSS convention, 275 cavers responded to questions concerning their caving activities, motivations for caving, and level of involvement in the sport. Four personality measures were administered with the survey, including an activity temperament, sociability temperament, thrill & adventure seeking (TAS), and experience seeking (ES). The average respondent had four years of college education, was typically involved in the sciences, had been caving about 11 years, and had been on 100–200 trips in that time. Women comprised 30% of the sample and as a group reported less involvement in caving and cave-related activities. They were more likely motivated to cave for the "beauty of the cave environment," whereas men were more motivated by "exploring the unknown."

Compared to a non-caving, age-matched group, NSS cavers scored significantly higher on ES but not on TAS, suggesting that they are attracted to caving more for the varied experiences it may provide rather than its 'thrill' aspect. Personality differences among cavers were also related to their caving activities. For example, sensation-seeking tendencies were associated with 'sport' rather than 'survey' caving. High TAS scorers reported visiting a high proportion of different caves as opposed to repeat visits to the same caves, whereas high ES scorers favored 'sport' and 'vertical' trips. Those scoring high on the measure of activity temperament rated caving as relatively more important in their lives than did those who scored lower on activity temperament.

INTRODUCTION

Cave exploring offers a diverse appeal to the relatively small number of participants in the sport. Motivations for cave exploration range from purely recreational to serious scientific study. Exploration of a cave may require anything from negotiating tight passageways to multiple wet drops and swimming to simply strolling through dry walking-height passage. Given this diversity, one would expect that caving offers different types of rewards to different individuals and that this would be reflected by their level of involvement in the sport and the type of caving they do. Some individuals may seek out caves that are more technically and physically challenging, while to others the presence of attractive speleothems may be more important. What individual differences (e.g., demographic, motivational, or in personality) relate to the type of cave trips (e.g., long or short, vertical or horizontal, etc.) an individual takes most frequently? We hypothesized that (1) compared to non-cavers, cavers have some distinctive aspect of personality that attracts them to caving, and (2) there are probably some identifiable personality differences that influence different caver's preferences in caving activities.

Although two articles have been written concerning motivations for caving, little sociological data have been gathered. The first such study was Wilson's (1978) analysis of responses from registers placed in selected Virginia and West Virginia caves. His analysis showed that over one-third of those visiting these popular caves were first-time cavers who were not members of the National Speleological Society (NSS). Lukin and Beck (1981) compared sensation seeking tendencies of NSS cavers with noncavers and observed no significant differences. As this study utilized one of the same personality scales used in our study, it will be discussed in greater detail later.

Like Lukin and Beck, this study attempted to examine individuals who are generally more involved in caving and thereby have greater experience with different types of caves and caving activities. This was done by distributing a questionnaire at the annual 1979 NSS Convention in Pittsfield, Massachusetts. The 3½-page questionnaire (partially reproduced in Appendix A) assessed various aspects of the respondents' caving practices and included four 'personality' scales: two scales from a temperament survey (Buss & Plomin, 1975) and two of Zuckerman's Sensation Seeking Scales (see Zuckerman, 1978, for review of research on this scale). As these scales formed an important part of this study, the personality traits they are designed to measure are worth considering in more detail.

Temperaments are theorized to be broad, inherited predispositions which modify personality. Buss & Plomin (1974) designed a scale which assessed four such temperaments including emotionality, activity, sociability, and impulsivity (EASI scale). Two scales were chosen for the purpose of this study. Activity temperament, as the name suggests, reflects one's tendency to maintain high levels of physical activity. The prototypic person with a high activity temperament is continually 'on the go,' climbing stairs two at a time, restless when he sits too long in one place, and never slowing down, not even while on vacation. Sociability, on the other hand, denotes a tendency to approach and initiate contact with others; it is essentially the opposite of shyness. Both the activity and sociability scales consist of a series of statements such as "I like to wear myself out with exertion" and "I have an easy time starting a conversation with strangers at a party." The respondent rates each of these items on a scale of 0 to 7 with 0 meaning "not true of me at all" and 7 meaning "very true of me."

Sensation-seeking is a personality trait with a hypothetical physiological basis. As formulated by Zuckerman (1978), the notion of sensation seeking presumes that individuals differ in the level of central nervous system arousal with which they are comfortable, each person having an optimal level which they seek to maintain. Increases in arousal are reflected physiologically by an increase in the frequency of brain waves and by activation of the sympathetic nervous system (i.e., increased heart rate and blood pressure, sweating, etc.). Such increases may be induced through various combinations of sensory, physical, or mental stimulation. The high sensation-seeker is one for whom the "optimal level of arousal" (Zuckerman, 1978) is set relatively high, and who therefore requires high levels of stimulation. Zuckerman's Sensation Seeking Scale contains various subscales designed to tap preferences for various modes of stimulation seeking. Two of these subscales were used in the present study. The Thrill & Adventure Seeking Subscale (TAS) assesses one's interest in performing potentially risky activities such as parachute jumping or scuba diving. The Experience Seeking Subscale (ES) taps preferences for new and varied experiences. The high experience seeker is one who likes to 'try everything,' from traveling to exotic places to meeting unusual people to trying psychoactive drugs (Zuckerman, 1978). The TAS and ES questions are presented in forced-choice format, each item on the scale consisting of two statements. The respondent must decide which of the statements best describes his preferences or the way he feels. An example is as follows: (A) "A sensible person avoids activities that are dangerous" or (B) "I sometimes like to do things that are a little frightening."

There were several issues which were to be explored by the questionnaire. First, it was planned to compare cavers with a non-caving population of similar age and educational level. It was hypothesized that cavers might score higher on both the sensation seeking and activity temperament scales but that they might score somewhat lower on sociability temperament. A second objective was to explore possible differences between subgroups of cavers, comparing the personality and descriptive variables. For example, what differences exist in the male and female subgroups or among cavers who only participate on survey or 'work' trips vs. those who prefer to tour caves without collecting scientific data Finally, data were gathered concerning individual's motivations for caving, the importance of caving in their lives, and how they became interested in caving. It was expected that these factors would relate to the type of cave trips a caver most enjoys.

METHOD

Data were gathered by means of a 3½-page questionnaire which was included in all convention registration packets at the 1979 NSS annual convention in Pittsfield, Massachusetts. Additional copies were made available at registration. Respondents returned their completed questionnaires to a box at registration although some were returned personally to the authors.

The questions consist of the two subscales from Zuckerman's Sensation Seeking Scale (thrill & adventure seeking and experience seeking), two subscales from Buss & Plomin's EASI-III temperament Survey (activity and sociability), and 30 items written by the authors (see Appendix A). These items use a variety of response formats, including multiple choice, open-ended questions, and quantitative estimates of various aspects of caving activity. The data from these items can be classified into seven distinct categories:

(1) Demographic/biographic—Questions in this category include age, sex, education, occupation, state of residence, marital status, and whether spouse is a caver.

(2) Caving frequency—These questions include the number of different caves previously visited, the total number of cave trips taken, the number of different states and countries where caves had been visited, the number of years the person had been caving, and the number of trips taken within the last year.

(3) Types of caving—Respondents were asked to estimate what percentage of their caving trips are one or more of various types. These are not all mutually exclusive categories (e.g., a trip could be both 'vertical' and 'wetsuit'), so each was to be considered separately. The descriptions used are terms commonly used by cavers, but are defined in Table 1 for the non-caving reader. Individuals were also asked about the average length of their trips and the type of caving equipment (e.g., survey gear, ropes, etc.) they own.

(4) Importance—The importance of caving in a person's life was assessed in 3 questions. Five graduated choices were offered to the question "how important is caving in your life?" The individual was also asked to consider how many days he might spend on caving and cave related activities if

Table 1. Definitions of common caving terms

'vertical'—a trip requiring use of ropes
'wetsuit'—a trip requiring a wetsuit to maintain warmth in water
'commercial'—a trip into a cave with artificial lighting and improvements such as walkways, etc.
'survey'—a trip in which measurements are taken to produce a cave map
'exploration/push'—a trip to discover previously unentered cave passage
'horizontal'—a trip requiring no use of ropes
'sport'—a purely recreational trip
'diving'—exploring underwater cave passage with dive gear
'leading novices'—guiding novices on their first cave trip
'ridgewalking and digging'—looking for new cave entrances
'bop/yo-yo trip'—a short trip into an easy cave

free of school or work obligations, and what percentage of his friends are cavers.

(5) Motivations for caving—Respondents were given a list of six reasons why people may go caving and asked to use a scale of 0 to 10 to rate each, in terms of its importance to them as a reason for going caving. Listed choices include "physical activity and challenge," "exploring the unknown," "beauty of the cave environment," "companionship," "scientific curiosity," and "personal glory." Subjects were also asked to briefly explain how they became involved in caving.

(6) Caving preferences—Respondents were asked to list their 3 favorite types of cave trips and their opinions of an 'optimal length' for a good cave trip.

(7) Cave-related activities—Respondents were asked to rate their involvement in each of the following cave-related activities: ridgewalking and digging, publishing or editing cave literature, organizational politics, designing caving equipment, and collecting cave memorabilia. Again, the scale ranges from 0 to 10, with 0 meaning "not involved at all" and 10 connoting "extremely involved."

RESULTS AND DISCUSSION

Data analysis

The data were transferred to computer-format coding sheets after categorical and open-ended questions had been coded. Analysis was performed with SPSS (Statistical Package for the Social Sciences) software, including descriptive and frequency statistics, chi-square, grouped t-tests, Pearson correlations, and partial correlations. All findings described as significant attained significance levels of .01 or better (two-tailed, unless otherwise stated). The three major emphases in data analysis follow: (1) to provide basic descriptive data concerning the respondents; (2) to examine personality and other differences between individuals based on the type of caving they do; and (3) to compare cavers and noncavers (from an outside sample) on the personality variables (activity, sociability, and sensation-seeking).

Sample Description

Two hundred seventy-three questionnaires were returned after being distributed to the total 1979 convention attendance of approximately 550 persons. This represents a return of about 50%, which is a respectable rate for a voluntary survey. Males composed 70% of the respondents, and females constituted 30%, which is comparable to the proportion of males and females in the NSS as a whole.

From the means listed in Appendix A, it can be seen that the average caver in our sample is 31 years old, has caved almost 11 years, lives in Pennsylvania or Virginia, and is a student, engineer, teacher, or computer scientist. Impressively, the average educational level is the equivalent of 4 years of college. The average caver of this sample has visited 51–100 different caves, has been on 101–200 cave trips, went on 6–15 trips last year, and has done most of his or her caving in either West Virginia, New York, or Kentucky. Since the convention was held in the Northeast, the sample no doubt contains a disproportionally large number of cavers from the Mid-Atlantic and Northeastern states and the Virginias. While the ratio of males to females in our sample is comparable to that in the NSS, it is not indicative that the sample is representative of the general caving population or even the NSS population. Since one of the purposes was to compare cavers with other cavers, representation of a broad range of caving styles and experience should provide the most predictive data. One would expect more experienced cavers to attend an NSS convention. The convention, however, was composed of a wide variety of cavers, from relative novices to seasoned cavers with years of experience.

An idea of the experience level of this sample, vis-à-vis the general caving population, can be gained by comparison with John Wilson's (1976) sample of respondents from Virginia and West Virginia cave registers. His sample of 1778 people contained a high percentage of non-NSS, first-time cavers (21%). Not surprisingly, no one in the present sample had been on only one cave trip. The mean number of cave trips reported by those signing Wilson's cave registers is 36, compared to 150 in the present sample.

It is interesting to note the high level of education among the respondents, which is the equivalent of 4 years of college. Moreover, there is a high proportion of engineers, geologists, computer scientists, and other scientific specialists. This may reflect the bias of a convention sample, or these trends may generally typify NSS cavers as a whole. In another study it was noted that a high proportion of scientists are found among participants in risk-taking sports, such as diving (Ross, 1974).

One question in this study asks how the respondent first

became involved in caving. The most frequent responses are listed in Table 2.

Table 2. Responses to "How did you get started in caving"?

Response	Proportion of sample
"Went with friends"	29.3%
"Went with a club"	21.1%
"Went with relative/spouse"	13.4%
"Always interested"	9.3%
"Through reading about it"	6.9%
"Went on a fieldtrip	5.7%
"Visited a commercial cave"	5.7%
"In to other outdoor sports"	5.7%
"Went for scientific studies"	2.8%

As the table shows, most people were introduced to caving by a friend or through a club. The majority of those in the latter group went with college outing clubs, others were part of Boy Scout troops, and a few had simply heard about a grotto and joined. Significantly more men than women started caving as members of a club. Men were also much more likely than women to have become interested in caving by reading about it beforehand (16 men but only 1 woman). On the other hand, women were more likely than men to have been introduced to caving by relatives or spouses. People who listed "outdoor activities" as the way they became involved in caving usually listed backpacking or rockclimbing as their original interests. As we shall discuss later, how one is introduced to caving is related to the amount and types of caving they later pursue.

Sex Differences

A t-test for independent samples was used to compare males and females on all measured variables. Table 3 shows means for variables on which the two groups differ significantly, and the probability (p) that this difference is due to chance alone. This probability may also be read as the likelihood that the same difference would not be found in a replication of the study.

From these and other analyses it appears that the females of this sample population are not as deeply involved in caving as the males in this sample. Women reported going on fewer trips, owning less caving equipment (wetsuits, survey gear, ropes, vertical gear), and participating less in other spelean pursuits such as ridgewalking, designing cave equipment and collecting memorabilia. The mean difference in "importance" appears to reflect a lack of women at the high end—of the fifteen people who chose the maximum responses ("I live to go caving"), only one was female! (See section on Importance of caving for further explanation.)

It is speculated that some of these differences could be due to the fact that the female sample had been caving fewer years than the male sample. However, when the variable "number of years caving" was statistically controlled, the majority of male/female differences remained. It is further

Table 3. Significant sex differences

Variable	Males	Females	p
number of years in caving	11.6	8.0	.001
number of different wild caves visited*	5100	556	.001
number of cave trips*	5220	580	.001
number of states you've caved in	10.4	7.3	.001
% of trips which are photographic	17.6%	11.2%	.05
% of trips when you lead novices	17.0%	9.4%	.001
importance of caving in your life**	3.3	2.9	.01
Motivations for caving***			
exploring the unknown	6.9	5.4	.001
beauty of the cave environment	7.0	8.0	.01
personal glory	2.3	1.6	.05
Other spelean pursuits:****			
ridgewalking and digging	3.4	2.1	.001
designing cave equipment	2.4	.9	.001

Notes:

*Responses to each of these questions were in categories such as "26–50" and "51–100." Mean responses were used to estimate a specific number to make the data more interpretable.

**scale of 1 to 5 with higher numbers reflecting greater importance of caving to the individual

***scale of 0 to 10 with 0 meaning "totally unimportant" to 10 meaning "extremely important"

****scale of 0 to 10 with 0 meaning "not involved" and 10 meaning "extremely involved"

suspected that some of the sex differences may simply reflect the high percentage of wives of active cavers who were present at the convention but who were not heavily involved in caving themselves. Indeed, the men in the sample were much more likely than the women to have a non-caving spouse. Thus, a second set of comparisons was performed using only those men and women who rated caving as being relatively high in importance to them (i.e., who responded with either of the two top choices, A or B). While the resulting means were different than those in Table 3, significant differences remained on all but one variable—"personal glory" (as a motivation for caving).

