BULLETIN

OF THE

NATIONAL SPELEOLOGICAL SOCIETY

VOLUME 35 NUMBER 3

Contents

JULY 1973

Pleistocene Vertebrate Fauna of Bat Cave, Pulaski County, Missouri

Oscar Hawksley, Jack F. Reynolds and Robert L. Foley *

ABSTRACT

Excavation of the Bone Passage in Bat Cave, Pulaski County, Missouri produced a late-Pleistocene vertebrate fauna. Of the 41 species recovered (minimum of 180 individuals), 34 were mammals. Twenty-seven percent of the mammals are northern or boreal. Such species as snowshoe rabbit (*Lepus americanus*), red-backed vole (*Clethrionomys gapperi*), yellow-cheeked vole (*Microtus xanthognathus*), northern bog lemming (*Synaptomys borealis*) and fisher (*Martes pennanti*) are included, suggesting the presence of spruce forests with openings during a cool, moist period. Extinct forms represented are dire wolf (*Canis dirus*), short-faced bear (*Arctodus simus*) and flat-headed peccary (*Platygonus compressus*) (at least 98 individuals). Statistical study of dire wolf metapodials provided evidence that the Missouri specimens may differ at least sub-specifically from those found at Rancho La Brea. The material is thought to have been deposited during a relatively short period estimated to have been somewhere between about 16,000 and 10,000 years BP.

INTRODUCTION

Location and Environment

Bat Cave, eight km northwest of Waynesville in Pulaski County, Missouri (Fig. 1), is located in the SE¼, NW¼, NE¼ of Sec. 4, T. 36 N., R. 12 W. and 260 m ASL. Its environs are shown on the Crocker Quadrangle, USGS 7½' series (Vineyard and Brod, 1968). In spite of the ruggedness of the terrain, average local relief is only about seventy-five meters. Local absolute elevations range from 232 m at the Gasconade River near the cave to 343 m at the town of Crocker, six and one-half km north of the cave. Pulaski County contains more known caves (212) than any other county in the nation (Vineyard and Brod, 1968). A number of these caves, including some close to Bat Cave, have yielded Pleistocene vertebrate remains.

The Gasconade River Valley is part of the Salem sub-province of the Ozark Dome (Bretz, 1965). The valley includes a number of entrenched meanders. Bluffs on the outside edges of the meander loops are 60 to 75 m in height, but the tops of the meander spurs are "much below the Ozark peneplain trace". Bretz proposes that there has been little meander enlargement since the river flowed at the level of the spur summits. The deeply incised valleys of Gasconade River, Big Piney River, Roubidoux Creek, and their numerous tributaries so thoroughly dissect the region that little level, tillable land is present except in the fairly narrow river bottoms. Except for pastureland on some of the less extreme slopes and ridge tops, the hills are covered with

* Central Missouri State University, Warrensburg, Missouri 60439.

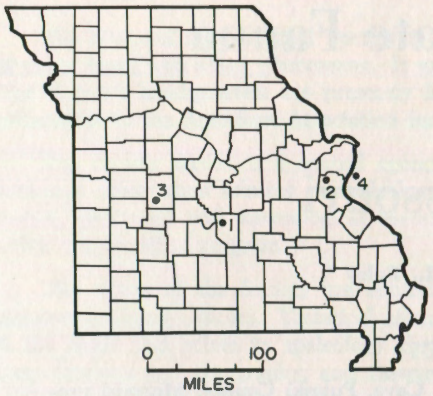

Fig. 1. County map of Missouri, showing relative locations of (1) Bat Cave, Pulaski County; (2) Crankshaft Cave, Jefferson County; (3) Boney Spring, Benton County; and (4) Meyer Cave, Monroe County, Illinois.

second or third growth deciduous forests dominated by oaks and hickories.

The main cave entrance is located in a west-facing Gasconade River bluff. It opens about ten meters above the flood plain and approximately ninety meters from the river. The bluff, not precipitous, is a steep, rocky hillside sparsely covered with oaks (*Quercus stellata, Q. alba, Q. velutina*), hackberry (*Celtis occidentalis*), redbud (*Cercis canadensis*), and relatively numerous red cedars (*Juniperus virginiana*). At the base of the bluff, black walnut (*Juglans nigra*) and sycamore (*Platanus occidentalis*) also are found.

January temperatures in the area range from an average low of 20 to 24°F to an average high of 42 to 46°F. For July, the average low is 64 to 68°F and the average high is 90 to 92°F. Total precipitation varies from 91 to 112 cm per year (U. S. Weather Bureau).

The site is located approximately ninety-six kilometers south of the southern limits of Kansan (the most extensive) glaciation in Missouri, which was just north of the Missouri River (Mehl, 1962). Drainage from the Pulaski County area flows generally northeast toward the Missouri River. The divide between the Gasconade and the White River watersheds is approximately 80 km south.

Site Description

Bat Cave is one of a group of three caves located in Bear Ridge. The caves are developed in Gasconade dolomite. Bretz (1956) describes Bat Cave as being "vadose modified from a phreatic origin." Tunnel Cave, 460 m north, passes completely through the ridge. Its eastern entrance, about three hundred meters distant from the western entrance, is in a sinkhole which has captured a small stream (Bretz, 1956). Tunnel Cave is connected to Spring Cave, which opens a short distance to the north in the west face of Bear Ridge. Spring Cave is not entered often, since it is used as a source of water, but neither of these adjacent caves has produced any significant fossils to date.

There are three entrances to Bat Cave (points A, B, and C on Fig. 2). The cave contains approximately eleven hundred m of passages on several levels. The main entrance, 10 m high and 12 m wide, is lowest in the bluff (Fig. 3). Sixty m inside this entrance, the ceiling becomes abruptly lower and the passage continues along the bed of an intermittent stream for about ninety meters until it becomes no longer crawlable. At the point where the ceiling becomes lower, a ceiling slot shows where the upper passage once crossed the lower one, about twelve meters above the present floor. The rock which once separated the two passages at their crossing is now gone but, just to the east of the slot, a recently discovered, low-ceilinged passage (dotted lines, Fig. 2) does pass over the main entrance passage. To the right, the upper passage continues 90 m to a low, wide opening in the bluff, higher than and south of the main entrance. Access to the left upper passage is gained by walking up a steep clay slope in a narrow passage 14 m in height. At the top of the slope, the passage continues a short distance to a junction with a left-hand passage. The latter meanders for over 100 m, then intersects the bluff

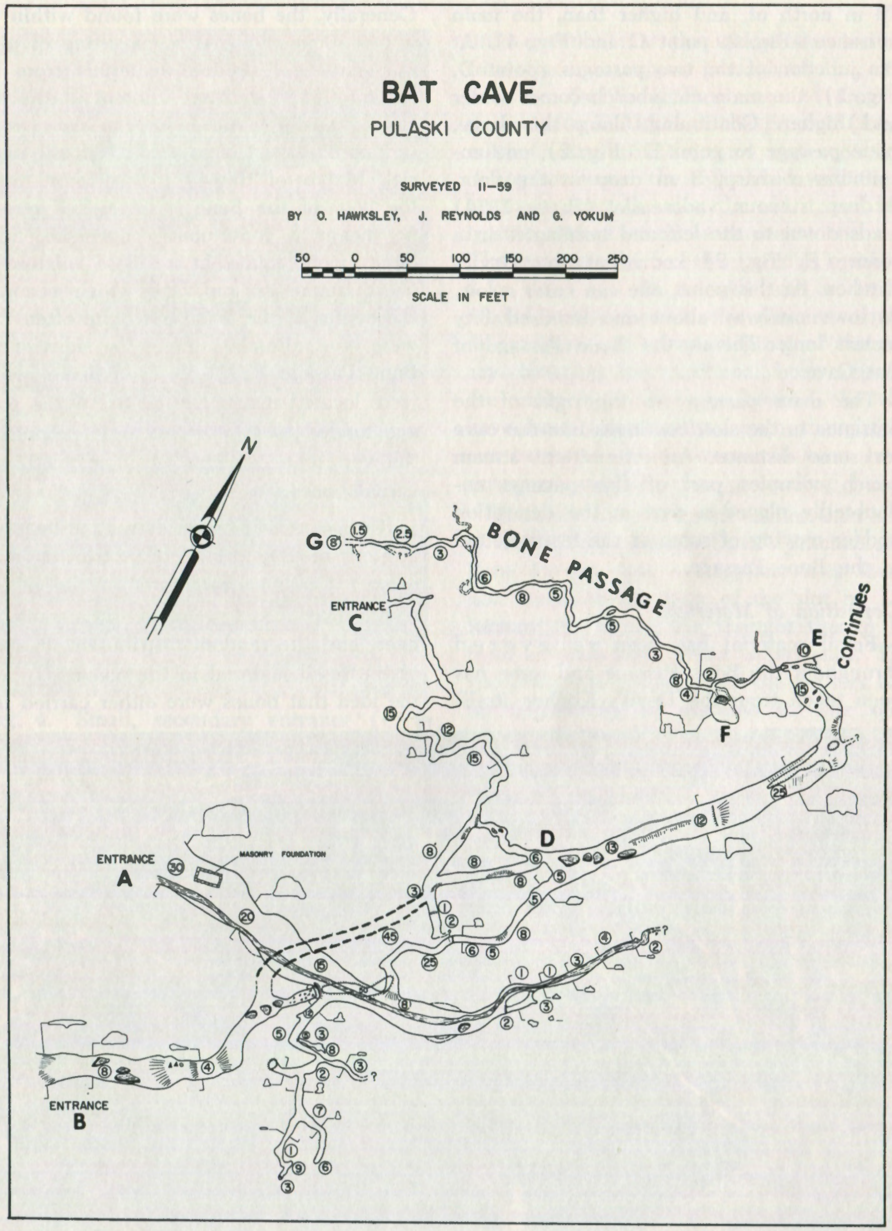

Fig. 2. Map of Bat Cave, Pulaski County, Missouri showing: (A) main entrance, (B and C) upper bluff entrances; (D) junction of passage from entrance C with main upper passage; (E) 3 m drop-off in main upper passage, near entrance slot to Bone Passage; (F) Devil's Kitchen; and (G) terminal end of Bone Passage (which may have been original entrance to this section).

76 m north of, and higher than, the main entrance (Fig. 2, point C and Fig. 4). At the junction of the two passages (point D, Fig. 2), the main chamber becomes wider and higher. Continuing along this large, wide passage to point E (Fig. 2), one encounters a sharp, 3 m drop in the floor. A deep, sinuous, vadose slot (Bretz, 1956) leads down to the left and terminates in a room (F, Fig. 2) known as the Devil's Kitchen. At this point, one can enter a low, narrow crawlway about one hundred fifty meters long. This is the Bone Passage of Bat Cave.

The main passage, to the right of the entrance to the slot, continues into the cave for some distance. An intermittent stream which occupies part of this passage undoubtedly played a part in the deposition and/or moving of some of the fossils found in the Bone Passage.

Deposition of Materials

Fossil material has been recovered throughout the Bone Passage and some has been taken from the Devil's Kitchen itself. Generally, the bones were found within the upper 30cm of a matrix consisting of phreatic clay and residual materials from the dolomite. The moisture content of the material was slight; not enough to have caused serious damage to most of the fossil material. Matrix of this type was found along the floor of the Bone Passage, but was by no means a continuous occurrence. Some bones were found in a dense mixture of chert fragments and clay which occupied the center of the floor, but quite often they were most abundant along the sides of the Bone Passage (Fig. 5). The bones which were located nearer the center of the passage tended to be the less fragile bones of the vertebrate skeleton, such as teeth and carpal bones.

It appears that bones may have been deposited in the passage by two or more means. The alluvial nature of the matrix, ripple marks and channel ridges on the floor, and the random distribution of much of the fossil material in the matrix supports the idea that bones were either carried into

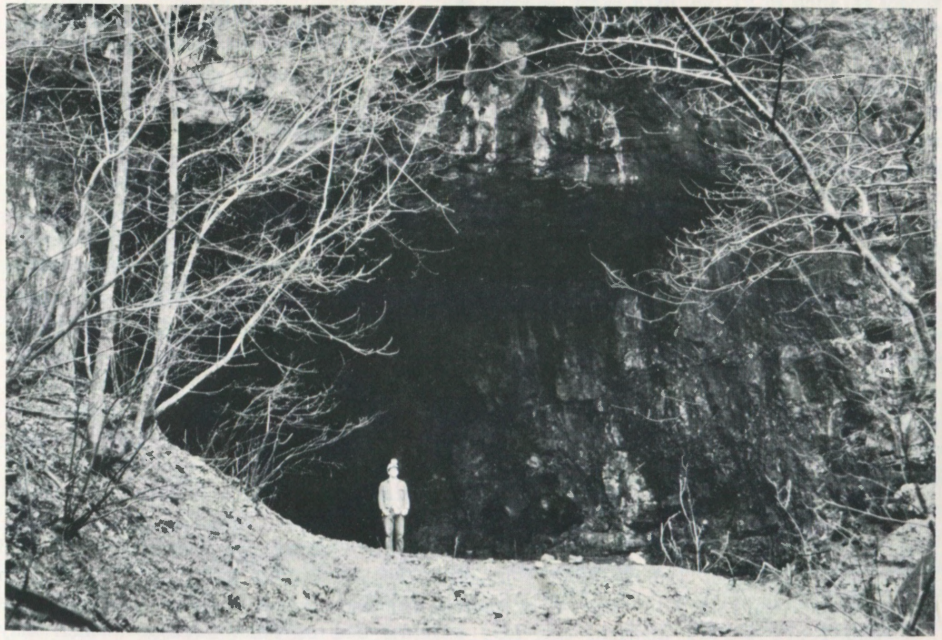

Fig. 3. Main entrance of Bat Cave, Pulaski County, Missouri. Photo by Jack F. Reynolds.

