Geologic history, stratigraphy, and paleontology of SAM Cave, north-central New Mexico

Karel L. Rogers, Charles A. Repenning, Fred G. Luiszer, and Richard D. Benson

New Mexico Geology, v. 22, n. 4 pp. 89-100, 113-117, Print ISSN: 0196-948X, Online ISSN: 2837-6420.
https://doi.org/10.58799/NMG-v22n4.89

This page is intentionally left blank to maintain order of facing pages.

NEW MEXICO GEOLOGY

NM Bureau of Mines & Mineral Resources
New Mexico Tech
Earth Science for the 21st Century

ISSN 0196-948X
Volume 22, No. 4, November 2000

Science and Service

Geologic history, stratigraphy, and paleontology of SAM Cave, north-central New Mexico

by *Karel L. Rogers*, Biology Department, Grand Valley State University, Allendale, MI 49401,
Charles A. Repenning, Denver Museum of Natural History, Denver, CO 80205,
Fred G. Luiszer, Department of Geological Science, University of Colorado, Boulder, CO 80309, and
Richard D. Benson, University of Minnesota, St. Paul, MN 55108

FIGURE 1—Before the excavations of Fidel Cisneros in the 1950s, the modern entrance to SAM Cave was a slight grassy depression in the sagebrush-covered hillside. San Antonio Mountain can be seen in the distance south of the SAM Cave entrance.

Abstract

San Antonio Mountain (SAM) Cave is one of the oldest lava tube caves in North America. Its walls, part of the Servilleta Basalt located north of San Antonio Mountain, New Mexico, date between 3.4 and 3.9 Ma. Well-explored parts of the cave are more than 170 m (558 ft) long, and some rooms are over 12 m (40 ft) high. Fifteen fossil localities have been identified within the cave ranging in age from ~1 Ma to younger than 0.74 Ma. Sediments contain evidence of the Brunhes–Matuyama paleomagnetic reversal, and faunal analysis provides evidence of warmer, more equable climates than characteristic of the region today. Deep sea Oxygen Isotope Stages 22–18 (core V28–239) glaciations were represented in the region by climates that sustained forests. Analysis is aided by the nearby, contemporaneous, and well-dated Hansen Bluff, Colorado, locality. The paleofauna includes many mammals and a few birds, reptiles, amphibians, fish, and molluscs. Biochronologic implications of evolutionary stages of *Lemmiscus*, *Microtus*, and *Allophaiomys* are discussed based on SAM Cave fossils (Bot 4) and other localities. The site contains the oldest record of *Clethrionomys rutilus* in North America.

Introduction

SAM Cave (Fig. 1) is located approximately 10 km (6.2 mi) northwest of San Antonio Mountain in Rio Arriba County, New Mexico, and it is approximately 4 km (2.5 mi) south of the Colorado–New Mexico State line in the San Luis Valley (Fig. 2). Originally discovered and explored in the early 1950s by the late Fidel Z. Cisneros of

Also in this issue

Coming soon

Arsenic in ground water in the Socorro Basin
$^{40}Ar/^{39}Ar$ geochronology of the Ocate volcanic field
Living Desert Zoo and Gardens State Park

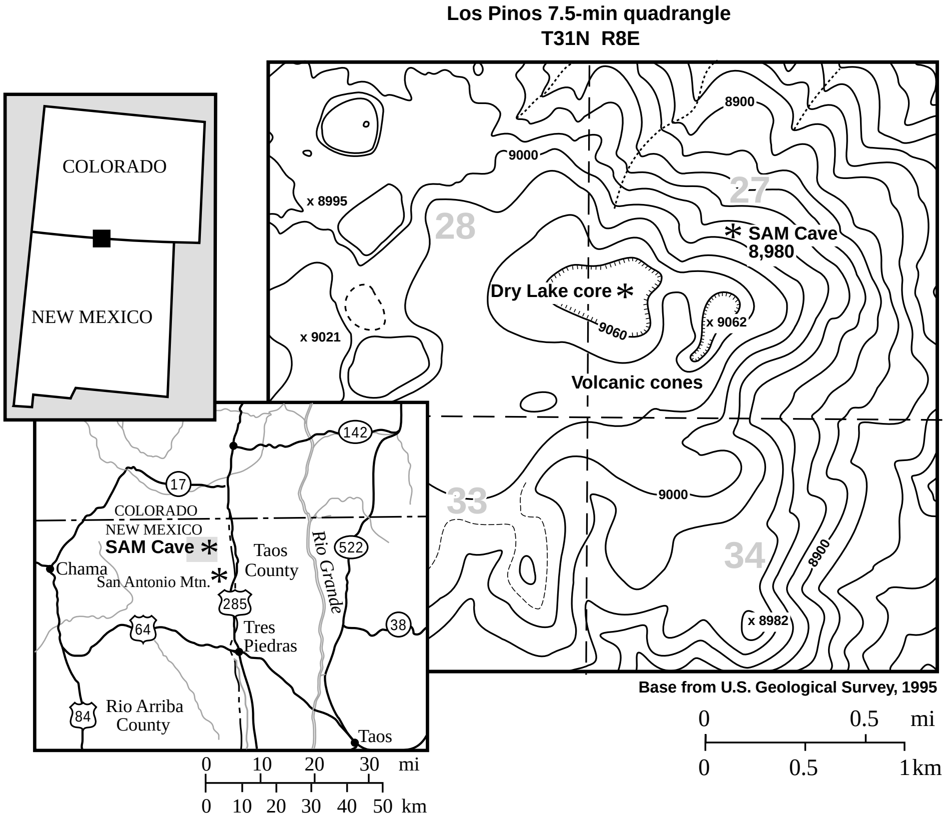

FIGURE 2—SAM Cave is located in north-central New Mexico, about 4 km south of the Colorado–New Mexico State line in the San Luis Valley. The modern entrance is slightly downhill to the north-east of the ancient volcano that gave rise to the lave tube. The cave is at 2,737 m (8,980 ft) elevation.

Antonito, Colorado, SAM Cave is an ancient lava tube in the 2–4.5 Ma Servilleta Basalt (Lipman and Mehnert, 1979; Dungan et al., 1984). The entrance to the lava tube is on a basalt hillside at an elevation of 2,737 m (8,980 ft). Fossiliferous sediments in the lava tube were excavated for more than 30 yrs by Fidel Cisneros under a mining permit through Carson National Forest. Thus, the cave is known as the Cisneros mine in official documents. Entrance to the cave is by means of a 12-m-diameter (40-ft) section where the lava tube collapsed during this century. The entrance was a low, rock-filled depression in the ground surface when Mr. Cisneros started mining and, according to Mr. Cisneros, was a shallow rock shelter with Native American artifacts before the roof caved in. In the 1950s, Mr. Cisneros removed tons of rock and fossil-bearing matrix and, in doing so, left an excellent outcrop of sediment layers as he exposed passageways into an extensive and ancient lava tube. The cave is located far from roads, so it is nearly pristine.

Geology

The lava tube most likely originated from one of two ancient volcanic cones represented today as loess-filled, grassy depressions uphill and south-southeast of the modern entrance. These volcanic cones are approximately 24 m (79 ft) higher in elevation than the modern entrance (Fig. 2). Eruptions from the volcanic cone gave rise to sheets of lava that cooled at the surface but continued to flow underneath forming the lava tube (Waters et al., 1990). Layers of basalt inside the cave indicate subsequent flows through the tube occurred at least seven times. From the volcanic cones, there is a relatively gentle downhill trend in a north-northwesterly direction with the slope dropping approximately 24.4 m (80 ft) per half kilometer (1,640 ft). In general, the lava tube is aligned with the slope of the hill downward.

SAM Cave may be the oldest known lava tube in the western United States. The basalt walls of the lava tube are magnetically reversed (E. Larson, pers. comm. 1990) with a K–Ar age of 3.5 ± 0.4 Ma (E. Larson, pers. comm. 1990). The K–Ar age is constrained by the end of the reversed Gilbert magnetic chron, so the cave was formed between ~3.4 and ~3.9 Ma (E. Larson, pers. comm. 1990). Because deposits older than about 1.0 Ma were not found in the cave, it appears the cave was sealed for ~ 2 m.y. after it formed.

Explored passages

Most of the lava tube was mapped using triangulation and measuring tape during July 1990. It is not possible to use a compass in the cave because old lightning strike areas distort readings. The measured part of the lava tube extends 30 m (98 ft) south-southwest and 130 m (427 ft) north-northeast from the entrance (Fig. 3). It is unlikely that any part of the cave is far below ground surface because the gentle slope of the cave floor approximates the slope of the ground surface.

Approximately 60–70 m (197–230 ft) of lava tube not pictured in Figure 2 extends farther north, but those passages are beyond a 15-cm-high (6-in.) opening. Most of the unpictured tunnel is nearly plugged with ceiling fall, and no fossiliferous sediment has been found in these relatively unexplored parts of the cave. It is possible that the lava tube extends beyond the unmapped section just described because cool, fresh air pours into the tube from between the blockage at the farthest point of the cave. It is exceptionally difficult to move rocks to open more passages because the spaces are small and the rocks are cemented together with calcium carbonate.

NEW MEXICO GEOLOGY

Science and Service

ISSN 0196-948X

Volume 22, No. 4, November 2000

Editors: Jane C. Love, Nancy S. Gilson, Susan Voss, and Beth Campbell

Cartographers: Kathryn E. Glesener and Leo Gabaldon

Published quarterly by
New Mexico Bureau of Mines and Mineral Resources
a division of New Mexico Institute of Mining and Technology

Subscriptions: Issued quarterly, February, May, August, November; subscription price $10.00/calendar year.

Editorial Matter: Articles submitted for publication should be in the editor's hands a minimum of five (5) months before date of publication (February, May, August, or November) and should be no longer than 20 typewritten, double-spaced pages. All scientific papers will be reviewed by at least two people in the appropriate field of study. Address inquiries to Jane C. Love, Editor of *New Mexico Geology*, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico 87801-4796.

