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A Review of the Invertebrate Fauna of Volcanic Caves in Western North America

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ABSTRACT

The known invertebrate inhabitants of volcanic caves are listed together with comments on their ecology and distribution. Several highly specialized troglobitic species are present in these caves. The microclimatic similarity of volcanic to limestone caves is discussed. The occupation of temperate volcanic caves was precipitated by changing Pleistocene climatic conditions, just as was the occupation of temperate limestone caves.

INTRODUCTION

Lava tubes and other types of caves in volcanic regions often are not well-regarded as potential sites for biospeleological investigation. Vandel (1965) entirely omitted them from his comprehensive review of biospeleology. He did, however, mention some of the fauna of volcanic caves, such as the crustaceans *Heteromysis cotti* and *Munidopsis polymorpha* from the Canary Islands. Howarth (1972) briefly mentioned the existence of a few troglobites from volcanic regions in other parts of the world and listed appropriate references. Additional data on Japanese lava cave fauna are presented by Uéno (1960, 1970, 1971a, 1971b). Lava cave fauna on the South Korean island of Cheju-do was briefly mentioned by Uéno, Pae, and Nagao (1966). Howarth recently (1972) reported on a remarkable assemblage of cave-adapted arthropods from lava tubes on the oceanic island of Hawaii.

The purpose of this paper is to summarize our knowledge of the invertebrate fauna of the volcanic caves .of continental North America, to point out how little is known about them, and to encourage future research and collecting. The caves included in the following list are lava tubes, caves in lava talus, and those formed as cracks or fissures by lava flow or cooling contractions. To date, knowledge on the invertebrate fauna of volcanic caves in western North America exists only for those in western continental United States. I know of no volcanic caves in Canada or Alaska, though they may exist and may be occupied by invertebrates. Mexico has extensive volcanic areas with volcanic caves. Nothing is known of the fauna in these caves; however, they should offer good potential for future work.

Some data exist only as general observations, such as those gathered by Halliday (1963) and others reported in the newsletters of various caving clubs (e. g.: the *Cascade Caver* and the *Speleograph*). I have not sought out these records, which usually give only common names such as "moths", "spiders", "mosquitos", "collembola", or "harvestmen", because they are not sufficiently trustworthy or lack detailed taxonomic data.

No obligate vertebrates are known to inhabit these volcanic caves. The report of a

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blind fish in Washington by St. Amant (1854) should be regarded as spurious, although a blind fish is known from a Japanese volcanic cave (Uéno, 1970).

Faunal List

Phylum Platyhelminthes

Class Turbellaria

Order Tricladida

Family Planariidae

Kenkia rhynchida HYMAN, 1937

This, the only species in the genus, is known only from the type locality, Malheur Cave, Harney County, Oregon. Mitchell (1968) placed the genus in the family used above but noted the need to restudy and redefine the genus, using live and better-fixed material.

Phylum Arthropoda

Class Crustacea

Order Isopoda

Family Trichoniscidae

Trichoniscus nearcticus ARCANGELI,
J. O. Maloney determination

Four males and three females, collected by Hubbs in Malheur Cave, Harney County, Oregon, were reported as an unspecified isopod by Hyman (1937, p. 416) and were deposited in the National Museum of Natural History (Smithsonian) at the time when the University of Michigan crustacean collection was transfered. The species was not found during recent collecting trips to the cave (Benedict, written commun.).

Order Amphipoda

Family Gammaridae

Stygobromus hubbsi SHOEMAKER, 1942

The species is known only from the type locality, Malheur Cave, Harney County, Oregon. Nieland (1971) mentions "sightless life forms" that may be this or another amphipod in a river in Deadhorse Cave, in southcentral Washington. According to J. R. Holsinger, who is presently revising the genus (written commun.), 14 undescribed subterranean species of the genus *Stygobromus* have been collected from scattered localities west of the continental divide in California, Arizona, Montana, Nevada and Oregon. Thirteen of these species are closely related to *S. hubbsi*. The animals have been collected from lava caves, limestone caves, springs, wells, and deep lakes.

Class Arachnida

Order Pseudoscorpiones

Family Chthoniidae

Apochthonius sp.

The species, from Malheur Cave, Harney County, Oregon, is being described by D. Malcolm and E. Benedict. The genus is widespread throughout much of the United States in forest litter and moss (Chamberlin and Malcolm, 1960); seven cavernicolous species are reported from the eastern United States (Muchmore, 1967).

Family Neobisiidae

Microcreagris columbiana CHAMBERLIN

The species was described from a male with reduced eyes "drawn from a well" at Clatskanie, Oregon. Chamberlin (1962) considered it to be either a soil or a subterranean species, fortuitously recovered from the well. Muchmore (1969) reports the species from Pillar of Fire Cave, 1.5 miles south of Trout Lake, Klickitat County, Washington. Many species in this genus are known from caves in both the eastern and western United States (Muchmore, 1969).

Parobisium charlotteae CHAMBERLIN

This species is known only from "Redmond Lava Cave" in Deschutes County, Oregon. It is a large, blind or nearly blind species considered to be a troglophile (Chamberlin, 1962).

Order Acari

Family Rhagidiidae

Rhagidia sp.

I have taken material in Boy Scout Cave, Craters of the Moon National Monument, Idaho. Several species in the genus occur in caves and seem to be widespread (Elliott and Strandtmann, 1971, and references therein).

Order Opiliones

Family Erebomastridae,
T. S. Briggs determination

Briggs (written commun.) reports an adult female of an undescribed species from Boy Scout Cave, Craters of the Moon National Monument, Butte County, Idaho (collected by S. and J. Peck), and large, pale-yellow, eyeless species from Gwendolyn Cave, Lincoln Co., Idaho and from a cave near Mammoth Cave, also in Lincoln County, Idaho. These are the first examples discovered of blind, fully troglobitic Erebomastrids. They are quite unlike specimens taken in limestone caves in the United States and Europe, which have eyes and relatively short appendages. The Idaho localities provide important links between eastern and western populations of the family. The family name was proposed by Briggs (1969) only recently and may not be generally accepted by other workers.

Family Ischyropsalidae

Taracus malkini
GOODNIGHT and GOODNIGHT

The type locality is Manzanita Lake, Shasta County, California (Goodnight and Goodnight, 1945). Briggs (written commun.) reports the species to be conspicuous on moist walls in Subway Cave, near Manzanita Lake. They have eyes, unpigmented abdomens, and thin, black chelicerae of considerable length. Briggs (written commun.) states that he has found similar *Taracus* in high-elevation limestone caves in the Sierra Nevada Mountains.

Sabacon sp.,
T. S. Briggs determination

Briggs (written commun.) reports a collection from Ape Cave, Skamania County, Washington. Probably, this is an accidental record of an epigean species, just as is the record of *Sabacon jonesi* from a cave in Alabama (Goodnight and Goodnight, 1942).

Family Travuniidae
T. S. Briggs determination

Briggs (written commun.) reports the recent collection of material from Jug and Nielsens caves, Skamania County, Washington. These are the first New World collections of the family, which is described by Vandel (1965, p. 90) as being cavernicoles of ancient origin. They are, in fact, true "living fossils."

Family Triaenonychidae
T. S. Briggs determination

R. Westcott collected a late instar specimen in Crystal Falls Cave, Clark County, Idaho. As with other cavernicolous members of the family, this specimen has eyes, but its relatively long second tarsi and lack of pigmentation suggest that it is an obligate troglophile. The species most closely resembles juvenile *Cyptobunus cavicolens* Banks (*Sclerobunus cavicolens* [Banks]), which are depigmented but have large eyes. *C. cavicolens* is found in a limestone cave (Lewis and Clark Caverns) at Limespur, 60 miles W. of Bozeman, in Madison County, Montana (Briggs, 1971, and written commun.).

Order Araneae

Family Linyphiidae

Bathyphantes diasosnemis FAGE

Reported (Ivie, 1969) from Subway Cave, Shasta County, California; otherwise known from caves and epigean situations in southern Oregon and northern California.

Family **Telemidae**

Telema sp.

An undescribed species from Subway Cave, Shasta County, California, (data of W. J. Gertsch) shows eye modifications and, possibly, is troglobitic. The genus, heretofore thought to comprise a single blind species from caves in the French Pyrenees, is widespread in western North America (our genus *Usofila* is a synonym). Several species are known from caves and from epigean situations.