Fig. 4. Small, secondary entrance (C in Fig. 2), higher in bluff and 76 m north of main entrance to Bat Cave. Photo by Jack F. Reynolds.

the passage by water or were moved within the passage by water after original deposition. However, there is little evidence of wear by tumbling, so the bones could not have been moved far. Some material, such as a dentary, isolated teeth, metatarsals, and phalanges of a single individual of the extinct bear, *Arctodus simus* (Reynolds, 1962; Hawksley, 1965), appear to have been found at the original site of a "bear bed". All were located within an area one meter square and could not have been assembled there by moving water, though other small elements of this same bear appeared in the matrix at other locations.

Whether the bulk of the material was merely moved from one location to another in the passage, or whether it was carried into the Bone Passage from another location in the cave, is less certain. There is little question that the vadose slot leading from the main upper passage of the cave into the Devil's Kitchen resulted from a stream piracy. Although the present (intermittent) stream in the main upper passage disappears under the right-hand wall 61 m upstream from the slot, the old stream bed is still evident at the entrance to the slot. The removal of fill at this point as much as 3 m deep and 4½ m wide and a deeply eroded stream bed in the remains of the fill upstream are adequate proof of the piracy. Searches for additional bone sites in the main upper passage beyond the slot have been unproductive, even though the cut banks of the upstream fill have been examined carefully for protruding bones.

The only bone material (other than that of bats) found outside Devil's Kitchen and Bone Passage was a fragment of a lower jaw found on the floor of the slot by Dr. Richard F. Myers. He thought this to be from a black bear, *Ursus americanus*. The specimen was not kept and the authors had no opportunity to examine it. The only other remains of *U. americanus* from Bat Cave appears to be a single metatarsal II collected by George Deike in October, 1959. Because the exact location at which the metatarsal was found is not known, we hesitate to use Dr. Myers' find as proof that bones were moved from the main upper passage into the Bone Passage by water. However, it is possible that certain animals, such as the large numbers of peccaries (*Platygonus compressus*), entered the cave via one of the present entrances at a time after the stream piracy route was well developed. In such a case, they might have been trapped in the slot and their bodies might later have been washed into the Devil's Kitchen and Bone Passage.

There is evidence that the terminal end (G, Fig. 2) of the Bone Passage was once its entrance. In this area, the matrix tends to be wetter, indicating seepage of moisture from outside the cave. Also at this point, where the ceiling becomes too low for further human penetration, the matrix at the surface has a texture and color similar to

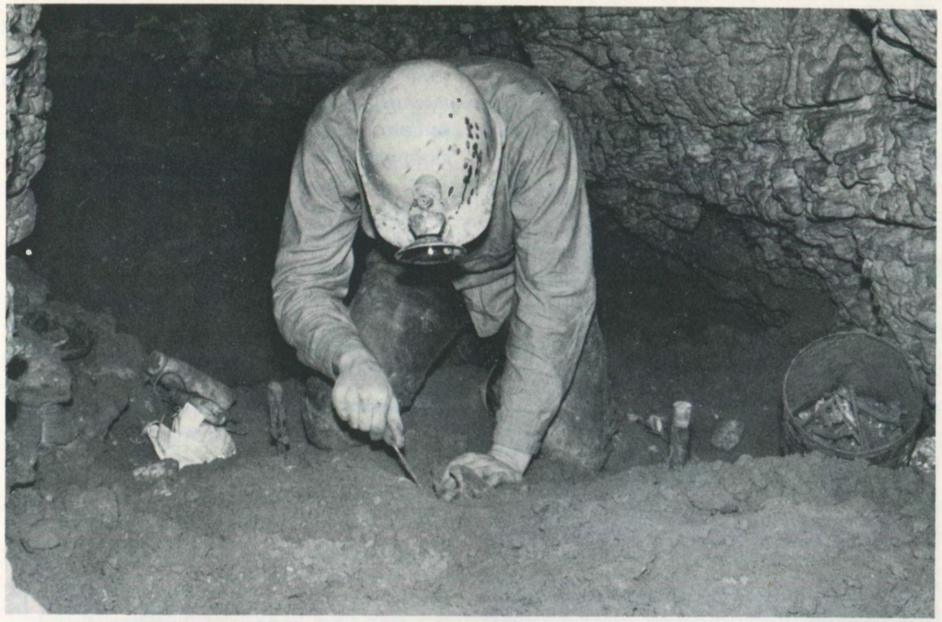

Fig. 5. Bat Cave, Pulaski County, Missouri. Excavating bones from semi-dry clay matrix on floor of Bone Passage. Dire wolf axis exposed near hand of excavator. Photo by Jack F. Reynolds.

those of topsoil. The particles are small (clay- and silt-sized) and reasonably homogenous in size, unlike the cave fill below and in the rest of the cave. In addition, this matrix contains horizontal laminations, indicating that the very thin layers were laid down in standing water at different periods of time, possibly during flood stages of Gasconade River. The laminated unit is thickest near the supposed closed entrance. It feathers out in the other direction and is covered with a progressively thickening layer of the typical cave fill. These facts also point to deposition in standing water near the mouth of the cave. This passage appears to end within a few m of the hillside (see Fig. 2). Collapse of the opening could have taken place after final deposition of the bones. A good possibility therefore exists that many animals entered the Bone Passage by this entrance.

In any event, Bat Cave was not the same sort of faunal trap as is represented by sinkhole sites such as Crankshaft Cave (Parmalee, *et al.*, 1969). The animals whose remains are found in it probably entered the cave of their own volition, or their bodies were carried in by predators. Thus, the species represented may present a somewhat less-typical cross section of the fauna of the times than do those randomly trapped in a sinkhole.

Fieldwork and Methods

Discovery and Excavation

Attention was first directed toward the bone deposits in Bat Cave during the fall of 1958, when members of a mapping-exploration team from the Missouri Speleological Survey discovered some bones in the floor of the Bone Passage and removed them for study. Reynolds (1962) began a general survey of bone deposits in Ozark caves in 1960 and, by the fall of 1961, decided that the deposits at Bat Cave merited a complete excavation. From September, 1961, until May, 1962, he devoted full time to the excavation and study of bones from the cave. However, this "preliminary" study resulted in the removal of remains from no more than a third of the passage and in detailed study of only the larger species represented.

Work, by numerous graduate and undergraduate students, continued under the direction of Hawksley from 1963 until the excavation was completed. Excavation of the site finally was completed by Foley in the summer of 1968.

The majority of the bones recovered were removed by careful excavation of the surrounding matrix. This was accomplished by digging by hand with small tools such as ice picks or screwdrivers sharpened to a point (Fig. 5). Digging began at the terminal end, near the hypothetical former entrance, and proceeded toward the Devil's Kitchen. Where the matrix was deep enough, a transverse trench was made across the passage. This was back-filled with crumbled matrix, which had been examined by hand for bones, as the leading edge of the trench moved slowly toward the Devil's Kitchen. Seldom was the trench made more than half a meter deep, because no bones were found at lower levels.

All bone material uncovered was packed into cylindrical paperboard or metal containers and packed with loose matrix. This served a two-fold purpose. It protected the bones during their removal from the cave and it permitted some of the matrix to be screened for small teeth and bones. In areas where small bones were found in the matrix while digging, they were packed separately and samples of matrix were collected for sifting in the laboratory. Since exit from the Bone Passage had to be made partly by belly crawl, samples could be removed only by rolling the cylindrical containers ahead of the workers. These circumstances, plus the fact that the slot also was difficult to negotiate, made it impossible to remove all matrix to an outside area for sifting. Although this meant that some small items undoubtedly were missed, the relatively dry condition of the matrix, which could be crumbled and sorted quite well by hand, reduced the likelihood of overlooking small specimens.

Upon return to the laboratory, bones and matrix were carefully dried. Although there was little moisture in the cave, there was enough in the matrix to make cleaning the bones without first drying them impractical.

After drying, immersion in water of clumps of matrix or of matrix-covered bones caused a sloughing-off of the matrix, making rough scrubbing unnecessary. What little matrix still remained could then be gently removed with a tooth brush. After cleaning, bones were dried for several days. All matrix brought back with bones was washed through three successive soil sieves (coarse, medium and fine) to recover any fossils which might have escaped detection.

After thorough drying, all bones were dipped into a clear plastic (Gelva V-15). This was absorbed by the more porous bones and covered all bones with a protective coating. Materials were then identified and catalogued in the vertebrate fossil collection of the Department of Biology, Central Missouri State University (CMS).

Attempts at pollen analysis

Several attempts were made in 1967 by Dr. James Urban to extract pollen from the Bone Passage matrix. A very small amount of pollen was obtained from these efforts, but it was so badly oxidized, apparently from being in wet clay, that it was not identifiable.

Dr. John Emerson ran samples of the matrix from the terminal end of the Bone Passage for pollen in 1971. The previously described topsoil-like appearance of the fill at this point made it seem hopeful that pollen might be recovered from this locality. Results were again negative, however, presumably due to oxidation.

Other workers have had similar difficulties in running pollen analyses on wet clay fills from Ozark caves.

TABLE 1. VERTEBRATES IDENTIFIED FROM BAT CAVE, PULASKI COUNTY, MISSOURI

(N—Modern range north of Missouri or Ozarks, E—extinct, P—occurring locally during historic times)

Species	No. of identified remains	Minimum no. of individuals	Range
AMPHIBIA			
Cryptobranchidae			
Cryptobranchus sp., hellbender	3	1	P
Bufonidae			
Bufo sp., toad	1	1	
Ranidae			
Rana sp., frog	1	1	
REPTILIA			
Colubridae			
Pituophis sp., pine/bullsnake	3	1	
Snake sp.	4	1	
AVES			
Passerine	1	1	
MAMMALIA			
Soricidae			
Sorex cf. *cinereus* Kerr, masked shrew	1	1	N
Sorex cf. *cinereus* or *longirostris* Bachman	1	1	
Blarina brevicauda brevicauda (Say), short-tailed shrew	3	2	N
Vespertilionidae			
Myotis cf. *lucifugus* (LeConte), little brown bat	1	1	P
Myotis cf. *griscescens* A. H. Howell, gray bat	10	3	P
Myotis sodalis Miller and G. M. Allen, Indiana bat	1	1	P
Myotis Kaup, ? spp., bat	10	7	
Pipistrellus subflavus (F. Cuvier), pipistrelle	1	1	P
Eptesicus fuscus (Palisot de Beauvois), big brown bat	8	2	P
Lasiurus cf. *cinereus* (Palisot de Beauvois), hoary bat	3	1	P
Lasiurus cf. *borealis* (Müller), red bat	3	2	P
Bat spp.	142		
Leporidae			
Sylvilagus floridanus (J. A. Allen), eastern cottontail	30	3	P
Lepus americanus Erxleben, snowshoe rabbit	142	4	N
Sciuridae			
Marmota monax Linnaeus, woodchuck	68	6	P
Tamias striatus (Linnaeus), eastern chipmunk	1	1	P
cf. *Tamias* Illiger, ? sp., chipmunk	1	1	
Tamiasciurus cf. *hudsonicus* (Erxleben), red squirrel	8	1	N
Geomyidae			
Geomys bursarius (Shaw), plains pocket gopher	15	3	P
Castoridae			
Castor canadensis Kuhl, beaver	3	1	P
Cricetidae			
Peromyscus Gloger, ? sp., white-footed mouse	12	3	P
Neotoma floridana (Ord), eastern wood rat	44	5	P
Clethrionomys cf. *gapperi* (Vigors), red-backed vole	1	1	N
Microtus pennsylvanicus (Ord), meadow vole	9	1	N

TABLE 1. VERTEBRATES IDENTIFIED FROM BAT CAVE, PULASKI COUNTY, MISSOURI—*Continued*

Species	No. of identified remains	Minimum no. of individuals	Range
Microtus xanthognathus (Leach), yellow-cheeked vole	26	4	N
Microtus Schrank, ? sp., vole	9	2	
Microtus sp. or *Pitymys* McMurtrie, ? sp., vole	2	1	
Ondatra zibethica (Linnaeus), muskrat	1	1	P
Synaptomys borealis (Richardson), northern bog lemming	1	1	N
Muridae			
Rattus Fisher, ? sp., Norway or black rat	1	1	P
Canidae			
Canis dirus Leidy, dire wolf	177	4	E
Canis latrans Say, coyote	5	2	P
Vulpes fulva (Desmarest), red fox	2	1	P
Ursidae			
Arctodus simus (Cope), short-faced bear	45	1	E
Ursus americanus Pallas, black bear	1	1	P
bear, immature	4	1	
Procyonidae			
Procyon lotor (Linnaeus), raccoon	1	1	P
Mustelidae			
Martes pennanti (Erxleben), fisher	1	1	N
Mustela frenata Lichtenstein, long-tailed weasel	1	1	P
Felidae			
Lynx cf. *rufus* (Schreber), bobcat	1	1	P
Tayassuidae			
Platygonus compressus LeConte, flat-headed peccary	6339	98	E
TOTALS	7148	180	

Accounts of Species

Non-mammalian Species

As can readily be seen from Table 1, the Bat Cave fauna includes very few non-mammalian remains. Invertebrates are represented only by a single shell of the gastropod *Mesodon elevatus.*

Locations for *M. elevatus* listed by Pilsbry (1940) indicate that the species is rather widely distributed in Missouri and is known as a "fossil" from Boone and Callaway Counties. Baker (1939) says that this land snail "is most abundant in ravines where there is a heavy growth of oak, maple, hickory or sycamore trees and a considerable cover of forest debris." Although some of these tree species are present, the habitat in the vicinity of Bat Cave today is much drier than that indicated by Baker. The Bat Cave specimen was taken from well below the surface of the matrix and probably is contemporaneous with the rest of the fauna, but it would be risky to draw conclusions from a single specimen.