Significant sex differences were also found with respect to the types of caving listed as favorites, based on chi-square analysis. Men were more likely to prefer vertical, photographic, biologic, and exploration trips, while women more often picked survey and horizontal trips as their favorites. Women's preferences for survey trips in this sample seem related to two factors. First, people married to a caving spouse report going on relatively more survey trips regardless of their sex, whereas those married to non-caving spouses report going on relatively more sport trips. Most females in the sample fall in the first group, i.e., they are more likely than the men to be married and are also more likely than the men to be married to a caving spouse.

The sample contained over twice as many men as women, and women as a group rated caving as less important and were less active than the men. This parallels observations from other risk-taking activities such as diving and rockclimbing (Ross, 1974). While women appear to tolerate a lower level of risk-taking in physical matters, Ross (1974)

suggests that cultural attitudes may account for less participation by women in risk-taking sports. The authors conclude that while the so-called 'hard man' role is an acceptable virile role, a comparable 'hard woman' role has only begun to be accepted in recent years. Women in our sample gave lower ratings to "personal glory" as a reason for caving than did the men. However, with women's increasing participation in a wide variety of athletic activities such as weightlifting, marathon-running, etc., it will indeed be interesting to see if their participation in caving and other risk-taking sports increases in future years.

Importance of Caving

Another aspect of this study compared subgroups defined by the importance that respondents attached to caving. Respondents were asked to choose one of five possible responses to the question: "How important is caving in your life?" The five choices and the portion of the sample choosing each response are shown in Appendix A.

Interestingly, of the 15 people who responded that they "live to go caving" in our sample, six became interested in caving through reading about it. This is highly significant considering that only sixteen people in the entire sample listed this as the way they started caving. On the other hand, those who rated themselves in category "D" (i.e., caving is low in importance) were significantly more likely to have started caving with their spouse or with relatives.

Correlations computed between importance ratings and other variables revealed some significant relationships. Individuals who rated caving higher in importance go on relatively more vertical, wetsuit, push, and survey trips, and on longer trips. On the other hand, those whose caving activities are of low importance take relatively more short trips and a higher proportion of sport caving trips. Judging from the type of trips those at the high end of the "importance" category enjoy, it is not surprising that they gave higher ratings to "exploring the unknown," "physical activity and challenge," "personal glory," and "scientific curiosity" as reasons why they cave. On the other hand, they give lower ratings to "beauty of the cave environment."

Personality Scale Scores

Respondents' scores on the temperament and sensation-seeking tests were used in subgroup comparisons within the sample (e.g., 'sport' vs. 'survey cavers') and also compared to non-caving groups using t-tests for independent samples.

For the activity and sociability temperament surveys, scores were available from a sample of 48 non-caver male college students (aged 18–24) who had participated in an unrelated study conducted by the first author at the University of Pennsylvania in Philadelphia. Their scores were compared to the responses of the males aged 18 to 24 in our sample. Cavers scored significantly lower than the non-caving group on the sociability scale, suggesting that cavers are generally less outgoing than the overall college-age male population. Interestingly, though, the female cavers in the sample had significantly higher sociability scores than the men in both samples; unfortunately, no sample of non-caving females was available. No differences emerged for the comparison involving activity temperament.

Within the caving sample, however, activity temperament showed significant correlations with involvement in and motivations for caving. Compared to "low activity" scorers, "high activity" scorers rated caving as higher in importance and indicated they would spend relatively more days per month on caving activities if free of job or school pressures. Interestingly, though, activity scores were unrelated to any of the other variables dealing with amount of caving (e.g., number of cave trips, etc.). High scorers also gave higher ratings to "physical activity and challenge" and "scientific curiosity" as reasons for caving. Finally, they are more likely than low scorers to design their own cave equipment and to prefer vertical over horizontal caving.

High sociability scorers (both males and females) tend to go on more 'push' and 'overnight' trips (as defined in terms of time spent in cave) but fewer trips overall than do those scoring low on sociability. Not surprisingly, high sociability scorers also gave higher ratings to "companionship" as a reason why they go caving.

Sensation Seeking

The two subscales from Zuckerman's Sensation Seeking Scale used were "Thrill and Adventure Seeking" (TAS) and "Experience Seeking" (ES). To perform a comparison of cavers and non-cavers, the authors utilized the normative values provided by Zuckerman (1978) for college-age individuals tested at the University of Delaware. A t-test was performed between the scores of college age cavers from our sample and Zuckerman's noncavers. The results show that cavers and noncavers do not score significantly different on TAS. However, cavers do score significantly higher on the ES scale relative to noncavers. As defined by Zuckerman, this suggests that individuals are not attracted to caving for the physical excitement it can provide, but rather, for the varied experiences associated with different caves.

Correlations within our convention sample of cavers indicate that scores on ES and TAS are predictive of various aspects of caving activity. Compared to low thrill and adventure scorers, high TAS scorers give higher ratings on the "physical activity and challenge" option as a reason for caving. The high TAS scorers also go on a greater percentage of very short trips and report a greater percentage of visits to different caves as opposed to repeat visits to the

same caves. High experience-seeking scorers, who are more likely to report 'sport' and 'vertical' as favorite trips, give higher ratings to "exploring the unknown" as a reason for going caving and would spend relatively more days per month on caving and/or cave-related activities than low ES scorers.

In a survey conducted a year after the one reported in this paper, Lukin and Beck (1981) mailed the Sensation Seeking Scale and a battery of questions about caving habits to randomly selected NSS members, 79 of whom returned completed questionnaires. This constituted a return rate of approximately 40%. They found no differences between cavers and Zuckerman's non-caving group on any SSS subscale. This contrasts with this study's observations that cavers score higher on experience seeking. Two factors may account for the discrepant findings. First, the sample in this study is about 3.5 times larger, resulting in greater statistical power to detect a true difference. Second, this study limited comparisons of SSS scores to cavers who were age-matched to Zuckerman's (college-age) non-caving groups, whereas Lukin and Beck compared their entire caving sample irrespective of age. SSS scores are known to decline with age (Zuckerman, 1978), and since the average age of Lukin and Beck's sample was greater (higher than the convention sample, which averaged 31 years old), the expected tendency would be for their sample as a whole to have lower SSS scores than the younger non-caving group. This could have obscured any trend towards higher scores in their sample of cavers.

Table 4. Comparison of 'Sport' and 'Survey' cavers

Variable	Sport	Survey	p
number different wild caves visited*	~67	~122	.030
number of total cave trips*	~88	~326	.0001
number of trips last year*	~12	~20	.001
% of trips which are wetsuit trips	7.0%	25.3%	.02
% of trips which are biology trips	.63%	12.66%	.03
% of trips which are 'push' trips	12.4%	45.57%	.001
% of trips which are sport trips	91.8%	6.5%	.0001
% of trips which are survey trips	6.4%	89.4%	.0001
% of trips which are over 12 hours	7.9%	42.5%	.0001
optimum length for a cave trip	7.4 hrs.	11.8 hrs.	.0001
Importance of caving in your life**	27.8	38.8	.0001
percentage of friends who are cavers	40.0%	69.0%	.0001
Motivations for caving***			
scientific curiosity	4.5	6.6	.008
Participation in other spelean pursuits:****			
participation in ridgewalking/digging	2.0	4.4	.007
participation in publishing	1.96	4.6	.0001

Notes:

*Responses to each of these questions were in categories such as "26–50" and "51–100." Mean responses were used to estimate a specific number to make the data more interpretable.

**scale of 10 to 50 with higher numbers reflecting greater importance of caving to the individual

***scale of 0 to 10 with 0 meaning "totally unimportant" to 10 meaning "extremely important"

****scale of 0 to 10 with 0 meaning "not involved" and 10 meaning "extremely involved"

'Sport' vs. 'Survey' Cavers

Two mutually exclusive groups were formed out of the entire sample to represent the extremes of 'sport' and 'survey' cavers. Those individuals who listed 75% or more of their trips as 'survey' were compared with those people who reported 75% or more 'sport' trips. There are 21 'survey' cavers and 62 'sport' cavers, by these definitions. Women composed roughly 50% of each group despite constituting only 30% of the overall sample. Table 4 presents the variables for which a t-test revealed a significant difference between the two groups and the probability (p) that this difference is only due to chance. Survey cavers spend more time caving than the sport group, because they report going on more and longer trips, particularly wetsuit and exploration/push trips. Caving is considerably more important to the survey caver and a higher percentage of his friends are cavers. Interestingly, there were no differences in the mean number of years that members of these two groups had been caving.

CONCLUSIONS

The descriptive data indicate that a wide level of caving involvement is represented by those attending the Pittsfield Convention, ranging from caving novices to seasoned veterans. It is hypothesized that the diversity of the sample increases the applicability of many of the present findings to cavers in general, e.g., high activity temperaments are related to greater involvement in caving, strong sensation-seeking tendencies are associated with 'sport' rather than 'survey' caving, and cavers score higher than non-cavers on experience-seeking, but not thrill-seeking measures.

This survey, largely exploratory, suggests further study. It would be interesting to administer the personality and sensation-seeking tests to new cavers and then follow up on them several years later to see if their scores might predict how involved they become in caving. Finally, it would be interesting to re-examine the sex differences observed here in several years and determine whether women's participation in caving is increasing as in other sports.

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APPENDIX A—Questions administered to respondents and mean * responses (in parentheses)

Age: (31) Sex: (70% male; 30% female) Education: (15.9 yrs.)

Occupation: (1. student; 2. engineer; 3. teacher or professor)

What state do you live in? (1. Pennsylvania; 2. Virginia)

How many years have you been caving?: (10.6 yrs.)

At what age did you start caving?: (20.7 yrs.)

How many different non-commercial caves have you visited?
10 or less 11–25 26–50 (51–100) 101–200 200 or more

How many cave trips have you been on (including repeat visits)?
10 or less 11–25 26–50 51–100 (101–200) 201–300 301–500 500+

How many different states have you caved in: (9.5)

In what state have you done the most caving: (1. West Virginia; 2. New York; 3. Kentucky.)

What equipment do you own?: rescue (18%) wetsuit (48%) ropes (66%) survey gear (43%) vertical gear (80%)

How many cave trips did you go on last year?
5 or less (6–15) 16–25 26–40 40 or more

What percentage of your cave trips are *each* of the following? (Consider each individually; the total may exceed 100%).
vertical (21%); commercial (6%); wetsuit (10%); photographic (16%); survey (20%); biology study (5%); geology study (11%); horizontal (65%); exploration/"push" trip (23%); cave diving (.5%); sport or "tourist" (38%); leading novices (15%)

Using the above categories, what are your favorite types of cave trips?
#1: (push & vertical) #2: (sport) #3: (photo)

What percentage of your cave trips are the following lengths?
(Total = 100%)?
overnight (2%); long (over 12 hrs.) (14%); medium (7–12 hrs.) (29%); short (2–7 hrs.) (41%); "bop" or "yo-yo" (less than 2 hrs.) (9%); other (5%)

What do you consider your optimal trip length?: (8.7 hrs.)

What caving awards (if any) have you won? (e.g., vertical, photo, mapping contests, NSS awards). Specify: **
none (68%); NSS awards (12%); vertical awards (6.5%); photo (6.2%); others (7%)

Briefly state how you got started in caving: **
through friends (26%); with clubs (19%); spouse or relatives (12%); other (43%)

If you didn't have to work for a living or go to school, how many days of the month would you spend on caving activities?: (10.8 days)

How important is caving in your life? (choose one)
A. Basically, I live to go caving. (6.5% chose this)
B. It's my primary leisure activity. (34.4% chose this)
C. It is important, but I also have other leisure interests of equal importance. (45.9% chose this)
D. It is only an occasional pastime. (9.4% chose this)
E. The social aspects of caving are currently more important than actually going caving. (8.2% chose this)

How many organized caving events do you attend a year? (e.g., Convention, grotto or regional events, OTR, etc.): (4.7)

Following are several reasons why people may go caving. On a scale of 0 to 10, rate each in terms of its importance to you as a reason for caving (Consider 0 as "totally unimportant" and 10 as "extremely important"):
Physical activity and challenge: (7.2)
Exploring the unknown (finding virgin cave): (6.4)
Beauty of the cave environment: (7.4)
Companionship: (5.9)
Scientific curiosity: (5.2)
Personal glory: (2.0)
Other: ("to escape" was the modal write-in response)

Compared to other cavers, how involved are you in each of the following? (Assign a number between 0 and 10 to each activity, 0 meaning "not involved at all" and 10 meaning "extremely involved":
Ridge walking and digging: (2.9) Cave politics: (2.6)
Publishing in or editing cave literature: (3.0)
Designing caving equipment: (1.9)
Collecting caving equipment or memorabilia: (2.6)

What percentage of your friends are cavers: (45%)

Are you married: NO (50%) YES (39%) WAS (6%) Cohabiting (4%)

If so, is your spouse a caver? YES (52%) NO (21%) "sort of" (12%) No response (15%)

*the modal response is provided for categorical data

**Open-ended question, i.e., no response choices were listed.

PROCEEDINGS OF THE NATIONAL SPELEOLOGICAL SOCIETY
ANNUAL MEETING, June 24 - June 28, 1985
FRANKFORT, KENTUCKY
G. Thomas Rea, Editor

ANTHROPOLOGY SESSION

THE ABORIGINAL EXPLORATION AND UTILIZATION OF BIG BONE CAVE, TENNESSEE

George M. Crothers, Dept of Anthropology, Univ of Tennessee, Knoxville, TN 37996

The discovery of perishable archaeological remains in the remote passages of a dry cave in central Tennessee has prompted investigations into the variety, extent, and period of human activity at this site. Superficially, the prehistoric remains in Big Bone Cave appear similar to those found in Mammoth and Salts Cave, Kentucky, where extensive exploration and mining occurred during the late Archaic and early Woodland periods (4,000-2,000 years ago). Current investigations indicate that the activity in Big Bone Cave occurred at least partly during the Middle Woodland period (ca 350 AD). Current research will be reviewed and the types of remains illustrated. Possible reasons for the extensive aboriginal activity in the cave will be considered.

PETROGLYPH CAVES IN THE SOUTHEASTERN UNITED STATES

Charles H. Faulkner, Dept of Anthropology, Univ of Tennessee, Knoxville, TN 37996

Petroglyphs are not uncommon on bluffs and boulders in certain areas of the southeastern United States, but only five caves are presently known in the Southeast that contain these prehistoric rock carvings in the dark zone. At least one of these sites may date as early as 3,000 years ago, but most of these drawings are probably associated with Mississippian period ceremonial activity occurring about 500 to 1,000 years ago. The meaning of these petroglyphs is presently unknown, although some motifs are similar to those used by the historic Cherokee and Muskogean speaking peoples. The carvings are sometimes difficult to discern, and additional unreported petroglyph caves probably exist in eastern North America. Cavers should be on the lookout for additional examples of this prehistoric art.

BUGTUSSLE ROCKSHELTER: AN UNUSUAL ARCHAEOLOGICAL SITE IN TENNESSEE

Charles L. Hall, Dept of Anthropology, Univ of Tennessee, Knoxville, TN 37996

Recently, an unusual rockshelter was discovered by Indian relic collectors in Macon County, Tennessee. The most significant aspect of this shelter was the remarkable preservation of materials which are normally not preserved archaeologically, including unprocessed plant remains, textiles, human paleofeces, and animal tissues (hair and hides). Test excavations, conducted during the summer of 1984, indicate that, while damage to the site has been considerable, intact aboriginal deposits are present. Preliminary analysis suggests that the primary prehistoric utilization occurred between 400 AD and 900 AD. Research to date will be reviewed with an emphasis on the perishable materials recovered.