Class **Diplopoda**

Order **Chordeumida**

Family **Conotylidae**

Plumatyla humerosa (LOOMIS)

Reported (Shear, 1971) from Indian Wells Ice Cave, Lava Beds National Monument, Siskiyou County, and Sunnyside Mine (type locality), Plumas County, California. I have seen it in other caves (Craig Cave, Frozen River Cave) in Lava Beds National Monument. Immature specimens of *Plumatyla* are known from a number of unspecified mines, limestone caves, and lava tubes (mostly in The Lava Beds) in northern California and adjacent Oregon (Shear, 1971). Shear considers the species to be troglobitic because it is unpigmented and because the ocelli are reduced to about 10, in two rows. However, its wide distribution suggests that the species is not an old cave inhabitant. Only one species is known in the genus, but the immature specimens may represent populations of other species. The milliped mentioned by Hubbs (in Hyman, 1937, p. 461) as a true cave species from Malheur Cave, Oregon may be of this genus.

Family **Conotylidae**

Idagona westcotti BUCKETT and GARDNER, 1967

Known only from Crystal Falls Cave (type locality), Clark County, and Boy Scout Cave, Craters of the Moon National Monument, Butte County, Idaho. I have taken it in Boy Scout and Beauty caves, Craters of the Moon. The numerous pigmented ocelli suggest that the species is not an old cave inhabitant. The genus contains only this species. Its familial relationships are discussed by Shear (1969, 1971).

Order **Polydesmida**

Family **Polydesmidae**

Halliday (1963) mentions polydesmid millipeds in Bat and Fish Hatchery caves, Skamania County, Washington.

Class **Collembola**

Order **Arthropleona**

Family **Entomobryidae**

Tomocerus flavescens (TULLBERG), K. Christiansen determination

This species is a common troglophile and is widespread in North America. I took it in Boy Scout Cave, Idaho. Westcott (1968) mentions undetermined Entomobryids from Idaho caves. There are several troglobitic species in this family.

Class **Insecta**

Order **Diplura**

Family **Campodeidae**

Plusiocampa sp.

Species of this genus are known from caves in the eastern United States. I have collected them in Boy Scout Cave, Craters of the Moon, Idaho, and in Craig and Frozen River caves, Lava Beds, California. Westcott (1968) reports them from Idaho and Halliday (1963) mentions them in Dry Creek Cave, Skamania County, Washington.

Order **Grylloblattodea**

Family **Grylloblattidae**

Grylloblatta chandleri KAMP

Reported (Kamp, 1963) from Eagle Lake Ice Cave (type locality), Lassen County, California. These caves are contraction crevices covered with talus blocks. They are not lava tubes, although some exist nearby. Another species, *G. barberi* Caudell, occurs not far to the south, at the confluence of Butt Creek and the North Fork of Feather River, Plumas County.

Grylloblatta chirurgica GURNEY

Reported by Gurney (1961) from Ape (type locality), Lake, and Nielsens caves, all in Skamania County, Washington. Halliday (1963) mentions what probably is this species in Bat Cave, also in Skamania County.

Grylloblatta gurneyi KAMP

Reported (Kamp, 1963, 1970) from Merrill Ice (type locality), Indian Wells Ice, and Skull caves, all in Lava Beds National Monument, Siskiyou County, California. I have taken it in Frozen River Ice Cave in The Lava Beds, and also have taken what may be this species on snowbanks at high elevations on nearby Mt. Shasta.

Grylloblatta rothi GURNEY

Reported from Edison Ice Cave, near Bend, Oregon (Kamp, 1970). This species typically is subalpine and here occurs sympatrically with an undescribed population.

Grylloblatta sp.

The following caves are known to contain *Grylloblatta*, but the populations either are undescribed or are known only from immature specimens, so that species determination is not possible. The records are those of Kamp, reported by Halliday (1962). **California.** Plumas County: Griffith Ranch Ice Caves (these caves are contraction fissures in lava); Siskiyou County: Jack Jones Ice Cave, Jake Bell caves, Mayfield Ice Cave, Starr Cave (These Siskiyou County populations probably are *G. gurneyi*); Tehama County: Wilson Ice Cave (near Wilson Lake, less than 20 miles NW of a *G. barberi* locality and less than 40 miles SW of a *G. chandleri* locality). **Oregon.** Deschutes County: Edison Ice Cave (Kamp 1970).

Order **Coleoptera**

Family **Leiodidae**

Glacicavicola bathyscioides WESTCOTT

Reported (Westcott, 1968; Peck, 1970, 1974) from **Idaho.** Butte County: Boy Scout Cave, Beauty Cave (both in Craters of the Moon National Monument); Clark County: Crystal Falls Cave; Power County: Crystal Ice Caves. This species is highly modified for cave life. Its biology and distributional history are discussed in the above references.

Family **Staphylinidae**

Subfamily **Aleocharinae**

Representatives of the subfamily are known from Idaho caves (Westcott, 1968).

Quedius spelaeus HORN

This species is widely distributed across most of the United States and southern Canada. It is a common cave inhabitant, but also is known from non-cave habitats, including mammal burrows. It is known (Halliday, 1963; Smetana, 1971) to occur in lava tubes in **California.** Siskiyou County: Sentinel Cave (Lava Beds Nat. Mon.); Shasta County: Subway Cave. **Idaho.** Clark County: Crystal Falls Cave. **Washington.** Skamania County: Fish Hatchery Cave.

Discussion

Definite ecological classifications can be assigned to some of the above-listed animals. Those animals known definitely to be troglobitic, from morphologic features such as reduced or absent eyes and pigment, are the listed species of *Kenkia, Stygobromus,* Erebomastrid and Travuniid harvestmen, and *Glacicavicola*. To this category may also belong the listed species of *Microcreagris, Parobisium, Apochthonius, Rhagidia, Telema,* and *Plusiocampa*.

Several of the animals do not show great modification for cave life, but now probably are ecologically confined to caves. These obligate troglophiles are *Plumatyla, Idagona,* the several species of *Grylloblatta* and, perhaps, *Rhagidia* and *Plusiocampa.* Those remaining on the list, the facultative troglophiles, will also be found in non-cave habitats. These are *Trichoniscus,* the Ischyropsalids and Polydesmids, *Bathyphantes, Tomocerus, Quedius,* and the Aleocharine staphylinids. Only when more taxonomic and ecological data is available can the above species be categorized with more certainty.

Among the terrestrial invertebrate troglobites and obligate troglophiles, at least, the cave occupation seems certainly to have been motivated by a search for cool, moist habitats. Such habitats are those occupied by the species most closely related to the troglobites. This conclusion is reinforced by the observation that caves with cooler air and with standing water or ice contain a richer fauna.

The lava plateaus in which the lava-tube caves of western United States occur are mostly located in the Columbia Plateau, in the contiguous semi-arid region of northern California, Oregon, Washington, and southern Idaho. This region today lies within the Upper Sonoran and the Transitional life zones, which are fairly dry and have moderately high summer temperatures. The caves, then, serve as moist, cool microclimatic refuges within a generally dryer and warmer habitat.

Much of the fauna probably came from higher elevations, reaching the caves overland by migration during the cooler and more moist conditions of the last glaciation (Kamp, 1963, 1970; Peck, 1974; Uéno, 1960, 1970, 1971a). As the glacial ice retreated and the warming and drying trends of the present interglacial continued, some of the populations retreated into the suitable environments offered by the caves. This mechanism is certainly true for *Plumatyla* and *Idagona,* and for the species of *Grylloblatta,* all of which show no special cave modification. The modified species, such as the Erebomastrid and Travuniid harvestman, *Glacicavicola,* and other possible troglobites, may have occupied caves during earlier interglacials.

It will be seen that most of the localities for the known fauna (Fig. 1) cluster around Craters of the Moon, Idaho; Lava Beds, California; Skamania County, Washington; central Oregon; and Malheur Cave, Oregon. However, it should by no means be assumed that the fauna of these areas is well known. It is hoped that this paper will encourage additional work in these areas, as well as in areas not yet explored biospeleologically.

In conclusion, the volcanic caves of western United States do possess a specialized fauna. Some of this fauna has affinities with the faunas of limestone caves in the United States to the south and east, such as *Stygobromus, Apochthonius, Microcreagris, Rhagidia, Bathyphantes,* and *Plusiocampa.* However, some of this fauna is unique and is limited to the caves or to the general cave-containing region of the Pacific Northwest. Examples of the latter are *Plumatyla, Idagona, Grylloblatta* and, especially, the Travuniids and *Glacicavicola.* A conclusion which may be drawn from this observation is that, although the caves themselves have histories different from those of caves in limestone regions, their internal environmental conditions have attracted, isolated, and supported faunas in the same way as have those of limestone caves.

Summary

Little is known, at present, about the invertebrate fauna of volcanic caves in the United States. However, there is enough data to show that a specialized fauna exists and that it is unique and significant. Virtually nothing is known about volcanic caves in Canada and Mexico, although a fauna should exist in the latter country. Abundant opportunities exist for enlarging our knowledge by field and laboratory studies of the taxonomy, ecology, distribution, and evolution of this fauna.