The amphibians and reptiles were represented only by post-cranial elements and none were identifiable to species. The toad, frog and snake could have wandered into the cave in search of food or shelter. The presence of *Cryptobranchus,* represented by a trunk vertebra, femur, and fragment of humerus, is of more interest. Because none of the mammals in the fauna is very likely to have carried a hellbender into the cave as prey, the animal must have come in from nearby Gasconade River. This lends some credence to the suggestion that the terminal end of the Bone Passage was once an entrance and might have been flooded during times of high water. It also raises the question of whether or not some of the mammals might have drowned in the cave at a time when it was flooded.

Mammalia

Both the Bat Cave fauna and the Crankshaft Cave fauna (Parmalee, *et al.*, 1969) from Jefferson County, Missouri, are primarily mammalian assemblages. Frequent comparisons between the two will be made below. Although it did not provide the massive amount of material or show the diversity of species that Crankshaft Cave did, Bat Cave nonetheless contained a rather significant mid-American Pleistocene local fauna. Of the 60 species of mammals represented at Crankshaft Cave, seven were extinct forms and 17 were species now extirpated in Missouri. If *Rattus* is excluded, only 33 species of mammals occur in the Bat Cave fauna. Of the eight Recent species which no longer are found in Missouri, six also were found in Crankshaft Cave and the remaining two, the yellow-cheeked vole and the fisher, are of considerable interest. The three extinct forms from Bat Cave do not duplicate any found at Crankshaft Cave; one, *Platygonus compressus*, represents a very large population worthy of separate study.

Family **Soricidae**: shrews

Shrews are poorly represented in the fauna, with only two species positively identified and a minimal number of only three individuals possible. This sharp contrast with the situation at Crankshaft Cave, where nearly 6,900 shrew elements were recovered, is undoubtedly due to the lack of a pit type trap at Bat Cave.

The masked shrew, *Sorex cinereus*, ranges as far south today as northern Kentucky, but is missing from western Illinois and southern Iowa. It was the most abundant *Sorex* at Crankshaft Cave and is, thus, a shrew to be expected at Bat Cave though other, more northern, shrews found at Crankshaft Cave are not represented at Bat Cave. An incomplete ramus with teeth, identified as S. cf. *cinereus* or *longirostris*, is more likely *cinereus* since there are no other southeastern species in the fauna.

Although two subspecies of the short-tailed shrew occur in Missouri today, *B. b. brevicauda* is found only in the northeastern part while *B. b. carolinensis* occurs in the remainder of the state. Stratification of the two forms in Crankshaft Cave indicates that a fluctuating climate persisted over a long period of time. Since *B. b. brevicauda* is the only subspecies recorded at Bat Cave (total length of two mandibles 16.1 mm; toothrow $C_1 - M_3$, 6.2 mm), this may indicate that the Bat Cave fauna represents a specific, limited time period during which little, if any, major climatic change occurred.

Family **Vespertilionidae**: bats

Bat remains were not particularly abundant or significant. All seven species of bats found at Bat Cave reside in or migrate through Missouri today. Of the species represented, *Lasiurus cinereus* and *L. borealis* are the most interesting. Although these tree bats are said rarely to use caves, Myers (1960) mentions records of lasiurine bats from caves in many states. His own data indicate that Bat Cave, Piquet Cave and Inca Cave, all of which lie within a 16 km radius of Bat Cave in Pulaski County, have had unusual numbers of these bats compared to those in the other 10 Missouri caves in which he found them. It would appear that lasiurines have tended to congregate and die "within specific areas, usually at the far end of an inner passage", a description which certainly fits the Bone Passage of Bat Cave. Banding of these bats by Myers indicated that they did not leave the caves, having once entered.

Family **Leporidae**: rabbits and hares

Both eastern cottontail and snowshoe hare elements were moderately abundant at Bat Cave, though a disproportionately large amount of cottontail material did not occur as it did at Crankshaft Cave. This may reflect the probability that Crankshaft was both open longer and open during warmer times, thus having been proportionally more available to cottontails. Both species probably entered Bat Cave for shelter, as there is no indication of bone crushing by predators (most of the long bones are intact).

Ideal cover for *L. americanus* in its present range (south in the midwest to central Minnesota and Wisconsin), consists of hardwoods for food and conifers for protection (Trippensee, 1948). Grange (1932) states that in Wisconsin, underbrush is needed by the hares and that "the lack of a goodly portion of either aspen or balsam fir or both seems to be a limiting factor in many cases". Thus, the presence of snowshoe hare indicates former conditions at least as boreal as those existing at the southern edge of the Canadian zone today.

Family **Sciuridae**: squirrels and relatives

Only three sciurids were specifically determined from Bat Cave. The most abundant of these was *Marmota monax*. The 68 elements of woodchuck represent only six individuals. Parmalee, *et al.* (1969) comment upon the dearth of woodchuck remains at Crankshaft Cave (only two or three individuals represented) in comparison with those found at a site such as Meyer Cave, Illinois (Parmalee, 1967). At Meyer Cave, it was the second most-abundant mammal, with no less than 597 individuals represented. It is very difficult to compare numbers at sites such as these three because there are at least three variables which must be considered: the type of entrance, habitat at the time of deposition, and time of deposition. Any one of these could account for numerical differences in faunal composition. *Tamias striatus* and *Tamiasciurus hudsonicus* seem to be represented by single individuals.

Both the woodchuck and the eastern chipmunk are common in the Missouri Ozarks today. Although the range for *T. striatus* presented by Hall and Kelson (1959) indicated no records from the central Ozarks at that time, this probably was due to a lack of collecting. A specimen in the mammal collection of Central Missouri State University was taken in Miller County, which is adjacent to Pulaski County. The red squirrel, on the other hand, may be regarded as a northern species since it has occurred in recent times only as close as southern Iowa and northern Illinois. It was well represented, however, in Pleistocene deposits from the Conard Fissure in northern Arkansas (Brown, 1908).

Family **Geomyidae**: pocket gophers

The plains pocket gopher, *Geomys bursarius*, was the only species in the Bat Cave fauna which might be considered a representative of prairie grassland habitat. Its range in Missouri is poorly known. It is found in the northern half of the state and ranges southward in the eastern half about to the Arkansas line, except in the lowlands of the southeastern "boot-heel". It is doubtful that Pulaski County today has the deep, moist soils or even small patches of the type of prairie grassland preferred by these gophers. We can find no evidence of its occurring locally during historic times. The species was represented at Bat Cave by a minimum of three individuals.

Family **Castoridae**: beaver

Beaver, *Castor canadensis*, occur on the Gasconade River today. A colony may be found a few miles downstream from Bat Cave. The authors have seen live beaver in caves (*e. g.* Great Scot Cave, Washington Co., Mo.) and have recovered remains of beaver from deep within extensive cave systems (*e. g.* Carroll Cave, Camden Co., Mo.). The foregoing data certainly indicate that these large rodents enter caves containing streams. Other investigators, who have found more-extensive amounts of beaver remains in cave deposits, feel that the animals were carried in by predators. In the case of Bat Cave, it seems likely that beaver merely wandered into the cave, possibly during times of high water in the Gasconade River. This strengthens, slightly, the idea that the present terminal end of the Bone Passage once was an entrance and was subject to flooding.

Family **Cricetidae:** cricetids

At least seven species of cricetids are represented at Bat Cave. Four of these are northern species, while the remainder are common in the area today.

Most significant is the presence of the yellow-cheeked vole, *Microtus xanthognathus*, which is the first record for this boreal, woodland form in Missouri. The only other occurrence of the species in the Midwest is at Meyer Cave, Illinois. Parmalee (1967) considers this to be, in part, an early post-Pleistocene site. Previous to the Meyer Cave discovery, it was known in late Pleistocene faunas only from Pennsylvania and Virginia (Guilday, Martin and McCrady, 1964; Guilday, Hamilton and McCrady, 1966; Guilday, 1962). The material consists of CMS 27, 28, 363, 364, which include one partial skull with teeth and two left and three right mandibles, representing four individuals.

Bat Cave is approximately 192 km west-southwest of Meyer Cave, while the present southernmost range of the species, in Manitoba, is at least 1900 km north. Although this does not greatly extend the range of the species to the south or west, it does establish a past affinity between the Meyer Cave and Bat Cave areas. Parmalee (1967) notes that the present day biota in the region surrounding Meyer Cave is more indicative of the Illinoian province of Dice (1943) than of the Carolinian province into which it actually falls. The Bat Cave location, however, is more typically Carolinian.

The meadow vole, *Microtus pennsylvanicus*, was not abundant, as it was at Crankshaft Cave, and is represented in the fauna only by a single individual. This species may occur in northern Missouri, but there apparently are no authenticated records of its occurrence in the state. Although not limited to a boreal habitat, it fits in well with one.

The northern bog lemming, *Synaptomys borealis*, is represented at Bat Cave by a single left mandible with teeth. Its southern counterpart, *S. cooperi*, is absent from the fauna, though it might be expected to be present since in its present range it approaches and may occur in Pulaski County. Both species are included in the Crankshaft fauna, though *S. borealis* is much less abundant (minimum of two) than is *S. cooperi* (minimum of 92). We hesitate to jump to conclusions on the basis of a single specimen, but the absence of *S. cooperi*, in this case, may be nearly as significant as the presence of the northern species. It is possible that the Bat Cave fauna was deposited at a time of advanced glaciation and cool temperatures, and that deposition stopped prior to a warming period. Such a situation could also help to explain the presence of only the northern subspecies of short-tailed shrew (previously discussed) and of *Microtus xanthognathus* and *M. pennsylvanicus*, while the common, local voles, *M. ochrogaster* and *M. pinetorum*, are notably absent. Inclusion of *S. borealis* in the Bat Cave fauna extends the range of the species a bit farther south and west than did the previous record at Crankshaft Cave. The present southern limit of its range in mid-America extends only to the Canadian border area of Minnesota.

The fourth cricetid of interest is the red-backed vole, *Clethrionomys* cf. *gapperi*, which is represented by a single right M^2 (CMS 376). Another boreal species, usually inhabiting damp, cool, forested areas, it ranges south in mid-America today only to northern Iowa. Getz (1968) found that in southern New England, *C. gapperi* was restricted to low, wet areas where standing water or an accessible water table existed.

Family **Muridae:** old world rats and mice

A single tibia of black, or Norway, rat, *Rattus* sp., apparently was taken from the surface of the Bone Passage. Coloration of the bone indicates that it was not imbedded in the matrix. The proximity of farm buildings to the cave probably explains this intrusion.

Family **Canidae:** foxes, dogs, wolves

The dire wolf, *Canis dirus*, ranked second in total number of identified elements (177). A minimal number of four individuals is based on right metacarpal III, although two left metacarpals III, which vary considerably in length from the rights, would raise the number to six. A skull fragment with left P^3—M^2, numerous isolated teeth, several intact limb bones, and a good selection of foot elements are included in the remains. Most of these were reported, with measurements, by Hawksley, *et al.* (1963). Previously unreported dire wolf material (CMS 110, 327, 360, 369, 379, 424, 489, 510, 562, 564) from Bat Cave, excluding phalanges and fragments, includes: one left P_3; one left P_4; one right P^4; one right and one left M_2; five canines; eight incisors; two right and three left MC II; two right and one left MC III; one left MC IV; two right and one left MC V; one right MT II; one right MT III; two left MT IV; one right and one left MT V; one right tibia; one cuboid; one magnum; one pisiform; three astragali; one calcaneus.