Circulation: 1,000

Printer: University of New Mexico Printing Services

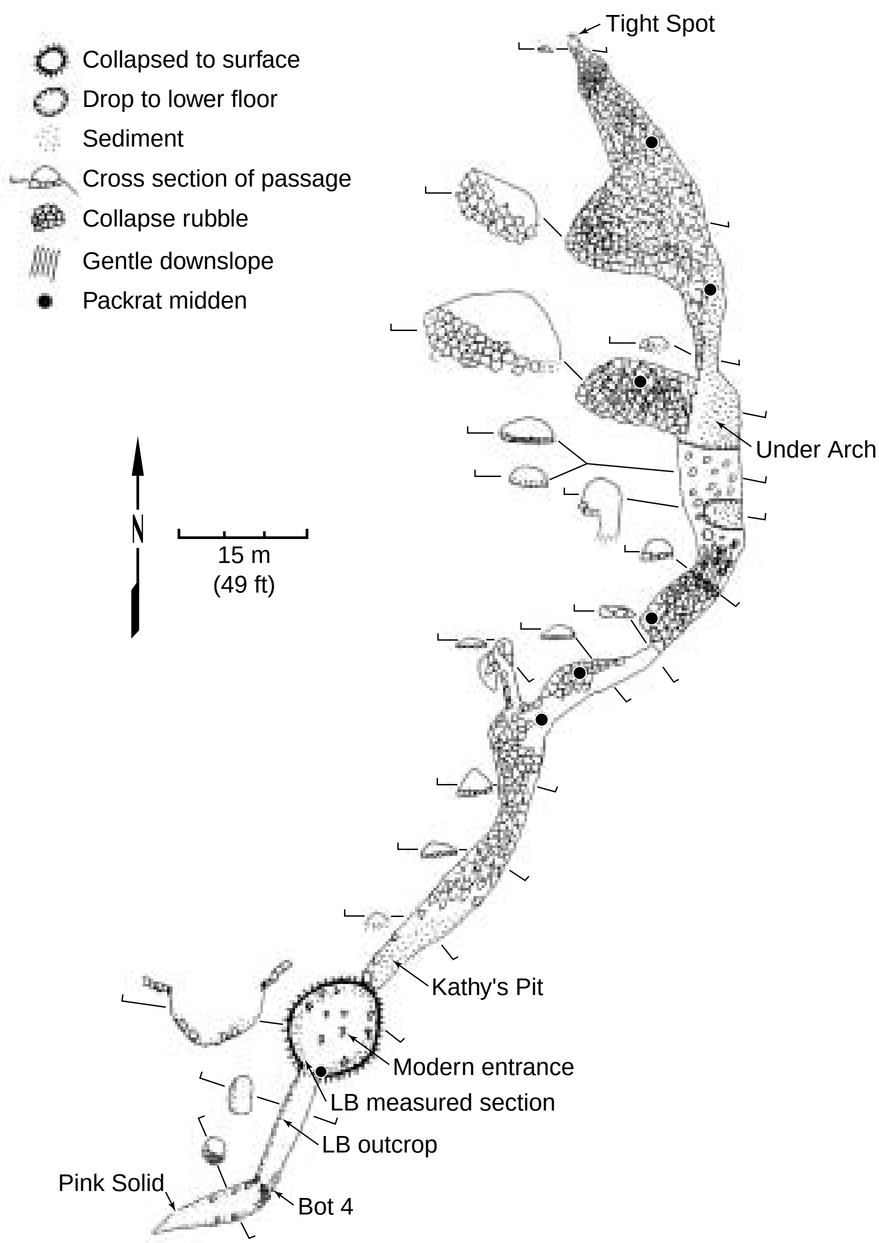

FIGURE 3—Plan view of explored part of SAM Cave, with major localities marked. Cross sections are drawn to the same scale as the plan view. Well-explored parts of the SAM Cave extend for more than 170 m (558 ft) in a southwest to northeasterly direction. The modern entrance is open to the surface as a result of excavations by the late Fidel Cisneros, who left excellent outcrops of sediment that can be readily studied. Unmapped areas of the cave extend at least another 60–70 m (197–230 ft) to the northeast.

Measured parts of the lava tube include a series of large rooms connected by constricted tunnels (Fig. 3). The floor of the cave varies from ancient ceiling fall coated with calcium carbonate to relatively modern ceiling fall (uncoated) and from ancient ponded sediments to recent packrat middens and debris. Many of the walls are coated with a thick, white fuzz of carbonate, and some lava drip stones (Waters et al., 1990) are present. A few bats use the cave for hibernation. Living vertebrate species seen in the cave include shrews (*Sorex*), packrats (*Neotoma*), Mexican free-tailed bats (*Tadarida*), tiger salamanders (*Ambystoma*), and chorus frogs (*Pseudacris*).

Fossiliferous sediments

Fossiliferous sediments originated from at least two different entrances that were active at different times in the history of the cave. Repeated sedimentation events occurred at each of the two entrances. In addition, packrats periodically redistributed material within the cave. Following is a chronological description of our best reconstruction of events that led to the formation of the localities described in this paper.

The earliest opening to the cave appears to have been uphill (south) from all areas of the cave shown in Figure 3. The first opening into the cave may have formed ~2 m.y. after the cave's formation in the wall of the volcanic cone that is today a grassy depression southwest of the modern opening. Regardless of its location, floodwater from this earliest opening deposited sediment at the four oldest localities in the cave. In order from oldest to youngest they are Under Arch, Bot 4, Pink Solid, and Tight Spot.

Bot 4 and Pink Solid are located near the modern entrance. Unfortunately, most of these sediments were removed during Fidel Cisneros' excavations, but remnants remain in some areas in the south-southwest tunnel (Fig. 3).

Under Arch is the name for a uniform flat bed of ponded sediments (D. Rasmussen, pers. comm. 1987) that are concentrated in the most open and largest rooms of the lava tube (Fig. 3). The sediments start approximately 75 m (246 ft) north-northeast of the modern entrance and extend northward approximately 35 m (115 ft). In this area there is an abrupt 4-m (13-ft) drop in floor level, and the lava tube is split into upper and lower channels. The sediment-covered floor of the lower tube is approximately 5 m (16 ft) below the upper rock-covered floor (Fig. 3). A thin section of this material indicates the grains are round (E. Larson, pers. comm. 1990). Thus, the sediment appears to be surface loess that washed into the cave system and was later enhanced with abundant fine-grained calcium carbonate. The surface of these ponded sediments is crusted with calcium carbonate, and the sediments themselves are unstratified and homogeneous. No differences in sediment or fossil faunal composition were apparent in a measured section (5 cm [2 in.] intervals over 113 cm [44 in.] depth). Slightly farther north is the Tight Spot locality, a small collection of fossils that appears to be younger than those of the Under Arch locality. Tight Spot is just past the measured areas of the cave.

The second and younger entrance to the cave is the modern one, which originally may have been quite small but has enlarged due to ceiling collapse in the past 50 yrs. It appears that the north-northeast tunnel was not open to the surface while the sediments of the LB outcrop were deposited (Fig. 3). These are the bulk of the sediments that were removed during Fidel Cisneros' mining operation, which was ongoing during sediment mapping and fossil recovery. In 1987, a section of these strata was measured at the entrance to the south-southwest tunnel (Fig. 4). Later, after more sediment was removed during mining, the outcrop of the remaining strata in the south-southwest tunnel was mapped (Fig. 4).

The last major sedimentation event in the cave appears to have been initiated when ceiling fall at the beginning of the north-northeast tunnel opened a channel

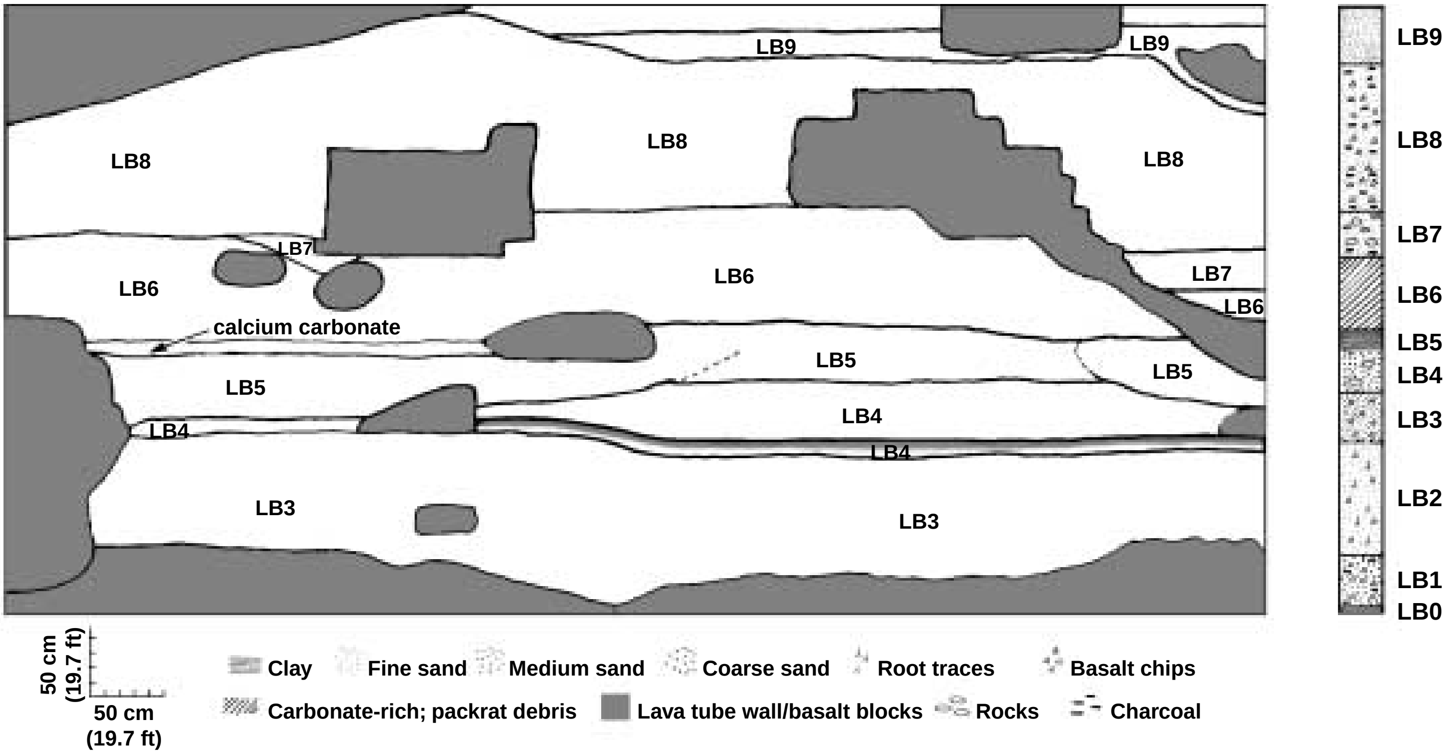

FIGURE 4—Measured section and cross section of the LB outcrop. The measured section was taken before parts of the LB outcrop were removed during Fidel Cisneros' mining operation.

in the corner of the modern entrance (Fig. 3) that allowed water and sediment to enter the proximal areas of the north-northeast tunnel. This last locality, Kathy's Pit, is a 1-m-thick (3-ft) fill that extends approximately 15 m (50 ft) along the beginning of the north-northeast tunnel (Fig. 3). Although there is no clear stratigraphy in these sediments and no faunal differences within a measured section, the area may have acted periodically as a deadfall trap for surface animals. The modern surface has a hard calcium carbonate crust.