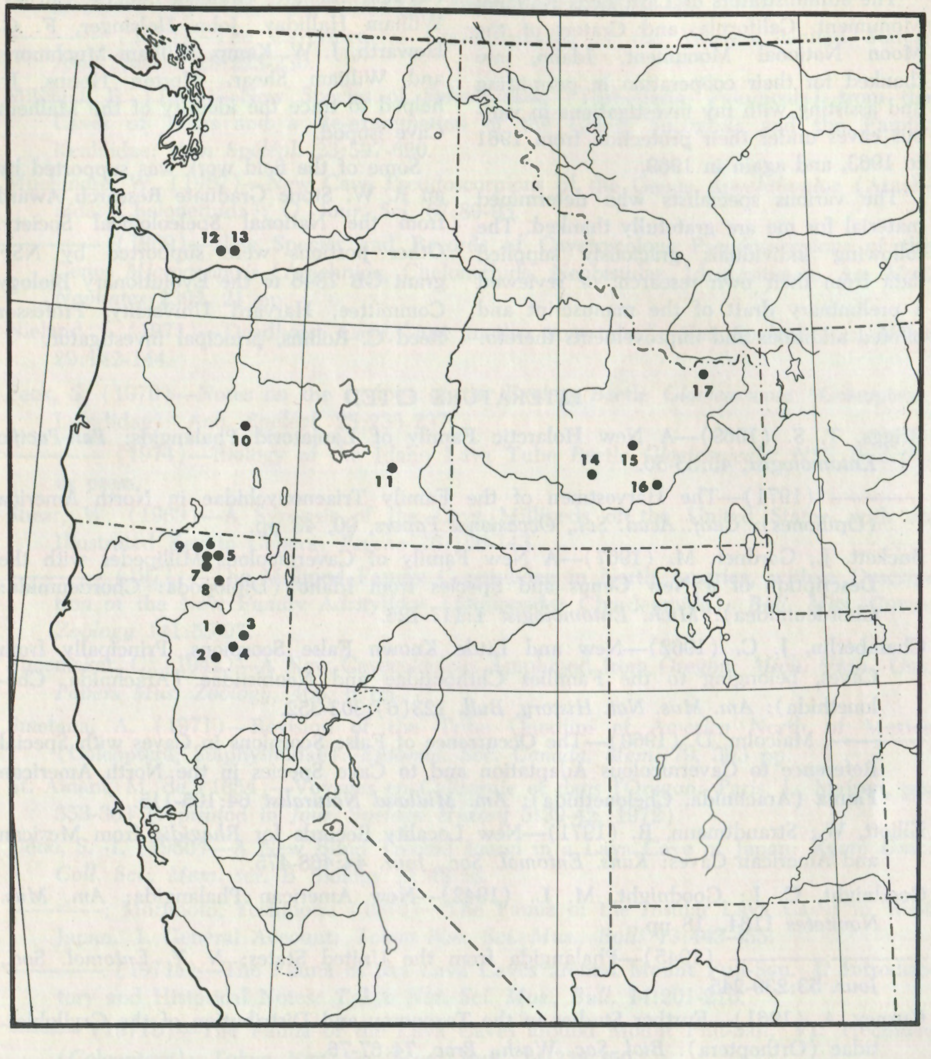

Fig. 1. Locations of volcanic caves in western continental United States from which invertebrates are known. 1. Subway Cave. 2. Wilson Ice Cave. 3. Eagle Lake Ice Cave. 4. Griffith Ranch Ice Caves. 5. Lava Beds National Monument (including Craig, Frozen River, Indian Wells Ice, Merrill Ice, Sentinel, and Skull caves). 6. Jack Jones Ice Cave. 7. Jake Bell Cave. 8. Mayfield Ice Cave. 9. Starr Cave. 10. Deschutes County (Edison Ice Cave and "Redmond Lava Cave"). 11. Malheur Cave. 12. Skamania County (including Ape, Bat, Dry Creek, Fish Hatchery, Jug, Lake, Nielsens, and (?) Deadhorse caves). 13. Pillar of Fire Cave. 14. Lincoln County (Gwendolyn Cave and a cave near Mammoth Cave). 15. Craters of the Moon National Monument (including Boy Scout and Beauty caves). 16. Crystal Ice Cave. 17. Crystal Falls Cave.

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Lee Cave, Mammoth Cave National Park, Kentucky

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ABSTRACT

Lee Cave is located beneath the northwestern edge of Joppa Ridge, in Mammoth Cave National Park. Entrance through a shaft and canyon complex leads into a large trunk passage. The trunk passage extends 7000 ft, with cross-sections up to 88 ft wide and 40 ft high, to an eastern terminal breakdown. Below the main trunk, is a complex of smaller tubes, canyons, and vertical shafts. The surveyed length, 1972, is 7.55 miles.

The trunk contains a thick clastic sediment sequence which varies in facies from cobbles in the west to fine silts and clays in the east. Breakdown activated by sulfate replacement and crystal wedging is common. Gypsum, epsomite, and hexahydrite occur as clumps of curved crystals. Blödite, a new cave mineral, occurs as thick crusts of material drifted onto up-facing sediment and breakdown surfaces. Cave life is sparse: There is a small bat colony and much evidence of cave rats. Smaller animals, except for crickets, have not been observed.

Pre-Columbian Indians entered the cave, probably through an entrance now closed, near the eastern breakdown. Fragments of cane-torch material are scattered along much of the main trunk passage. Two stone cairns of unknown purpose occur. There is, however, no evidence of the mining activity common to Mammoth and Salts Caves. Lee Cave was named for T. E. Lee, pioneering cave explorer of South Central Kentucky, who descended the entrance pit in 1876.

Introduction

The Chester cuesta in the Central Kentucky Karst is dissected by karst valleys into three mesa-like ridges. These ridges are capped with the resistant Big Clifty sandstone and other, younger, rocks of the Chester series of Mississippian Age. Beneath the Big Clifty lie the cavernous Girken, Ste. Genevieve, and St. Louis limestones. In Mammoth Cave National Park, some 300 ft of these massive limestones are exposed above base level and contain the large cavern systems for which the region is noted. Flint Ridge, the northern-most of the group, contains a substantial part of the Flint-Mammoth Cave System, with some 85 miles now mapped, and a number of smaller caves. In the center, more than 50 miles of the Flint-Mammoth System lies under narrow Mammoth Cave Ridge. The southern-most of the ridges is Joppa Ridge, with no known large cave system (White, W. B.; Watson, R. A.; Pohl, E. R.; Brucker, R. W., 1970; Quinlan, 1970).

Of the large number of known cave entrances on Joppa Ridge, few lead to caves

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of any consequence. Only Procter Cave, with more than 6000 ft of survey, is under the main ridge. The other large caves, Long Cave near the southern Park boundary and Smith Valley Cave in Cedar Sink, lie to the south of the main body of the ridge. However, the evidence for a large drainage system through Joppa Ridge is good. One of the largest karst springs in the Central Kentucky Karst rises at the Turnhole, at the western end of Joppa Ridge.

An intensive surface reconnaissance has been conducted on Joppa Ridge by the Cave Research Foundation. Techniques employed include aerial reconnaissance, infrared photography, detailed valley-by-valley search on the ground, and interviews with local residents who inhabited the area before it became a National Park. The aerial infrared photography has produced a number of discoveries, including that of an additional rising in the bed of Green River near the Turnhole spring. No real substitute has been found, however, for systematic search on the ground. It was this technique that led to the discovery of Lee Cave on November 25, 1968, by Gordon and Judy Smith.

Lee Cave is unique in several respects. It is the first *new* cave of significant size to be discovered in the Mammoth Cave Area in recent years. The cave was explored by pre-Columbian Indians, presumably through an entrance which has been closed since white settlers entered the area. The most impressive part of the cave is Marshall Avenue, a 7000 ft fragment of main trunk passage comparable in dimensions to Broadway in Mammoth Cave and to Upper Salts Cave in Flint Ridge. The cave contains a complicated suite of sulfate minerals not duplicated elsewhere in the area. This paper is an overview description of Lee Cave and, especially, of Marshall Avenue.

Description and Survey

The entrance to Lee Cave is a 50 ft vertical shaft near the head of Sand Cave Hollow, at 37° 10′ 15.5″ N, 76° 08′ 23″ W, elevation 635 ft ASL. The route from the bottom of the shaft leads along the drain to a narrow canyon eight to 12 in. wide and 15 ft deep, cut by the shaft stream. From the bottom of this canyon, a second drop of 20 ft leads through the ceiling of a large breakdown chamber. A crawl to a second breakdown chamber and an additional crawl through breakdown bring one into the western end of the main trunk channel. The terminal breakdown of this passage is clearly visible on the surface as a slumped area a few hundred feet down the hollow from the entrance shaft.