The dire wolf is now known from at least seven other sites in Missouri: Herculaneum Crevice, Jefferson County (Olsen, 1940); Carroll Cave, Camden County (Hawksley, *et al.*, 1963); Perkins Cave, Camden County (Hawksley, 1965); Powder Mill Creek Cave, Shannon County (Galbreath, 1964); Brynjulfson Caves, Boone County (Parmalee and Oesch, 1972); Bushwacker Cave, Pulaski County (unpublished); Zoo Cave, Taney County (excavation in process). The last-mentioned site has only been sampled, but it has an abundant supply of the peccary *Platygonus compressus* and promises to yield additional dire wolf material.

Galbreath (1964) obtained a radiocarbon age determination of 13,170 ± 600 years BP for the adult female specimen from Powder Mill Creek Cave. He regarded the specimen to be essentially contemporaneous with the dire wolves of pit 3 at Rancho La Brea (Howard, 1960) although the radiocarbon age for his specimen was roughly a thousand years less. Galbreath also suggested, however, that the Missouri dire wolves might be a larger subspecies which lived at a slightly later date. This suggestion was based on the facts that the adult female from Powder Mill Creek Cave was as large as the largest Rancho La Brea material and that the Carroll Cave specimen, which he regarded as a male, is even larger (see Tables 2 and 3 for comparisons). Although Galbreath, as well as Hawksley, *et al.* (1963), were reluctant to conclude that Missouri dire wolves are consistently larger than those from Rancho La Brea, additional data accumulated since 1964, largely from Bat Cave, tend to bear this out.

Certain post-cranial elements, which Merriam (1912) considered important, are compared in Table 2. It can readily be seen that the Missouri means are well above the measurements given for "relatively large" specimens from Rancho La Brea and that even the smallest Missouri specimens exceed the size of those from Rancho La Brea. Curiously enough, there is greater conformity in size of the teeth between those from Rancho La Brea (Table 3), and those from Missouri, excepting M_2, M_3, M^1, and M^2, which tend to be larger in the Missouri specimens.

The La Brea population must be restudied before any taxonomic revision of *C. dirus* can be attempted. However, an excellent statistical study of thousands of dire wolf metapodials (Nigra and Lance, 1947) provides us with at least one interesting comparison, since we have accumulated a fair number of metapodials from Missouri sites and have more metapodials than any other type of element. Table 4 compares the mean lengths of Bat Cave metapodials, as well as means for all presently known and available Missouri specimens, with the means of the large samples from Rancho La Brea. No significant differences were found between Missouri and Rancho La Brea populations by F test comparisons of variance. Figure 6 contrasts Missouri and Rancho La Brea data graphically. It still is not clear whether the large dire wolves from the Ozarks represent a temporal or a geographic difference from those of Rancho La Brea.

TABLE 2. *Canis dirus,* measurements (in mm) of important post-cranial elements. Missouri specimens compared with "relatively large" specimens from Rancho La Brea.

	Bat Cave	Carroll Cave	Powder Mill Cr. Cave	Brynjulfson Caves	Mo. $\overline{X}$	Rancho La Brea
Atlas, greatest width	. . .	123	113*	. . .	118	120.5
Axis, greatest anteroposterior length of neural spine	80.5	. . .	. . .	. . .	. . .	73.7
Humerus, greatest length	. . .	252	247*	. . .	249.5	240
Radius, greatest length	240 258	245	236	257	247.2	220
Metacarpal IV, greatest length	98 102 102.7	105.5	104.7	108 109	104.3	90.5
Femur, greatest length	. . .	278.5	270	. . .	274.3	260
Tibia, greatest length	243 265	267	265	. . .	260	237
Metatarsal IV, greatest length	110.7 111.2	. . .	117**	117 118	114.2	102.3

Rancho La Brea elements do not represent any one individual; data from Merriam, 1912. Powder Mill Creek Cave (Shannon County, Missouri) data from Galbreath, 1964. Carroll Cave (Camden County, Missouri) data from MU 2870-CMS 14 (single individual). Brynjulfson Caves (Boone County, Missouri) data from Parmalee and Oesch, 1972.

* Measurements involving cemented parts or made from a center line to one side.
** Estimated length, not included in mean.

TABLE 3. *Canis dirus,* tooth measurements (in mm.) of Missouri specimens compared with those of a "large specimen" from Rancho La Brea.

		Bat Cave	Carroll Cave and Perkins Cave*	Powder Mill Cr. Cave	Mo. $\overline{X}$	Large Rancho La Brea
C_I	L	18.0–18.6–16.0	18.0	18.0	17.7	17.5
P_1	L	6.7–7.1	7.7	. . .	7.2	7.7
P_2	L	. . .	16.0	. . .	. . .	15.4
P_3	L	15.6	17.5	. . .	16.6	16.7
P_4	L	19.6	18.3*–20.2	19.5	19.4	20.0
M_1	L	. . .	36.9	34.9	35.9	35.7
	W		14.7	13.7	14.2	14.3
M_2	L	14.6–14.8	14.0	14.0	14.4	12.8
	W	12.5–11.0	11.4	10.0	11.2	10.0
M_3	L	. . .	8.7	. . .	. . .	6.5
C^s	L	18.8–17.0–18.5–17.7	. . .		18.0	17.0
P^3	L	19.0–17.3	18.5*–19.8	. . .	18.7	19.0
	W	9.0–8.2	7.9*–8.9		8.5	
P^4	L	32.0–32.0–31.3	33.2	. . .	32.1	32.0
	W	13.0–14.0–12.8	14.0	. . .	13.5	13.0
M^1	L	19.0	20.7	. . .	19.9	20.0
	W	26.0	25.7	. . .	25.9	24.0
M^2	L	11.0	12.0	. . .	11.5	10.0
	W	16.0	16.2	. . .	16.1	15.4

Rancho La Brea data from Merriam, 1912. Some widths not available. Powder Mill Creek Cave (Shannon County, Missouri) data from Galbreath, 1964. Carroll Cave (Camden County, Missouri) data from MU 2870-CMS 14 (single individual). Perkins Cave (Camden County, Missouri) specimen (*), CMS 176.

TABLE 4. *Canis dirus,* metapodial measurements (in mm) of Bat Cave and of all Missouri specimens compared with those of specimens from Rancho La Brea.

Metapodial	Source	N	O. R.	$\overline{X}$	S. D.	V	C. V.
MC II	R. La Brea	2382		77.17	3.1	9.61	4.02
	Bat Cave	7	89.9–95.0	91.59	1.68	2.83	1.83
	All Mo.	9	89.9–95.0	92.12	1.87	3.51	2.03
MC III	R. La Brea	2500		88.00	3.6	12.96	4.09
	Bat Cave	7	98.0–109.3	102.76	3.39	11.49	3.30
	All Mo.	9	100.9–109.3	103.31	3.14	9.84	3.04
MC IV	R. La Brea	2441		87.10	3.5	12.25	4.02
	Bat Cave	3	97.9–102.7	100.87	2.59	6.72	2.57
	All Mo.	7	97.9–109.0	104.26	3.79	14.36	3.64
MC V	R. La Brea	2566		73.85	3.2	10.24	4.33
	Bat Cave	6	85.1–95.8	90.22	4.66	21.69	5.17
	All Mo.	10	85.1–95.8	90.83	3.57	12.76	3.93
MT II	R. La Brea	2515		83.35	3.4	11.56	4.08
	Bat Cave	2	98.9–100.0	99.45	.78	.61	.78
	All Mo.	5	98.9–106.0	100.94	2.86	8.21	2.83
MT III	R. La Brea	2532		94.01	3.8	14.44	4.04
	Bat Cave	3	110.0–115.5	112.47	2.80	7.80	2.49
	All Mo.	3	110.0–115.5	112.47	2.80	7.80	2.49
MT IV	R. La Brea	2459		96.30	3.8	14.44	3.95
	Bat Cave	2	110.7–111.2	110.95	.35	.13	.32
	All Mo.	4	110.7–118.0	113.16	4.07	16.55	3.60
MT V	R. La Brea	2224		88.10	3.4	11.56	3.86
	Bat Cave	2	102.8–103.0	102.90	.14	.02	.14
	All Mo.	5	101.6–111.0	104.56	3.73	13.95	3.57

Missouri specimens not from Bat Cave are from Carroll Cave (Camden County), Powder Mill Creek Cave (Shannon County), and Brynjulfson Caves (Boone County). Rancho La Brea data from Nigra and Lance, 1947. All values for Rancho La Brea based on weighted means adjusted for rights and lefts.

Dire wolf material from Texas is too scarce to be of much help, but some estimates of age have been made for Texas deposits containing dire wolves. A humerus (233 mm) and a femur (256 mm) reported from Laubach Cave (Slaughter, 1966) fall within Rancho La Brea measurements, but are considerably s m a l l e r than presently known Missouri specimens. Slaughter (*op. cit.)* also mentions a humerus from the Ingleside local fauna measuring 251 mm in length, which is very close to the size of M i s s o u r i specimens. An ulna from the Moore Pit local fauna (Slaughter, *et al.,* 1962) has an over-all length of 267 mm, larger than that of some Rancho La Brea specimens but considerably smaller than those of ulnas from Powder Mill Creek Cave (285.6 mm) and Carroll Cave (290 mm) in Missouri. Slaughter indicates a date of 45,000 years B. P. for the Moore Pit fauna and considers the Ingleside fauna to be slightly y o u n g e r, while the Laubach Cave deposit is estimated at 25,000 to 45,000 years B. P.

Eight metapodials of a large wolf from Cherokee Cave, St. Louis were not assigned to species by Simpson (1949) because teeth were absent and because the metapodials were so much larger than were those from

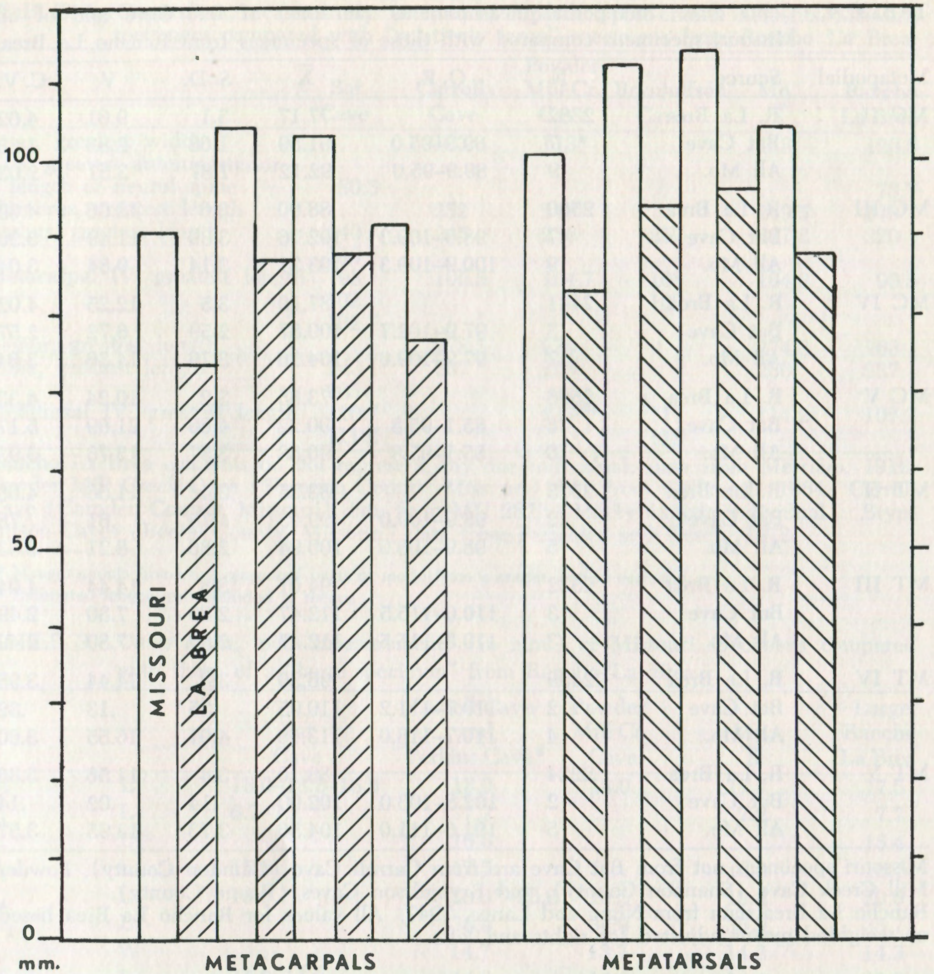

Fig. 6. *Canis dirus.* Mean lengths (in mm.) of metapodials of Missouri specimens (open columns) compared with those of Rancho La Brea specimens (hatched columns). Rancho La Brea data from Nigra and Lance, 1947.

two Rancho La Brea specimens of *C. dirus* in the American Museum of Natural History collections. Half of these fall within the observed ranges of presently known Missouri specimens, but the remainder are still larger, with one MT IV reaching the length of 126.6 mm. Due to the uncertainty of identification, these metapodials cannot be included in statistical studies of Missouri dire wolves, but the size and apparent stoutness of the bones leads one to believe that they probably are dire wolf.