Modern sediments and bone are also present in SAM Cave. Occasional lost animals have died in the cave, and packrats have carried many bones into all parts of the cave. For example, ring-necked pheasant (*Phasianus colchicus*), introduced to the United States from Europe in the 1800s, was found in the Kathy's Pit area as a surface find. Packrats have also reworked fossils from their original sediments. For example, the ancient mouse, *Allophaiomys*, is found in recent sediments. Modern packrat activity is apparent in packrat middens and in urine trails. The largest packrat middens are shown in Figure 3.

Methods for study of sediments

The ages and origin of sediments in SAM Cave have been difficult to decipher. To facilitate dating, we hand cored the sediments filling the original volcanic cone because this area appears to have acted as a lake / grassland sediment trap since the volcano became inactive. Our intention was to recover and study a continuous sequence of sediments against which the sporadically deposited sediments of the cave could be correlated. Coring was done during August 1991, using a homemade hydraulic-powered coring apparatus. A depth of 8.75 m (28.7 ft) was reached, but the core is not that long because the sediments compressed during coring. This oriented core is referred to as the "Dry Lake core" in this paper.

To document stratigraphic relationships, measured sections were established in the three thickest cave deposits (Under Arch, LB section, and Kathy's Pit) and systematically sampled. Collections were taken over a period of about 6 yrs. In some cases, emergency salvage work was done as Fidel Cisneros proceeded with his mining operations. The thickest and most complex sequence of deposits was in the LB outcrop.

One measured section was established at the north end of the LB outcrop; subsequently, the entire outcrop was mapped using a 10-cm [4-in.] grid (Fig. 4). A second measured section was established in the Under Arch sediments. No stratigraphy was apparent, but samples were taken in 5-cm (2-in.) increments. Lastly, Kathy's Pit had no evidence of stratigraphy, but the sediments were sampled by depth.

Fossiliferous sediment was removed from the cave in burlap bags (small paper bags for the fine-grained sediments) and returned to the lab for washing and picking. Pollen samples were taken from the LB outcrop in whirlpacks. No pollen samples were taken of Dry Lake core sediments, the Under Arch sediments, or from Kathy's Pit. Sediment samples were collected in paper and plastic bags.

After sediment was washed through a 100-mesh screen and hand picked under a microscope, the resulting fossils were sorted by taxonomic group. Fish fossils were identified by G. Smith (University of Michigan), carnivores by E. Anderson (Denver Museum of Nature and Science), and molluscs by G. Mackie (University of Guelph, Ontario). Reptiles and amphibians were identified by K. Rogers, birds by R. Benson, and mammals other than carnivores by C. Repenning. Clean lumps of sediment stored in whirlpacks were analyzed for pollen by O. Davis (University of Arizona, Tucson), and plastic bags of packrat midden material were analyzed by J. Betancourt (U.S. Geological Survey, Tucson). All fossils have been accessioned to the New Mexico Museum of Natural History and Science (NMMNH) in Albuquerque, New Mexico.

Paleomagnetic sampling was done by F. Luiszer and consisted of carved sediment blocks in the upper, coarse sediments of the LB outcrop and of plastic cubes (2.2 cm^3 [0.34 in^3]) in the lower, finer sediments. The Dry Lake core was split, and paleomagnetic samples were taken in plastic cubes at intervals of 5 cm (2 in.) or less. In the lab, the natural remanent magnetization (NRM) of all samples was measured. Subsequently, the samples were subjected to alternating-field demagneti-

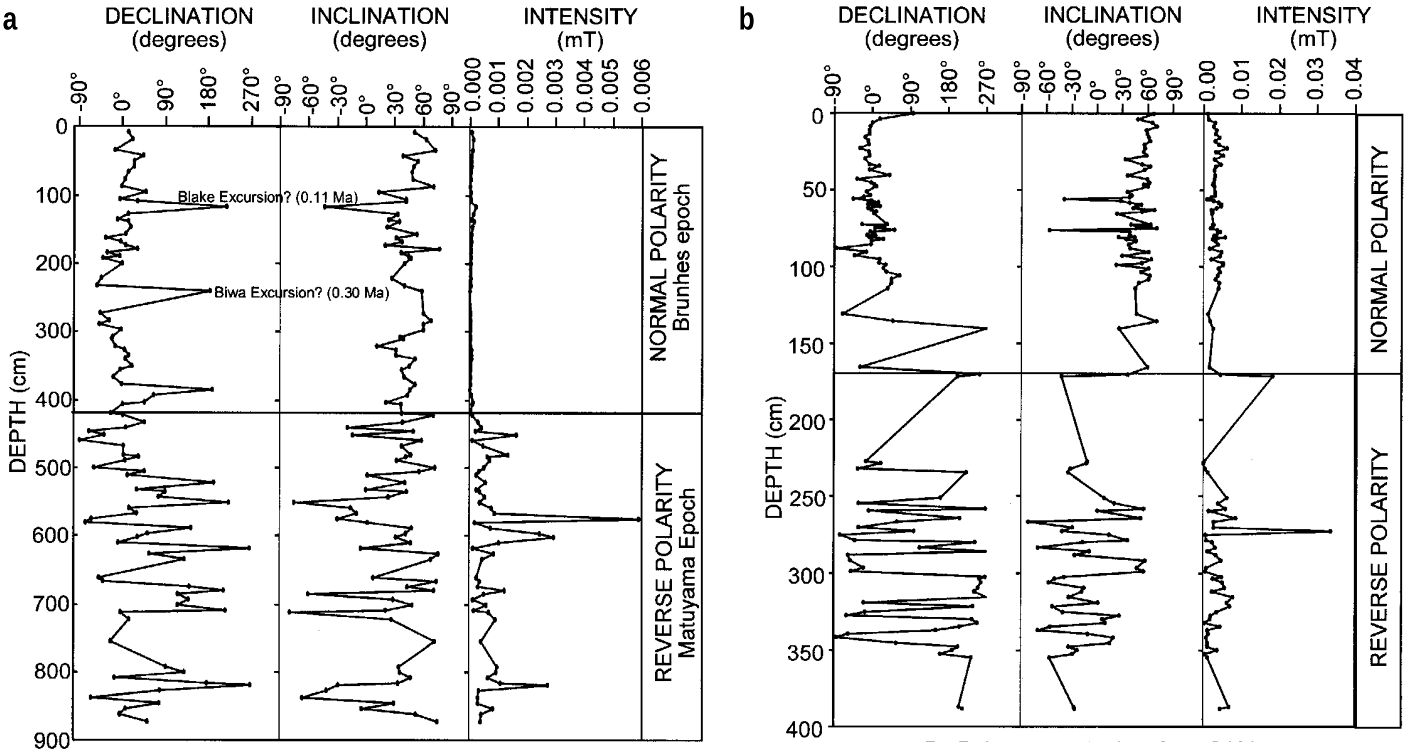

FIGURE 5—Declination, inclination, and intensity of paleomagnetic samples of (**a**) the Dry Lake core and (**b**) the LB outcrop. In the LB outcrop, units LB6 and above have normal polarity (Brunhes) and LB5 and below exhibit reversed polarity (Matuyama).

zation and measured again. All samples were demagnetized at 5 milliteslas (mT), and the core samples were additionally demagnetized at 10 mT. All remanence measurements were made at the University of Colorado on a Schonstedt SSV 1A spinner magnetometer with a sensitivity of 1×10^{-4} A/m. Repeat measurements indicate an angular reproducibility of ~2° at an intensity of 1×10^{-6} emu.

Data

Paleomagnetism—Dry Lake core and LB outcrop

The results of the paleomagnetic study are depicted graphically in Figure 5. The top 438 cm (172 in.) of the Dry Lake core has a predominantly normal polarity (Fig. 5a). Because there is no evidence to indicate the sediment flux into the closed basin, in which the dry lake is located, has changed greatly in the last few million years and because there is no indication of major hiatuses in deposition or erosional events in the lake core, the reversal at ~438 cm (172 in.) should represent the Brunhes–Matuyama boundary (~0.78 Ma). The apparent excursions represented by single samples at 117 cm (46 in.) and 241 cm (95 in.) may correlate to the Blake excursion (0.11 Ma) and the Biwa (0.30 Ma) (Tarling, 1983). Alternatively, these two samples, as well as the sample at 384 cm (151 in.), may have contained magnetic material like hematite, which is not affected by the low levels of alternating-field demagnetization to which the samples were subjected. A single large grain of previously magnetized hematite, which would have been aligned by wind or water currents more readily than by the Earth's magnetic field, could be enough to give a sample an anomalous reading. The samples below ~438 cm (172 in.) have a predominantly reversed polarity with a normal-polarity overprint.

The upper 160 cm (63 in.) of LB outcrop sediments have a predominantly normal polarity, and the remainder of the section is reversed (Fig. 5b). See Figure 4 for LB outcrop stratigraphy. Given the stratigraphy and the paleomagnetism, sediments from the calcium-carbonate layer upward (LB6 and above) were deposited during the Brunhes and are younger than 0.78 Ma; sediments below the calcium-carbonate layer (LB5 and below) were deposited during the Matuyama and are older than 0.78 Ma.

Outcrop and Dry Lake core correlation

Partial sedimentary analysis of the Dry Lake core and LB outcrop reveals that:

(1) LB1, LB7, and LB8 contain charcoal as do several intervals in the Dry Lake core. The charcoal suggests that periodic fire and subsequent erosion of the denuded ground surface occurred in the area.

(2) Sediment color, grain size, and sorting are similar in the LB outcrop and in the Dry Lake core, suggesting that the two locations shared a common sediment source. Because Dry Lake receives no external drainage, the source of the well-sorted silt must be eolian. The volcanic cone (Dry Lake) sediment may have been reworked and carried into the cave, or the sediment for the LB outcrop infiltrated the cave. The absence of cross-laminae, micrograding, and other current structures in the cave suggests that the sediments were not deposited by running water or by current flow through the lava tube.

(3) The LB outcrop sediments contain some material that is not present in the Dry Lake core: cinders are present in LB0; basalt chips are present in LB1, LB2, LB3, and LB8; and fairly large rocks are present in LB7. These materials probably are from mass wasting in the cave while the silt was being deposited. Root traces are present in LB2 (the deposits are located near the surface opening). LB6 is carbonate rich and contains what appears to be ancient packrat debris.

(4) Iron content of sediments (pink to red color) is most pronounced below LB6 in the magnetically reversed sediments of the outcrop. Similarly, iron is most pronounced in the Dry Lake core sediments below 438 cm (172 in.; Matuyama chron).

(5) The oldest age represented in the Dry Lake core is not known. Bedrock was not reached during coring, so presumably, sediments older than those sampled are present below the lowest level cored.