There are two distinct parts to Lee Cave. The first is Marshall Avenue, extending 7000 ft eastward from the entrance pit to a terminal breakdown against the side of Deer Park Hollow. The second is a complex of lower level passages that extend west and south from the entrance area to a limit of penetration against the side of Smith Valley. The lower level complex connects with Marshall Avenue at a single junction some 600 ft southeast of the western terminal breakdown. Except for a short passage leading to two shafts near the eastern terminal breakdown, no other side passages to the main trunk are known to exist. Most of the lower level complex is related to a series of north-flowing valley drains that are hydrologically distinct from the trunk passage. A new entrance has been discovered in Carpenter Hollow. Exploration in that direction is not complete. At this writing, 7.55 miles of passage have been surveyed in the entire system. The location of the cave with respect to local topography and to other nearby caves is shown in Fig. 1.

Lee Cave was surveyed as part of the Cave Research Foundation cartographic program. Horizontal surveys were done with Brunton compass and steel tape. Vertical control was obtained in the nearly flat trunk passage with the water-filled plastic tube level technique devised by A. N. Palmer. A map of Marshall Avenue is shown in Fig. 2. The portion of the lower levels shown in Fig. 2 is that known through June, 1969, only. The complete survey of

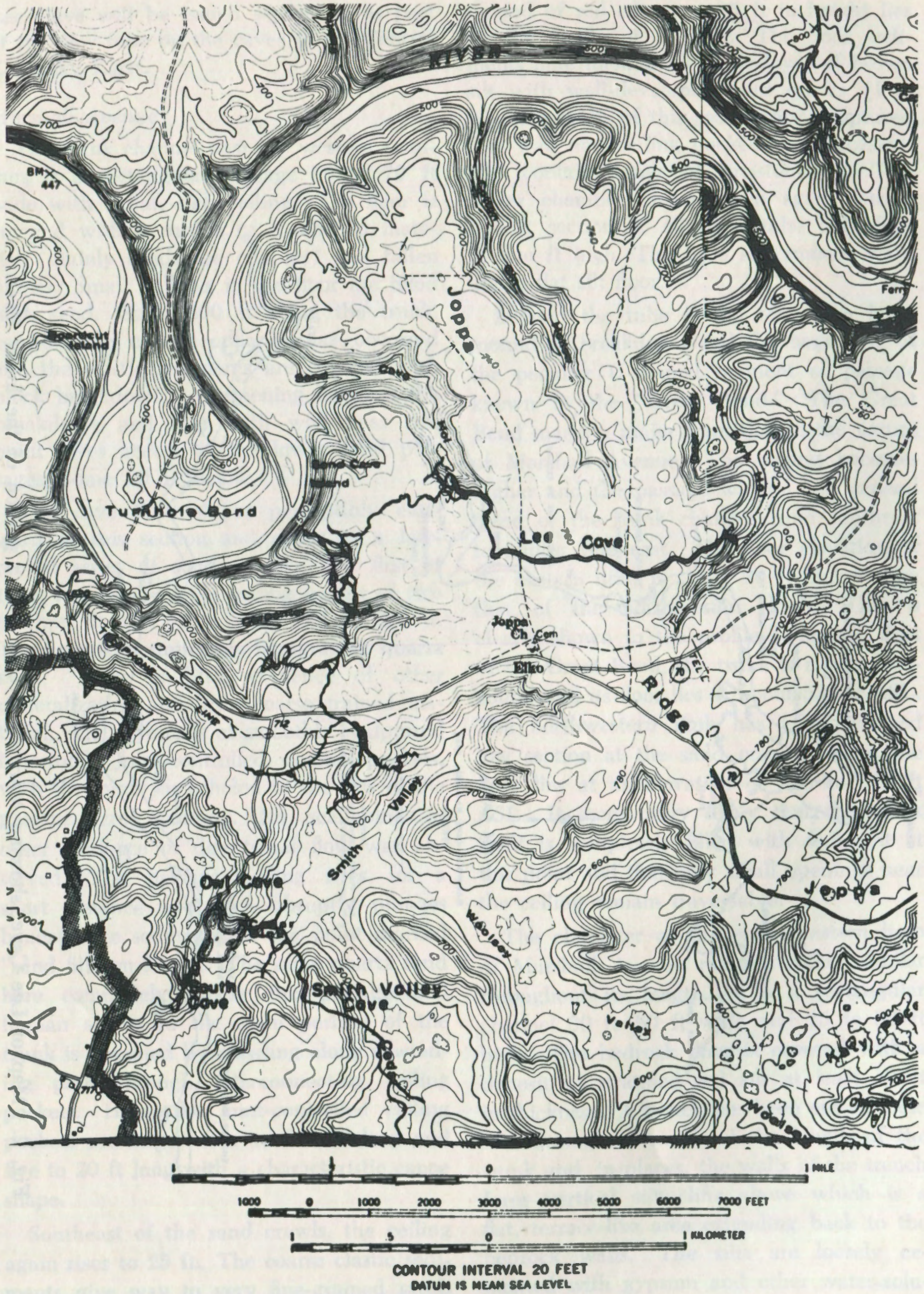

Fig. 1. Caves of western Joppa Ridge: Lee Cave map complete to CRF surveys of spring, 1972, Smith Valley Cave from Hosley (1969), topography from USGS 7½′ Rhoda and Mammoth Cave quadrangles.

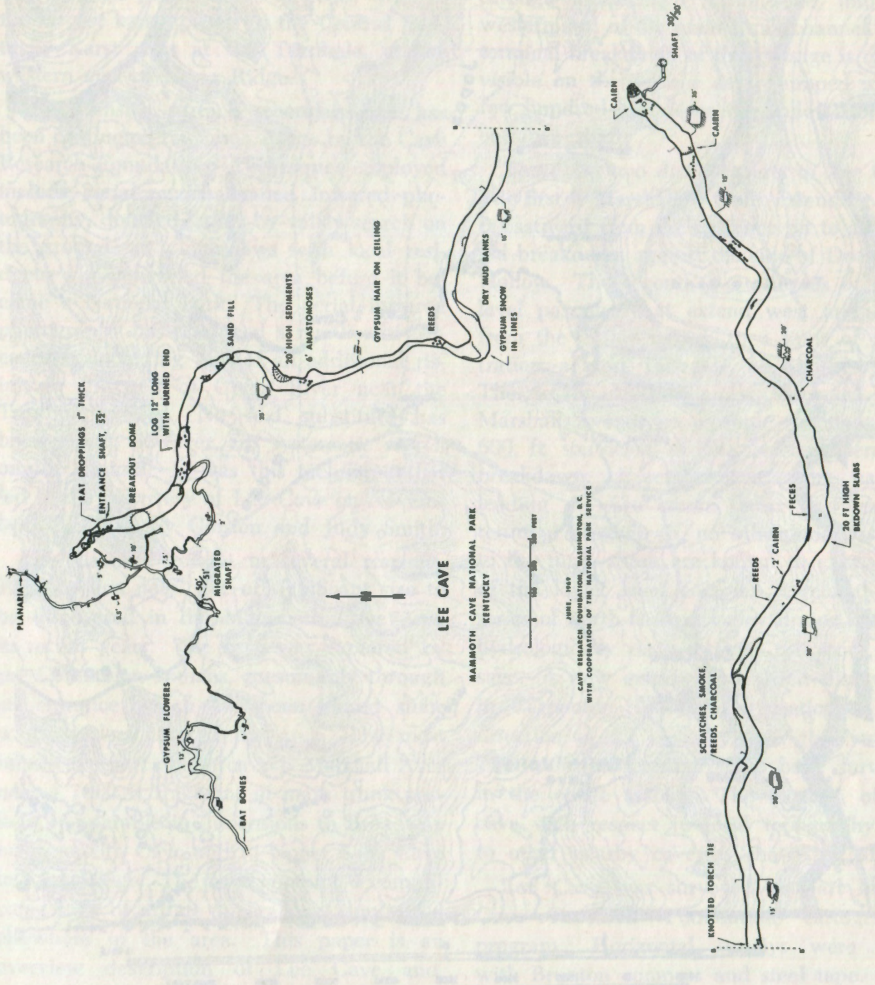

Fig. 2. Map of Lee Cave, showing Marshall Avenue and a portion of the lower levels.

Lee Cave will be issued separately as part of the new folio on the caves of the Central Kentucky Karst.