MIDDLE WOODLAND QUARRYING AND USE OF ARAGONITE FROM WYANDOTTE CAVE, INDIANA

Cheryl A. Munson, Patrick J. Munson, and Kenneth B. Tankersley, Indiana Univ, Bloomington, IN

Wyandotte Cave in southern Indiana was utilized during the Terminal Archaic through Middle Woodland periods for the extraction of a variety of minerals. Aragonite, a relative rare form of speleothem material that occurs in this cave, was extensively quarried during the Middle Woodland period. The quarrying activities are described, the microscopic and chemical "fingerprints" of Wyandotte aragonite are presented, and artifacts of this material are identified from Middle Woodland sites in the midwestern United States.

THE 1985 SAVAGE CAVE PROGRESS REPORT

Pamela A. Shenian, Dept of Sociology and Anthropology, Murray State Univ, Murray, KY 42071

Savage Cave in Logan County, south central Kentucky, is a large multi-component archaeological site acquired by Murray State University in 1982. This site has been the locus of extensive excavation and collection by amateur and professional archaeologists for several decades but few publications or professional papers have followed from the field studies. Murray State University is attempting to document these past excavations and collections, to obtain all artifacts and field notes from Savage Cave studies, and to analyze the Savage Cave materials already curated at the MSU Archaeology Laboratory. Carstens (1980) and Schenian (1984) document the progress made in these tasks to the respective dates of authorship. A considerable amount of archival and laboratory research has been completed since Shenian (1984). This paper will summarize the revised site excavation and collections analysis history. It will also summarize the nature of Savage Cave collections curated at MSU.

PREHISTORIC SELENITE MINING IN THE MAMMOTH CAVE SYSTEM, KENTUCKY

Patrick J. Munson, Kenneth B. Tankersley, Patty Jo Watson, and Cheryl Ann Munson

Selenite crystals occur in dry clay fill deposits in numerous locations in Mammoth Cave and Salts Cave. Evidence for prehistoric mining is extensive at these locations. "Lost John," a prehistoric miner who was crushed by a falling boulder, was digging for these crystals. This paper documents the evidence for and extent of selenite mining and proposes possible prehistoric uses for selenite.

HUMAN BONES IN ALABAMA CAVES

Kenneth R. Turner, Dept of Anthropology, Univ of Alabama, PO Box 6135, University, AL 35486

The history of discoveries of prehistoric human skeletal remains in north Alabama caves is a disconcerting example of permanently lost knowledge about our past, particularly in terms of our species' biological experiences. Several examples are cited, although emphasis is placed upon attempts to rescue such materials in a recent instance. Complications of proper recovery of remains in a cave setting are presented, together with a description of the utility of such remains in reconstruction of the history of humankind. Recommendations are offered concerning appropriate responses of speleologists who discover human skeletal remains in caves.

HUMAN BONES IN TENNESSEE CAVES

P. Willey, Anthropology Dept, Univ of Tennessee, Knoxville, TN 37996

Early accounts indicate that many Tennessee caves contained skeletal remains. A great number of the larger caves in the state were mined for nitrates during the War of 1812 and the Civil War and during these mining operations many skeletons and a few mummies were discovered. Despite the destruction of a great number of burials during the 19th century, skeletons are still being found in the caves of the state.

Within the past 5 years, human skeletons have been found in at least 7 Tennessee caves. All of the discoveries were made by people without formal training in osteology or archaeology.

Following discovery, the manner in which the material is observed and collected is crucial in preventing loss of potentially valuable information. When bones are collected by the untrained and delivered to the laboratory door, little more than a descriptive analysis of the bones is possible. Conclusions concerning the origin, transport, and deposition must remain conjectural. On the other hand, systematic collection at the site by trained archaeologists and osteologists permits more thorough analyses leading to firm conclusions. Examples of differing collection techniques and goals are presented.

BIOLOGY SESSION

GENE FLOW IN CAVE ANIMALS: A QUALITATIVE AND QUANTITATIVE APPROACH

A. Caccone, Dept of Biology, Yale Univ, New Haven, CT 06511

Levels of gene flow and patterns of genetic differentiation in 11 species of cave organisms are analyzed, using Slatkin's methods (1981, 1985) based on the spatial distribution of rare alleles in natural populations. The value of these estimates in describing historical patterns of gene exchange more than present level of gene flow in highly subdivided species is stressed.

The species structure of four terrestrial cave species, with varying degrees of association with the cave environment, is comparatively analyzed and related to the importance of past or actual gene flow and stochastic processes in determining the patterns of distribution observed.

Patterns of gene flow in three cave species living in the same limestone region are compared to discuss the relative importance of availability of dispersal routes and ecological requirements of each species in determining the patterns observed.

THE CAVE FAUNA OF CALIFORNIA

William R. Elliott, D. Craig Rudolph, James R. Reddell, and Thomas S. Briggs, Texas Speleological Survey, 12102 Grimsley Dr, Austin, TX 78759

Since 1979 the authors have compiled an exhaustive faunal list and bibliography which will be published in the near future. Many new species and records were added during intensive field work sponsored by the US Army Corps of Engineers and the US Fish and Wildlife Service in 1977-1979. Most of this work was done in the Stanislaus River canyon of the northern Sierra Nevada.

About 650 species and subspecies have been recorded from 281 caves, 23 sea caves, 26 mines and 10 groundwater localities. Non-cave faunas are included because of their frequent relationship to the cave faunas. Cave types include limestone and lava caves ranging from present or former coastlines to desert and alpine environments. Boreal and tropical drelics are represented, but the true zoogeographic relationships of most of the fauna remain to be elucidated.

At least eight regional cave faunas are recognized: Marble Mountains wilderness, Shasta Lake, lava beds, northern Sierra Nevada, southern Sierra Nevada, Mojave Desert, coastal ranges, and sea caves. The northern Sierra Nevada has the best known cave fauna and the highest number of troglobites. A few other small areas have been intensively studied, but most of the caves are poorly known biologically.

About 75 troglobitic/phreatobitic species occur in the state, many of which are yet undescribed. The proportion of the fauna that is troglobitic is rather high in some regions, changing the commonly held conception of the state's cave fauna. However, the troglobitic fauna does seem to be depauperate in certain taxonomic groups when compared to other North American cave areas.

Geologic and physiographic factors that have contributed to the high degree of endemism in some of the cave faunas are also discussed.

CAVE SOIL MICROBIAL ACTIVITY AND BIOMASS: RELATIONSHIP TO WATER AND ORGANIC CARBON AVAILABILITY

David J. Feldhake and Robie Vestal, Dept of Biological Science, Univ of Cincinnati, Cincinnati, OH 45221

The heterotrophic microbiota of cave soils is believed to fulfill an important role in the cave ecosystem, converting recalcitrant detritus and other organic matter to forms which can be utilized by higher trophic levels. However, little is known about the interaction of these microbes with the cave environment. A survey was conducted on 5 dates during 1983-84 in which 12 diverse sites in 5 Kentucky caves were studied to examine the relationship of the microbiota with soil water content and organic content. The survey data suggested that organic matter may be important in regulating both microbial activity (measured as carbon 14 acetate incorporation into lipids) and microbial biomass (measured as total lipid phosphate content of soil) in caves.

The importance of organic matter in caves to the microbiota has been suggested many times but never actually proven. A cave site low in water content, organic content, and physical disturbance was chosen to experimentally test the effects of 3 treatments: physical disturbance, single pulse water addition, and water plus glucose enrichment. Disturbance was shown to have a short-term effect in stimulating microbial activity but had no effect on microbial biomass. Water amended plots were not significantly different from those in the disturbed treatment. Water plus glucose enrichment resulted in a significant increase in microbial biomass after 7 days. However, the activity per unit biomass was similar for all treatments by day seven. These data indicate that disturbance of relatively stable cave soil environments results in increased metabolic activity, but not necessarily growth of the microbiota. The cave soil microbial community at this site was apparently limited by organicarbon, and may be adapted to using infrequent inputs of carbon for cell maintenance and growth.

MICROBIAL ECOLOGY OF TWO KENTUCKY CAVES

James Greer, 3410 Eastside Dr, Louisville, KY 40220

Caves represent a delicately balanced ecosystem. Slight disturbances can result in drastic and often irreversible damage to the ecosystem, resulting in the elimination of most if not all of the existing life forms present there. This life obtains its food through hydrological input from the surface. Organic matter is thus carried into the cave and supplies the inhabitants with the food necessary for their existence.

Within the cave, aquatic ecosystems are the most sensitive to disturbances in the food input. Unlike the non-aquatic residents of the cave, they are restricted to live only within the confines of their subterranean habitat. Food levels are already low to begin with, and any alteration could completely remove existing sources. Because of these low food levels, cave organisms generally have a lower metabolic rate than their above-ground counterparts, greatly elongated life span, low reproductive rate, and infrequent breeding periods. Rebound rates of cave populations are much slower than their above-ground counterparts.

Although this project involved a survey of cave organisms, the primary focus was on the aquatic microbiology of the cave community. Sewage contamination from above-ground sources entering the cave can cause an explosion of bacterial populations in the cave. This can result in the death of larger-sized species of organisms by favoring fast reproducing decomposers which use up the oxygen dissolved in the water. Also, because the study caves are located within a recreational area and are fairly well traveled, contamination could pose a significant health risk to cavers using the cave.

The purpose of this project was to separate and classify the various micro-organisms present in two caves in Meade county and determine if pollution is entering the caves from external sources, as well as assess any health risk which might be present. It is hoped that this research can be continued to gain more knowledge of these ecosystems and cave microbiology in general.

EVOLUTIONARY PATTERNS IN CAVE CARABID BEETLES

Thomas C. Kane, Dept of Biological Sciences, Univ of Cincinnati, Cincinnati, OH 45221

In the eastern United States approximately 250 species of trechine carabid beetles are troglobitic forms. These species are presumably relics of surface dwelling ancestral forms which were wides+pread during cooler, wetter climates associated with glacial maxima. Presently, many of these trechine species are relatively abundant and show interesting patterns of distribution within the karst regions to which they are restricted. As predators, many of these species also play important ecological roles in the various terrestrial and riparian cave communities.

Population structure and geographic variation have been examined in selected taxa of troglobitic carabid beetles using the technique of gel electrophoresis. The taxa selected have been chosen variously because 1) they are appropriate for assessing the efficacy of presumed dispersal barriers; 2) they represent different levels of differentiation to include subspecies, semispecies and full species; and, 3) they represent different ecologies which have presumably been shaped by different selection pressures. Portions of two major plateau karst regions, the Cumberland Plateau (MP-II) in southeastern Kentucky and northern Tennessee and the Pennyroyal Plateau region in west central Kentucky and its extension in southern Indiana, have been investigated in this study. Further, the taxa studied come from two distinct phylogenetic series of trechine carabids.

MICROORGANISMS ASSOCIATED WITH THE CROP OF THE CAVE CRICKET HADENOECUS SUBTERRANEUS

K. H. Lavoie, E. H. Studier, J. Edwards, and M. Apgar; Biology Dept, Univ of Michigan at Flint, 1321 E Court St, Flint, MI 48502-2186

The digestive systems of all organisms are colonized with a diverse population of microorganisms. Studies of some insects have shown that the enzymes needed for the digestion of food may come from microbes ingested or already growing in the gut. Examining the digestive system of Hadenoecus subterraneus showed a greatly enlarged crop region, which serves a storage function for food in most insects. A Gram stain of the cricket crop contents showed a remarkably consistent group of microbes, including a yeast and three morphologically different Gram-positive rods. The same group of microbes were found in both sexes of crickets from five caves over nearly a year of study. The same organisms were also seen in the gut of a newly-hatched cricket which presumably had not yet fed. Preliminary studies have shown that the crop contains large amounts of digestive enzymes. The possible contribution of these microbes to the processing of food by H. subterraneus remains to be studied.

POSSIBLE FOOD STORAGE STRATEGIES USED BY THE CAVE RAT, NEOTOMA FLORIDANA

K. H. Lavoie, L. Sawyer King, and L. Simonuvic; Biology Dept, Univ of Michigan at Flint, 1321 E. Court St, Flint, MI 48502-2186

Cave rats (Neotoma floridana) inhabit the entrance areas of most caves in Kentucky and Indiana. These rats generally store nuts, grains, and other foods in the caves. The high humidity and relatively warm cave temperatures provide ideal conditions for the growth of food-spoilage microbes, including the fungi which produce mycotoxins. It has been observed that cave rats almost universally have cedar in their nests and middens. We though that the volatile compounds in cedar might provide a natural fungicide which would reduce food spoilage of stored material in caves. A laboratory study showed no significant difference in the plate counts of fungi and bacteria on corn and sunflower seeds placed directly on cave mud with or without cedar. Placement of foods on the cedar instead of directly on the mud did reduce the growth of microbes on both corn and sunflower seeds, and also reduced the rate of germination of stored food. Ungerminated seeds would provide richer sources of nutrients for cave rats than germinated seeds. Cedar may be used by cave rats to preserve both the nutritional quality of stored foods and to reduce their spoilage.

ECOLOGICAL CORRELATES OF TERRESTRIAL CAVE-DWELLING INVERTEBRATES IN LARGE RIVER PASSAGES IN PUERTO RICAN CAVES

Edward A. Lisowski

In February, 1984, I collected invertebrates in sets of five pitfall traps at 22 sites in three Puerto Rican caves: Boca del Infierno, Cueva de los Angeles (Sistema del Rio Camuy), and Cueva del Rio Encantado. At each site I placed nothing around the first pitfall trap, rocks around a second, rotting twigs around a third, fresh piper leaves around a fourth, and peanut butter around a fifth. After one week I removed the pitfall traps and, by using Berless funnels, extracted invertebrates from the remaining twigs, leaves, and peanut butter. I also estimated height of the sites above the cave river and the size of soil particles around the traps.

I performed canonical correlation analyses of the correlation between abiotic and biotic variables. Three correlations were significant at the 2% level and a fourth was significant at the 7% level. The first correlation identified a tendency for adult and larval flies to be near rivers, in areas with coarse sand, near peanut butter, and away from twigs. Collembola correlated negatively with adult and larval flies. The second correlation identified a tendency for roaches, crickets, and beetles to be collected in pitfall traps, and for larval flies, isopods, and collembola to be collected in Berless samples. The third correlation identified a tendency for burrower bugs to be present in Cueva de los Angeles, and for beetles, crickets and roaches to be present in Cueva del Rio Encantado. The fourth correlation identified a tendency for roaches to be near peanut butter and rivers and away from leaves. Isopods and burrower bugs correlated negatively with roaches. In factor analyses of biotic variables, beetles, roaches and crickets loaded heavily on the first factor and isopods, collembola, and spiders loaded heavily on the second factor.