Dating—microtine rodents and climate correlations

Species composition of microtine rodents in SAM Cave deposits, correlation with the nearby Hansen Bluff locality, 40 km (25 mi) northeast and 437 m (1,434 ft) lower in elevation (Rogers et al., 1985, 1992), and biochronology data from similar sequences of climate-change indicator species constrained by paleomagnetic stratigraphy and the ocean climate record provide further age estimates of sediments.

The oldest faunas in SAM Cave are dated by the presence of *Mictomys kansasensis* and *Allophaiomys*. The genus *Mictomys* entered the United States from Eurasia ~2.7 Ma as the species *M. vetus* and dispersed to the east side of the Rocky Mountains by 2.11 Ma (Borchers fauna of Kansas; Fejfar and Repenning, 1998, with paleomagnetic reversal ages revised as in Berggren et al., 1995). The genus was represented as *M. vetus* until ~1.5 Ma (Froman Ferry fauna of Idaho; Repenning et al., 1995). By 1.31 Ma, it was evolving into *M. kansasensis* (Sappa fauna of Nebraska; Martin and Schultz, 1985), which is the species found in SAM Cave.

The oldest record of *Allophaiomys* in the United States is from the base of the Olduvai subchron (~1.96 Ma) in the nearby Hansen Bluff core (Rogers et al., 1992), but this genus is not present in the oldest Hansen Bluff outcrops dated at ~0.86 Ma (Rogers et al., 1985). *Allophaiomys*, a warm-climate indicator, evolved into *Pedomys* in the Great Plains and may have avoided extinction until later at lower, warmer elevations; it is considered to have gone extinct at high elevation with the first major glaciations ("Nebraskan") of the Pleistocene by about 0.85 Ma (Repenning, 1992). Thus, the presence of *Allophaiomys* in the Tight Spot, Pink Solid, Bot 4, and Under Arch localities at SAM Cave indicates the age of these deposits is older than 0.85 Ma. Coupled with *Mictomys kansasensis*, the age is bracketed between ~1.3 Ma and more than 0.85 Ma. The Sappa fauna of Nebraska (1.3 Ma) contains both *M. kansasensis* and *Allophaiomys* (Martin and Schultz, 1985).

The oldest SAM Cave faunas are estimated to be younger than the Sappa fauna because all but the Under Arch localities contain a species of the genus *Microtus* that is unlikely to be older than the beginning of the Jaramillo event (1.0 Ma) based on dates from east of the Rocky Mountains (Repenning, 1992).

Further approximation of ages of these four localities is provided by the frequency of primitive and advanced morphotypes of the sagebrush vole and by correlations of faunal habitat preferences with climate records from Hansen Bluff (Rogers et al., 1985, 1992) and the Norwegian Sea (Jansen et al., 1988). These criteria provide relative ages for the localities, in order from old to young, Under Arch, Bot 4, Pink Solid, and Tight Spot.

The LB outcrop contains the Brunhes–Matuyama polarity reversal that dates to 0.78 Ma. Faunal composition further defines ages within the LB section. Three horizons in the LB section contain tree squirrels, *Sciurus aberti*, an indication of forested conditions. Two of these, LB3 (Brunhes chron) and LB6 (Matuyama chron), also contain the red-backed vole *Clethrionomys*. Together, these species indicate glacial (cool and wet forest) conditions. Correlation with Hansen Bluff, which is well dated, indicates an age for LB3 of 0.82–0.84 Ma or 0.80–0.78 Ma and an age for LB6 of 0.78–0.74 Ma. These are Oxygen Isotope Stages 22–18 (core V28–239) glaciations (Rogers et al., 1985).

Finally, the Kathy's Pit sediments are considered to be late Pleistocene or Holocene in age based on their stratigraphic position and on their faunal composition. These sediments are clearly younger than the top of Hansen Bluff (0.74 Ma) because they contain only representatives of the modern fauna but with a composition that would indicate closer water than occurs at SAM Cave today.

Paleontology

All fossils have been accessioned to the New Mexico Museum of Natural History and Science (NMMNH). A complete list of fossil species with elements recovered, localities, and accession numbers is in the appendix, pages 113–117.

Pollen and packrat material

No pollen was recovered from the sampled cave sediments (O. Davis, pers. comm. 1990) and all packrat midden material was recent (J. Betancourt, pers. comm. 1988).

Molluscs

Mollusc fossils are rare in SAM Cave sediments, but two species of land snails have been identified by Gerry Mackie (University of Guelph, Ontario). *Discus cronkhitei* (2 shells) and *Pupilla muscorum* (1 shell) were found in the Under Arch locality; *Discus cronkhitei* was also found in Pink Solid sediments. These species of land snails have broad distributions. Today, *Discus cronkhitei* occurs from Maine to Maryland and west to Washington and California. *Pupilla muscorum* occurs in the northeastern United States west to Oregon and south to Arizona and Texas. Fragmentary snail shells are also present in the LB6 locality. The presence of these snails indicates considerably wetter terrestrial conditions than those near SAM Cave today (G. Mackie, pers. comm. 1990). See Table 1 for stratigraphic position of mollusc fossils.

Fish

Fish fossils are rare at SAM Cave. The following species have been identified by Gerry Smith (University of Michigan). Bot 4 contained one trout vertebra and LB3 sediments contained five trout vertebrae, four of which represent 1-yr-old individuals, and one represents a 3-yr-old individual. In addition, one vertebra of a small minnow or sculpin from Kathy's Pit represents a 9–10 yr-old individual. Trout indicate the presence of cold, perennial water. See Table 1 for stratigraphic position of fish fossils.

Amphibians and reptiles

Two amphibians and three reptiles were identified as fossils at SAM Cave. They include *Ambystoma tigrinum* (tiger salamander), *Pseudacris triseriata* (chorus frog), *Crotalus viridis* (prairie rattlesnake), *Thamnophis elegans* (wandering garter snake), and *Phrynosoma douglassii* (short-horned lizard). These fossils are within the modern range of the species and typical of high-altitude populations except for the fossils of *A. tigrinum* and *P. triseriata* in Kathy's Pit sediments. In Kathy's Pit, tiger salamanders were abnormally large for the San Luis Valley and are more similar in size to those found today in Kansas. Similarly, the fossil ilia of *P. triseriata* from Kathy's Pit sediments are morphologically atypical of San Luis Valley *P. triseriata* and are much larger than those found today in the region. The fossils are identical to the largest specimens of *P. triseriata* from Kansas in the Michigan State University collection (J. A. Holman, pers. comm. 1991). The size differences in these two species indicate a much milder climate (fewer temperature extremes, shorter winter, and longer growing season) than occurs near SAM Cave today. In addition, the chorus frog, *Pseudacris triseriata*, is extremely abundant in LB2 and LB3 sediments, an indication of much wetter conditions during those time spans than occurs in the area today. See Table 1 for stratigraphic position of identified fossils.

Birds

Identifications based on diagnostic avian specimens, and their stratigraphic occurrences in SAM Cave, are listed in Table 1. The corresponding fossils are listed in Appendix I. All identifications of fossil specimens to species are equivocal (e.g., "*Asio* cf. *A. flammeus*" rather than "*Asio flammeus*") in view of the fragmentary nature of the material, as well as our lack of knowledge of Pleistocene avian species diversity within modern genera. All of the following identified taxa, except one, presently occur in New Mexico. As noted above in the section on fossiliferous sediments, a gnaw-marked humerus of *Phasianus colchicus* (ring-necked pheasant) occurred as a surface find at Kathy's Pit. The introduced status of this species is an unambiguous indicator of the relative recency of this specimen.

Asio cf. *A. flammeus* (short-eared owl) is identified on the basis of a nearly complete 12th cervical vertebra from Pink Solid. The vertebra most closely resembles that of *A. flammeus*; it is more robust than that of the very similar *A. otus* (long-eared owl) and smaller than *A. stygius* (stygian owl) and *A. priscus* Howard 1964 (Pleistocene of California). Short-eared owls are broadly distributed throughout the Americas in open country, marsh, grassland, and montane forest. Their diet includes rodents, shrews, other small mammals, passeriforms and other small birds, and grasshoppers and other insects.

Tachybaptus cf. *T. dominicus* (least grebe) is identified from the proximal end of a left pedal phalanx III:1 from Bot 4. The phalanx is diagnostic due to its lateral compression and monocotyly, which is unique to this family. The phalanx is indistinguishable from that of *T. dominicus*, the smallest extant grebe. *Pliolymbus baryosteus* Murray 1967, known from the Pliocene of Idaho and the Pleistocene of Mexico (Howard, 1969) and Colorado (Rogers et al., 1985), is of similar linear size but more robust. The least grebe tends to be a lowland marsh species, but its altitudinal range does include the elevation of SAM Cave.

Vireo sp. (vireo) is identified from a rostrum collected from the Under Arch locality (78–73 cm [31–29 in.]). The rostrum has the configuration unique to the vireo family, a wide, relatively blunt bone with the narial opening near the anterior tip. The anterior end of the specimen's narial opening is rounded, as in *Vireo*, rather than more pointed as in *Hylophilus*. A vireo the size of the warbling vireo or the solitary vireo (*V. gilvus* or *V. solitarius*) is represented, but the rostrum cannot be identified to species. Vireos are indicative of woodland.

Corvini gen. indet. (jay) is indicated by a complete pedal phalanx I:1 from Kathy's Pit. The phalanx is that of a jay the size of *Aphelocoma ultramarina* (gray-breasted jay) or *Cyanocitta stelleri* (Steller's jay). The species inhabit woodland.

Two taxa of wrens are discernable at SAM Cave. *Troglodytes* cf. *T. troglodytes* (winter wren) is identified from several associated troglodytine bones, including the proximal end of a left ulna and distal ends of a right femur and left tarsometatarsus, from the bottom floor of Kathy's Pit. The most diagnostic of these is the tarsometatarsus, displaying the deep, distomedially flaring metatarsal facet characteristic of wrens. This specimen is the size of *T. troglodytes* and *Cistothorus platensis* (sedge wren). The associated bones permit generic assignment. The femur is distally broad as in *Troglodytes* rather than narrower as in *Cistothorus*, and the wing/foot size ratio is that of *Troglodytes* rather than *Cistothorus*. Also present is a larger wren of the size of *Thryothorus ludovicianus* (Carolina wren), but it is not identifiable to genus. This taxon is represented by the distal end of a right humerus and five cervical vertebrae from Kathy's Pit. Wrens inhabit forest undergrowth.

Parus sp. (chickadee) is identified from two horizons. LB3 yielded the proximal end of a right tibiotarsus of *Parus* sp., and this taxon is also represented at Kathy's Pit by fragments of mandible, coracoid, furcula, sternum, humeri, tarsometatarsi, and eight cervical vertebrae including atlas and axis. The various species of *Parus* utilize a variety of habitats including woodland, thickets, and swamps.