Marshall Avenue

The trunk channel near the western terminus is a rectangular passage 50 to 70 ft wide with a flat, slab ceiling. The floor is covered with a rubble of in-washed material (mainly sandstone cobbles) and fallen blocks. Small hollows in the floor are filled with sand. Some 600 ft along the trunk, considerable ceiling collapse has occurred and the clastic sediments are covered with block breakdown. An opening between the breakdown and the south wall near this point gives access to the lower level passages, some 20 ft below.

The cave floor slopes perceptibly eastward in this section and drops to a low-roofed series of sand crawls. The first of these has an available ceiling height of two to three ft and extends for 100 to 200 ft. The floor is of uniformly fine-grained quartz sand. There is little evidence of other mineralization and little coarse-grained material. The ceiling is of smoothly sculptured limestone. Joint-controlled ceiling pockets, with the joints en echelon to the axis of the passage, are common. No scalloping or other evidence of directional flow was observed. The passage ceiling rises for a short distance and then abruptly plunges beneath the sediments at the point marked "sand fill" on Fig. 2. The same quartz sand here completely blocks the passage and human access to the main portion of the trunk is obtained by crawling along a winding path through interconnecting ceiling pockets. Here, the joint-controlled ceiling pockets are large—four to five ft deep and five to 20 ft long with a characteristic canoe shape.

Southeast of the sand crawls, the ceiling again rises to 25 ft. The coarse clastic sediments give way to very fine-grained sands and silts of a characteristic red color, which replace the yellow sands of the low sections. An obviously stratified, flat-topped residual mound of red silt some 15 ft in height lies on the inside of a bend. The floor sediments here include an upper layer of brown silt with well-developed mud cracks (Fig. 3). The walls of this section are sculptured into wall and ceiling pockets and occasionally contain zones of anastomoses. This larger chamber closes down again into a 500 ft section of elliptical tube only four to five ft high. The tube has smooth walls and a flat silt floor.

Beyond the tube is the foot of a large mound of breakdown and the beginning of the peculiar U-shaped segment of passage known as the "Great Bend." The Great Bend marks a major transition in the nature of Marshall Avenue. The ceiling becomes higher and the passage wider. The general trend of the trunk changes from southeast to almost due east. The floor elevation of the eastern limb is about 20 ft higher than that of the northwestern limb. This is clearly shown in the profile (Fig. 4). East of the Great Bend, the trunk is nearly horizontal and its floor lies at about 530 ft ASL. The northwestern limb has a pronounced low section at the sand crawls, where the floor lies at an elevation of 505 to 510 ft ASL. It seems very likely that the trunk itself is completely filled with sediment at this point and that only small openings near the ceiling remain traversable.

The character of the entire eastern limb of Marshall Avenue remains rather similar throughout its length. It is a rectangular channel 30 to 50 ft wide and 25 to 30 ft high. The bedrock floor is covered with a deposit of stratified red silt at least 10 ft in thickness. A trench has been cut in these silts throughout much of the length of the trunk and, in places, the walls of the trench form vertical silt cliffs above which is a flat, terrace-like area extending back to the bedrock walls. The silts are loosely cemented with gypsum and other water-soluble minerals and have been fractured in a columnar pattern along the walls of the trench (Fig. 5). The trench becomes pro-

Fig. 3. Mud cracks in brown silt in the chamber south of the sand crawls.

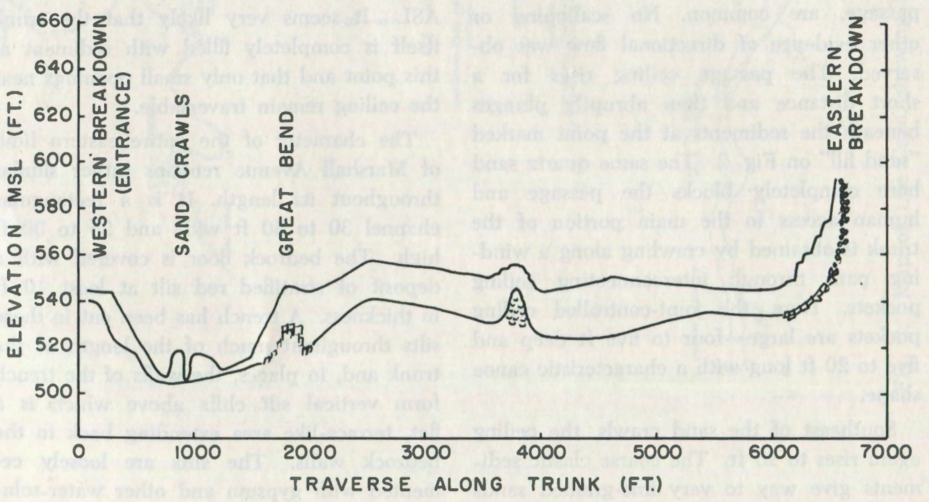

Fig. 4. Profile along Marshall Avenue, based on leveling surveys. Passage slopes are highly exaggerated due to differences in vertical and horizontal scale.

gressively less distinct to the east. Breakdown, much of it activated by the wedging action of growing crystals of sulfate minerals and by the chemical attack of sulfate-bearing solutions, has pulled loose the beds along the upper corners of the passage and has altered the cross-section to a more rectangular shape. These elongate slabs of breakdown form long rows or piles along the sides of the passage. The ceiling tends

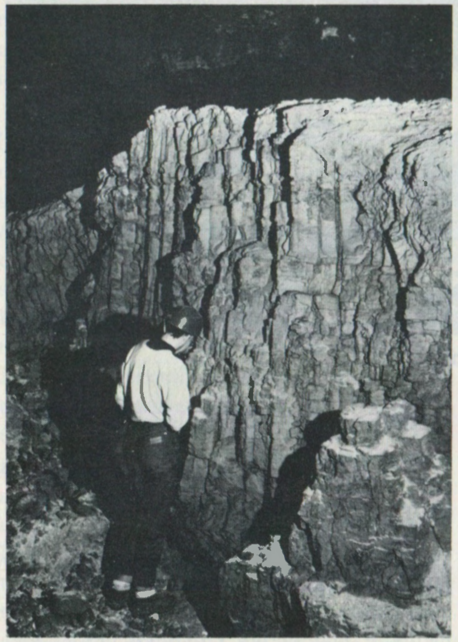

Fig. 5. Red silt cliffs in Marshall Ave. several hundred yards east of the Great Bend. Note columnar jointing of sediments and piles of white sulfate minerals on up-facing edges.

to be formed by a single, high-strength slab, yielding a nearly flat ceiling in most segments of the passage. The cross-section shown in Fig. 6 is typical.

The eastern terminal breakdown is a sandstone tumbledown that completely blocks the passage. Extensive probing into the wet breakdown has not revealed any continuation. The single small side passage near the terminal breakdown leads several hundred feet to a vertical shaft without any obvious continuation.

Lower Levels

As is typical of other caves of the Central Kentucky Karst, Lee Cave possesses a complex system of lower level passages of relatively small dimensions. No artifactual material has been found in these lower passages.

About 600 ft from the extreme northwestern end of Marshall Avenue, one may enter a crouchway low on the right-hand (south) wall. This extremely dry passage leads south, then west, descending gently for 1000 ft through crouchways and dusty crawlways to a spacious junction with a 10 ft canyon running roughly north and south. To the right (north), the canyon becomes progressively lower until one's advance is stopped by a low, stream-cobble blockade. Our survey shows this point to be only a few feet from the place where Lee's entrance canyon intersects the main trunk. Voice connection has been attempted here, unsuccessfully. As the map shows, the northwestern and eastern branches of this arm of the canyon soon become impassable. The extreme northwestern arm contains shafts under the axis of Sand Cave Hollow. This pit complex has not yielded additional passage.

About 200 ft southwest of the canyon junction, a large, perfectly dry migrated shaft (50′/51′) is suddenly encountered. The shaft almost severs the passage, but belayed cavers can continue forward without descending by carefully crawling 20 ft across a narrow ledge on the right-hand (west) wall. The exposure of the traverse led an early survey party to dub this spot the Pit of Doom. The shaft has been descended and its abandoned drains found to be merely cracks.

Farther along, the southwestern branch becomes a gypsum-lined crouchway. Gypsum flowers decorate the walls in a locally larger area about 1000 ft from the migrated

Fig. 6. Representative cross-section of Marshall Avenue.

shaft. This passage continues to the south, eventually to join the Carpenter Hollow portion of the complex.

Most of the section south of Marshall Avenue is less than 500 ft ASL. These passages are not directly related to the trunk. Scallop markings indicate that water movement was from south to north. Most of these passages appear to have been valley drains for Smith Valley and for Carpenter Hollow, carrying water from these catchment areas to discharge points in the vicinity of Sand Cave Hollow and Turnhole Bend. The connecting passage with Marshall Avenue carried water from the trunk into the lower levels and was, perhaps, a bypass route for water in the trunk after collapse closed the western end of the trunk. The passage has a steep slope. Scallops indicate flow velocities on the order of feet per second.