BIOENERGETICS OF HADENOECUS SUBTERRANEUS

E. H. Studier, X. Wares, K. H. Lavoie, and J. Linn; Biology Dept Univ of Michigan at Flint, 1321 E Court St, Flint, MI 48502-2186

Hadenoecus subterraneus, the cave cricket, is a major source of energy input into caves in central Kentucky which lack a large bat population. The metabolic requirements of H. subterraneus determine how often the cricket must leave the cave to forage. The relationship of crop-empty live weight (CELW) to femur length (FL) for both sexes is curvilinear and expressed by:

$$CELW_{(gms)} = 0.002698FL^{2}_{(mm)} - 0.05007FL_{(mm)} + 0.2741$$

Crop content can therefore be estimated if total live weight and femur length are determined. Fed females have heavier crops than fed males. Weight loss of fed, caged males (1.19 mg/hr) is not different from females (1.55 mg/hr). Based on weight loss data and the CELW to femur length relation, large (20-22 mm FL) crickets would digest full crop contents every 6.8-11.2 days for males and every 10.0-13.4 days for females. Physiological adaptations to surface stresses will determine how long the cricket can remain outside the cave while foraging.

WILDFLOWERS OF THE APPALACHIAN KARSTLANDS

Anne Whittemore, 4107 Ranch Road, Johnson City, TN 37601

Every spring, summer and fall our caving trips are enhanced by the beauty of delicate wildflowers which flourish only briefly. Often finding cave entrances far off the beaten path, we are privileged to see many rare wildflowers. This slide presentation provides the viewer with a close-up of each flower, as well as a listing of edible and/or medicinal uses. Have you ever wondered what the pale pink and white flower was that you annihilated with your caving rope? This is the time to find out.

NEW SPECIES OF CAVE FAUNA FROM THE SOUTH PACIFIC

Dennis Williams

A recent NSF funded, four-month long cave diving expedition to the South Pacific resulted in the exploration of caves on Ponape, Guam, Palau, and the Philippines. This presentation will provide a "sneak preview" of the many new species of cave fauna collected during the expedition.

A CLOSER LOOK AT REMIPEDIA

Jill Yager, Old Dominion Univ

In 1979 an unusual troglobitic crustacean was discovered in an anchialine cave in the Bahamas. Due to the characters of this animal, a new class, Remipedia, was proposed. Since the discovery of the first remipede, Speleonectes lucayensis, additional representatives of the class have been found in anchialine caves throughout the West Indies and the Canary Islands. Due to the abundance of several of the new species, more details concerning the functional morphology, feeding habits and general characteristics of the class are now available.

INTERNATIONAL SYMPOSIUM ON REGRESSIVE EVOLUTION

REGRESSIVE EVOLUTION IN COLLEMBOLA

K. Christiansen, Grinnell College, Grinnell, IA 50112

Regressive evolution in collembola is examined in two habitats-caves and soil. Four genera are examined: Friesia, Folsomia, Schaefferia, and Pseudosinella. The first genus shows regression only in soil, the second largely in soil, the third mainly in caves and the fourth almost entirely in caves. Six features show clear regression in collembola: 1) eyes, 2) furcula size, 3) tenant hair structure and size, 4) pigment, 5) unguiculus, 6) water retention ability. The first three of these were chosen for analysis. The regression of these features was examined in soil and cave forms with the end goal of seeing which of the 12 major theories used to explain regressive evolution best fitted the data observed.

The first conclusion was that there is little correlation between features displaying regressive evolution. A second is that regressive evolution in caves displays features quite distinct from those seen in the soil. The result is that different features undergoing regressive evolution behave as though they were under different evolutionary regimes even when they are subjected to analogous selective forces.

These data do not fit any extant explanation very well, but they are least in conflict with 1) direct selection of obscurely adaptive features, 2) material compensation, 3) evolutionary trap theory and 4) the indirect effect of pleitotropy if these can be integrated so as not to be mutually exclusive.

SELECTIVE NEUTRALITY FOR REDUCTIONS IN TROGLOBITES: PLAUSIBILITY ARGUMENTS AND DATA FOR LINYPHIID SPIDERS AND AMBLYOPSID FISH

Thomas L. Poulson, Dept of Biological Sciences, Univ of Illinois, Box 4348, Chicago, IL 60680

Culver's calculations (Cave Life, 1982) show that evolutionary reduction of structures is plausible. In this paper I discuss possible mechanisms for direct and indirect selective reduction and show that they are not as likely explanations as selective neutrality.

Natural experiments show that energy conservation is not a likely basis for direct selection against eyes or pigment. There is a lack of pattern of reduction across trophic levels and there are many cases of reduction in non-cave systems which are not energy limited. Nor is there a pattern between reduction and likely food limitation among and within cave regions.

In energy limited cave areas, costs of construction and maintenance of eyes and pigment, absolutely and relative to costs of other structures; reproduction; and whole animal metabolism make energy conservation an unlikely selective basis for reduction. This is illustrated by partitioning costs at scales of lifetime, developmental time, and short time extreme food scarcity. I use spiders and fish with emphasis on troglophiles where the energetic constraints would seem to be most severe in caves.

A plausible mechanism of selection for some structures and reduction of others is through allometric effects during development. Data are virtually lacking for the critical early stages of development and eyes and pigment are positively related to increasing body size during growth. Changes in sign of allometric growth constants and changes in number and size of embryological anlages at points of growth inflection are likely candidates for direct and pleiotropic effects. Data on pigmented melanophores among populations of a troglophilic fish show how labile these sorts of relationships can be. On the other hand, lack of pattern in sequence of loss in eye and retinal structures among species of troglobites makes reduction based on size of eye anlage an unlikely explanation.

If selection operates through negative genetic correlation among visual and extravisual sensory systems, then it should be expected where there is morphogenetic overlap during development and neurological overlap in pathways, connections, and integrative centers. There is precedent for overlap in visual and tactile systems in fish.

The reduction and loss of behavioral and physiological traits, which are no longer maintained by selection, argues for accumulation of loss mutations since pleiotropic interactions with maintained systems are unlikely. This is illustrated by new data on increased sensitivity of metabolic-swimming performance to temperature change among amblyopsids. It is also consistent with decreased sensitivity to predators by a startle-escape response (Poulson) and simplification and reduction of agonistic behavior (Bechler) among the same species.

CAN EVOLUTION REGRESS?

Aldemaro Romero, Dept of Biology, Univ of Miami, Coral Gables, FL 33124

An analysis of the idea of "regressive evolution" is made under semantic, historic, and descriptive viewpoints, and the conclusion is reached that the term does not accurately describe the

evolutionary trend toward reduction or disappearance of features in, among others, cave and deep-sea animals. Since the trend of reduction can be explained using the current evolutionary conceptual framework, it is proposed that we eliminate "regressive evolution" as a descriptive term for what are really only examples of convergent evolution.

NON-ALLOPATRIC SPECIATION IN CAVE FISHES: STUDIES IN EPIGEAN AND HYPOGEAN ASTYANAX POPULATIONS (CHARACIDAE, PISCES)

Horst Wilkens and Kathrin Lubeck, Zoologisches Institut und Zoologisches Museum der Universitat Hamburg, Martin-Luther-King-Plaz 3, 2000 Hamburg 13, West Germany

The process of speciation of most cave living animals starts within the distribution area of their ancestral form. The phylogenetically young Micos cave population of the caracin A. fasciatus (Pisces) may even be found associated with large numbers of its epigean ancestor in the natural cave biotope. Although epigean and hypogean populations are still interfertile, no hybridization occurs. In competition for the reduced energy input into the cave the epigean individuals suffer starvation. This has been shown by comparison of the condition factors of epigean and hypogean Astyanax individuals.

The origin of cavernicolous populations depends on a general preadaptation for cave life. The radical habitat niche change, which is characteristic of cave colonization, is coupled with radical changes in some environmental factors. The loss of light and a reduced food supply work as disruptive selection factors. Only a few individuals of the epigean form are able to found a cave population of its own under these circumstances. They are specimens characterized by a more than average preadaptation, which is probably based on an oligogenic polymorphism of advantageous features. All other epigean genotypes are displaced in competition with their own kin in the cave biotope.

In this initial phase of speciation there is still a reduced gene flow. Thus more advantageous genes out of the epigean gene pool become concentrated in the newly founded cave population. On account of the energy economy being only slightly improved, the population density is low.

Genetic isolation is only achieved when further adaptations to cave life are postadaptively acquired and improved. By better mechanisms for finding and more efficiently using the energy sources available and by increasing population size all epigean genotypes are finally displaced.

CAVE METEOROLOGY SESSION

METEOROLOGY OF EAGLE CAVE

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

Observations of ice formations and the discovery of a winter bat hibernaculum in Eagle Cave on Chimney Mountain in the Adirondacks of New York have proven that the cave meteorology is a combination of a cold trap for the lower levels and a temperature averaging rock heat storage bed for the middle levels. Variations of ice thickness in the lower levels indicate that the cave is not a true glaciere.

LANDMARK STUDIES ON BAROMETRIC FLOW

Warren C. Lewis, 2225 Oxford St, Rockford, IL 61103

Wind and Jewel Caves, South Dakota, USA: Simultaneous recording of air flow and barometric pressure. Cave shape addressed.

Wupatki Fissures and Blow Holes, Arizona, USA: Double reversal in flow related to daily barometric change. Thunderstorm recorded.

Gigante Grotto, Italy: Barometric flow confirmed. Microbarometer utilized to link rapid reversals with atmospheric waves. Resonance considered.

Caves du Pays de Caux, Seine Maritime, France: Speed and direction of flow correlated with pressure change. Porosity of rock addressed.

Mullamullang and Nullarbor Plain Caves, Australia: High flow shown independent of temperature. Simultaneous air reversal demonstrated near mouth and 2.25 mi in cave. Lateral shift of flow pattern found with change of direction of air. Loss of air into imperceptible spaces. Strong flow caused fretting of ceiling and sand dunes. Some characteristics of barometric flow are considered.

BLOWING WELLS

Warren C. Lewis, 2225 Oxford St, Rockford, IL 61103

Canton of Geneva, Switzerland: Water wells were reported that drew in air and blew it out in synchrony with changes in the barometer. The wells were used to predict the weather. Water was found in alluvial gravel overlain by relatively impervious earth. The water level would rise when atmospheric pressure was low.

Nebraska, USA: Some water wells were called roaring, breathing, singing, or weather wells. One would sing like a tea kettle when bad weather was coming. Water was found in a gravel or sand layer overlain by four inches of dense limestone. This was covered by 50 to 100 ft of subsoil and soil. Some wells were abandoned because they froze deeply in winter. Other wells might freeze down a few ft but these wells froze to 80 or even 120 ft. It is true that when air reversed after several days the well usually thawed itself. A column of steam at 56 degrees F would rise out of the well. When the wind blew from the north or northwest the cave would blow and the water rise. A change of 1 degree F in surface air might start the well blowing or sucking. Air flow was attributed to natural gas, tidal action of "sheet water" and wind on the Platte River.

COMPUTER, SURVEYING, AND MAPPING SESSION

A FORTRAN SURVEY PROGRAM WITH PLOTTING ROUTINE

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

A FORTRAN cave survey program is described which incorporates a plotting routine which gives a rough plot of the last digit of each survey station in its approximate position on one page of the output. The program alternates one page of input data with one page of computations which include not only X, Y and Z coordinates, but also the horizontal polar vector with an angle that can be used for plotting with a protractor and ruler. A coding system allows a survey over a level body of water in the cave to be done without using vertical angle measurements. The program also prints the Z coordinate in meters. Another feature allows the correction of individual sightings for changes in the magnetic declination when the survey extends over several years.

CAVE CARTOGRAPHY BY COMPUTER

Don Conover, 467 West Krepps Rd, Xenia, OH 45385

Adding the third dimension to a cave map gives a more accurate representation of the relative height and depth of cave passages. This is particularly helpful in the study of the hydrology of a particular cave system. The maps also show the multiple levels of the passages relative to each other in the cave system. The computer program draws the passage walls and ceiling in the shape of the cross-section of the passage.

THE SMAPS PROGRAM

Doug Dotson, Frostburg State College, Dept of Computer Science, Frostburg, MD 21532

The SMAPS system is an interactive, integrated system which supports all phases of cave survey data reduction. It has been implemented to allow portability to a wide variety of computer systems from mid-sized microcomputers to large mainframes. Since its introduction at the 1983 NSS convention, SMAPS has received much attention throughout the caving community and many suggestions have been made regarding improvements. As a result of this feedback, major design changes have been implemented. This presentation will discuss both the successful and unsuccessful improvements to the SMAPS system as well as the techniques used in their implementation.

PGD - Printer Graphic Driver

Robert Thrun, 8123 14th Ave, Adelphi, MD 20783

Drawing lines on paper is an essential part of cave survey data reduction. The lack of suitable commercial software for doing this task was the motivation for writing the Printer Graphics Driver program. The program reads a file containing the coordinates of the line endings and produces line plots of the data on the printer. The existing textbook algorithms fail to consider the real world limitations of existing microcomputer systems. Printer Graphics Driver produces large plots at high resolution. It plots at the full printer speed, using limited memory. This paper describes the design considerations that went into the program.

A PARTITIONED SEMANTIC NET DESIGN FOR FIELD COMPUTER APPLICATIONS

Duane Vore, 2407 W Alex-Bell Rd, Centerville, OH 45459

A pad of paper and a pencil are a more practical in-cave data system than a computer unless the computer's programming is able to assist the caver by making inferences from the data and drawing conclusions. Artificial intelligence technology can reach this goal, but current environments for its development like LISP, Smalltalk, and OP55 typically require hundreds to thousands of bytes per instance (node, frame, rule, etc.). This paper describes a

knowledge representation scheme appropriate for a small portable computer.

Because of its hierachical nature, cave knowledge, including implicit knowledge assumed by current survey data techniques and geological and biological knowledge, is easily represented by a semantic net. By using a system of attribute chaining and adding the notion of frame slots, a conventional semantic net can be modified to optimize memory requirements. Arcs are implemented as a linked list of typed pointers, and nodes are data structures whose elements (slots) are defined by parallel nodes in another network partition.

Although the original intent of this design was to represent specific knowledge about a cave, it proved to be effective for other aspects of knowledge processing, allowing a common set of operators to be used. The final network is partitioned into specific knowledge, production rules and scripts, dynamic blackboards, metaknowledge, and node descriptions.

CAVE DIVING SESSION

UNDERWATER EXPLORATION OF RIO ENCANTADO, PUERTO RICO

Kevin Downey, 18 Forthill Ave., Northampton, MA 01060

This paper will be a slide presentation featuring the 1985 expedition to explore the sumped sections upstream and downstream of the Tito entranceto Rio Encantado. This joint effort of NSS and Cave Diving Section members has led to the discovery of continued passages beyond the upstream sump. The logistics of moving diving equipment from a vertical entrance through river passage and waterfalls should prove educational to all cave explorers.

MINE DIVING

Stephen C. Omeroid, 629 W Fourth St, Marysville, OH 43040

Man's continued curiosity for underground passages has led him to exploration of abandoned and flooded mine shafts. Documenting the mining techniques, historical artifacts and geological data are a few of the valid reasons for caving in these man made caves. The hazards of diving in passages supported by water soaked timbers and cluttered with mining equipment will be analyzed and discussed.

UNDERGROUND UNDERWATER EXPLORATION

Wes Skiles, PO Box 73, Branford, FL 32008

A look at the techniques and difficulties involved in the exploration of other than classic spring entrance cave systems. An incorporation of vertical, sump, side mount and Florida cave diving equipment and training.

CAVE DIVING EDUCATION

Steve Straatsma, 11209 N. Dale Mabry, Tampa, FL 33618

A beautiful representation of the many forms and types of phreatic cave passages throughout Florida and the Bahamas. The diving techniques and equipment required for the exploration of these unique and pristine underwater labyrinths is demonstrated in a flowing slide presentation.