Junco sp. (junco) occurred in the Under Arch locality. The distal end of a left tarsometatarsus (108–103 cm [42–40 in.]) is that of an emberizine with a relatively shallow metatarsal facet as exhibited by *Junco* and *Pooecetes*, but it better matches *Junco* in size. In addition, a *Junco* right tarsometatarsus and two cervical vertebrae were found in Under Arch sediments. Juncos live in thickets, open shrub and woodland, and bogs.

Passerculus cf. *P. sandwichensis* (savannah sparrow) is identified from Pink Solid on the basis of the distal end of a left tarsometatarsus indistinguishable from that of this species. Savannah sparrows inhabit grasslands, meadows, bogs, and marshes.

Ammodramus sp. (sparrow) is identified from the proximal ends of left and right humeri, the distal end of a left tarsometatarsus, and the 4th and 5th cervical vertebrae from Bot 4. Members of this genus live in a variety of habitats, including wet meadow and marsh.

Two size classes of Parulini (wood warblers) are represented at SAM Cave, the larger by the proximal half of a left tibiotarsus of a species the size of *Seiurus aurocapillus* (ovenbird), and by the dorsal end of a left coracoid of a smaller parulin such as *Dendroica petechia* (yellow warbler). Both specimens are from the Under Arch locality (103–98 cm [40–38 in.] and 68–63 cm [27–25 in.], respectively). Parulin warblers are indicative of woodland.

Mammals

Mammal fossils are extremely numerous in SAM Cave deposits. They are represented by 26 genera in five orders, but all are of small size, the largest being the red wolf. The species and their stratigraphic distributions are presented in Table 2; a detailed list of fossils is presented in the appendix, pp. 113–117. Temporal importance of some species has been discussed previously.

TABLE 1—Mollusc, fish, amphibian, reptile, and bird species identified from SAM Cave. deposits. Identifications are listed by fossil locality, which, in turn, are arranged in temporal order from old (bottom of table) to young.

Locality	Fish and molluscs	Amphibians and reptiles	Birds
Surface finds; Packrat middens		*Ambystoma tigrinum*	*Phasianus colchicus*
Kathy's Pit	Minnow or sculpin	*Ambystoma tigrinum* *Phrynosoma douglassii* *Pseudacris triseriata* *Thamnophis elegans*	Corvini gen. indet. *Parus* sp. *Troglodytes* cf. *T. troglodytes* Troglodytinae gen. indet.
LB9			
LB8			
LB7			
LB6	Mollusc shells	*Ambystoma tigrinum* *Pseudacris triseriata*	
LB5			
LB4			
LB3	Trout vertebrae	*Ambystoma tigrinum* *Crotalus viridis* *Pseudacris triseriata*	*Parus* sp.
LB2		*Crotalus viridis* *Phrynosoma douglassii* *Pseudacris triseriata* *Thamnophis elegans*	
LB1			
LB0			
Tight Spot			
Pink Solid	*Discus cronkhitei*	*Ambystoma tigrinum*	*Asio* cf. *A. flammeus* *Passerculus* cf. *P. sandwichensis*
Bot 4	Trout vertebra	*Ambystoma tigrinum* *Pseudacris triseriata*	*Tachybaptus* cf. *T. dominicus* *Ammodramus* sp.
Under Arch	*Discus cronkhitei* *Pupilla muscorum*	*Ambystoma tigrinum* *Crotalus viridis*	*Junco* sp. Parulini 2 gen. indet. *Vireo* sp.

TABLE 2— Mammals identified from SAM Cave deposits. Identifications are listed by fossil localities arranged in temporal order. Oldest is to the right.

	Recent	Kathy's Pit	LB9	LB8	LB7	LB6	LB5	LB4	LB3	LB2	LB1	Tight Spot	Pink Solid	Bot 4	Under Arch
CHIROPTERA															
sp. indet.		X											X		
CARNIVORA															
Canis sp.															X
Canis cf. *C. latrans*		X													
Canis rufus													X		
Lutra canadensis		X													
Mephitis mephitis		X													
Mustela erminea													X		
Spilogale putorius													X		
Taxidea taxus														X	
Vulpes vulpes														X	
INSECTIVORA															
Soricidae gen. et sp. indet.						X									
Sorex sp.		X											X		
LAGOMORPHA															
Leporidae gen. et sp. indet.										X					
Lepus sp.		X													X
Lepus californicus		X											X		
Sylvilagus sp.		X					X							X	
RODENTIA															
CRICETIDAE															
Neotoma sp.	X											X	X		
Neotoma cinerea		X												X	
Peromyscus sp.	X	X												X	
Peromyscus cf. *P. crinitus*	X											X	X		
Reithrodontomys sp.	X	X				X									
Reithrodontomys megalotis		X												X	X
MICROTINES															
Microtine gen. et sp. indet.		X										X	X	X	X
Allophaiomys sp.	X											X	X	X	X
Allophaiomys or *Lemmiscus*														X	
Lemmiscus curtatus (SAM)	X									X		X	X	X	X
Lemmiscus curtatus (modern)							X								X
Clethrionomys sp.											X				
Clethrionomys cf. *C. rutilus*						X			X						
Microtus sp.		X						X			X	X	X		
Microtus cf. *M. californicus*		X												X	
Mictomys sp.									X			X			
Mictomys kansasensis								X					X	X	X
Phenacomys cf. *P. intermedius*	X	X									X				
ERETHIZONTIDAE															
Erethizon sp.		X													X
GEOMYIDAE															
gen. et sp. indet.										X					
Thomomys sp.		X						X				X	X	X	X
SCIURIDAE															
Cynomys sp.												X	X	X	X
Cynomys ludovicianus		X												X	X
Eutamias minimus		X													
Sciurus aberti						X			X	X					
Spermophilus sp.	X														
Spermophilus lateralis													X	X	
Spermophilus leucurus										X					
Spermophilus tridecemlineatus		X										X	X	X	X
Spermophilus variegatus	X												X	X	

Only fossils of evolutionary, climatic, or distributional significance will be discussed here.

The evolutionary stage of the extinct immigrant vole genus *Allophaiomys* in SAM Cave is "advanced" except for two "typical" individuals in a total of 67 identifiable specimens that have been found in the four oldest SAM Cave localities. Two isolated *Allophaiomys* teeth in recent sediments are considered to be contaminants from early packrat scavenging of older SAM Cave localities because there are no other records of *Allophaiomys* that young any where in the world, including the nearby Hansen Bluff. This variation of "typical" and "advanced" individuals is not unusual for any microtine species, and the entire SAM Cave assemblage is considered to be an advanced, but unnamed, species of *Allophaiomys*.

***Lemmiscus*–SAM Cave morphs**. The oldest fossil faunas of SAM Cave (measured section Under Arch and associated test material; 21 first lower molars, m1s, of *Allophaiomys* and 25 m1s of *Lemmiscus curtatus*–SAM Cave morphs, described below) appear to document the derivation of the living sagebrush vole. Both genera persist in younger SAM Cave faunas but show decreasing intergeneric morphologic variation until *Allophaiomys* apparently becomes extinct in the region. The publication of this SAM Cave paper has been long delayed, so the SAM Cave morph of *Lemmiscus curtatus* has been referred to in print earlier. Thus, background is presented below.

All microtine rodents that derived from the ancestral genus *Mimomys* 5 m.y. ago or more in Asia (subfamily Arvicolinae) have a first lower molar that consists of a posterior loop followed anteriorly by three alternating triangles, called "basic triangles," that derive from the cusps of the first lower molar of the low-crowned cricetid ancestors of *Mimomys* (Repenning, 1968). These are preceded anteriorly by a structure, called the "anteroconid complex," which is derived from the ancestral cricetid anterocone. The anteroconid complex of microtines increases in complexity with evolution, and in ancestral *Mimomys* it has already developed a pair of additional salient angles, called "primary wings," which separate it from high-crowned ancestral cricetids for the most part. In front of the primary wings is a rounded and varyingly shaped structure called the "cap," at the back of which additional salient angles, called "secondary wings," may develop bilaterally with evolution. These primary and secondary wings may evolve into fully formed additional triangles, very similar in form to the primary triangles. In some lineages other than the Arvicolinae, this process of adding alternating triangles from the cap of the anteroconid process may continue to the point where there are tertiary wings, making a total of six salient angles in addition to the three basic triangles.

Lemmiscus is characterized by both primary wings having fully developed into alternating triangles (five alternating triangles including the basic three). There is only one secondary wing on the buccal side of the tooth—its lingual counterpart is never present. This sixth alternating triangle is varyingly confluent with the fifth alternating triangle. The lack of confluence between triangles five and six is typical of living *Lemmiscus*; the confluence of triangles five and six (or the lingual primary wing and the buccal secondary wing) was

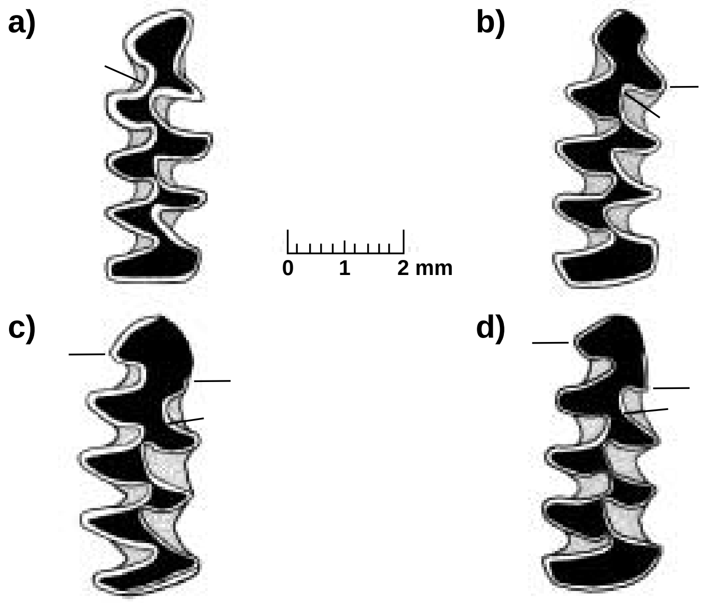

FIGURE 6—*Allophaiomys, Lemmiscus*, and *Microtus* (voles), first lower molars, right side. Black is dentine, white is enamel, and stippled is cement. Lines point to specific features. These teeth have no roots. (**a**) *Lemmiscus curtatus*, Malheur County, Oregon, modern specimen from Repenning's reference collection, no. 6409. This modern morphotype is first found in SAM Cave in the Under Arch locality. (**b**) *Lemmiscus curtatus* SAM morphotype, NMMNH P-31267 from Under Arch locality L-4395. With closure of the dentine confluence between the lingual primary wing (completing triangle five) and the buccal secondary wing (which is confluent with the cap), the SAM morph becomes the modern morph. (**c**) Advanced morphotype of *Allophaiomys* sp., NMMNH P-31235 from Bot 4 locality L-4394, with angle on lingual side of the anteroconid cap, only slight angle on the posterobuccal corner, and broad confluence between primary wings (triangles four and five) and between lingual primary wing and cap. (**d**) *Microtus* sp. NMMNH P-31131 from Kathy's Pit locality L-4381 with primitive and transitional morphology from *Allophaiomys* in narrower confluence between lingual and buccal primary wings (almost triangles four and five), slightly narrowed confluence between lingual primary wing and cap, and distinct angles forecasting secondary wings on the cap.

first noted in the samples from locality Bot 4 of SAM Cave (Repenning, 1992) and is referred to as the SAM Cave morphotype. The SAM Cave morphotype is more common in older deposits than in younger deposits, but it does not seem further distinctive of age. These two morphotypes (Fig. 6a and 6b) are present in the SAM Cave faunas; these are probably the oldest records of the genus. The tendency to have more SAM Cave morphotypes in older deposits clearly suggests a derivation of *Lemmiscus* from the genus *Allophaiomys*, as was suggested by Repenning (1992), but intermediate morphotypes between the two have yet to be found. The primitive *Lemmiscus* morphotype persists in SAM Cave faunas only until the end of the Matuyama chron, 0.78 Ma (except as reworked fossils in recent deposits), although the morph is known in deposits from eastern Nevada that are younger than 15,000 yrs old (Bell and Mead, 1998). Schmelzmuster (enamel pattern) of these specimens has not been studied.