Remains of *C. dirus* from the Ozarks continue to accumulate slowly and, eventually, there should be sufficient material to provide a more comprehensive picture. New material recently discovered in northwestern Arkansas (Quinn, 1969) was associated with *Platygonus compressus* subsequently carbon dated at 16,700 years BP (Quinn, pers.

comm.). Although we do not yet know anything about the relative size of the Arkansas material, it is certainly noteworthy that the Missouri material so far reported has been rather consistently larger than the dire wolves from Rancho La Brea.

The only other canids recovered from Bat Cave were coyote *(Canis latrans)* and red fox *(Vulpes fulva)*. The coyote remains consist of a right M_1, a partial right M_1, and three phalanges which appear to be from this species. Those of the red fox are a partial left mandible with C and P_2–M_1 and a right maxillary fragment with P^4 and M^1. The red fox material was large. It exceeds not only the means but, also, the observed ranges of four Recent Missouri specimens with which it was compared. Tooth and jaw comparisons are presented in Table 5.

Family Ursidae: bears

The occurrence of *Arctodus simus* at Bat Cave previously was reported in some detail by Hawksley (1965). At that time, however, Kurtén (1963), who had made a preliminary study of North American arctotheres, had concluded that there was no basis for recognizing more than one species of *Arctodus*. The name used was, therefore, *Arctodus pristinus* Leidy. After a more complete review of North American specimens, including those from Missouri, Kurtén (1967) concluded that there were, indeed, two North American species. He considers the eastern arctodont, *A. pristinus*, to be Yarmouthian to Illinoian and the stratigraphic range of the great North American short-faced bear, *A. simus*, to extend from the early middle-Pleistocene to the end of the Wisconsinan. Kurtén (1967) feels that, although the temporal ranges of the two species overlapped, it is less likely that they overlapped geographically. He summarizes the geographic range of *A. simus* as being "from Alaska in the north to Mexico in the south, and from California eastward to Pennsylvania".

It is surprising that there is so little bear material in the Bone Passage of Bat Cave.

TABLE 5. *Vulpes fulva*, measurements (in mm) of teeth and lower jaw of Bat Cave specimens compared with those of four recent Missouri specimens.

		CMS 22; 73	Recent Missouri $\bar{X}$	O. R.
C_1	L	7.2	6.2	5.7–6.7
	W	4.7	4.3	4.1–4.5
P_2	L	8.6	7.8	7.5–8.0
	W	3.5	3.0	2.8–3.1
P_3	L	9.8	8.3	8.2–8.7
	W	3.7	3.1	2.9–3.2
P_4	L	10.6	8.9	8.6–9.0
	W	4.5	3.8	3.6–4.2
M_1	L	14.6	14.0	13.5–14.1
	W	6.2	5.6	5.3–6.1
Hgt. lower jaw between P_4 and M_1		15.2	12.7	11.9–13.2
Ant. end P_2 to posterior end M_1		47.3	41.2	40.1–42.8
P^4	L	15.4	13.6	13.3–13.7
	W	6.6	6.4	6.2–6.5
M^1	L	9.4	8.7	8.4–9.4
	W	11.2	10.3	10.0–10.6

Excepting the single individual of *A. simus*, the only materials are a metatarsal and three phalanges of an immature ursid and a single metatarsal II of *Ursus americanus*. The black bear once was abundant in Missouri, as is indicated by its abundance in the bone deposits (both fossil and recent) of many Ozark caves.

Family Procyonidae: raccoons

Procyon lotor, which is common today in Missouri and might be expected to be common in the Bat Cave fauna, also, is represented by the distal half of a somewhat aberrant radius.

Family Mustelidae: weasels, mink, skunks, and relatives

The mustelids are represented by a single bone, each, of the fisher, *Martes pennanti*, and of the long-tailed weasel, *Mustela frenata*. The weasel tibia, judging from its large size, is that of a male (Guilday, pers. comm.). The left ulna of the fisher, according to Parmalee (1971), who has published this and three other Missouri records of the fisher, appears to be that of a "large (male?)." Fisher had not previously been reported from the state, although there is a record from the Conard Fissure (Brown, 1908) in northern Arkansas. Two of the Missouri records are from archeological sites: Graham Cave, Montgomery County and Arnold-Research Cave, Calloway County. These two "caves" are rock shelters which were inhabited by "peoples of the Archaic and Woodland cultures". The remaining record is from Brynjulfson Cave in Boone County, which contained remains of several extinct Pleistocene species along with those of numerous recent species (Parmalee and Oesch, 1972). The fisher today ranges no closer to Missouri than the northern side of Lake Superior, in Ontario.

Family Felidae: cats

Only a single element of *Lynx*, probably *L. rufus*, was recovered. This is a metatarsal V. The bobcat is reasonably common in much of the Ozarks today.

Family Tayassuidae: peccaries

If caves were named for their most outstanding feature, Bat Cave undoubtedly would be known as "Peccary Cave". The 6,339 elements of *Platygonus compressus* recovered from Bone Passage and Devil's Kitchen represent no less than 98 individuals. This may be the largest single sample of *Platygonus* obtained from any North American cave to date. Minimal number is based on 77 lower left canines of adults and 21 upper left canines of juveniles (milk dentition).

One of the more interesting things about the peccary "population" is that it includes numerous elements of juveniles, including many deciduous canines. Very few milk teeth, other than canines, were found.

Since detailed measurements and comparisons of the Bat Cave peccaries will be included in a proposed paper on Pleistocene peccaries being prepared by Elaine Anderson and John Guilday, they will be omitted here. However, since fair numbers of upper and lower third molars are available from Bat Cave, a size comparison is made (Table 6) with samples from Welsh Cave, Kentucky; Guy Wilson Cave, Tennessee; Cherokee Cave, Missouri; and Laubach Cave, Texas. This comparison indicates that the Bat Cave specimens fit well within the size range demonstrated and that they overlap all of the four other populations. If all cheek teeth are considered, the Laubach Cave population shows the greatest size, but Slaughter (1966) does not consider the Laubach deposit to be late Wisconsinan. He estimates its age at between 25,000 and 45,000 years BP, so a chronocline may possibly be indicated.

A study of 66 upper and 65 lower canines from Bat Cave failed to show any bimodality when width was plotted against length of the crown. It would therefore appear, at least on the basis of material from Bat Cave, that there is no definite s e x u a l dimorphism in canines. Although their sample was smaller, a similar study on Welsh Cave specimens by Guilday, *et al.* (1971) forced them to the same conclusion.

TABLE 6. *Platygonus compressus*, measurements (in mm.) of upper and lower third molars from Bat Cave compared with those of populations from Kentucky, Tennessee, St. Louis, and Texas.

Site	Length N	Length O. R.	Length $\bar{X}$	Width N	Width O. R.	Width $\bar{X}$
Upper						
Bat Cave, Mo.	13	18.8–21.1	19.8	13	14.6–16.2	15.4
Welsh Cave, Ky.	16	16.7–21.4	18.4	16	13.9–16.1	15.2
Cherokee Cave, St. Louis, Mo.	12	19.0–23.6	21.0	26	14.8–17.9	16.2
Laubach Cave, Tex.	13	18.9–23.5	20.5	13	15.0–17.7	16.2
Lower						
Bat Cave, Mo.	36	19.7–23.8	21.9	36	11.4–14.0	12.8
Welsh Cave, Ky.	22	19.4–23.0	21.4	22	11.5–13.7	12.5
Guy Wilson Cave, Tenn.	3	20.3–23.2	22.2	..	....	...
Cherokee Cave, St. Louis, Mo.	24	21.2–26.5	23.7	43	12.0–14.6	13.4
Laubach Cave, Tex.	14	21.6–27.3	24.1	14	12.0–14.6	13.3

Welsh Cave, Kentucky, data from Guilday, *et al.*, 1971.
Guy Wilson Cave, Tennessee, unpublished data from Guilday.
Cherokee Cave, St. Louis, Missouri, data from Simpson, 1949.
Laubach Cave, Texas, data from Slaughter, 1966.

The large numbers of canines from Bat Cave afforded us an opportunity to make some observations on "gum-line notching", a curious type of wear near the base of the crown of the lower canines. Scott (1913) observed a similar notching in the lower canines of entelodonts and suggested that it was caused by the digging of roots. Supposedly, if a root, held in the ground at both ends, were looped over the tooth and pulled until it broke, and if such root were covered with grit, abrasion by the root as it passed by the tooth eventually, after many repetitions, would wear notches in the teeth. Mehl (1966) became interested in the notching frequently seen in lower canines of *P. compressus* (Figs. 7 and 8) and made a preliminary study of the phenomenon. Mehl stated that the wear "in every case is on the outer posterior side as though the animal had tilted its head to the right or to the left". He concluded, because of "strong evidence of 'rooters' among platygonids and the actual associations of peccary and mastodon remains, that there was a t e n d e n c y toward food gathering in coarsely vegetated, swampy areas".

Although Mehl examined canines from Bat Cave, as well as from Brynjulfson Cave in Boone County, his sample from Bat Cave was not complete. We now are better able to determine the percentage of notching, its most frequent location, and some of its relationships to age. We cannot agree that the wear is "outer posterior" and there are other possible explanations for its cause.

Of the 76 lower left canines from Bat Cave, 56 are sufficiently intact to have retained gum-line notching, if ever it had been present. Of these, 25 show slight to very deep grooving. In two cases, grooving was so extreme that the distal portion of the tooth was broken off and the stump was worn smooth and round. The grooving always is on the inside (medial) and, although there frequently is some wear at the inner posterior corner, we would describe the wear as largely medial. In at least 18 of the 25, there also is some grooving on the anterior side, but there are no cases among the lower canines with anterior grooving, only. The anterior wear presumably could be produced as the animal raised its head with a twist to the right as it jerked on the food plant being utilized.

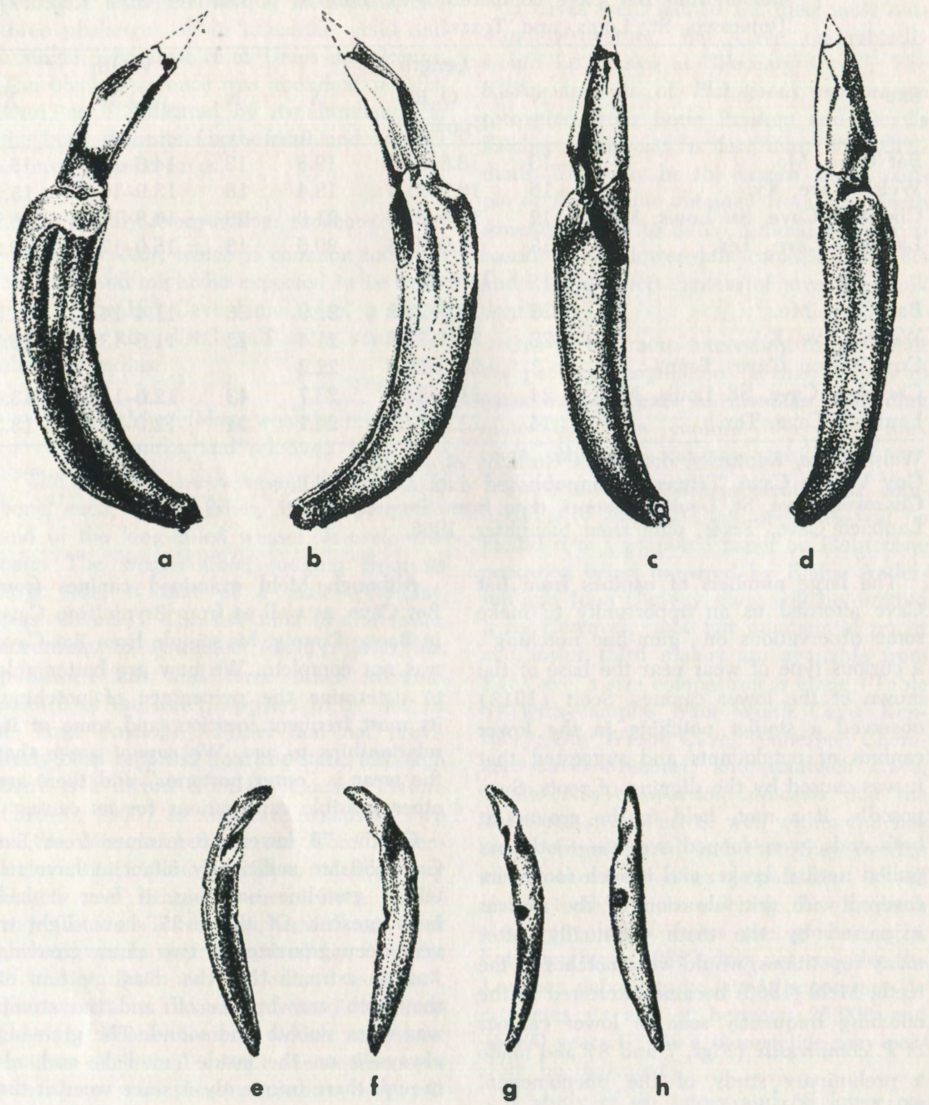

Fig. 7. Examples of "gum-line notching" in lower canines of *Platygonus compressus.* Upper figures (drawn from a single lower right canine [CMS 577.56] of an adult): a) medial view showing both medial and anterior wear, b) lateral view, c) posterior view showing wear pattern from upper canine, d) anterior view. Lower figures (depicting a single lower left canine [CMS 581.33] of the milk dentition): e) lateral view showing wear from upper canine, f) medial view showing notching (presumably) from feeding, g) posterior view, feeding wear to right, h) anterior view. Drawing by L. R. Eudy.