ADVENTURES IN PARADISE

Dennis Williams, Box 491, Opa Locka, FL 33054

A once-in-a-lifetime excursion to the karst regions of the South Pacific. Four months of travel and exploration in Paula, Guam, Ponape, the Phillipines and Hawaii have produced an exciting look at underwater caving from around the world.

INTERNATIONAL EXPLORATION SESSION

PRELIMINARY RESULTS OF THE NSS JAMAICA COCKPITS PROJECT - EXPEDITION OF 1985

Fred Grady

In January of 1985 a party of nine cavers plus several Jamaican guides explored and surveyed 5 horizontal caves and 16 pits. Nearly all of the work was done in the cockpit area near Quickstep, Trelawny Parish, Jamaica. One cave surveyed in 1985 was near Acompong, while two pits were found in the Red Mountains.

About 1500 ft of horizontal passage were surveyed including Stephenson, Bonafide, Under Nose, Colin's Crack, and Big Well Caves. In addition a small amount of surveying was done in Marta Tick Cave to complete that map. Of the 16 pits, Menical's Glory Hole was the most impressive, being some 270 ft deep. A Tyrolean system was used to rig most of the pits making for safer descents and ascents.

Faunal remains noted in the caves included pseudoscorpions, spiders, millipedes, insects, and bats. Sub-fossil remains of vertebrates and mollusks were discovered in Bonafide and Stephenson caves.

THE CAVES OF THE SELMA PLATEAU, THE SULTANATE OF OMAN

W. Donald Davidson Jr, TT1 Suite 403, 1911 N Fort Myer Drive, Arlington, VA 22209

The Selma Plateau on Jabal Bani Jabir in the Sharquiyah of the Sultanate of Oman, contains a fossil karst system which is currently being explored as part of a water resources study. Six major caves have been located and partially explored with one and two person teams. Exploration has been conducted in one system to 4 kilometers and a depth of approximately 400 m from the entrance. The depth of four of the vertical systems exceeds 200 m and each is believed to extend well beyond the current depth of penetration. The longest free drops are 160, 140, and 120 m with mixed drops up to 165 m in depth. Ceiling heights of over 200 m are known. A subterranean chamber has been mapped which may be the second largest cave room reported in the world. The Selma Plateau stands at an elevation of 1200 m, and the base level for karstification is below the present sea level.

RIO CAMUY CAVE: EXPLORATION, DEVELOPMENT, AND RESTORATION

Jeanne and Russell Gurnee, RFD 852, Arecibo, Puerto Rico 00612

Recent explorations will be discussed as well as techniques used during the development and restoration of Cueva Clara de Empalme, a part of the Rio Camuy system, Puerto Rico. Slides of the system will also be shown.

THE 1984 MICRONESIAN KARST RECONNAISSANCE

Bruce W. Rogers and Charmaine J. Legge

A 2 1/2-month long karst reconnaissance throughout Micronesia was undertaken at the beginning of 1984. The Territory of Guam, the Commonwealth of the Northern Marianna Islands, the Republic of Belau, and the states of Yap, Truk, and Ponape of the Federated States of Micronesia were visited. Many small to moderate-sized limestone caves, blue holes, and spur and groove caves as well as volcanic rock shelters and lava tubes were studied and several important archaeological sites discovered.

In the Federated States of Micronesia, Yap possesses only groove and spur caves along the windward reef fronts. Ponape has shelters in volcanic rocks ranging from several tens of ft to over 120 ft wide and 100 ft high. Many have been modified by waterfall action and are important in local beliefs. On Truk is a 200-ft long and 30-ft in diameter segment of lava tube in a Miocene—aged basalt flow. In addition there is a pinnacle karst on Pliocene-aged nepheline basalt. Groove and spur caves are also present along the reef fronts.

The Republic of Belau possess an extensive Miocene(?) to Holocene drown karst that includes many heavily decorated, large, multicyclic caves; blue holes; and now marine lakes. Spitzkarren, "mushroom" islands, and cockpit karst are present as are phosphatized paleo-spitzkarren karst. Most older and newer generations of speleothems are calcite. However, some of the older flowstones quarried for Yapese stone money are aragonite.

In the Miocene to Holocene-aged limestones of Guam are many moderate sized caves and large discharge springs. Again the caves are multicyclic and have mostly calcite speleothems. Irregular hackly karst is the predominant surface form with some areas of spitzkarren and cockpit karst. Groove and spur caves are present along the reef fronts.

In the Miocene to Holocene-aged limestones of the Commonwealth of the Northern Marianna Islands are many moderate sized caves. On Saipan are several large springs as well as one large cave. On Rota are several moderate sized caves and one large spring. Tinian has several moderate sized caves. Pagan has many small to moderate sized lava tube caves, some of which are contemporary in age.

THE EXPLORATION OF TIGER CAVE, BELIZE, CENTRAL AMERICA

Bernie Szukalski, P. H. Dougherty

Tiger Cave, appropriately named because of the discovery of jaguar prints deep within the cave, is located near a large resurgence in the foothills of the Maya Mountains in southern Belize. Based on an initial reconnaissance of the cave and surrounding area by Percy H. Dougherty in the summer of 1983, a follow-up investigation was planned in May of 1984. During this trip two survey teams mapped nearly 2 km of mostly large trunk passage ranging from 15 to 30 m wide and 25 to 50 m high. Also surveyed were two large interconnected chambers, both measuring roughly 70 m wide and 120 m long with ceiling heights up to 70 m. Despite

finding no continuation of the main trunk beyond the chambers several relatively smaller leads seemed promising.

Another trip was organized during March of 1985, and teams mapped an additional 1.4 km of passage bringing the total to over 3 km. The major discovery of this trip occurred when a short climb and crawlway were pushed and a continuation of the main trunk was found. Later, survey teams would find Mayan artifacts in this section. Many leads remained unentered. Also partially explored and surveyed were lower-level stream passages that required vertical work as well as swimming or rafting. Although the total amount of new passage surveyed was less than was hoped, the importance of the trip was in discovering many large and promising leads, dramatically opening up the cave after the previous exploration.

KENTUCKY EXPLORATION SESSION

PINE MOUNTAIN OVERVIEW

Charlie Bishop

A general overview of Pine Mountain, its topography, geology and caves. Limited exploration has taken place due to the difficulty of accessing the limestone outcrop and limited potential for large cave systems. The potential does exist for numerous discoveries of unique caves.

CROOKED CREEK ICE CAVE, ROCKCASTLE COUNTY, KENTUCKY

Gary Bush, 6066 Shelrich Ct, Cincinnati, OH 45247

The exploration and history of this typical cave system in Rockcastle County will be discussed. The lower level of the cave has been known for many years and was used for saltpetre mining in the early 19th century. The more extensive upper levels, however, have only been explored in the last two decades. Virgin sections have been uncovered as recently as this past fall.

The cave typifies those found in the region, with meandering canyons developed along controlling joints. The multi-level nature of this cave is also typical of Rockcastle County caves. Current length is only 6100 ft, but a proper visit requires at least seven hours.

PRECINCT #11 CAVE, ROCKCASTLE COUNTY, KENTUCKY

Gary Bush, 6066 Shelrich Ct. Cincinnati, OH 45247
Dennis Green, 3216 Royal Oak Ct, Edgewood, KY 41017

Precinct #11 Cave, which was found in June, 1980, now stands as the second longest cave in Rockcastle County with over 9 km of horizontal passage. The expanse of ridge along the hillside promises significantly more passage. Significant paleontological remains have sparked interest in a careful plan to explore the cave with minimal impact.

A general discussion of the cave and its exploration via a slide tour through it will be presented. The gating of the cave, subsequent to the events of April 1983 will also be discussed.

TEN YEARS OF WESTERN KENTUCKY SPELEOLOGICAL SURVEY CAVING

Preston Forsythe, Hwy 431, Browder, KY 42326

Since 1975, the objective of the Western Kentucky Speleological Survey has been the systematic exploration and survey of the major cave area west of the Barren River. Before this time only a few caves had been documented from this Pennyroyal sinkhole plain, which averages 30 km wide (north-south) and 125 km long (east-west). Now, over 200 caves have been recorded with more than 93 km surveyed. Eight caves have been mapped to over 3 km. Most of the caves are of the phreatic tube type with active streams. Easy passage and large rooms are common, but long crawlways are more typical. Speleothems and vertical caving are at a minimum. To avoid lost data and duplication of effort, annual reports have been published for each year of work with the distribution limited and controlled to protect the caves.

HICKS—HIDDEN RIVER COMPLEX, HART COUNTY, KENTUCKY

Phil O'Dell, 120 Victory Ave, Lexington, KY 40502

This study was originally an Upland Research Lab project under Dr. James Quinlan and his cavers. Nurtured by Tom Ehlers, the group attained approximately 20 floodable miles through an entrance approximately 30 ft from the Green River. Penetration limits and constant danger of flooding restricted exploration to the summer months until Quinlan decided to drill a new entrance in the "J" survey where over 100 going leads infringe on Fisher Ridge Cave territory. The drill hole lay untouched for several years until summer 1984 when the landowner issued an ultimatum: The 17" drill hole, now a 6-ft sinkhole due to erosion, was to be finished or filled in. Tom Ehlers, Phil O'Dell, Dave Weller, and others blasted and are presently finishing the new entrance that is approximately 80 feet deep. Exploration will resume this summer with spectacular results expected, similar to those found in Fisher Ridge Cave.

MILLERS CAVE, ROCKCASTLE COUNTY, KENTUCKY

Gary O'Dell and Doug Carroll, 120 Victory Ave, Lexington, KY 40502

In the 1970s, Caves of Rockcastle County, by Rebman and O'Dell, reported on Millers Cave. Ten years later the Bluegrass Grotto became interested and has mapped over two miles. Millers Cave has two parallel walking passages, Pit Fall Passage and Opaline Way. Pit Fall Passage crosses over many pits and crevices. These two passages and several others come together in the complex "Malfunction Junction." Millers cave has a little of everything - waterfalls, pits, domes, drops, climbs, and chimneys. The Millers system now includes Millers, BFR, and Joint Caves through dug connections. The Millers system has five entrances including the "Hawg Hole" pit entrance.

LOGANS - GREENSNAKE CAVE SYSTEM

Mark Turner, 8161 Cinti-Dayton Rd Apt 306-Cadiz, Westchester, OH 45069

Logans Cave is located in Pulaski County, Kentucky. It has been explored since 1978 by the Miami Valley Grotto. Mapped passages now total a little over 3.5 km, with several going leads and an over 2-mi long cave nearby called Big Sink (or Deathtrap Cave) waiting to be connected. Logans-Greensnake is a complex cave with vertical and horizontal passages of many varieties and interesting geological features distributed throughout the cave. It has not yielded its passages easily, and continues to be a mystery in that the big main stream has yet to be discovered.

GEOLOGY - GEOGRAPHY SESSION

THE DEVELOPMENT OF SECONDARY POROSITY BY ASCENDING HYDROGEN SULFIDE GAS IN THE GUADALUPE MOUNTAINS, NEW MEXICO

Donald W. Ash and William L. Wilson, Dept of Geography and Geology, Indiana State Univ, Terre Haute, IN 47809

The morphology and depositional history of caverns within the Guadalupe Mountains of southeastern New Mexico indicate that their origin is completely different from that proposed for most caverns. These caverns are not related to subsurface water drainage nets, specific erosion levels, and do not display integrated subsurface nets. Present-day models for the development of these caverns invoke dissolution by sulfuric acid or gypsum replacement of limestone at the fresh water/saline water interface. These models are all subject to reinterpretation on hydrologic, stratigraphic, geochemical or morphologic grounds. These existing models may be modified to explain the mechanism of cavern development for Guadalupe-type caves as follows: hydrogen sulfide is produced by bacterial reduction of gypsum along the Castile-Bell Canyon contact or the Castile-Capitan contact in non-oxygenated, saline waters. The hydrogen sulfide ascends through the saline water, probably as microbubbles, to the fresh water - saline water interface. Since the fresh water is oxygenated, the hydrogen sulfide oxidizes to sulfuric acid which reacts with the limestone. some hydronium ions diffuse downward where they randomly dissolve voids which become boneyard. Boneyard is thus linked to the formation of large rooms and develops in poorly oxygenated groundwater. The location of major rooms are controlled by the location of the ascending hydrogen sulfide plume while the size and shape of individual rooms are controlled by the size and shape of the plume, the pattern of joints, the thickness of the fresh water lens, the length of time the plume persists, and the position of the fresh water - saline water interface.

STRATIGRAPHIC SECTIONS IN THE STE. GENEVIEVE FORMATION EXPOSED IN CAVERNS IN WESTERN MONROE COUNTY, INDIANA

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The Ste. Genevieve Formation and related strata in the Blue River Group comprise more than 250 ft of middle Mississippian carbonate deposition across the Indiana flank of the Eastern Interior Basin in Valmeyeran seaways. Karst outcrop and cavern exposures of these strata occur in the strike oriented Crawford Upland physiography. Karst valleys are a striking topographic feature along the margin of this rugged escarpment of Chester clastic strata.

Twenty-five mi of surveyed subterranean passages lie beneath the Garrison Chapel karst area occupying a western portion of a karst valley in the headlands of Indian Creek, an area of fifteen mi^2. Descriptions of drainage and cavern systems extending from sinkholes to springs have been the focus of previous investigations.

The bedrock floor of this karst valley is locally accordant with a continuous horizon of lithographic limestone ranging nine to fifteen ft in thickness within the lower Levias member as indicated

by structure mapping at five measured cavern sections. This lithographic unit is a decisive structural reference for mapping thickness and continuity variations in algal, breccia, and sandy facies in the overlying Paoli and Popcorn beds, and the subjacent Rosiclare member.

HEALTH ADVISORY ISSUED FOR BOWLING GREEN, KENTUCKY DUE TO HAZARDOUS FUMES RISING FROM CAVES

Nicholas C. Crawford, Center for Cave and Karst Studies, Western Kentucky Univ, Bowling Green, KY 42101

In March, 1985, the US Centers for Disease Control issued a health advisory for the Bowling Green, Ky area due to hazardous fumes rising into homes and buildings from caves beneath the city. The advisory initiated action by the US Environmental Protection Agency Emergency Response Team (Superfund) to investigate and correct the problem. This is the second Superfund response by EPA due to cave fumes in Bowling Green in the past two years. On both occasions Dr. Nicholas Crawford and the Center for Cave and Karst Studies at Western Kentucky Univ were employed by EPA to assist with the investigation.

Potentially explosive fumes containing low levels of benzene, toluene, xylene and other toxic chemicals began rising into several homes in December, 1983, in the Forest Park area, located above the Lost River groundwater basin. In November, 1984, fumes became a problem in the Parker-Bennett area, located above the Double Springs groundwater basin. The fumes have affected sixteen homes, one commercial building, one church, and two elementary schools.

Research and corrective activities include the following: a)ventilation of fumes by fans attached to pipes extended into bedrock crevices exposed by excavation, b) dye traces of suspected sources of the chemicals, c) investigation of volatile organics in the Lost River, and d) location of caves by: 1) exploratory drilling , 2) water levels obtained from wells, 3) dye traces, 4) micro-gravity, 5) down-hole cameras, 6) excavating entrances, and 7) cave exploration and survey.

Research findings are that fumes result from the volatilization of liquid chemicals in the underground streams. The sources of the chemicals include deliberate dumping into wells and sinkholes, accidental spills, and leaking underground storage tanks.