Microtus. An advanced species of the vole genus *Microtus* is sparingly present in all but the oldest of the SAM Cave localities. All *Microtus* m1s have five closed triangles and two well-formed secondary wings confluent with the cap, and many are in the same samples with complex third upper molars (M3s) that are not similar to those of the other microtines in the SAM Cave faunas (Fig. 7a). There are a number of modern *Microtus* species with similar teeth, but their identification from dental morphology is not yet certain and requires sample sizes large enough for significant average morphology for identification. Unfortunately, the fossils from the SAM Cave faunas are too few in number for such analysis.

Microtus paroperarius was identified throughout the Hansen Bluff fauna (Rogers et al., 1985), but this work was done well before it was known that there might be more than one species of *Microtus* in the type population of *M. paroperarius* (Bell and Repenning, 1999). Certainly some of the *Microtus* from Hansen Bluff, whose oldest fauna is about 0.86 Ma, belongs in the species *M. paroperarius*; uncertainly others may not. There are no forms comparable to typical *M. paroperarius* in SAM Cave. Very primitive morphotypes of *M. paroperarius* are believed to have evolved in the Appalachian Mountains about 0.84 Ma (Repenning and Grady, 1988; Repenning, 1992), and some of the advanced forms of *Microtus* in SAM Cave are possibly as old as 1.0 Ma.

The SAM Cave *Microtus* teeth are similar to the teeth of a species of *Microtus* from California (fig. 10 of Repenning, 1992, p. 45), *Microtus californicus*, reported from two localities that are both older than 0.83 Ma. It is thought that this species represents an immigrant lineage of *Microtus* that evolved earlier in Eurasia, and it is the only known possible source for the *Microtus* of SAM Cave. Hence, the SAM Cave *Microtus* is assigned to *Microtus* cf. *M. californicus*. This implies a previously unrecognized dispersal from west of the

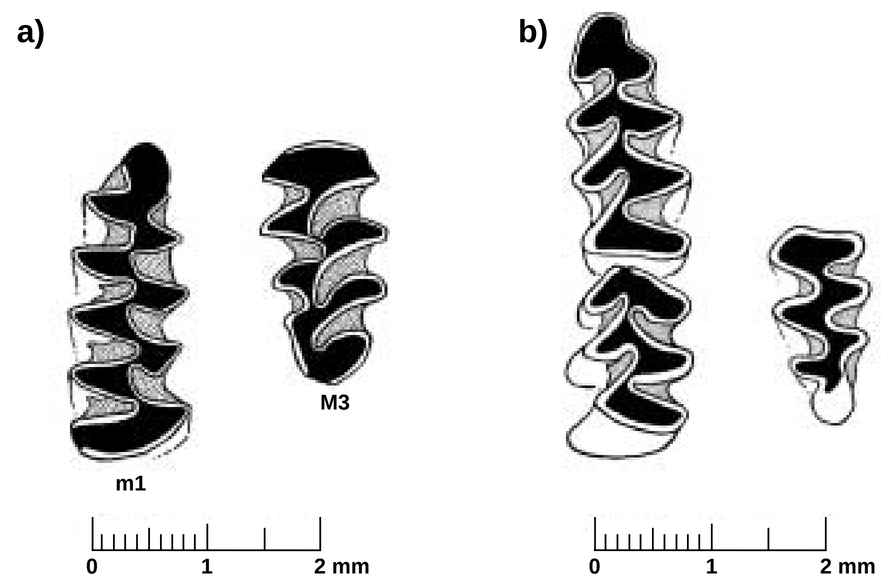

FIGURE 7—(**a**) *Microtus* cf. *M. californicus* from Kathy's Pit locality L-4381, SAM Cave, NMMNH P-31130. These teeth have no roots. Right first lower molar (m1) with five triangles and two well-developed (alternating) secondary wings (or seven triangles with the anterior one open anteriorly). The right last upper molar, M3, is a complicated tooth with a posterior loop formed of two incompletely developed triangles and a posterior hook. Such complicated third upper molars are found in very few microtine genera except *Microtus* and not in all species of that genus. (**b**) *Clethrionomys* cf. *C. rutilus*, first and second lower molars and last upper molar (NMMNH P-31167), from the LB3 locality L-4388 of SAM Cave. Left side. These teeth have roots. This is the oldest record of the genus in North America and is from reversely polarized deposits of the LB section.

Rocky Mountains to its east side, and the earliest occurrence in Bot 4 suggests that it took place about 1.0 Ma at the beginning of essentially continuous intensive glaciation of the Northern Hemisphere. Such climates are known to have made areas around the south end of the Rocky Mountains more humid and favorable for microtine habitats.

Clethrionomys. Two horizons, LB3 and LB6, in the LB section contain fossils of the red-backed vole *Clethrionomys*. (*Clethrionomys* sp. is also present in LB1.) The former horizons are on opposite sides of the Brunhes–Matuyama polarity reversal (0.78 Ma) and as such are among the oldest records of the genus in North America. Although presumably ancestral to the living southern red-backed vole, *C. gapperi*, they are more similar in tooth structure to the northern *C. rutilus* and are therefore referred to *Clethrionomys* cf. *C. rutilus*. The comparison is, however, with those forms assigned to this species in northern Eurasia (compare Gromov and Polyakov, 1977, p. 155, fig. 24 with Fig. 7b of this report). The SAM Cave fossils are less derived in the slight development of the fourth triangle on the first lower molar. Their dental pattern is simpler than that of living forms assigned to *C. rutilus* in North America and that of fossil and living forms assigned to *C. gapperi*. They clearly are more like fossil forms of about the same age and older in Eurasia that have been assigned a variety of species names (see fig. 19 of Gromov and Polyakov, 1977). The history of *Clethrionomys* is not yet well known, but they are mice of cool forests.

Sciurus aberti. Possibly the most ecologically surprising records from the SAM Cave faunas are the three occurrences of the tree squirrel, *Sciurus aberti* (Abert's squirrel). The teeth of this genus are distinctive; *Sciurus aberti* is the only species of this genus recognized in this part of the Rocky Mountains before the introduction of the eastern species of *Sciurus* by humans. *Sciurus aberti* is present in LB2, LB3, and LB6; the latter two localities also contained *Clethrionomys*. These faunas clearly represent glacial conditions during which the SAM Cave area was forested, contrasting strongly with the modern and remaining fossil environment of sagebrush and grass. These records of *Sciurus aberti* are unusual and are possibly the oldest for this species in the United States.

TABLE 3—Climatically important species with their significance. Fossil localities are arranged in temporal order.

Locality	Climate/vegetation	Climate indicators
Surface finds; Packrat middens	Dry, sagebrush-grassland with small stands of ponderosa pine	
Kathy's Pit	Woodland, swamp	chickadees, jays, wrens
	Permanent water nearby	minnow or sculpin (small, 9 yrs old)
	Milder temperatures, long growing season	big, Kansas-sized tiger salamanders and chorus frogs
	Dry, grasslands	short-horned lizards, *Spermophilus tridecemlineatus*
	Cool, sage-grassland	*Phenacomys* cf. *P. intermedius*
LB outcrop:		
LB8	Fire, flood?	charcoal
LB7	Fire, flood?	charcoal
LB6	Forests (genuine, up to tree line in So. Rockies)	Abert's squirrel, *Clethrionomys*
	Surface water, cool summer days	mollusc shells
LB5		
LB4	Surface water, cool summer days	abundant *Mictomys*
LB3	Woodland, swamp	chickadees
	Cold, running water	trout
	Wet	abundant chorus frogs
	Forests (genuine, up to tree line in So. Rockies)	Abert's squirrel, *Clethrionomys*
	Surface water, cool summer days	*Mictomys*
LB2	Forests (genuine, up to tree line in So. Rockies)	Abert's squirrel
	Wet	abundant chorus frogs
LB1	Fire, flood?	charcoal
	Cool, sage-grassland	*Phenacomys* cf. *P. intermedius*
Tight Spot	Dry, warm, sage-grassland	*Allophaiomys*, *Spermophilus tridecemlineatus*
	Surface water, cool summer days	*Mictomys*
Pink Solid	Wet	land snails
	Grassland, marsh	short-eared owl, savannah sparrow
	Dry, warm, sage-grassland	*Allophaiomys*, *Spermophilus tridecemlineatus*
	Surface water, cool summer days	*Mictomys*
Bot 4	Lowland marsh	least grebe, *Ammodramus*
	Dry, warm, sage-grassland	*Allophaiomys*, *Spermophilus tridecemlineatus*
	Cool running surface water, cool summer days	*Mictomys*, trout
Under Arch	Wet	two species of land snails
	Woodland, bogs	vireos, juncos, wood warblers
	Dry, warm, sage-grassland	*Allophaiomys*, *Spermophilus tridecemlineatus*
	Surface water, cool summer days	*Mictomys*

Taphonomy

Based upon the frequency and condition of the various types of fossils (mainly broken rodent bones), it appears that the SAM Cave fossil accumulations are a result of predation and subsequent packrat scavenging. Most species found as fossils in the cave likely lived within a radius of approximately 7 km (5 mi), the approximate range of hunting by raptors. There is no evidence from modern species distributions that bones were transported farther.