Geologic Relations of Lee Cave

The entrance to Lee Cave is at 635 ft ASL. The contact between the Big Clifty sandstone and the Girkin limestone in Sand Cave Hollow is at about 670 ft ASL. Marshall Avenue lies at about 520 ft ASL, 100 ft below the entrance. According to the geologic map of Rhoda quadrangle (Klemic, 1963), the Girkin limestone is about 160 ft thick in the area of Sand Cave Hollow. The main trunk channel, therefore, should lie very close to the Girkin-Ste. Genevieve contact.

The eastern limb of Marshall Ave. is nearly parallel to the strike of the gently dipping limestones. The elevation of the northwestern limb between the Great Bend and the sand crawls drops about 20 ft in 1000 ft of passage. Probably, it follows the bedding down the dip. The northwesternmost segment cuts across the bedding and rises, somewhat, in the section. The low section of passage in the region of the sand crawls may well record another instance of ground water having been forced into a shallowly artesian circulation by the confining influence of a less soluble bed. Similar undulating conduits occur, although on a smaller scale, in Mammoth Cave (White and White, 1970).

Although Marshall Avenue is comparable in size to the largest trunks known in the Central Kentucky Karst, it is difficult to assign it a proper hydrologic role. The trunk lies almost parallel to the river, has a very gentle and irregular slope, and lacks clearly defined indications of the direction of flow of the water which once filled it. In the last respect, Marshall Ave. is unlike most of the other large trunks. Most of them contain distinct scalloping, at least in some segments.

Either of two hydrologic functions could be assigned to the trunk, but the criteria are not presently available by which to decide between them. The first is that Marshall Ave. served as a piracy route for the cave complex presumed to exist in the downstream ends of Doyel Valley and Deer Park Hollow. The only cave presently known in this extensive collapse area is Deer Park Avenue, a recently discovered segment of the New Discovery portion of Mammoth Cave. However, the linear segment of Deer Park Hollow and very deep dolines on the surface also suggest a major trunk system draining toward the present day location of Echo River. The role of Marshall Avenue, therefore, could have been that of a subterranean piracy route, carrying water parallel to the river and discharging it either near the mouth of Sand Cave Hollow or at Turnhole Bend. Such channels are not unknown in Flint Ridge. Great Onyx Cave must have played some such role, as did Swinnerton Avenue in the Flint Ridge Cave System. In both cases, water moving along trunk conduits more or less directly toward the river was diverted and caused to flow for some distance downstream parallel to the river. However, Marshall Avenue seems unusually large to have formed by such a process. Our knowledge of the cave systems that underlie or have underlain Deer Park Hollow is too fragmentary to make this suggestion more than speculation.

A second possibility is that Marshall Avenue is actually a relict channel of Green river itself. The river presently occupies a sweeping meander bend to the north before flowing south around the tight meander of Turnhole Bend. From Fig. 1, it can be seen that a plausible ancient river channel could be drawn up Deer Park Hollow, through Marshall Avenue, and down Sand Cave Hollow to make a sweeping bend not unlike the present meander in the river, except that a large portion of it would be underground. Caves are known in the Central Kentucky area that have served the role of meander bend cut-offs. Marshall Avenue, by this hypothesis, would be an underground oxbow. It would not have been necessary that the entire flow of the river be diverted underground at any one time, and indeed the absence of a cobble fill or bed-armoring material in the main trunk sediments argues against a complete diversion of the river from its surface route. Again, conclusive evidence is not available and this interpretation must be considered speculative, likewise.

Mineralization

In common with most caves of the Central Kentucky Karst, Lee Cave has a very sparse carbonate mineralization. A few stalactites occur near the eastern terminal breakdown, where there is some active seepage beyond the end of the caprock. A particularly interesting area occurs some 400 to 700 ft east of the Great Bend. At one point here, is a scattering of stalactite fragments and thick, stumpy helictites on the floor material.

Sulfate minerals occur in Lee Cave in a variety of forms: as loose, powdery material between the shards of mineral-activated breakdown, as curved crystals shaped like gypsum flowers protruding from walls and ceilings, as fine, hairlike crystals growing from bedrock surfaces, and as drifts of snow-like material which have sifted down over all upward-facing surfaces in the western and central parts of the east-west segment of Marshall Avenue.

About a dozen samples from various points in the trunk channel were removed in July and November of 1969 and in November of 1971. All specimens were subjected to x-ray diffraction analysis. Infrared spectra and emission spectroscopic analyses were obtained on several.

Gypsum is moderately common and occurs mainly as fragments of gypsum flowers scattered about the floor or as fragmentary gypsum crusts. Some of these clearly show a single cleavage across the crust, indicating that they each are formed by a single gypsum crystal.

One of the principal water-soluble sulfate minerals in Lee Cave is epsomite, $MgSO_4 \cdot 7H_2O$. It occurs as fine, hair-like crystals on the ceiling of the low tube between the Great Bend and the Mud Crack Room. East of the Great Bend, an epsomite speleothem over a foot high is growing between the top of the breakdown bank and the ceiling (Fig. 7). Fragments of epsomite up to three and four inches across are scattered over the floor at this point. Epsomite also occurs in many of the loose crusts in the ceilings and, somewhat more sparsely, in the thick "snowdrift" crusts on the floors.

Certain samples of fibrous crystals collected from ceilings in the highly mineralized zone east of the Great Bend contain up to 50% hexahydrite, $MgSO_4 \cdot 6H_2O$. Identification of hexahydrite as a new cave mineral is a rather delicate matter, since epsomite could lose one of its waters of crystallization between the times of collection and of analysis. To check this point, samples were collected in sealed vials. The material appeared loose and powdery in the laboratory, with no evidence of released water. It appears probable, therefore, that the low relative humidity of Lee Cave causes some natural dehydration of the epsomite and, thus, hexahydrite should be considered a valid cave species. In support of this, most of the massive epsomite crystals, such as the one illustrated in Fig. 7, appear to be etched as if they had been partially dissolved. This texture would be expected if there were a hydration-dehydration process that fluctuated with the changing water vapor pressure in the cave atmosphere.

The floor of Marshall Avenue in the 3000 ft segment east of the Great Bend is covered with a drift or crust of white to grey or brown powdery crystals that have sifted down onto all upward-facing surfaces. Layers of this material can be seen on the silt ledges in Fig. 5. Every breakdown block or overhanging ledge has a "drip line," suggesting that these crystals continually drift down from the ceiling. Analysis of some 15 randomly picked samples shows that the mineralogy of the crusts is very variable, even over short distances.

The predominant mineral in the crusts is blödite, $Na_2Mg(SO_4)_2 \cdot 4H_2O$, a sulfate mineral not previously reported from a cave (Moore, 1970). Blödite in Lee Cave takes the form of clear-white grains a few millimeters across, giving the floor crusts a rather sugary texture. It has not thus far been found in the form of large crystals. Other minerals in the crusts include epsomite, gypsum, and a sodium sulfate. The x-ray patterns of the crusts obtained in the laboratory indicate that the sodium sulfate is thenardite, Na_2SO_4. However, this is likely to be present in the cave as mirabilite, $Na_2SO_4 \cdot 10H_2O$. Mirabilite loses its water of crystallization rapidly when removed from the cave atmosphere and would not survive the trip to the laboratory. A summary of the known sulfate minerals is given in Table 1. Not all bands in the x-ray diffraction patterns have been identified. There is likely to be at least one other mineral in the crusts.