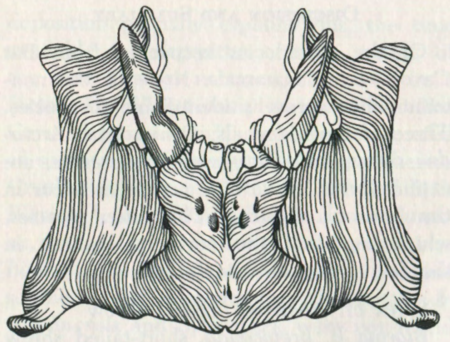

Fig. 8. Frontal view of lower jaw (CMS 28) of *Platygonus compressus,* showing "gum-line notched" lower right canine in place. Drawing by Laura Bradley.

Of the 72 lower right canines, 53 are sufficiently intact to have retained gum-line grooving, if ever it had been present. The wear pattern seems to be quite different from that on the left canines. Seventeen show grooving both on the medial and on the anterior surfaces. In six of these, wear is slight, even though they are large tusks. Eleven show very pronounced wear on both surfaces, four of them to the extent that they have broken off (3 proximal and 1 distal segments). This is in definite contrast to Mehl's observation that more rights than lefts show deep grooving. However, there are 13 additional lower rights which show slight to moderate anterior grooving only. It is possible that this anterior wear could have resulted from jerking the head downward and to the left when the initial upward yank to the right did not produce the desired result. Though the significance of right or left "handedness" in extinct peccaries seems dubious, it appears that the Bat Cave population, at least, tended to utilize the left tusk more frequently in its feeding.

Mehl (1966) indicated that gum-line notching was limited almost exclusively to mature or old individuals, but we doubt this. Rather, it would appear that some individuals utilized this method of feeding and others did not. We selected the nine largest lower tusks from both right and left groups and found that, of these, only three from each side were notched. The Bat Cave peccary population includes many juvenile and sub-adult individuals and many canines which are not complete enough to show gum-line grooving. Of the jaws which have canines in them, only one appears to be from a moderately old individual (M_1^1 cusps worn smooth). It shows no grooving. Three or four jaws represent young adults with all teeth erupted (M_1^1 moderately worn) and nine are of young adults with some molars and/or canines still erupting. Of the 27 lower milk canines intact enough to have retained it, 17 (six of 11 rights and 11 of 17 lefts) show gum-line notching. There also are some upper milk canines (both rights and lefts) which are notched, on the medial side in most cases. This notching or grooving seen in milk canines is not to be confused with the wear scars or grooves which result from abrasion by erupting and lengthening permanent opposing canines. Both types of wear can be seen on many of the lower milk canines (Fig. 7).

Although a minimum of 31 individuals of *P. compressus* was included in the fauna of Welch Cave, Kentucky (Guilday, *et al.,* 1971), grooving of lower canines was not noted. Guilday (pers. comm.) has offered some noteworthy comments on the grooving phenomenon which we wish to include. He suggests that the difference between Welch Cave and Missouri specimens may be due to regional variation in food plants and/or to the amount of siliceous dust on low vegetation. He disagrees with Scott's (1913) interpretation of entelodont tooth grooving and points out that it could have been produced by a browsing habit in which leaves and fruit were stripped from the plants by clenching the branches between the teeth and tossing the head to one side or the other. He further points out that the size of *P. compressus,* its relative length of limb, and its hypsodont molars are more compatible with browsing than with rooting, though they probably rooted on occasion. The difference in wear between right and left, described above, does seem to fit Guilday's suggestion much better and his suggested method of feeding seems less awkward for the animal than the type of rooting which Scott proposed. Upon examination of the grooves under magnification, we find them usually to have a high polish, as would be expected to result from the stripping of dusty vegetation or of vegetation with some silica content. There are no harsh scratches in the grooves, such as might be expected from root snapping and grubbing.

One other question about the Bat Cave peccary population might be discussed here, to wit: Were the peccary bones brought into the cave by predators, or is the accumulation due to normal mortality in a cave used for shelter? Mehl (1966) favored the predator theory, at least for Brynjulfson Cave, because he found relatively few unbroken bones and large quantities of fragments which, he felt, illustrated "green-bone fracture". Because there was no evidence of percussion instruments in the cave, he concluded that these fragments were produced by "bone-cracking predators".

Although there are large numbers of fragments of the type described by Mehl, at Bat Cave, we do not feel that these are due to the feeding of large predators, even though such species are included in the Bat Cave fauna. There are large numbers of intact, adult and sub-adult long bones and there are a surprising number of tiny, spongy, juvenile long bones. Surely the latter would have been consumed entirely by anything the size of a dire wolf! The presence of so many milk canines also favors the idea of a shelter used over a period of time. Dr. Lyle K. Sowls (pers. comm.) has indicated that he does not believe that there is resorbtion of milk-canine roots in collared peccaries (*Tayassu tajacu*). There is none in the domestic pig, *Sus scrofa*, and it seems unlikely that there was any in *Platygonus*. If not, it would suggest that the milk canines may represent a naturally shed accumulation and not teeth from animals which died in a natural trap.

Discussion and Summary

Of the 41 species recovered from Bat Cave, 34 are mammals. None of the non-mammalian forms is identifiable to species. Three of the mammals, *Canis dirus, Arctodus simus*, and *Platygonus compressus*, are extinct forms, while nine no longer occur in the Missouri Ozarks. The latter species, which represent the northern element in the fauna, include the following:

Sorex cf. *cinereus*, masked shrew
Blarina b. brevicauda, short-tailed shrew
Lepus americanus, snowshoe rabbit
Tamiasciurus cf. *hudsonicus*, red squirrel
Clethrionomys cf. *gapperi*, red-backed vole
Microtus pennsylvanicus, meadow vole
Microtus xanthognathus, yellow - cheeked vole
Synaptomys borealis, northern bog lemming
Martes pennanti, fisher

All other species included in the fauna have occurred locally during historic times, with the possible exception of the pocket gopher.

Modern contamination of the bone deposits is minimal, probably due in part to the distance of the Bone Passage from present day entrances to the cave. It appears to be limited to *Rattus* sp. (a single element) and, possibly, to some of the surficial bat material. In most of the Bone Passage, there was no stratification of the matrix containing the bones. Thus, we are left with the conclusion that the bulk of the material represents a relatively homochronous assemblage. If this is correct, Bat Cave provides us with a faunal sample from a more limited period of time than do other rich faunal sites in the midwest, such as Meyer Cave (Parmalee, 1967) and Crankshaft Cave (Parmalee, *et al.*, 1969). The latter appear to have continued to accumulate fauna into warmer, drier times.

There is considerable other evidence that Bat Cave represents a relatively short period of accumulation. Except for the peccary, the number of individuals of each species represented in the deposit is extremely small. Although the method of deposition partially explains this, the time available for deposition, before sealing of the Bone Passage entrance, also could be a factor. The almost complete absence at Bat Cave of forms which could be interpreted as southern or western is striking. Whereas Crankshaft Cave and Meyer Cave had both *Blarina b. brevicauda* and *B. b. carolinensis*, and Crankshaft Cave had *Synaptomys borealis* and abundant *S. cooperi*, the more southern and contemporary forms, *B. b. carolinensis* and *S. cooperi*, were not found at Bat Cave. *Microtus ochrogaster* and *M. pinetorum*, common throughout Missouri today, are missing at Bat Cave, though *M. pennsylvanicus* is present. With the exception of *Geomys bursarius*, none of the plains species found at Meyer and Crankshaft caves have turned up at Bat Cave. However, Guilday, *et al.* (1971) point out that *G. bursarius* "ranges north into Canada in prairie or semi-prairie areas avoiding dense forest on the one hand and the short-grass plains to the west on the other" and that this pocket gopher might conceivably be considered to have been contemporaneous with other boreal species in the Pleistocene fauna of Welsh Cave, Kentucky. Its presence with numerous other boreal species at Bat Cave, in the absence of any other plains species, seems to strengthen this contention. In any case, the warm, dry period (xerothermic) during which the Prairie Peninsula extended eastward into Illinois and Indiana dates from mid-postglacial time. Wright (1968) believes this to have been approximately 8,000 to 4,000 years BP. He points out that the chronology which placed the xerothermic interval at 4,000 to 1,500 years BP was based on pollen sequences in New England and Ohio, and that this interval is not necessarily consistent with the regional climatology of the Prairie Peninsula. Transeau's (1936) map of the Prairie Peninsula, with outliers, indicates that in historical times small areas of prairie at the northern edge of Pulaski County extended northward into Miller County, and that a few small prairies existed in Laclede and Camden Counties to the west. Thus, Bat Cave may lie close to what once was the southeastern edge of the Prairie Peninsula. However, there is little evidence in the Bat Cave fauna for the previous existence of well-established prairie in this portion of the Ozarks.

One must be cautious about making assumptions based on too few specimens, and it is unfortunate that greater numbers of individuals of some of the indicator species are not present at Bat Cave. However, the method and probable short duration of deposition should be kept in mind. When these conditions are coupled with the fact that species which might be expected to be abundant in the fauna are absent, the lack of abundant material from some of the northern elements in the fauna is less disturbing. Bat Cave does, at least, have a plurality of species which indicate boreal forest conditions, even though the amount of material present is not sufficient to indicate the relative abundance of the various species. If the Bat Cave fauna represents only a period when boreal forest was present, fewer ecological niches would have been available and the lesser number of species present, when compared with other midwestern sites, becomes more understandable. The only deviation from strictly boreal forest which seems possible would have been forest openings, or parkland. Forest forms such as red squirrel, red-backed vole, and fisher are somewhat balanced by grassland species such as the plains pocket gopher and meadow vole. The chipmunk is a timber borderland animal, and the long-tailed weasel may be found in similar situations, though it prefers woodlands. The yellow-cheeked vole and northern bog lemming may occur in extremely small grassy situations, such as bogs, scattered through a forest. Redbacked vole and northern bog lemming, also, suggest the presence of low, moist areas.

Because no carbon-14 dates are available for Bat Cave, and because attempts at pollen extraction were not successful, the age of the deposit can only be approximated by comparison with other midwestern sites.

The closest such site which has produced evidence of a late-Pleistocene boreal forest is Boney Spring, near the Pomme de Terre River about ninety-five km west of Bat Cave (Fig. 1). Mehringer, *et al.* (1970) reported pollen spectra from this site which included high percentages of spruce (*Picea* sp.), larch (*Larix laricina*) and up to 20% Cyperaceae. Spruce and larch macrofossils also were present. The proportion of pine (*Pinus* sp.) pollen was less than five percent and was thought to represent long-distance transport, though the spruce forest represented apparently had minor deciduous elements. Both Boney Spring and Bat Cave lie at elevations between 210 and 250 m. The fauna recovered from Boney Spring included sloth (*Paramylodon* cf. *harlani*), giant beaver (*Castoroides* sp.), mastodon (*Mammut americanum*), and deer (*Odocoileus* sp.), but no small mammals. Radiocarbon dates were approximately 16,500 (spruce log) to 13,500 years BP (plant materials from pulp cavity of mastodon tusk). Three miles southeast of Boney Spring, at Trolinger Spring, materials dated at about 32,000 to 25,000 years BP were associated with a mastodon — horse (*Equus* sp.) — muskox (*Symbos* sp.) fauna and with pollen spectra indicating "open vegetation, possibly a pine parkland, lacking spruce". Both suggest a mid-Wisconsinan interstadial (Mehringer, *et al.*, 1970). The faunal assemblage at Bat Cave seems to fit the apparent floral assemblage at Boney Spring, a spruce forest with minor deciduous elements and sedge openings, better than it does that of Trolinger Spring.