Climate reconstruction

Climate indicators for each locality are summarized in Table 3. The oldest four localities represent warm, mild, pre-glacial climate in the region as indicated by the fossil genus of microtine rodents, *Allophaiomys*. Possibly moisture varied during this period, ranging from relatively wet to relatively dry terrestrial conditions; Under Arch and Pink Solid contain land snails, but Bot 4 and Tight Spot do not. Bot 4 has more indication of nearby water than Tight Spot as indicated by the presence of the least grebe and trout in the former locality and the presence of *Spermophilus tridecemlineatus* (13-lined ground squirrel) in the latter.

The fossils present in the LB outcrop suggest a series of climatic conditions associated with glacial growth and recedence. Some units in the LB outcrop may represent severe drought, fire, and flood runoff events associated with climate instability. Evidence for the most pronounced glacial climate at SAM Cave is present in LB3 sediments, and it is slightly less pronounced in LB2 and LB6. During these periods the species present indicate that surface water in running streams, swamps, and marshy areas was abundant and that the dominant vegetation was forest. This is in contrast to the modern conditions that allow growth of only small patches of ponderosa pine interspersed with vast tracts of high-desert plants. In the area today, no surface water is present nearby most years, although the volcanic cone uphill from SAM Cave contains water at least part of the year in exceptionally wet years. The key climatic factors that differ between modern and glacial conditions are total amount of precipitation, both as snow and as rain, and the amount of evaporation and, hence, the cloudiness and high summer temperatures. Modern tolerances of the fossil species indicate that the glacial climates do not seem to be associated with extreme cold temperatures, but rather with moderate temperatures coupled with clouds and increased effective moisture.

Unstable, transitional climates may be represented by LB1, LB7, and LB8. During these times, abundant charcoal is present in the sediments, and almost no fossils are present. Possibly, severe prolonged droughts occurred that made the forests vulnerable to fire; subsequent heavy rain may have led to erosion of the ground surface with deposition in the cave and other low areas. Only a few fossils are present in LB1, and none were found in LB7 and LB8, so deposition was relatively fast or packrat scavenging was not occurring.

The youngest sediments and possibly mildest climate represented at SAM Cave is in Kathy's Pit. Tiger salamanders and chorus frogs, whose growth is normally stunted in the severe climate of this altitude, are present with characteristics of these species as they occur today in areas with a longer growing season and more moderate temperatures. Summer rainfall was not sufficient to support forests in the area as indicated by the absence of forest species and by the presence of grassland species such as short-horned lizards and 13-lined ground squirrels. Permanent, cold water was nearby because a tiny, old minnow or sculpin was present. Taken together, these fossils indicate a warmer, milder climate than today, but with a moisture regime similar to, but wetter than, today.

Discussion

These climate reconstructions provide the opportunity for further refinement of SAM Cave sediment dates. All SAM Cave localities except Kathy's Pit overlap the time span previously studied in detail at the nearby, but lower elevation, Hansen Bluff, Colorado, site. The Hansen Bluff outcrop sediments range in age from 0.86 to 0.74 Ma (Rogers et al., 1985), and the Hansen Bluff core extended this nearly continuous sequence back to the Gauss magnetic chron, more than 2.5 Ma (Rogers et al., 1992). Several climatic events in the Hansen Bluff sequence were reliably correlated with the oxygen isotope stages of the deep sea record and with terrestrial records elsewhere. Thus, given the proximity of Hansen Bluff to SAM Cave and the obvious temporal overlap of the two sites, further observations are possible.

The most obvious commonality between the two localities is the presence of the Brunhes–Matuyama magnetic reversal, dated at 0.78 Ma. Here we use the $^{40}Ar/^{39}Ar$ ages of Berggren et al. (1995); these ages are slightly older (~0.04 Ma) than the K–Ar ages we used in the Hansen Bluff outcrop. At both localities, the magnetic reversal is bracketed by periods of glaciation. At Hansen Bluff, the older of these glacial periods was correlated to the Oxygen Isotope Stage 22 in the deep sea cores V28–239 (Rogers et al., 1985).

Both Hansen Bluff and the SAM Cave area are high-elevation deserts today, but both areas had forests at (SAM Cave) or near (Hansen Bluff) the localities during the Oxygen Isotope Stage 22 glaciation. Today in the San Luis Valley, forests generally begin at elevations higher than Hansen Bluff, where snowfall and summer precipitation are sufficient to sustain the trees. Most areas in the San Juan Mountains as high as SAM Cave (2,737 m, 8,980 ft) are forested, but the open, exposed area of the cave today appears too dry for pine seed germination and seedling survival. Thus, it is likely that the most pronounced difference between glacial and modern climates in this region is in the moisture regimen.

In addition to the above similarities between the two localities, the climate of both localities during the periods of fossil record overlap was considerably warmer, less evaporative, and more equable than modern times. This equability appears to be different than the post-glacial warm of Kathy's Pit, a period not represented at Hansen Bluff. Body size of the SAM Cave amphibians indicates a much longer growing season than is apparent in the pre-Pleistocene warm periods at either locality.

Thus, the regional response to climate change appears to affect mainly precipitation and evaporative patterns, with overall temperature changes generally remaining within a narrower range.

Microtine biochronology discussion

Although there is no evidence of the Jaramillo subchron (normal polarity) in the SAM Cave Matuyama chron sediments, the faunas provide new data for mammalian biochronology in its records of *Clethrionomys*, *Allophaiomys*, *Microtus*, and *Lemmiscus* and present an interesting question regarding the lack of *Terricola*. These revise the information and biochronologic interpretation published in Repenning (1987, 1992).

(1) The genus *Terricola* is believed to have immigrated to North America from Eurasia about 0.85 Ma; this was first approximated about 20 yrs ago, and, surprisingly, since then no contradictory evidence has been found. *Terricola* should be present in the younger faunas of SAM Cave, especially the LB series of localities that straddle the beginning of the Brunhes chron, but none were found. It is a common element in the Hansen Bluff faunas fairly nearby, but at a lower elevation and, possibly, in less forested conditions.

(2) The genus *Lemmiscus* was first discovered to have a slightly more primitive dental morphology from samples from SAM Cave locality Bot 4 (Repenning, 1992, p. 33, fig. 6), and it had been expected that its transition from *Allophaiomys* would be found in SAM Cave. Although a near gradation of individuals exists in this fauna (NMMNH sample P-31236), Bot 4 has turned out, on faunal composition, to be nearly the oldest fauna in SAM Cave, and it is now expected that earlier *Lemmiscus* existed.

The SAM Cave morph is of little value in biochronology as it is present in much younger faunas, younger than 15,000 yrs (Bell and Mead, 1998), and the modern morph is present, but rare, in the oldest fauna of SAM Cave.

It should be noted that *Lemmiscus* appears to derive directly out of *Allophaiomys*, rather than through an intermediate form called *Lasiopodomys*, as did at least one lineage of *Microtus*. *Lemmiscus* is thus not a sister genus of at least one species of *Microtus*, but of *Lasiopodomys*. The number and identity of lineages included in the species of living *Microtus* are not yet known, so some living species of *Microtus* may have a sororal relationship to *Lemmiscus*. This is actually suggested by the gradation of morphotypes assigned to *Allophaiomys* and to *Microtus* in SAM Cave (Fig. 6c, d).

(3) The form called *Microtus* cf. *M. californicus* presents the usual uncertainties that are found with this genus. *Microtus paroperarius* is believed to have evolved in the eastern United States by 0.83 Ma, as shown in the Cumberland Cave fauna of Maryland, yet an apparently much older form, *Microtus* cf. *M. californicus*, is known from deposits possibly 1.2 Ma (based upon loose paleomagnetic control) in southern California. *Microtus* cf. *M. californicus* has been considered an earlier immigrant from Eurasia, where conflicting evidence suggests several separate origins of *Microtus* out of the *Allophaiomys* lineage. Yet mor-

photypes of a very primitive nature (Fig. 6d) are found in the Kathy's Pit locality. Thus the SAM Cave record suggests that the genus has appeared several times out of the ancestral *Allophaiomys* lineage in North America as well. The great variation in individual morphology of the genus (Bell and Repenning, 1999) further complicates the interpretation. No *Allophaiomys* morphotypes were found in Kathy's Pit.

(4) The genus *Allophaiomys* itself exhibits considerable morphologic variation throughout the Northern Hemisphere that is difficult to interpret (see fig. 6 in Repenning, 1992, for illustrations of the variation from SAM Cave locality Bot 4), but the genus is not known from deposits as young as 0.78 Ma. It apparently diversified itself into nominal extinction by 0.78 Ma.

(5) The record of *Clethrionomys rutilus* from both below and above the beginning of the Brunhes normal-polarity chron in the LB sequence of localities, although more resembling Asian living forms of the species than North American ones, is by far the oldest record of this genus in North America and the only one from the Irvingtonian land mammal age. It confirms the earlier assumption that it immigrated to North America about 0.85 Ma.

Acknowledgments. We express our sincere gratitude to the late Fidel Cisneros who spent many laborious hours uncovering SAM Cave. Without his work, this study would not have been possible. We also thank Elaine Anderson, Julio Betancourt, Owen Davis, Lori Harvey, J. Alan Holman, Glen Izett, Bob Kirkham, Kathy Konishi, Frank Kottlowski, Ed Larson, Gerry Mackie, Nikki Martin, Adrienne Minerick, Gary Morgan, Bill Neal, Don Rasmussen, Darren Rogers, and Gerry Smith for various aspects of help on the project. Reviewer comments substantially improved the manuscript. We thank Bruce Allen, Chris Bell, and an anonymous reviewer. This work was performed under antiquities act permits through Carson National Forest and was supported by a grant from the New Mexico Bureau of Mines and Mineral Resources.

References

Bell, C. J., and Mead, J. I., 1998, Late Pleistocene microtine rodents from Snake Creek Burial Cave, White Pine County, Nevada: Great Basin Naturalist, v. 58, pp. 82–86.

Bell, C. J., and Repenning, C. A., 1999, Observations on dental variation in *Microtus* from the Cudahy Ash Pit fauna, Meade County, Kansas, and implications for Irvingtonian microtine rodent biochronology: Journal of Vertebrate Paleontology, v. 19, no. 4, pp. 757–766.

Berggren, W. A., Hilgen, F. J., Langereis, C. G., Kent, D. V., Obradovich, J. D., Raffi, I., Raymo, M. E., and Shakleton, N. J., 1995, Late Neogene chronology—new perspectives in high resolution stratigraphy: Geological Society of America, Bulletin, v. 107, pp. 1272–1287.

Dungan, M. A., Muehlberger, W. R., Leininger, L., Peterson, C., McMillan, N. J., Gunn, G., Lindstrom, M., and Haskin, L., 1984, Volcanic and sedimentary stratigraphy of the Rio Grande Gorge and the late Cenozoic geologic evolution of the southern San Luis Valley; *in* Baldridge, W. S., Dickerson, P. W., Riecker, R. E., and Zidek, J. (eds.), Rio Grande rift—northern New Mexico: New Mexico Geological Society, Guidebook 35, pp. 157–170.