The mineralogy of the Lee Cave deposits indicates that the seepage solutions from which the sulfate minerals are precipitated are magnesium-rich. The magnesium-bearing minerals epsomite, blödite, and hexahydrite even predominate over gypsum. Mirabilite, one of the most common sulfate minerals in the Flint Ridge Cave System (Benington, 1959), is one of the least common in Lee

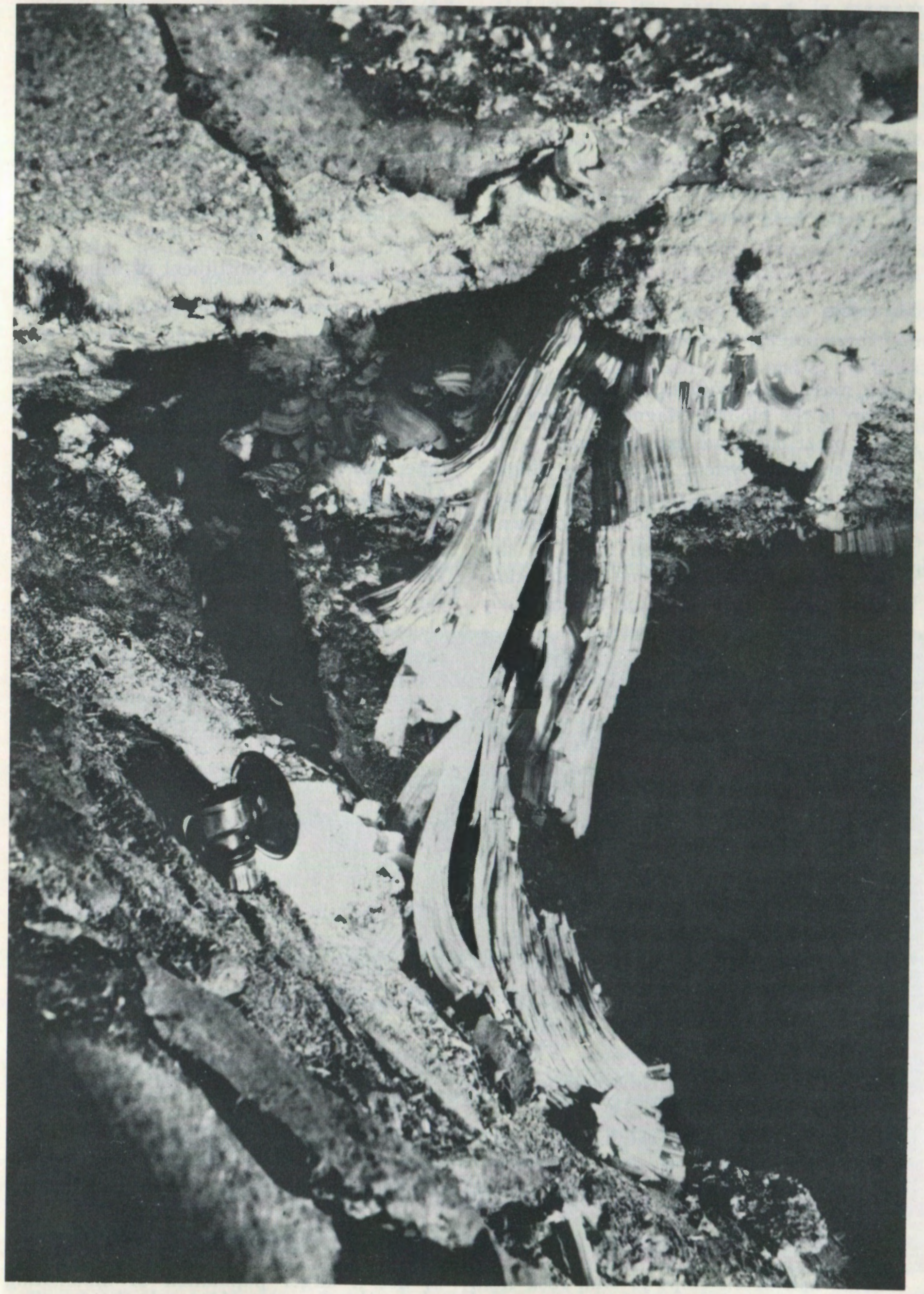

Fig. 7. Massive epsomite crystal near ceiling of Marshall Avenue, 400 ft east of Great Bend.

TABLE 1. Sulfate Minerals Identified from Lee Cave.

Mineral	Formula	Occurrence
Gypsum	$CaSO_4 \cdot 2H_2O$	Floor crusts Loose and curved crystals Wall effervescences
Epsomite	$MgSO_4 \cdot 7H_2O$	(Mainly) wall effervescences
Hexahydrite	$MgSO_4 \cdot 6H_2O$	Wall effervescences
Blödite	$Na_2Mg(SO_4)_2 \cdot 4H_2O$	Main constituent of floor crusts
Mirabilite	$Na_2SO_4 \cdot 10H_2O$	Accessory mineral in floor crusts

Cave; most of the sodium in the solution is tied up in the blödite. Magnesium minerals, on the other hand, are extremely rare in the Flint-Mammoth System. Gypsum is ubiquitous; mirabilite occurs profusely in isolated localities, but only a few isolated fragments of epsomite have ever been found in this gigantic cave system. Some explanation, therefore, must be found for the uniquely different Lee Cave mineralogy.

The sulfates in Lee Cave apparently form by a mechanism similar to that proposed for the gypsum in other parts of the system (Pohl and White, 1965). The ultimate source of the sulfur is pyrite in the upper part of the Big Clifty sandstone. Oxidation of the pyrite forms sulfuric acid. The acid migrates downward until it reaches the vicinity of a cave passage. The cave acts as a sink for the carbon dioxide formed when the sulfuric acid reacts with the carbonate wall rock and allows the reaction to proceed. The sulfate minerals are, therefore, formed *in situ*. Since all of the hydrated sulfates have larger molar volumes than calcite, there is both a chemical attack by the acid solution and a mechanical wedging by the sulfate crystals that replace the calcite in the limestone. This results in much prying off of small chips and shards of bedrock by the encroaching sulfates and, indeed, may result in massive breakdowns.

Some half-dozen chips of wall rock from Marshall Avenue were analyzed as limestone. However, tiny shards of carbonate rock included in bits of fallen sulfate mineral were analyzed as dolomite. Several thin dolomite beds are recognized in the lower Girkin and upper Ste. Genevieve limestones (Pohl, 1970). Although these beds are discontinuous laterally, there apparently are some dolomite beds above or at the ceiling of Marshall Avenue. The reactions that produce sulfate minerals yield the observed magnesium-rich assemblage when the percolating solutions encounter dolomite instead of limestone.

Biology of Lee Cave

The interesting thing about the biota of Lee Cave is its extreme rarity. Aside from an occasional isopod or flatworm, and one crayfish in the small shaft drain complexes, no aquatic forms have been seen during more than 10 trips.

The only live terrestrial biota that we have seen are bats. There are about 20 *Myotis* spp. at the Great Bend during the summer and several dozen hibernating *Myotis lucifugus*, the little brown bat, at the beginning of Marshall Avenue and in the breakdown-modified shaft just entranceward from that point during the winter. Previous knowledge about the microclimate of this species' hibernacula suggests that this area had a temperature of 7 to 9°C and a relative humidity of 80 to 90% at the time (the end of November). It is initially surprising that there is not a larger population of hibernating bats, since there are relatively few undisturbed caves in the area that are potentially

suitable hibernacula. We can only speculate that the tight canyon near the entrance produces a sharp microclimatic gradient from the entrance to Marshall Avenue and that this, in combination with the dry trunk passage beyond, restricts the suitable hibernating area to the small passage segment near the wet shaft complex between the entrance canyon and the beginning of the trunk.

By this argument, the occurrence in Lee Cave of *Myotis sodalis*, the social bat, is precluded because there are not sufficient flat hanging places with the right microclimate. The characteristically large hibernating bats of this species require temperatures of 2 to 6°C and breezes that are found only in the small, irregular entrance canyon. The other bat that commonly hibernates in caves in central Kentucky, the pipistrelle, *Pipistrellus subflavus*, requires virtually 100% RH and temperatures of 10 to 15°C in areas that never flood. These conditions apparently are rare in Lee Cave as it is presently known. In fact, we found a dried pipistrelle in the main section of Marshall Avenue that had died during hibernation. This trunk passage, like Turner Avenue in Flint Ridge and the Main Cave in Mammoth Cave Ridge, appears to be a biological desert, since other desiccated animals have also been found, e.g.: several cave crickets, *Hadenoecus subterraneus*, and a pack rat, *Neotoma floridana* (Fig. 8).

There are some pack rat nest areas, with fecal dumps, and some twigs and seeds both at the beginning and at the end of the trunk. However, even at the terminal breakdown at the east end of the trunk, where there is some moisture seepage, the dryness of the feces makes it questionable whether the observed nests are currently used. Conditions seem damp enough for life, and the closeness of the surface might make this an ideal place for cave crickets, but there are none.

Fig. 8. Pack rat (*Neotoma floridana*) found desiccated in tube between sand crawls and Great Bend. Note rim of mineral deposit surrounding the body.

Persistence of cave cricket populations may depend on availability of egg-laying sites adjacent to entrance feeding areas. The loose substrate of the trunk seems suitable for egg-laying, but the dryness created by the hygroscopic sulfate minerals in the soil may preclude hatching of the eggs. There appear to be old cave beetle, *Neaphaenops*, diggings here and there along the trunk. These suggest occupancy by beetles and by their cricket prey at some time in the past.