Ogden (1967) presents evidence from sites in southern Minnesota, Indiana, and western Ohio to support the idea that a "rapid and dramatic change in temperature and/or precipitation (occurred) approximately 10,000 years ago", accompanied by the disappearance of spruce and its replacement by pine and followed by oak and elm. The Bat Cave fauna clearly appears to have accumulated before this time.

A comparison of the relative number of northern and extinct species recovered from Bat Cave with those from Meyer and Crankshaft caves may furnish some clues to their relative chronological positions. As shown by Table 7, the percentage of northern species at Bat Cave is greater than that at either of the other two sites, while the number of extinct forms at Crankshaft suggests that deposition there began earlier there than at the other two sites. Crankshaft Cave also has at least three prairie species, which indicate that it still was trapping animals during the post glacial xerothermic period (Parmalee *et al.*, 1969).

Meyer Cave, though it has the largest faunal list, has only one extinct species (the passenger pigeon, *Ectopistes migratorius*) and fewer northern species. Western elements in its fauna also indicate deposition during the post-glacial xerothermic, but the smaller percentages of extinct and northern species point to initial deposition at a time later than that at either of the other two sites; yet, both Meyer and Crankshaft caves seem to represent a longer sampling period than does Bat Cave.

Most of the evidence indicates that the Bat Cave fauna was accumulated during a relatively short period of time, a period earlier than the beginning of deposition at Meyer Cave (that is, earlier than 11,500 to 9,500 BP) and, quite possibly, as early as a late-Wisconsinan glacial stade at 16,500 to 13,500 years BP.

TABLE 7. Comparison of faunas from Meyer Cave (Illinois), Crankshaft Cave (Missouri), and Bat Cave (Missouri) with respect to occurrence of northern and extinct vertebrates. Domestic and introduced species omitted from totals.

Site	Category	No. species	Northern species No.	Northern species Percent	Extinct species No.	Extinct species Percent
Meyer	vertebrates	115	8	7	1	1
Cave	mammals	39	7	18	0	0
Crankshaft	vertebrates	86	15	17	7	8
Cave	mammals	60	14	23	7	12
Bat	vertebrates	39	9	23	3	8
Cave	mammals	33	9	27	3	9

Acknowledgements

We are particularly indebted to John E. Guilday of the Carnegie Museum for his valued assistance in identifying mammals, especially shrews and small microtine materials, for his many helpful suggestions and comments at various stages of the project, and for his critical review of the manuscript. We doubt that the project could have been completed without his help.

Dr. Paul W. Parmalee, Illinois State Museum, also provided assistance with identification, as well as in loaning study materials, in providing copies of references unavailable to us elsewhere, and in making advance copies of some of his own manuscripts available to us.

A former graduate student of the senior author, Ronald D. Oesch, made many contributions to the project, including loans of specimens, assistance with literature, and in some phases of the excavation work.

Dr. James Stitt, University of Missouri, loaned Bat Cave specimens which had been deposited in the collections of the Department of Geology there and Dr. William H. Elder, University of Missouri, provided access to skeletal material in the UM wildlife collections.

Geologists who advised us or who provided special services included Jerry D. Vineyard, Missouri Geological Survey and Water Resources, Dr. James Urban, Southern Methodist University (palynology), and Drs. John Emerson and Fred Bachhuber, Central Missouri State University (palynology and cave fills).

The long and arduous task of excavating the Bone Passage was accomplished through the volunteer efforts of Tom Christopher, George Deike, Russ Ecklund, Joel Elrod, John Hawksley, John Logsdon, Jerry McGowan, Kenneth Ornes, Gary Powell, Alan Pragman, David Theis, Tom Tucker, Jack Williams, and numerous zoology students from Central Missouri State University.

David Webster and Don Rimbach provided suitable copies of the Bat Cave map. Art work was prepared by Lawrence R. Eudy and Laura Bradley.

Finally, special acknowledgement should be made of the contributions of the late Dr. Maurice G. Mehl, Professor Emeritus, Department of Geology, University of Missouri. In his later years, Dr. Mehl did much to stimulate the study of Pleistocene vertebrates from Ozark caves, to the extent, even, of participating in arduous trips into some of the caves. He gave us much initial encouragement and guidance.

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Sulfur In Cottonwood Cave, Eddy County, New Mexico

Donald G. Davis *

ABSTRACT

Sulfur is found in a gypsum vein and in massive blocks of gypsum in Cottonwood Cave, New Mexico. It occurs both in porous, rhombic-crystalline and in dense, massive forms and appears to be of subaqueous origin. Probably, it was deposited late in the phreatic history of the cave and was derived from hydrogen sulfide in groundwater, either by anaerobic oxidation of hydrogen sulfide by ionic sulfate or by aerobic oxidation of hydrogen sulfide by oxygenated surface water or air flowing through the cave.

Description of the Cave

Cottonwood Cave is developed in (Permian) Seven Rivers dolomite, near elevation 6800 ft in the Guadalupe mountains of southern New Mexico (Fig. 1). The geology of the adjacent area has been described by Hayes and Koogle (1958). The cave is a network in pattern. It includes more than one mile of passages and contains an estimated 200 to 300 ft of vertical relief.

Cottonwood Cave clearly is of phreatic origin, as evidenced by its three-dimensional network pattern and by its lack of stream channels and vertical shafts. Like other Guadalupe caves, it has been dissected by canyon-cutting and must have developed when the land surface and groundwater level were higher than they now are. The Guadalupe caves probably completed their phreatic enlargement before the Pliocene epoch (Bretz, 1949). Cottonwood Cave is widely known for its secondary deposits of sulfate minerals, including gypsum and epsomite (White, 1960). Perhaps more remarkable, though inconspicuous and little-known, are the two distinct forms of free sulfur which exist in the cave.

* ℅ Jerry Davis, P. O. Box 25, Fairplay, Colorado 80440.

Sulfur Deposits

The largest sulfur deposit is a vein embedded in a thicker vein of gypsum exposed in the passage ceiling about 300 ft north of the point of entry into the second parallel passage. It is difficult to examine closely and is not noticed by most visitors to the cave, as it is several yards above the floor and does not contrast sharply with its surroundings under carbide light. The sulfur vein, estimated to attain at least 18 in. in width, appears abruptly at a point where the gypsum vein is about three feet wide. It continues north as an irregular but sharply demarcated stringer (Fig. 2) for about 50 ft before pinching out. A few isolated pods of sulfur appear to be present in the next 50 ft, but they were too high up to be seen clearly. North of this point, the gypsum vein widens to a maximum of about six feet within 100 ft, then it pinches out still further north.

Examination of fallen sulfur fragments on the breakdown floor reveals variations in the texture and density of the sulfur. Some pieces are granular, somewhat porous, and have cavities lined (in part) with well-formed rhombic crystals up to ⅛ in. or more in diameter (Fig. 3). Others are massive (Fig. 4), breaking with a conchoidal fracture and waxy lustre; in some cases frag-

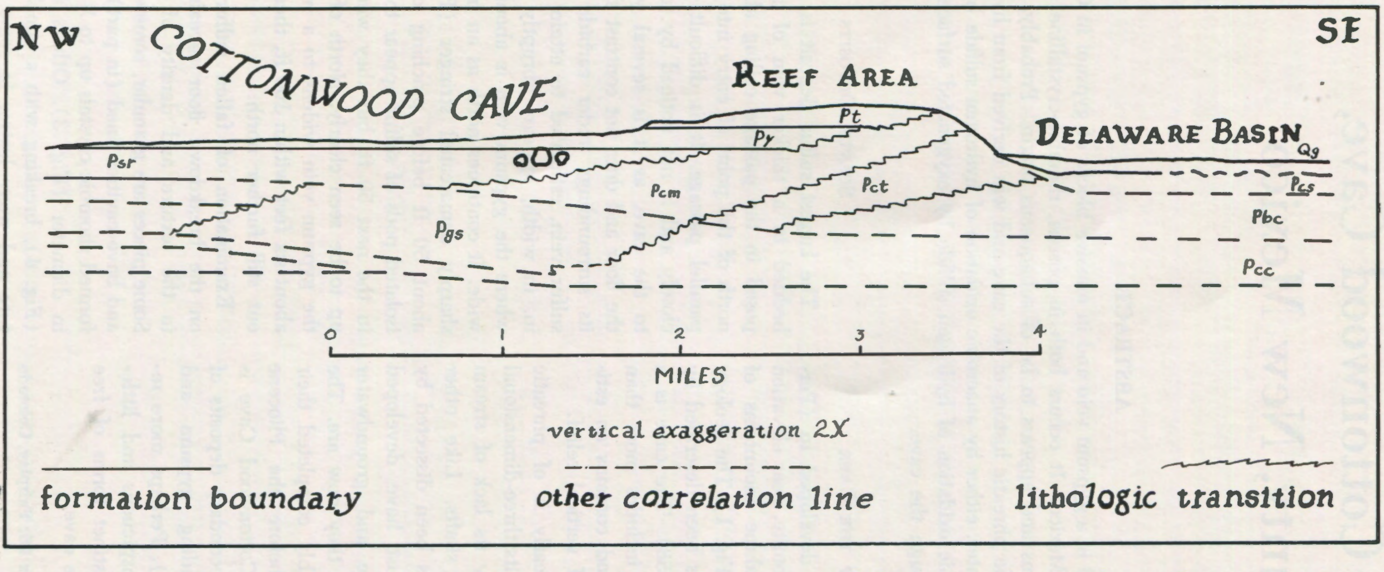

Fig. 1. Generalized stratigraphic diagram of Permian rocks in the Cottonwood Cave area, showing facies changes, after Hayes and Koogle (1958). Pt—Tansill fm, Py—Yates fm, Psr—Seven Rivers dolomite, Pcm—Capitan limestone, Pgs—Goat Seep limestone, Pct—Capitan reef talus, Pcc—Cherry Canyon formation, Pcs—Castile formation (gypsiferous), Pbc—Bell Canyon formation, Qg—quaternary gravel.

Fig. 2. Massive sulfur in gypsum vein.

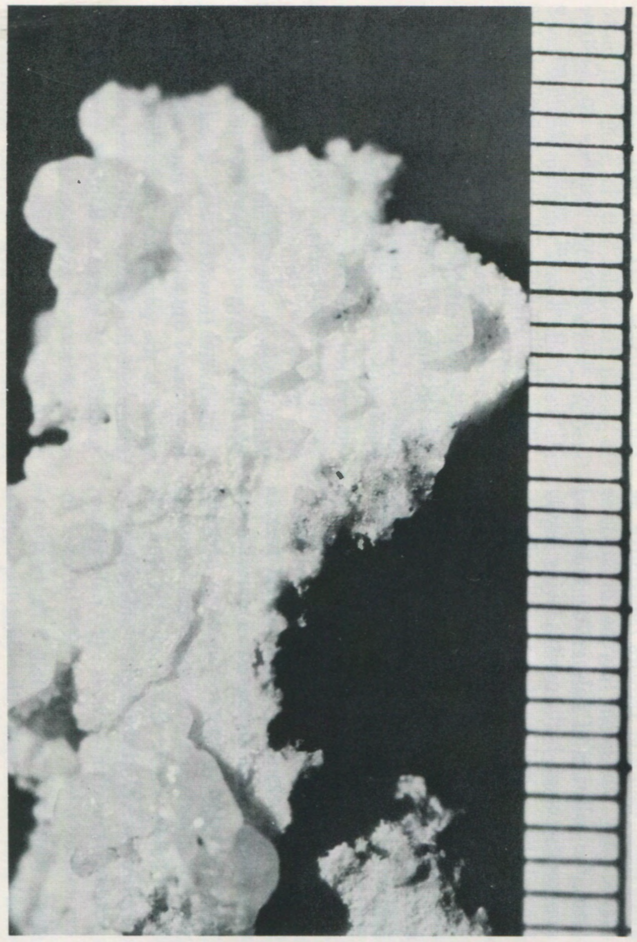

Fig. 3. Well-developed crystals of rhombic sulfur. Scale in mm.

Fig. 4. Typical block of massive sulfur.

ments show faint, contorted banding and elongated, fusiform cavities suggestive of plastic flow. In either porous or massive form, the sulfur is of pale yellow color and apparently is of high purity, being easily ignited by a carbide lamp, although the flame sputters enough to suggest that minor inclusions of water or gypsum are present.