AN OVERVIEW OF KARST IN THE SULTANATE OF OMAN

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The Sultanate of Oman, on the eastern tip of the Arabian Peninsula, has extensive areas of active and fossil karst. The karst in northern Oman is developed mainly in the carbonates of the Umm Er Radhuma (UER) formation and the Wasia group, of Eocene and Middle Cretaceous age, respectively. Hoti Cave, developed on the monoclinal southern limb of the Jabal Akhdar Anticline, drains 28 km^2. Nearby Misfah Hell Hole transmits water to over 200 m below the surface; artesian wells have been drilled into the Wasia group downdip. On the Selma Plateau, in the Eastern Province, known caves exceed 4 km in length and 400 m in depth with the base level for karstification exceeding 1200 m below the plateau. The history of development has been partially defined and surface capture of subsurface drainage has been documented.

In the southern Dhofar Province the UER is extensively karstified and 94 km2 of surface drainage capture is associated with three major swallow and sinkholes between Tawi Atain and Tayq. The Tayq sink controls over 50 km2 of drainage and is 1.5 km x 250 m deep.

The varying precipitation patterns, which control present day karstification of the northern and southern regions, are controlled by the position of the Intertropical Convergence · Zone (ICZ). Troglobytic fish are reported from Hoti Cave and Tawi Atair.

IDENTIFICATION OF SECONDARY MINERALS IN VUGS FROM CAMPS GULF CAVE, TENNESSEE

Christopher G. Groves and John F. Hoffelt, Dept of Geography and Geology, Western Kentucky Univ, Bowling Green, KY

A group of secondary minerals are found in vugs within breakdown blocks in Camps Gulf Cave, Tennessee. These vugs contain various minerals which are uncommon in caves along the Cumberland Plateau escarpment of Tennessee.

Samples were collected of each mineral and of the vug matrix. Observations and measurements were recorded within the cavern to determine the position of the cave room in the stratigraphic section. The minerals were identified through simple chemical tests, measurements of specific gravity and hardness, observation of crystal form and color, measurement of refractive index (by oil immersion), and spectrographic analysis. The host rock was also analyzed to determine its position in the stratigraphic section.

The minerals from the vugs were identified as calcite ($CaCO_3$), dolomite ($CaMgCO_3$), barite ($BaSO_4$), celestite ($SrSO_4$), and fluorite (CaF_2). The breakdown blocks containing the vugs were identified as Bangor Limestone, a Late Mississippian, gray, petroliferous sparite. The vugs are developed between 20 and 35 ft above the base of the formation. The barite and celestite samples were found to be intermediate members of the barite-celestite solid solution series; therefore, the physical properties of the samples varied with the barium-strontium ratio.

The vugs and associated secondary minerals are thought to be a result of trapped seawater since there is no evidence of hydrothermal veins or of any igneous activity.

STORM WATER DRAINAGE WELLS IN KENTUCKY AND TENNESSEE: A STORM WATER MANAGEMENT TOOL FOR URBANIZED AREAS ON KARST TERRAINS

Christopher G. Groves and Nicholas C. Crawford, Center for Cave and Karst Studies, Western Kentucky Univ, Bowling Green, KY 42101

Karst landscapes formed upon carbonate rock often consist of concave depressions known as sinkholes which funnel runoff into integrated subsurface drainage networks. Sinkholes flood when 1) the quantity of storm water runoff received exceeds the capacity of the sinkhole to transmit water to the subsurface, 2) when the capacity of the underlying cave system is exceeded, and 3) when there is a backwater effect upon groundwater flow from the sinkholes with bottoms lower than the level of surface or subsurface streams at flood stage. Sinkhole flooding is particularly common in urban karst areas where pavement and other impervious surfaces increase the quantity of runoff and where sinkholes are often filled with debris, reducing storage capacity. In urban areas, homes and businesses are often affected by sinkhole flooding.

In order to increase the capacity of sinkholes to transmit runoff to the subsurface, many storm water drainage wells have been drilled or dug in the urbanized karst areas of Kentucky and Tennessee. A total of 572 drainage wells in the two states have been located and investigated for this research.

Investigation of these wells has shown that many have been successful in reducing or eliminating flooding problems, but that there are several potential problems associated with their use. These include: 1) pollution of the aquifer from contaminants associated with urban storm water runoff, 2) sinkhole collapse, and 3) mixing of groundwater between aquifers.

THE SALTPETRE - MOON CAVE SYSTEM, CARTER COUNTY, KENTUCKY

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The Saltpetre - Moon Cave system is one of the longest cave systems in Carter Caves State Park, Carter County, Kentucky, having a total length of 3005 m (9860 ft) and a maximum depth of slightly more than 25 m. Moon Cave is developed a the contact of the Pennsylvanian Lee sandstone and the Mississippian limestones, and the passages of Saltpetre Cave are found in the lower Chester and upper Ste. Genevieve Mississippian limestones. Four entrances provide access to this complex of passages, two in close proximity to one another in the small Moon Cave and two more widely separated in the relatively extensive Saltpetre Cave.

Most Major passages of the system are phreatic in origin, yet considerable vadose formation and enlargement of tunnels has also occurred, particularly in the lowest level. Moon Cave has been formed by solution action accompanied by much collapse associated with the rocks found along the contact between the sandstone and limestone as well as along bedding planes in the limestone.

Small pits (maximum 8.1 m), domes, three distinct levels, dry and dusty passages, and much evidence of a long history of use by man are characteristic features of this system. In addition, numerous 'kettles' are found in the ceiling of many portions of Saltpetre Cave and a large volume of earth has been excavated for pathways and/or mining operations along the intermediate level (major passage) of this northern Kentucky karst feature.

THE KARST HYDROGEOLOGY OF CANE CREEK, TENNESSEE

John F. Hoffelt and Nicholas C. Crawford, Center for Cave and Karst Studies, Western Kentucky Univ, Bowling Green, KY

The Cane Creek gorge, Van Buren County, Tennessee, is a karst region along the western escarpment of the Cumberland Plateau. The recent discoveries of some of the largest cave rooms in the United States and extensive subterranean rivers prompted an investigation by the Center for Cave and Karst Studies into groundwater flow routes, cavern development, and landform evolution.

Hypotheses were formulated concerning the association between the local geology, sinking streams, caverns, springs, and related karst landforms. Dye trace techniques, mapping of the geologic structure, and fracture trace analysis were used in testing the hypotheses.

Research proves that sinking streams from Cane Creek and Cave Hollow flow through Davis Tire Cave and Rice Cave. These streams join and this water is seen again in Dark River Cave and the Natural Bridge Sinks Caves. It then flows through Camps Gulf Cave and Inspiration Cave before resurging at Cane Creek Spring. The sinking stream from Dry Fork, a tributary of Cane Creek, resurges into Cane Creek at Big Spring. A sinking stream from Turkey Cot Cove, a karst valley, also resurges at Big Spring.

Fracture trace analyses compared with maps of caverns and subsurface streams show that groundwater flow routes and cave passages parallel major joint orientations. Surface valleys are also developed along major joints and in certain areas joints are exposed along the valley floor.

The Hartselle formation is a significant confining layer for subsurface streams; thus, the attitude of the formation influences groundwater flow routes. Maps of caverns and sub-surface streams used in conjunction with a structure map drawn on the top of the Hartselle formation show that subsurface streams flow downdip on the Hartselle until breaching the formation. This direction is often opposite surface drainage and drainage within the other Mississippian limestones.

The geologic structure map reveals the influence of structure upon landforms. Surface stream valleys do not appear to be significantly influenced by geologic structure, but karst valleys have formed along anticlines and domes.

SPELEOGENTIC RESPONSE TO ABRUPT CHANGE IN BASELEVEL, BALCONES FAULT ZONE, CENTRAL TEXAS

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The karstic Edwards Plateau of central Texas is bounded on the east and south by the 400 km long Balcones Escarpment. this topographic inflection corresponds to a broad zone of normal, en echelon faults produced by epeirogenic uplift and subsidence during the early Miocene Epoch. Concomitant lowering of regional baselevel and increase in relief along the fault zone imparted sufficient disequilibrium in the evolving geomorphic system so the asurficial streams in the vicinity of the escarpment began to incise rapidly. Lowering of potentiometric surfaces and oversteepening of hydraulic gradients within the extensive carbonate aquifers of the Edwards Group kept pace with topographic adjustments. Accordingly, caves of the region reflect both rapid change in baselevel and readjustment of drainage in response. Numerous relic caves in the uplands of the deeply dissected margin of the plateau were abandoned by groundwater soon after faulting. These caves consist largely of isolated or poorly integrated chambers. They represent the youthful character of the karstic aquifer prior to the Miocene. In contrast, caves at lower elevations and closer to present-day baselevel generally consist of lengthy, well integrated conduits. However, large cave systems (e.g. Cascade Caverns, Cave without a Name, Natural Bridge Caverns, and Inner Space Cavern) represent former flow of groundwater confined to fault blocks. Such compartmentalization of flow is characteristic of the phreatic zone of the extensive Edwards aquifer of central Texas. Furthermore, most caves (including those listed above) clearly demonstrate the role of fractures (largely induced during Miocene faulting) in conveying flow toward points of discharge at baselevel.

GEOLOGY OF FULTON CAVE, COLORADO

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Fulton Cave is a 1620-ft long alpine stream cave in the Flat Tops Wilderness on the White River Plateau in northwestern Colorado. Cave development is related to the uplift of Blair Mountain by Laramide-aged (65MYA-latest Cretaceous) thrust fault, which has thrust Precambrian granite from the west over Mississippian Leadville limestone. Late Pleistocene (10-30,000 YA) alpine glaciation was localized above 10,000 ft atop Blair Mountain, which later provided meltwater runoff into the relatively small catchment of the limestone on Blair Lake bench. Glacial runoff invaded extensional vertical fractures related to the faulting (which may have already had some early phreatic enlargement) and formed the 30 to 50-ft tall, vadose, scalloped, fissure stream passage. The eastward flowing cave stream is perched on sandy dolomites of the lower member of the Leadville limestone. Downcutting by the White River to the north resulted in the cave stream sinking through approximately 175 ft of Devonian Dyer dolomite along a fault or vertical fracture near the Fulton entrance to the present resurgence above the top of the Devonian Parting quartzite. The base level of the White River now lies 1240 ft below the resurgence. Massive fracturing in the limestone at the rear of the cave resulted in breakdown collapse into the stream fissure and formation of the highly decorated Boot Room. This probably will remain the westernmost extent of the cave, as the limestone soon terminates against the fault. Potential cave development may extend south of the Boot Room along the strike of the fault, but has not been found. Small streams flowing off the glacial cirque west of the cave sink upon reaching the upturned Leadville limestone to emerge below the Boot Room breakdown.

THE SKYDUSKY HOLLOW PHOTOGRAMMETRIC MAPPING PROJECT

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The Skydusky Hollow Photogrammetric Mapping Project is an excellent example of the application of surveying and photogrammetry to cave and karst study. It is the first part of a project to perform an overland control/entrance location survey connecting the surveys of the caves in the Skydusky Hollow system in Virginia. The resulting bi-level map will be of great service to the VPI Grotto of the NSS and the farmers of the area. It will show the relationship of the caves in the system to each other and the overlying karst topography.

This report describes the photogrammetric compilation of the topographic map, as well as describing the establishment of the control in the field necessary to compile it, locate the eight cave entrances and their resurgence spring, and orient and adjust the low order (Brunton and tape) cave surveys. It was planned from start to finish as an independent study project. All of the map compilation and much of the surveying was performed by a surveying and photogrammetry student at Virginia Tech working on her undergraduate degree in civil engineering.

LIMITS ON TIME AND DEPTH FOR THE DEVELOPMENT OF PHREATIC SOLUTION FEATURES

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Solution conduits generally contain features that developed above (vadose) or below (phreatic) a water surface. Many investigators record observations of solutional features whose form is interpreted to have developed by slowly moving waters over a long period of time far below the water surface, an environment called "deep phreatic".

Theoretical equations and laboratory experimentation predict that macroscopic (r>2m) solution conduits can develop in limestone under phreatic conditions during a minimum time of approximately 10,000 years. Field evidence from San Salvador Island, Bahamas, has allowed conduit formation time to be determined. Amino acid racemization analysis of the wall-rock enclosing a macroscopic (r>2m) solution conduit provide an age of approximately 85,000 years. A stalagmite in the conduit dated by U/Th methods was determined to be approximately 50,000 years old. Based on published Pleistocene sea level curves, within the 35,000 year time span available for conduit development the fresh water lens (which floats on sea level in a small carbonate island) needed to form the conduit could have been in the required position for no more than 10,000 years. These data agree with both the theoretical and laboratory findings.

Additionally, this tectonically stable island has not experienced a high sea level (and hence slightly higher fresh water lens position) of more than +6 m in the last 150,000 years. Caves on the island exhibit phreatic solutional features as much as 7 m above present sea level, thus precluding their development as deep phreatic phenomena.

PALEOSOLS AND KARST DEVELOPMENT, SAN SALVADOR ISLAND, BAHAMAS

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The surficial weathering of limestones by solution results in a weathering front consisting of insoluble residue and reprecipitated micritic calcite, often called a paleosol or calcrete. This weathering front, when preserved in the rock record, is an important indicator of subaerial conditions, with implications for climate, and correlation of widely spaced outcrops.

San Salvador Island, Bahamas, consists entirely of Pleistocene and Holocene limestones. Paleosols (or calcretes) are abundant, and are found overlying only Pleistocene limestones of a variety of types: subtidal, reef, intertidal, and eolian. The occurrence of paleosols commonly correlates with macroscopic karst features including vadose shafts, collapse sinks, and solution conduits. Paleosols can often be traced from the surface into underlying caves, indicating terrestrial depositional processes more recent than the time of cave formation.

Paleosol correlation and chronology was attempted using stratigraphic relationships, paleomagnetism, and amino acid racemization of available terrestrial gastropods (Cerion). Paleomagnetic analysis revealed that nearly all of the paleosols are normally polarized, and are thus indistinguishable on that basis. However, after RF and thermal demagnetization, samples from one stratigraphically distinct paleosol (lacking Cerion data) yielded a predominantly reversed polarity. The samples retained that reversed magnetic polarity through a range of temperatures. This reversed magnetism is the result of an in situ chemical event, and there is no plausible secondary source of reversal. These results suggest that this paleosol has an original reversed magnetic polarity with a chemically induced normal polarity overprint. These initial data indicate that this paleosol is at least 700,000 years old, as that is the minimum age of the Matuyama reversed epoch, the most recent reversed polarity epoch recognized by paleomagnetists. More recent transient reversal events (e.g. Blake Event) are possible but unlikely causes for the reversal. This paleosol thus covers the oldest surface rocks yet discovered in the Bahamas. The amino acid racemization data places active soil information for other overlying paleosols at approximately 10,000 to 20,000 years and 80,000 to 90,000 years

ago. It is postulated that these major soil formation episodes represent times of rapid denudation during Pleistocene pluvial climatic episodes.