In a comparable situation in Great Onyx Cave, neither animals nor cricket eggs occur in an area floored by gypsum and quartz sand but there are many beetles, crickets, springtails, and bristletails in otherwise similar areas only 500 feet away. Both areas have relative humidities of over 95 percent. The critical difference appears to be substrate moisture content. As small animals live directly in contact with the substrate, its characteristics are more important than are those of the passage macroclimate.

Archeological Observations

Cultural debris in Lee Cave is basically similar to that in Upper Salts Cave (Watson, 1969). Aboriginal activity in Lee Cave may have involved some mining, as it did in Salts Cave, but definite indications of that are slight. There may have been collecting of epsomite and other minerals now abundant there, also. The epsomite, in particular, at one place occurs as big chunks. A seam of chert crops out from the limestone at a few places along Marshall Avenue.

Aboriginal debris is found between J-46 and K-20[1]. That between approximately J-46 and J-55 may have been redeposited by water.

Though the remains in Lee Cave are qualitatively similar to those in Upper Salts, the proportion of cane in Lee is markedly greater than that in Upper Salts, suggesting a readily available source near the cave entrance. Items left by the Indians in Lee Cave include: fragments of torch canes (Figs. 9, 10), charcoal fragments, occasional torch smudges on walls and ceiling, bark and wood fragments, rare grass ties from torches and fuel bundles, one fecal deposit, and two limestone cairns (Fig. 11). We tentatively assume the cairns to be prehistoric, because we have found no trace of post-aboriginal visitors to Marshall Avenue before our discovery of it. One cairn stands near L-10. It is composed of rock piled loosely to a total height of about two feet. There are a few fragments of cane charcoal on the cave floor nearby, but no other prehistoric remains.

Another cairn composed of limestone slabs stands about half-way between K-35 and K-36. It is covered with fallen sulfate crystals and has several fragments of cane charcoal on it (a further indication that the cairn is aboriginal in origin).

Our preliminary inspection of the cairns did not lead to any conclusion as to their possible purpose.

The Indians certainly did not enter Lee Cave as we do. It seems more likely that they came in through an entrance which once existed at the eastern terminal breakdown. This is not a completely satisfactory suggestion, however, because there is very little aboriginal debris in this area. Perhaps this end of the cave was damper when the entrance was open and, hence, organic material was not preserved here.

In sum, the aboriginal material in Lee Cave consists, for the most part, of abundant cane torch fragments. It appears that the Indians went into Lee Cave, perhaps to remove the minerals and the chert, but that they did not spend a great deal of time there and, probably, did not penetrate far beyond the entrance. This is a different pattern of activity from that evidenced in Salts Cave, which was explored by the Early Woodland Indians and was intensively exploited for gypsum and, presumably, for mirabilite. The single radiocarbon date obtained on the cane

[1] Specific locations refer to survey stations in Marshall Avenue, shown on the Cave Research Foundation master map.

Fig. 9. Fragments of cane torch material strewn along bottom of sediment trench in Marshall Avenue. This material is typical of dozens of fragment piles strewn along the central sediment trench.

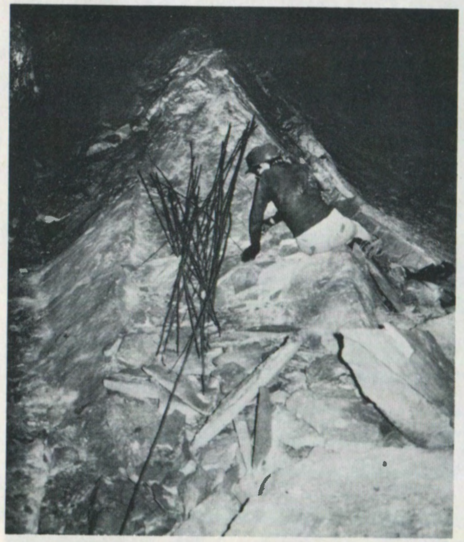

Fig. 10. Intact cane torch on breakdown blocks above trench in Marshall Avenue. Complete torch bundles are rare.

torch material (Table 2) indicates that Indian visits to Lee Cave were among the earliest of those to any of the central Kentucky caves.

A most remarkable anomaly in Lee Cave, one probably not associated with aboriginal usage, is the log that lies propped on the breakdown near the point where the passage descends to the lower levels (Fig. 12). One end of the log is burned and a radiocarbon date on the charcoal indicates that the tree lived about 6000 years ago. This date precedes known Indian visitation to the central Kentucky caves by almost 2000 years. If it had been brought in by them for some purpose, a much earlier period of aboriginal visitation would be implied. Because the log could not physically pass through the present entrance route, it must date from a time when there was an entrance somewhere in the vicinity of the western terminal breakdown. This segment

Fig. 11. One of the limestone cairns found near the eastern terminal breakdown.

Fig. 12. Charred log near western end of Marshall Avenue.

TABLE 2. Radiocarbon Dates from Lee Cave.

Number	Material	Age (Years BP)
UCLA 1729 A	Cane torch material	4100 ± 65
UCLA 1729 B	Charred log	6050 ± 60

of the passage lies at an elevation of about 510 feet, 85 feet above pool stage of Green river. An alternative explanation is that the log records an exceptional flood that took place 6000 years ago. Flood rises of 60 feet on Green river have occurred several times during the past two decades. This hypothesis also would explain the influx of sandstone cobbles and sand near the western terminal breakdown, but it is surprising that no other organic debris remains.

Historical Notes

Lee Cave was named for T. E. Lee, who descended the entrance pit in 1876 and scratched his name on the wall of the shaft drain just at the point where one descends the narrow canyon (Fig. 13). Whether Lee descended the canyon and the second drop beyond it is not known. There is no evidence for post-Indian human penetration in Marshall Avenue. The fine silt floor would have preserved footprints in many places.

Thomas Edward Lee, the son of Bobby Lee, was born on March 29, 1852, in Jefferson County, Kentucky. On September 21, 1884, he married Mary Kennedy, by whom he had a son, Arthur, on February 8, 1886. Arthur is buried in the Mammoth Cave Church Yard. Lee died in Oklahoma on March 24, 1909.

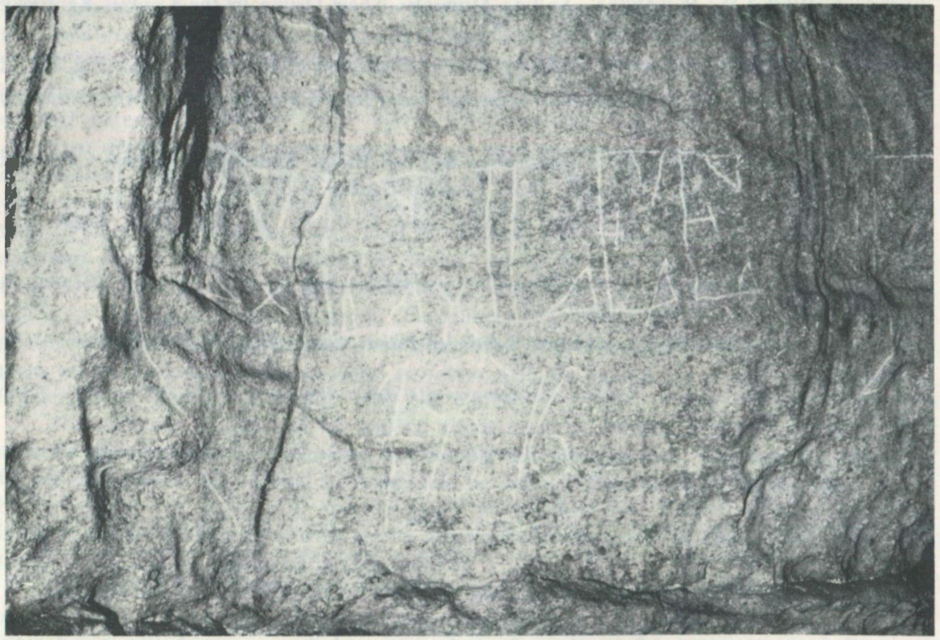

Fig. 13. Signature of T. E. Lee scratched on wall of shaft drain just above point where descent is made into narrow canyon. This bold signature is typical of the record that Lee left in many parts of Salts Cave and in other caves of the Central Kentucky Karst.

T. E. Lee deserves to be ranked with the great cave explorers of the mid-to-late 19th Century (Sides, 1971). His signature appears in many places in Salts Cave and, also, in Long Cave, where there is a Lee Avenue. With his brother, John L. Lee, and William D. Cutliffe, Lee discovered the mummy "Little Alice" in Salts Cave on March 8, 1875 (Robbins, 1971). Most of the signatures in Salts Cave are dated in the mid 1870's. It is apparent that Lee did most of his cave exploring during this decade. When Horace Carter Hovey made his first visit to Mammoth Cave in 1878, Tom Lee was his guide.

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