In the second sulfur-bearing area, several hundred feet south of the point of entry into the second parallel passage, the deposits are small but, perhaps, more informative. This area of the cave is floored with breakdown blocks of dolomite, among which lie scattered blocks of gypsum several feet in height and width. In the lower parts of two of the gypsum blocks are zones of irregular cavities about four feet long and one foot high. Partly lining these cavities and extending two or three inches into them are porous, granular masses of pale-yellow, crystalline sulfur (Fig. 5). The masses include distinct rhombs up to ⅜ in. in diameter. Where not lined with sulfur, the cavities are coated with granular selenite of about the same crystal size as the sulfur or somewhat coarser. In one block, the sulfur and selenite are intimately intermingled; in the other, they are not. The sulfur-bearing cavities probably were completely enclosed in gypsum, originally. Those now visible probably were exposed by solution of the matrix. However, there is a possibility that they may have originated by localized solutional attack on the surfaces of blocks; no blocks have been broken in order to examine their interiors. In either case, the cavities appear to have been formed when the gypsum was under water; sulfur and selenite were selectively deposited in them before drainage. The gypsum blocks subsequently have been attacked by dripping water. That they are perforated at varying angles by solutional drip-pits indicates that the blocks have shifted position as many as three or four times since they were exposed to air. This shifting was perhaps caused by solution of gypsum within the breakdown, by the compaction of sediments below the blocks, by repeated rockfalls, or by earthquakes.

Origin of the Deposits

The sulfur/gypsum deposits in Cottonwood Cave are not easily explained. To know whether they are cave deposits in the proper sense, it is necessary to establish whether the gypsum matrix is of secondary (post-cave) origin or predates the cave. The gypsum vein in the ceiling is ambiguous in that the relationship of the vein to the original ceiling level cannot be precisely determined, for the present ceiling is the result of post-drainage collapse. Possibly, the vein was a filling in a pre-existing fissure effectively sealed off from the developing cave until exposed by post-drainage breakdown. However, such a seal does not seem very likely, for the vein closely parallels the permeable controlling joint (or joints) of the passage. In view of the high solubility of gypsum in most groundwater and evidence of phreatic solution extending more than 100 ft higher in the dolmite, any pre-existing gypsum more likely would have been removed during cavern solution.

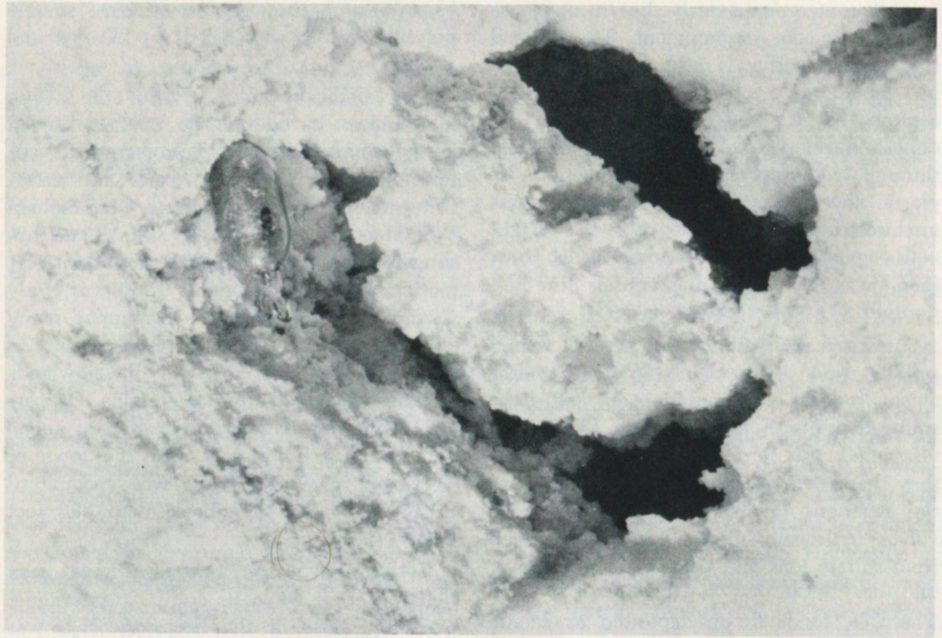

Fig. 5. Sulfur crystals filling cavity in gypsum.

This suggests that the vein was deposited after the close of the solutional phase of the history of the cave. Narrow, upper-level solution passages above this area are partially filled with similar deposits of massive gypsum.

The sulfur-bearing gypsum blocks on the floor of the second area very probably are secondary in origin. The drip pits indicate that these blocks are out of their original relationships with their surroundings; they could conceivably be interpreted as breakdown from another gypsum vein above (the ceiling here is inaccessible at the top of a high chimney and is poorly visible by ordinary light). However, a few similar, but smaller, gypsum blocks are found in at least two other passages in the cave, where there is no possibility of a hidden source vein. Hence, it is likely that the blocks are remnants of massive secondary gypsum floor deposits such as are to be seen in the Big Room of Carlsbad Caverns and (in remnants) in New Cave and in other Guadalupe Caves. In Carlsbad Caverns, these deposits seem to have been laid down in quiet water prior to final drainage of the cave; a similar origin may be assumed for the fragmentary deposits surviving in other caves; such as in New Cave and Cottonwood Cave (which are, respectively, 9 and 19 miles from Carlsbad Caverns). The gypsum in Carlsbad Caverns has been interpreted as having been precipitated as a consequence of the cooling of gypsum-saturated groundwater as it moved from the surface into the cave. This water may have been derived from gypsiferous lakes formed during deposition of the Pliocene (?) Ogallala gravel in the area (Good, 1957). It recently has been suggested, however, that the gypsum was derived at least in part by replacement of the carbonate bedrock (Queen, 1973).

Origin of the Sulfur

I conclude that the Cottonwood Cave sulfur probably was deposited soon after deposition of its gypsum matrix, or perhaps in part contemporaneously, but in any case in a subaqueous environment. The original state of the sulfur is probably represented by the porous, pocket-lining deposits. I assume that the massive part of the vein deposit developed from the porous material through compression and compaction by plastic flow due either to compressive stress in the surrounding bedrock or to the weight of the gypsum and sulfur mass itself. How, then, was the original porous sulfur deposited?

Anaerobic derivation from petroleum and sulfate rocks is a widely-accepted mechanism for the accumulation of salt-dome sulfur deposits. Feely and Kulp (1957) investigated this process and reported that they had demonstrated in the laboratory the reactions involved. The chemistry involves hydrogen sulfide, which is derived from sulfate ions and petroleum, as follows:

$$2H^+ + SO_4^= + CH_4 \xrightarrow[\text{catalysis}]{\text{bacterial}} H_2S + CO_2 + 2H_2O. \quad 1.$$

The CO_2 tends to be deposited as calcite replacing anhydrite. If the H_2S cannot escape to the surface, sulfur may then appear via inorganic oxidation of hydrogen sulfide by ionic sulfate in the groundwater, thus:

$$SO_4^= + 3H_2S \rightarrow 4S + 2H_2O + 2OH^-. \quad 2.$$

Davis and Kirkland (1970), who studied the sulfur deposits of the Gypsum Plain in west Texas, agree with Feely and Kulp as to the means of generation of hydrogen sulfide. However, they could not duplicate those authors' experimental production of sulfur by sulfate—hydrogen sulfide reaction. Davis and Kirkland postulate, instead, the simple oxidation of hydrogen sulfide by oxygenated groundwater:

$$2H_2S + O_2 \rightarrow 2S + 2H_2O. \quad 3.$$

This reaction is spontaneous and easily demonstrated, but, if the Cottonwood Cave sulfur developed in this way, it is difficult to account for its localization in gypsum-enclosed pockets. It should have been precipitated on any rock surface along the anaerobic/aerobic interface. In either case, the resulting sulfur presumably would have been colloidal or microcrystalline at first. The crystalline deposits may indicate recrystallization through formation of soluble polysulfides, as described by Davis and Kirkland (p. 115).

The conditions necessary for the above mechanisms to operate do in fact prevail in the Guadalupe area. Petroleum and sulfate rocks, particularly gypsum and anhydrite, are plentiful. Hinds and Cunningham (1970) confirm that "Ionic sulfate and hydrogen sulfide are commonly found in formation waters throughout most of Eddy County." These authors have mapped many subsurface occurrences of sulfur in the dolomites and evaporites of the lowlands flanking the Guadalupe Mountains. Of particular interest is their publication of an oil well test log for a well near the town of Carlsbad, in which sulfur was encounterd in a water-filled cave more than 800 feet below the surface.

Cottonwood Cave may also have been deeply buried when its sulfur was forming. Probably, little of the necessary H_2S was generated in the cave itself, as the cave displays no evidence of the replacement of sulfate rock by calcite. I assume, rather, that the H_2S was mobile in the groundwater and that its hydrocarbon sources may have been either near or remote. However, as sulfur has not been observed in other enterable Guadalupe caves—some of which presumably were associated with the same groundwater body—Cottonwood Cave may have had some special geomorphic/hydrologic configuration acting as an H_2S trap. Erosion has left the cave thinly roofed, and no apparent morphological trap now exists, but the dense Yates sandstone just above the cave may have had a capping effect. If H_2S tended to accumulate beneath this sandstone, the absence of the sandstone from the reef front would explain the apparent absence of sulfur from the caves of that area, including Carlsbad Caverns and New Cave.

The Yates sandstone itself contains a potential sulfur source, as indicated by abundant pseudomorphs of limonite (?) after pyrite. In an acid medium, pyrite may yield free sulfur on oxidation (Pohl and White, 1965) or it may be reduced to H_2S (Sato, 1960). In solutions buffered near neutrality by contact with carbonates, the sulfide of pyrite should be oxidized to sulfate. However, free sulfur as such is virtually insoluble in water, and non-pyrite sources of sulfur compounds were certainly far more abundant in the area. Thus, pyrite weathering is unlikely to have provided more than a minor fraction of the sulfur in Cottonwood Cave.

Sulfur Speleothems in Other Caves

Several persons have given me verbal reports on the discovery of at least small amounts of sulfur in several other Western caves, including Frustration Cave, Texas (in association with pyrite); Parks Ranch and Torgac caves in New Mexico (caves developed in gypsum); Groaning Cave in Colorado (again with pyrite); and the Kane Caves (hot-spring caves) and Shoshone Cavern in Wyoming. As far as I know, none of these occurrences has been discussed in print. I hope this report will stimulate others to publish their observations on this neglected cave mineral.

Acknowledgements

My thanks to Donald Standiford, formerly a guide at Carlsbad Caverns, who in 1962 first told me of the massive sulfur vein; to Alan Malkiel and Peter M. Jones of Denver, Colorado who showed me the pocket deposits; and, particularly, to Tom Meador of San Angelo, Texas for providing the photographs used in this report and for calling to my attention pertinent publications. Drs. Norman and Bernadette Pace of Denver, Colorado gave technical advice. Dr. Robert S. Irving of the University of Montana reviewed the manuscript and offered useful suggestions.

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Vertical shafts, widely distributed through the Interior Lowlands and Appalachian Plateaus provinces, are very short-lived and occur only at the margins of clastic caprocks. They are formed by films or sheets of descending vadose water passing along joints from the surface to master drains. Water takes up $CaCO_3$ and loses CO_2 in travelling from the top to the bottom of a shaft. (EWW)

Ford, D. C. (1973)—Development of the Canyons of the South Nahanni River, N.W.T.: *Canadian Jour. Earth Sci.* 10:366-378.

South Nahanni River flows through canyons formed by river entrenchment during the uplift of an anticlinal arch by at least 1,600 feet. Stratigraphies of cave fills and radiologic ages of speleothems indicate the occurrence of an interglacial stage here 300,000 to 200,000 years ago. This was preceded by the "First Canyon Glaciation", which was the last glaciation in this area. (EWW)

Harmon, R. S.; et al. (1972)—Chemistry of Carbonate Denudation in North America: *Cave Research Group Great Britain, Trans.* 14:96-103.

Analyses of 230 samples of karst water show that the chemical evolution of karst waters can be traced and that these waters develop characteristic chemical signatures. Geomorphic interpretation requires the taking into account of water types, seasonal variations, geologic factors ,and long-range climatic factors. (EWW)

LeGrand, H. E.; Stringfield, V. T. (1973)—Concepts of Karst Development in Relation to Interpretation of Surface Runoff: U. S. Geol. Survey, *Jour. Research* 1:351-360.

Streamflow in karstic regions differs markedly from that in non-karstic regions. Variations in the distribution of permeability causes loss or gain of water by surface streams where permeability is, respectively, high or low. Floods and lesser stream-flow variations tend to be smoothed in karst terrains. Big springs are the rule. Significant amounts of water are exchanged between the surface and the subsurface along the outcrop lines of contacts between soluble and insoluble rocks. (EWW)

Spalding, R. F.; Mathews, T. D. (1972)—Stalagmites from Caves in the Bahamas—Indicators of Low Sea Level Stand: *Quaternary Research* 2:470-472.

Presently submerged Bahaman stalagmites can be used to date Pleistocene low sea level stands. Good precision was obtained using both C^{14} and Th^{230}/U^{234} methods. The respective dates obtained were 21,000 ±600 and 22,000 ±350 years BP. (author)

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The BULLETIN is published quarterly. The subscription rate in effect January 1, 1972: $6.00 per year.

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