DISCOVERY OF SEPARATE FLOW REGIMES TO THE SAN MARCOS SPRINGS: NEW METHODS FOR SUSTAINING THEIR DISCHARGE

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The San Marcos Springs are the third largest springs in Texas with a historic range in discharge of 46 to 316 cfs and an average of 161 cfs. An Edwards Aquifer model by Klemt et al (1975) proposed that the flow to the springs could cease as early as the year 2020 due to increasing water use by San Antonio. This model assumed homogeneous flow to all the spring orifices for the surrounding area. Initial dye tracing to the springs showed that some of the various spring orifices were separated hydrologically. Subsequent weekly sampling of the springs showed that "older" water from the San Antonio "pool" of the aquifer was higher in temperature and dissolved oxygen content. These southern most spring orifices show much less fluctuation of all measured chemical parameters than the northern spring orifices, which are believed to be recharged primarily from "younger" and local recharge water.

A detailed potentiometric surface map was then constructed from eighty water level measurements in a 50 mi^2 study area surrounding the San Marcos Springs. This map was constructed in November, 1984, during an extended drought period when spring discharge averaged around 70 cfs. The resultant potentiometric surface map shows flow to occur in separate fault blocks with average hydraulic gradients of only 5 ft/mi. The map shows distinctly that recharge takes place from the sinking waters of the Blanco River along a stretch about 6 mi to the north. Also, one dye trace from a cave beneath this river reached the springs in about 380 days. Therefore, by either drilling shallow holes in the river bottom, diverting river water to bedrock sinkholes along the river banks, or by constructing a dam, up to 80,000 acre-ft/yr of recharge water could be contributed to the aquifer to maintain spring flow.

THE HORN HOLLOW CAVE SYSTEM, CARTER COUNTY, KENTUCKY

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The Horn Hollow Cave system is located in Carter Caves State Park in the northern portion of the Easter coal field in north central Carter County, Kentucky. The picturesque downstream entrance is located in a 5.5 m high face. There are two entrances to the cave. The other walk-in entrance is located at the upstream end of the cave, and is approximately 4.5 m high. A small tributary stream enters from the north whose source is a 6 m high dome with a stream entering from the top. As one enters the 4.5 m high entrance the floor rises steeply and within 25 m the height is reduced to 2m. The elliptical tube continues to the west and north with dimensions varying from 5-10 m wide and 1.4-2 m in height until the upstream entrance is met. About half way down the passage a small crawlway goes to the right. The passage eventually meets with Rimstone Cave (Boundary Cave) and also leads to another short crawl through water to a surface window. As one enters Rimstone Cave there is a breakdown room about 5 m into the cave. Above this breakdown it levels off and to the left it continues as a mud flat area but to the right it opens into two domes and at the far end many small rimstone dams can be found. These two caves combine to have an overall length of about 601 m (1973 ft).

BOULDER CAVES OF CALIFORNIA

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California has some great limestone, lava tubes, and sea caves but it also has some of the best talus systems in the world. Work over the last couple of years has lead to talus systems in excess of 2 km long and depths of over 150 m (500 ft). These caves can only be explored in low water, for active Sierra streams feed these caves. Climbs and swims through scalloped granite walls make these caves unique in the world of caving.

EVALUATION TECHNIQUES AND CONCLUSIONS FOR UNCONTROLLED HAZARDOUS WASTE SITE INVESTIGATIONS IN KARST AREAS

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Karst areas are noted for having deranged surface topography and well integrated subsurface drainage. The movement of groundwater in karst areas commonly occurs in well defined conduits and has a relatively high velocity. The investigation of groundwater pollution in karst areas occurring from spills, intentional dumping, and uncontrolled hazardous waste sites requires a good understanding of karst hydrology. Many traditional site investigation techniques cannot supply the needed information for proper evaluation. This paper will use a case study approach to discuss proper and improper investigation techniques and conclusions to determine groundwater contamination in karstic aquifers.

Emphasis will be placed on delineation of drainage basins, selection of sampling locations, placement of monitoring wells, and consultant conflict of interest problems.

HYDROLOGY OF THE INNER BLUEGRASS KARST IN NORTHERN FAYETTE AND SOUTHERN SCOTT COUNTIES, KENTUCKY

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Nine major groundwater basins have been delineated by dye tracing techniques within an area of approximately 115 mi^2 in northern Fayette and southern Scott counties, immediately north of Lexington, Kentucky. The study area is bounded by North and South Elkhorn Creeks and Town Branch. This area is underlain by predominantly horizontal limestones of the Lexington Limestone (Tanglewood and Grier Members) of Middle Ordovician age.

Optical brightener (FB28) and Direct yellow (DY96) dyes were employed as the primary groundwater tracing agents in the study area. In order of decreasing, minimum basin size (and also spring discharge), these are: Royal Spring (9 mi^2), Russell Cave Spring (6 mi^2), Slacks Spring (4.5 mi^2), Lindsay-Spring Lake Springs (2.5 mi^2), Silver Springs (2 mi^2), Vaughan Springs (2 mi^2), Nance Spring (1.5 mi^2), Gano Spring (1 mi^2) and Santen Spring (.75 mi^2).

Distance from input to output ranges from about .25 mi to over 9.0 mi, averaging almost 2.0 mi. All dye traces exhibited travel times no longer than one week. Interpreted groundwater flow paths indicate basin morphology ranging from essentially linear (Royal Spring) to highly dendritic (Russell Cave Spring) with flow appearing to be controlled in part by fracture trends and dip. Groundwater basins may or may not correlate with surface water basins and in the Nance and Vaughan Springs basins, actually breach local base level streams. Discharge estimates of the major springs from May, 1979, to May, 1981, yielded base or average low flows ranging from about 0.5 cfs to 7 cfs, with peak flows estimated from 7 cfs to at least 70 cfs.).

FORMATION OF SINKING VALLEY, KENTUCKY AND THE BIG SINK CAVE SYSTEM

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Sinking Valley is located on the western edge of the maturely dissected Cumberland Plateau in Pulaski County, Kentucky. It is a north to south trending valley parallel with Buck Creek which drains into the Cumberland River. This paper investigates the formation of this 80 km^2 karst valley through the evidence left by paleo-drainage and cave passage development. It shows that the valley, which is approaching a near polje condition, has been formed through the progressive horizontal stream capture of surface and groundwater basins. This has been aided by the regional dip of the strata and the occurrence of faulting in the area. Results of dye tracing and cave mapping show the stages in the development of the valley. Superimposed on the natural processes at work in developing the karst valley are the human influences which have resulted in alluviation of the valley floor and frequent flooding.

SLOANS VALLEY CAVE SYSTEM

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At nearly 40 km, the Sloans Valley Cave System is the second longest in the state of Kentucky since the merger of Roppel with Mammoth Cave. Sloans Valley is located in the dissected western edge of the Cumberland Plateau where the Cumberland River has become entrenched. Since this is the largest cave near the convention site, a detailed analysis will be presented in two parts. The areas around the Post Office entrance, Hall of Giants, Hughes Passage, P Passage, and the Big Room will be discussed by Gary Bush. The Minton area, Martins Creek, Great Rock Sink, Railroad Entrances, and other areas will be presented by P. Dougherty.

MOONMILK AND RELATED MINERALS IN MISSOURI CAVES

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"Moonmilk" and associated minerals were investigated in Missouri caves during the period 1967-1970. The information gained still appears significant today.

At the time, all known occurances of moonmilk in Missouri were investigated, in a total of approximately 20 caves. The deposits range in size from a few gm to several hundred kg. In most cases the powdery to pasty white deposits were found to be hydromagnesite. A few occurances of huntite, sometimes admixed with hydromagnesite, were found, and a single deposit of magnesite was discovered.

An associated mineral, forming white crystalline crusts or rinds is nesquehonite. Once discovered, nesquehonite was found in

every cave visited and is apparently the third most common cave mineral, after calcite and aragonite. All nesquehonite was found in proximity to entrances or near surface passage terminations. It can be used as an indicator of surface proximity. Its occurance in apparently related to the entrance area micro-climate. The rarity of its recognition is perhaps due to its being mistaken for gypsum.

A single occurance of white moonmilk veins in clay banks was composed of an unidentified mineral which gave sharp x-ray diffraction peaks, and was soluable without effervescence in hydrochloric acid. It remains unidentified.

Other minerals found include dolomite flowstone, apparently secondary after calcite, and dolomite after aragonite anthodites. A single sample of cave coral which was examined was found to be composed of monohydrocalcite. Perhaps this mineral is a necessary precursor for the formation of this type of speleothem.

The occurance of these several magnesium bearing carbonates is undoubtedly enhanced by the caves being formed in dolomite or dolomitic limestone.

CALCITE TREE LIMB CASTS IN A NORTHERN ALABAMA CAVE

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Unusual speleothems were found at one site along a narrow canyon passage in a previously unexplored cave in northern Alabama. The speleothems were located 1 to 1.5 m above the passage floor immediately before a constriction in the passage. the speleothems extended perpendicularly from both walls of the passage and were up to 0.7 m long and 0.15 m thick at their base. The speleothems were hollow and upon close examination it was clear that they were casts of tree limbs. The texture of the bark as well as knots and branches were clearly visible. In one case an exquisite impression of an oak leaf was found. The mechanism by which the casts were formed is not immediately obvious. We speculate that the tree limbs were deposited with leaves and other debris on the floor of the stream passage at the constriction. Subsequently, calcite up to several cm thick was deposited at a rate that was probably slowed as a result of entombment. The casts were later exposed due to approximately 1 m of downcutting of the passage by stream action.

FAULTING AND SEDIMENTATION IN BLACK WALNUT CAVE (ALA 194)

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Previous investigations in the southern half of Newsome Sinks have identified a normal fault (15 ft displacement, dip 70 degrees to east and strike N 17 W) approximately coincident with the topographic axis of Newsome Sinks Valley (Varnedoe, W.W. and Lundquist, C.A., NSS Bulletin Vol 45, No 2, insert between pp 34 and 35, 1983; Varnedoe, W.W. and Lundquist, C.A., Geo^2, Vol 11, p 48, 1984). Black Walnut Cave lies essentially on this axis at the north end of the valley. The cave lies just under the Pottsville Sandstone which caps Brindley Mountain around Newsome Sinks. A fault with nearly the same strike and dip as that previously studied crosses the cave; however, its exposed displacement is only two feet. The cave is basically a short east-west canyon segment, still actively developing at the west end and plugged with breakdown on the east end where it intersects the fault and the valley. In the present cave passage on top of the breakdown, a five foot thick section of sediment is exposed in the walls. This seems to be a previous void, i.e. fossil cave, that was subsequently completely filled with layers of sediment. The small fault passes through the sediment and exhibits evident plastic deformation of the sediment beds. This can be interpreted to show that faulting and solutional speleogenesis were contemporary or interspersed processes in the development of Newsome Sinks.

ORIGINS OF THERMAL WATERS IN GRUTAS DE TOLANTONGO, HIDALGO, MEXICO

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Grutas de Tolantongo is a large hydrothermal karst spring developed in highly folded Cretaceous limestone within Mexico's Central Geothermic Zone. Over over 3 cms (cubic meters per second) of water discharge from the cave spring and an additional 5 cms from minor springs. Springflow temperature is 40 degrees C due to groundwater circulation through the 2.2 km deep Chalmita syncline. The high geothermal gradient of the syncline raises groundwater temperatures to 83 degrees C, and subsequent cooling occurs as water rises towards the surface and by mixing with non-thermal waters. This hypothesis is supported by use of the geothermometer, a geochemical equation which determines water temperature at the heat source. Further work is required in defining the Tolantongo drainage basin. The basin as described in the literature does not balance the region's water budget; discharge greatly exceeds the proposed recharge. Geochemical and structural evidence indicate the springs' drainage basin extends further to the northwest, and some piracy may be occurring from areas designated to other drainage basins.

SINKHOLE COLLAPSES INDUCED BY CHANGES IN SURFACE DRAINAGE

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Sinkhole collapse of unconsolidated material often occurs as the water table falls below the regolith-bedrock contact during droughts or because of excessive pumping. However, in areas where the water table is normally well below the regolith-bedrock contact, such as the Pennyroyal sinkhole plain of Kentucky, collapses usually occur during or after major rains. An investigation of sinkhole collapses in the Bowling Green, Kentucky, area by the Center for Cave and Karst Studies has revealed that the great majority of the collapses investigated were the result of 1) land use changes which increased storm water runoff and 2) modification of surface drainage by the construction of ditches, storm water retention basins, drainage wells, etc. The rapidly growing Greenwood area of Bowling Green was selected for an intensive investigation which included the following: a) the excavation of several sinkhole collapses, b) exploration of shallow caves where regolith arches are visible form below, and c) the installation of water level recorders on wells, one of which records the level of the main subsurface stream draining the Greenwood area.

Preliminary findings indicate that construction and land use changes which concentrate surface runoff in drains and impoundments may locally increase the downward movement of water, resulting in piping of saturated regolith into openings in the bedrock. The resulting regolith arch may then grow upward by piping and spalling, resulting in a collapse on the surface. Other collapses may occur due to increased runoff directed into subsurface streams, causing them to rise locally above the regolith-bedrock contact. Thus regolith arches may become saturated from below, and spalling may occur as the water level drops because of the extra water weight added to the arch.

SPELEOGENESIS: A GEOCHEMICAL - MASS TRANSPORT MODEL

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New models for the development of caves can be constructed by integration of models for the chemical dissolution of calcite, models for fluid flow in fractures and conduits, the hydrogeologic setting, and the specific discharge characteristics of the catchment area with which the cave is integrated. Integration phases are most sensitive to the arrangement of hydraulic pathways provided by the structural setting. Three critical thresholds mark the transition from fracture aquifers to conduit aquifers. The usual development is toward a deeper and more extended fracture system draining toward a shallow, high transport rate conduit system.

Cave passage size is determined by base level stability and by catchment area. Vertical development is a balance between continuous downcutting driven by slow and continuous base level lowering and abrupt shifts to lower levels triggered by irregular shifts in rate of base level lowering and by critical thresholds of sediment transport.

THE APPLICATION OF MICROFOCUS RAMAN SPECTROSCOPY TO THE IDENTIFICATION OF MINERALS FROM CAVES.

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Raman Spectroscopy is an inelastic light scattering experiment that permits the measurement of the fundamental modes of vibration of a crystal or molecular material. The spectrum serves as a characteristic "fingerprint" for identifying minerals. The excitation source for the sight scattering is an argon ion laser that can be focused onto a thin section or powder mount to a limiting spatial resolution of 1 um allowing the examination of individual grains in polymineralic samples. Carbonate and sulfate minerals each have one or more intense Raman bands in the range of 900 to 1,100 cm^{-1} due to the symmetric stretching motions of the CO_3^{2-} and SO_4^{2-} molecular anions. These bands undergo chemical shifts depending on the details of the crystal environment allowing the identification of individual minerals. Reference spectra are provided for the carbonate and sulfate minerals commonly found in caves and the application of the method to the characterization of fine-grained crusts and other nondescript cave deposits is illustrated.

EVOLUTION OF GROUNDWATER FLOW PATHS IN THE GARRISON CHAPEL KARST VALLEY, INDIANA

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Garrison Chapel Karst Valley is located 11 km southwest of Bloomington in western Monroe County, Indiana. Prior to karstification, the valley drained 4 km south to Indian Creek. At

present, drainage is westward through cavernous routes to springs within tributaries of Richland Creek at elevations 40 to 50 m below the floor of the karst valley.

Richland Creek became deeply incised as a result of diversion of the Teays River into the Ancestral Ohio River during the early Pleistocene. Subsequently, the valley was partially filled by clay deposited in an ice-marginal lake that was probably associated with a pre-Illinoian glacier. Cavernous drainage of the area provides an especially fine example of subterranean piracy and groundwater flow path evolution in response to base level changes.

The Paoli and Ste. Genevieve limestones (Mississippian) are the host rocks for cavernous drainage. The formations constitute a karst aquifer 34 m thick that dips generally west at 6 to 11 m/km. Interbedded sandstone, shale and thin limestone units overlie the karst aquifer. In Garrison Chapel Valley and the adjacent ridges there are 12 major caves and more than 27.3 km of surveyed passage. One to four abandoned levels and one active drainage level occur in each of the caves. Out of 27 passages studied in caves on the west side of the valley, 24 are developed in the middle 11 m of the limestone section. The stratigraphic positions, gradients, and flow nets of abandoned and active flow paths indicate a major change in the character of flow paths from pre-glacial non-entrenched to post-glacial entrenched conditions.

Pre-glacial karst drainage usually consisted of large diameter (3 to 10 m), strike-oriented tubes with dip-oriented tributaries on the up-dip side. Collapses of some passage segments produced complex diversion routes. Passages are usually accordant with lithologic units. Strike-oriented segments have gradients of 3.8 to 9.8 m/km and formed under at least 2.4 to 4.6 m of hydrostatic pressure. Dip-oriented upper levels have gradients of 3.8 to 9.8 m/km. Surface stream entrenchment and base level lowering cause abandonment of many phreatic flow routes. Modern cave streams are dip-oriented, gravity flow systems that down-cut through the stratigraphy. Passage cross-sections range from low tubes to canyons that have gradients of 8.5 to 73.1 m/km. Active Streams are located above the modern water table during low flow conditions, and discharge through occluded cave springs near the top of the unconsolidated valley fill.

SEA CAVE DEVELOPMENT ALONG THE CENTRAL CALIFORNIA COAST

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An inventory of the sea caves and other allied forms of the central California cost, including Pt. Reyes National Seashore, Golden Gate National Recreation Area, and the San Mateo Coast District of the California Department of Parks and Recreation has been underway for nearly a year. As of the end of March, 1985, over 160 sea caves have been located, mapped and studied. The size of the features inventoried range from short, albeit impressively sized, 40 ft (112 m) in diameter arches to 315 ft (96 m) long, multi-passaged caves extending into the dark zone.

In the southern portion of the study area the caves are developed in Tertiary aged marine sedimentary rocks, generally sandstone, siltstone, and conglomerate. In the central and northern portions of the area are located crystalline and metamorphic rocks of Mesozoic age that include Cretaceous granodiorites and a complex suite of subduction derived graywackes, cherts, diabases, and greenstones of the Franciscan Assemblage. The development of the majority of the sea caves in the softer sedimentary rocks is guided by jointing, except in massive sandstones where faulting is responsible. In the harder crystalline and metamorphic rocks, faults play a more important role with nearly a third of the caves developing along them. Lithologic and other structural controls play a very minor role in all rock types.

Secondary mineralization in the sea caves is sparse with sodastraw stalactites, draperies, flowstone, coralloids, crystals, and crusts having been recorded. Most of these forms are comprised of calcite; however, jarosite, gypsum, halite, and taranakite have been identified.

Many of the caves are inaccessible to the casual tide pool enthusiast and thus have a relatively intact biota. Encrusting sponges, hydroids, hydrocorals, anemones, chitons, snails, limpits, mussels, barnacles, crabs, sea stars, and sea squirts are among the most visible marine forms observed along with various green and brown sea weeds, sea grasses, and coralline seaweed.

SPELEAN HISTORY AND SOCIAL SCIENCE SESSION

GEOGRAPHIC DISTRIBUTION OF KENTUCKY SALTPETER SITES

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This paper records the geographical distribution of saltpeter and gunpowder sites in Kentucky. There are 172 saltpeter and 31 gunpowder installations inventoried in this state. Cultural influences exercised by pioneer explorers and later the settlers is an over-riding criteria for selecting saltpeter and gunpowder sites. This is visible as a direct relationship to site selection adjacent to early wagon roads. This produced a cluster phenomena related to road position, hydrogeologic considerations, and the the presence of forest. Absence of forest cover insured the cave or rockshelter would not be a profitable venture. There are no saltpeter sites known from the Inner Blue Grass section nor from the Sinkhole Plain in the Mississippian Plateau region between Brandenburg and Bowling Green. Powder factories were built closer to wagon roads and nearer to population centers.

Eastern Kentucky is the real heart of the saltpeter industry where rockshelters under production probably out numbered the cave saltpeter sites by about 100 to 1.

Based upon on-site visitation and the review of 59 available saltpeter cave maps, I found the saltpeter miners had a site preference for certain kinds of caves. 66% of the population occurs in caves with maze-like features and 34% are found in dendritic type caves. The excavations are concentrated in the maze features of the cave. Also, 62% of the population has one entrance and 38% has multiple entrances. Maze features probably maximized soil-rock contact needed for saltpeter generation/regeneration within a limited horizontal area. The saltpeter caves account for less than 4% of the more than 3,700 caves inventoried in Kentucky. This is a very small percentage which helps to strengthen the idea that the saltpeter entrepreneurs were even more site selective.

SAMUEL BROWN AND HIS 1806 MEMOIR ON SALTPETER AND GUNPOWDER

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Between 1802 and 1806 Dr. Samuel Brown, M.D., became the leading authority on the manufacture of saltpeter and gunpowder from caves and rockshelters in Kentucky. His investigations into the manufacture of these commodities differs from his predecessors in that he went to the saltpeter sites and talked with the operators and observed refining methods. By 1904 he became part owner with Thomas Hart Jr. in the saltpeter-gunpowder venture at Great Saltpeter Cave in present day Rockcastle County, Kentucky.

A monograph on the manufacture of saltpeter and gunpowder was finished on November 10, 1805 and sent to his life-long associate, President Thomas Jefferson. The paper went with instructions to send it to the Secretary of the Navy, Robert Smith, and to bring it to the attention of the American Philosophical Society. There is enough circumstantial evidence to suggest that Brown orally delivered his paper on February 7, 1806 to the American Philosophical Society in Philadelphia. His paper was published to a less than enthusiastic audience in 1809.

From 1806 to 1819, Samuel Brown seems to have gone into a kind of self-imposed exile in Natchez, Louisiana, and Huntsville, Alabama. The reason seems to be his involvement in the Arron Burr conspiracy to invade Mexico, Florida, and secede the Louisiana Purchase and New York State from the Union. Samuel Brown was indicted as a co-conspirator but was never brought to trial.

MONK ESTILL: KENTUCKY'S FIRST EXPERIENCED POWDER MAKER

Angelo L. George, A.L. George Consultants, 1869 Trevillan Way, Louisville, KY 40205

Lewis Collins (1847), in his History of Kentucky, credits Monk Estill as the first gunpowder maker in Kentucky, Monk was a slave to Captain James Estill, who learned the art of saltpeter-gunpowder manufacture in an exposed settlement in the Greenbrier Valley of Virginia. In 1775, James Estill built a fortified station about 15 miles south of Fort Boonesborough, Kentucky. One year later Monk moved to Kentucky and took up residence with his master at the station.

Monk set about the task of saltpeter mining from Adams (Payton) Saltpeter Cave in present day Madison County and probably made the gunpowder at Estill Station. He manufactured emergency gunpowder supplies at Boonesborough in the spring of 1780. Monk figures prominently in the March, 1782, defense of Estill Station and at the Battle of Little Mountain near Mt. Sterling, Kentucky. He was made a hero and given his freedom by his new master, Wallace Estill (Smith, 1886).

LINNVILLE SALTPETER CAVE

Cato Holler, Jr.

The first documented saltpeter cave in North Carolina has recently been discovered in northern McDowell County. Unlike many of the large, better known saltpeter caves around the country which were mined for military nitrate supplies, evidence suggests that this small cave was the secret source of domestic saltpeter for one of the early settlers of the area. Using the cave deposits, he would manufacture his own high grade of gunpowder and sell it along with homemade bullets to other residents of the community.

A recent analysis of the cave soil shows an unusually high yield of nitrate, for surpassing that of thirty other saltpeter caves sampled in the southeast.

THE LOST CAVES OF MARIBEL

Norbert H. Kox and George Zachariasen

The history of the area near Maribel in east central Wisconsin has been studied because of old re[ports and photos of several large, extensive caves in the area. While no extensive caves have yet been found, many small caves and much information about the area have been discovered.

A property referred to as "Cooperstown Caves" in early plat books was sold to the Steinbrecker family in 1892. Charles Steinbrecker designed a health spa and resort with the purpose of exploiting the caves and mineral springs on the property. A stone hotel with spring water piped to each room was opened in 1900. This was known as the Maribel Caves Hotel, perhaps named for Charles' wife Mary. The resort attracted many customers in the early 1900's. Advertising in a 1903 brochure included mention of "...four wonderful caves...open for anyone to go as far as he will, for on one has yet sounded their depths."

Up until the mid 1920's the caves were open and at one time admission was charged and a refreshment stand was set up near the caves. By 1930 the caves were closed by rockfall, perhaps natural, perhaps dynamited. A search in 1930 turned up no entrance to the main cave.

In early 1984 Norbert Kox initiated a search for the lost caves. A few days of ridgewalking turned up 33 unknown caves and five previously known ones on 450 acres which were formerly part of the resort. All caves were small and several digging projects have been started in an attempt of find the main caves.

CAPTAIN SYMMES AND MAMMOTH CAVE

Harold Meloy, Shelbyville, IN

Mammoth Cave has a rich heritage of history, legend, and folklore. It has been described as a "repository of slowly accumulating historic and biographic fact, of wit and humor and imaginative interpretation, handed down in the form of place names and more or less apt remarks flowing from the lips of jovial guides." Some features were named to honor the memory of notable people, such as Rafinesque, Silliman, and Cleveland. Others were named perhaps with tongue-in-cheek, such as Tribble's Trouble and Symmes Pit. Long before the days of Stephen Bishop, the guides knew of the deep pit far from the entrance in a remote avenue of the cave beyond Chief City. This pit was to receive a colorful name.

Captain John Cleves Symmes (1780-1829) lived in southwest Ohio. After he turned 21, he enlisted in the army and rose through the ranks to become a Captain during the War of 1812. After the war he retired from the army to Newport, Kentucky, and devoted his time to scientific and geographic subjects. He lectured throughout the country and wrote on the theory that the world was a hollow sphere, open at the poles, and that within were races of men and animals different from those on the surface. At a public meeting held in Frankfort, a resolution was adopted that the United States Congress should fit out an expedition to the Arctic Circle, under his command, in order to find, if possible, such a polar pit.

Symmes died in 1829. Within two years the people at the cave were showing "Symmes Hole," and since 1835 it has been known as Symmes Pit.

DURHAM CAVE, PENNSYLVANIA

Jack H. Speece, 711 E Atlantic Ave, Altoona, PA 16602

Although Durham Cave is not a significant speleological feature, its recorded history dates back to 1770. The cave was partially destroyed in the mid 1880s, but became the site of an archaeological study by Henry Mercer in 1893. It has been a local attraction form the time of the first settlers. This natural curiosity has been described by numerous historians throughout the years.

PALEONTOLOGY SESSION

SECOND ANNUAL REPORT ON THE PALEONTOLOGY OF THE CAVES AT THE JOHN GUILDAY CAVE PRESERVE

Fred Grady

During 1985 work on paleontology at the caves near Trout Rock centered in the deposits in Hamilton and to a lesser extent Trout Cave. Twelve trips were made into Hamilton Cave centering on areas where large felids had been previously found. Additional elements of two saber toothed cats, Smilodon sp., were recovered mostly by screen washing of cave sediments. Several additional parts of the large Pleistocene cheetah were also recovered. Foot elements of a large wolf sized canid are the first such remains from Hamilton Cave. The screen washing produced many small vertebrate bones and teeth.

Five trips were made into Trout Cave, and about 1,500 pounds of sediment were collected for screening. A tooth from Trout has been tentatively identified as the extinct wolf Canis armbrusteri. Measurements of the extinct muskrat Ondatra annectens suggest the deposits in Trout Cave are in part more than 600,000 years old. A new (third) locality in Trout Cave was prospected with good results.

A PRELIMINARY REPORT ON THE FAUNA FROM WORMHOLE CAVE, PENDLETON COUNTY, WEST VIRGINIA

Fred Grady

In 1984 three excavation trips were made into Wormhole Cave, Pendleton County, West Virginia, following up on the discovery of a tapir tooth. A fauna including some 40 mammalian species was recovered mostly by screen washing cave sediments. Three or possibly four species are extinct. Several taxa are northern species not now found in West Virginia, while two are prairie species. The fauna is believed to be late Pleistocene in age and is similar in many respects to several other faunas recovered from Pendleton County caves.

RECREATIONAL CAVING SESSION

YOUTH GROUP CAVING

Catherine Bishop, Route 7, Box 635, Frankfort, KY 40601

By assisting organized youth groups with caving activities, experienced cavers can help to meet goals of the NSS and of the youth groups. Attention must be given to preparation of leaders and group members, selection of suitable caves, and safety precautions including the use of a comprehensive waiver of liability.

CAVING: MORE THAN MEETS THE EYE

Tom Clark, Blacksburg Parks and Recreation Dept, Blacksburg, VA

Caving totally involves all participants in an environment unlike any other. An environment not only of beautiful formations, unique wildlife, and open pages of history, but also of experimental outdoor recreation/education. In the truest sense, it is a benefit to any person willing to take his time and learn about these special places. With this in mind, I will provide positive reasons for recreational caving as an activity for a responsible municipal government. Caver responsibilities, environmental ethics, safety, physical skills, inner awareness, group support, respect for human rights, and clean, healthy fun are the cornerstones upon which this paper is elaborated.

IRRESPONSIBLE CAVING: AT WHOSE EXPENSE?

Gary G. Nussbaum, Dept of Recreation and Leisure Services, Radford Univ, Radford, VA

Irresponsible caving, recreational or otherwise, can adversely impact the cave, its community of cave inhabitants, the cave owner, other responsible cavers, and if we are the irresponsible cavers, ourselves. Rock climbers pioneered a "clean climbing" ethic. Given the extremely fragile nature of the cave environment, there is even greater need and urgency for cavers to promote a "clean caving" ethic. Because caves (at least in the East) are typically on private land, cavers apply a private, personal code of conduct and behavior to caving. A universal code of conduct and behavior must be formulated and promoted so that an ethical and ecological rather than personal standard will be applied. Ecological and ethical standards are the "restraints" through which the individual caver may become more aware of himself as well as the totality of the cave and its community of inhabitants. The cave is not merely a playground for the satisfaction of sporting needs, but ultimately an arena for the transcendence of ego- and anthropo-centric viewpoints.

GOING WITHIN - RESPONSIBLE THERAPEUTIC AND RECREATIONAL CAVING

Huldah Warren, Counselling Coordinator, Sierra II, Juvenile Court, Virginia Beach, VA

One may ask if environmentally sound caving can truly exist. True, once man has plunged into the dark spaces of a virgin cave, the fragile ecosystem will be altered to some extent forever. Nevertheless, outdoor educators have been able to rationalize and justify the use of caves as a means to the achievement of recreational and therapeutic ends. A group that is technically prepared in training, equipment, and experience; emotionally primed; and experientially reinforced is able to have a healthy experience that also minimizes impact on the cave environment. The amount of environmental impact is directly related to the technical and psychological readiness of the leaders and participants. The factors of technical and psychological readiness help lessen the levels of stress and anxiety for the caver and permit a natural experience.

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