Fejfar, O., and Repenning, C. A., 1998, The ancestors of the lemmings (Lemmini, Arvicolinae, Cricetidae, Rodentia) in the early Pliocene of Wölfersheim near Frankfurt am Main, Germany: Senckenbergiana Lethaea, Germany, v. 77, pp. 161–193.

Gromov, I. M., and Ya Polyakov, I., 1977, Voles (Microtinae): Fauna of the USSR, Mammals, v. III, no. 8, 504 pp (in Russian).

Gromov, I. M., and Ya Polyakov, I., 1992, (1977) Voles (Microtinae): Fauna of the USSR, Mammals, v. III, no. 8, 504 pp. (English translation); Smithsonian Institution Libraries and The National Science Foundation, Washington, DC, 725 pp.

Howard, H., 1964, A fossil owl from Santa Rosa Island, California, with comments on the eared owls of Rancho La Brea: Southern California Academy of Science, Bulletin, v. 63, pp. 27–31.

Howard, H., 1969, Avian fossils from three Pleistocene sites in central Mexico: Los Angeles County Museum, Contributions to Science v. 172, pp. 1–11.

Jansen, B., Henrich, U., Henrich, R., Kringstad, L., and Slettmark, B., 1988, Paleoenvironmental changes in the Norwegian Sea and the northeastern Atlantic during the last 2.8 m.y.—Deep Sea Drilling Project/Ocean Drilling Program sites 610, 642, 643, and 644: Paleoceanography, v. 3, pp. 563–581.

Lipman, P. W., and Mehnert, H. H., 1979, The Taos Plateau volcanic field, northern Rio Grande rift, New Mexico; *in* Riecker, R. E. (ed.), Rio Grande rift—tectonics and magmatism: American Geophysical Union, Washington, DC, pp. 289–311.

Martin, L. D., and Schultz, C. B., 1985, Small mammals of the Seneca and Sappa local faunas (post Ogallala of Nebraska): Institute for Tertiary–Quaternary Studies, TER–QUA Symposium Series, v. 1, pp. 163–179.

Murray, B. G., Jr., 1967, Grebes from the late Pliocene of North America: Condor, v. 69, pp. 277–288.

Repenning, C. A., 1968, Mandibular musculature and the origin of the Subfamily Arvicolinae (Rodentia): Acta Zoologica Cracoviencia, v. 13, no. 3, pp. 29–72 (Polish and Russian summaries).

Repenning, C. A., 1987, Biochronology of the microtine rodents of the United States; *in* Woodburne, M.E. (ed.), Cenozoic mammals of North America—Geochronology and biochronology: University of California Press, Berkeley, pp. 236–268.

Repenning, C. A., 1992, *Allophaiomys* and the age of the Olyor Suite, Krestovka Sections, Yakutia: U.S. Geological Survey, Bulletin 2037, 98 pp.

Repenning, C. A., and Grady, F., 1988, The microtine rodents of the Cheetah Room fauna, Hamilton Cave, West Virginia, and the spontaneous origin of *Synaptomys*: U.S. Geological Survey, Bulletin 1853, 32 pp.

Repenning, C. A., Weasma, T. R., and Scott, G. R., 1995, The early Pleistocene (latest Blancan–earliest Irvingtonian) Froman Ferry fauna and history of the Glenns Ferry Formation, southwestern Idaho: U.S. Geological Survey, Bulletin 2105, 86 pp.

Rogers, K. L., Repenning, C. A., Forester, R. M., Larson, E. E., Hall, S. A., Smith, G. R., Anderson, E., and Brown, T. J., 1985, Middle Pleistocene (late Irvingtonian: Nebraskan) climatic changes in south-central Colorado: National Geographic Research, v. 1, pp. 535–563.

Rogers, K. L., Larson, E. E., Smith, G., Katzman, D., Smith, G. R., Cerling, T., Wang, Y., Baker, R. G., Lohmann, K. C., Repenning, C. A., Patterson, P., and Mackie, G., 1992, Pliocene and Pleistocene geologic and climatic evolution in the San Luis Valley of south-central Colorado: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 94, pp. 55–86.

Tarling, D. H., 1983, Palaeomagnetism: principles and applications in geology, geophysics, and archaeology: Chapman and Hall Ltd., London, 379 pp.

Waters, A. C., Donnelly-Nolan, J. M., and. Rogers, B. W., 1990, Selected caves and lava-tube systems in and near Lava Beds National Monument, California: U.S. Geological Survey, Bulletin 1673, 102 pp.

Appendix, Faunal list from SAM Cave, can be found on page 113.

Appendix

(continued from page 100)

Faunal list from SAM Cave with locality and accession numbers. **NMMNH**, New Mexico Museum of Natural History and Science. Localities are in Figs. 3 and 4.

Taxonomic group	Species	Locality	Location number	Elements	Accession number (NMMNH)
Mollusca (mollusks)					
	Discus cronkhitei				
		Pink Solid	L-4393	1 shell	P-31203
		Under Arch	L-4395	2 shells	P-31252
	Pupilla muscorum				
		Under Arch	L-4395	1 shell	P-31253
	sp. indet.				
		LB6	L-4385	fragmentary shells	P-31114
Osteichthyes (bony fish)					
	minnow or sculpin				
		Kathy's Pit	L-4381	1 vertebra	P-31108
	trout				
		LB3	L-4388	5 vertebrae	P-31164
		Bot 4	L-4394	1 vertebra	P-31223
Amphibia (salamanders and frogs)					
	sp. indet.				
		Kathy's Pit	L-4381	frog maxilla, vertebrae, leg bones	P-31105
Order Urodela, Family Ambystomatidae					
	Ambystoma tigrinum				
		Kathy's Pit	L-4381	20 bones	P-31106
		LB4	L-4387	3 vertebrae	P-31161
		Pink Solid	L-4393	3 vertebrae, 1 leg element	P-31202
		Bot 4	L-4394	5 vertebrae, skull and leg elements	P-31222
		Under Arch	L-4395	5 vertebrae, miscellaneous elements	P-31251
		recent	L-4396	part of whole skeleton	P-31283
Order Anura, Family Hylidae					
	Pseudacris triseriata				
		Kathy's Pit	L-4381	5 ilia, 1 urostyle, 1 sacral vertebra	P-31107
		LB6	L-4385	1 ilium	P-31151
		LB2	L-4389	1 ilium, 3 vertebrae	P-31174
		Bot 4	L-4394	8 ilia, sacral vertebra	P-31219
Amphibia/Reptilia (amphibians / reptiles)					
	misc. elements				
		Bot 4	L-4394	some salamander, mostly frog	P-31220
Reptilia (snakes and lizards)					
	sp. indet.				
		Kathy's Pit	L-4381	snake vertebrae	P-31104
		LB2	L-4389	1 snake maxilla, miscellaneous elements	P-31173
		Under Arch	L-4395	lizard vertebrae, miscellaneous elements	P-31249
		Under Arch	L-4395	1 snake rib, 1 lizard leg bone?	P-31250
Order Sauria, Family Phrynosomatidae					
	Phrynosoma douglassii				
		Kathy's Pit	L-4381	1 maxilla	P-31141
		LB2	L-4389	1 broken scapula (cf.)	P-31182
Order Serpentes, Family Colubridae					
	Thamnophis elegans				
		Kathy's Pit	L-4381	2 vertebrae	P-31142
		LB2	L-4389	4 vertebrae	P-31183
Order Serpentes, Family Viperidae					
	Crotalis viridis				
		LB2	L-4389	1 vertebra	P-31181
		Under Arch	L-4395	1 vertebra	P-31279
Aves (birds)					
Order Ciconiiformes, Family Podicipedidae					
	Tachybaptus cf. *T. dominicus*				
		Bot 4	L-4394	proximal left pedal phalanx III:1	P-31362
Order Galliformes, Family Phasianidae					
	Phasianus colchicus				
		recent	L-4396	partial right humerus	P-31372
Order Passeriformes, Family Certhiidae					
	Troglodytes cf. *T. troglodytes*				
		Kathy's Pit	L-4381	prox. end L ulna, dist. end R femur and of L tarsometatarsus	P-31375
	Troglodytinae gen. et sp. indet.				
		Kathy's Pit	L-4381	distal end right humerus, 5 cervical vertebrae	P-31371

Appendix, continued.

Taxonomic group	Species	Locality	Location number	Elements	Accession number (NMMNH)
Order Passeriformes, Family Corvidae					
	Corvini gen. et sp. indet.				
		Kathy's Pit	L-4381	left pedal phalanx I:1	P-31374
Order Passeriformes, Family Fringillidae					
	Ammodramus sp.				
		Bot 4	L-4394	distal end left tarsometatarsus, 2 prox. L & R humeri, 2 cervical vert.	P-31363
	Junco sp.				
		Under Arch	L-4395	2 distal L & R tarsometatarsus, 2 cervical vert.	P-31366
	Parulini gen. et sp. indet.				
		Under Arch	L-4395	dorsal end L coracoid	P-31367
		Under Arch	L-4395	prox. half L tibiotarsus	P-31368
	Passerculus cf. *P. sandwichensis*				
		Pink Solid	L-4393	partial left tarsometatarsus	P-31370
Order Passeriformes, Family Paridae					
	Parus sp.				
		Kathy's Pit	L-4381	2 left tarsometatarsi, distal end L humerus, prox. end R humerus, 8 cervical vert., mand. frag., L coracoid, furcula & sternum.	P-31373
		LB3	L-4388	prox. right tibiotarsus	P-31364
Order Passeriformes, Family Vireonidae					
	Vireo sp.				
		Under Arch	L-4395	rostrum	P-31365
Order Strigiformes, Family Strigidae					
	Asio cf. *A. flammeus*				
		Pink Solid	L-4393	12th cervical vertebra	P-31369
Mammalia					
Order Carnivora, Family Canidae					
	Canis cf. *C. latrans*				
		Kathy's Pit	L-4381	astragalus	P-31109
	Canis rufus				
		Pink Solid	L-4393	m2 (F4) (unusual fossil)	P-31204
	Canis sp.				
		Under Arch	L-4395	teeth	P-31254
	carnivore				
		LB2	L-4389	1 element	P-31175
	Vulpes vulpes				
		Bot 4	L-4394	mandible frag. w/ milk teeth and unerupted adult teeth, tooth frags.	P-31225
Order Carnivora, Family Mustelide					
	Lutra canadensis				
		Kathy's Pit	L-4381	femur (abraded)	P-31110
	Mephitis mephitis				
		Kathy's Pit	L-4381	mandible w/ p3-m1	P-31111
	Mustela erminea				
		Pink Solid	L-4393	P4	P-31205
	Spilogale putorius				
		Pink Solid	L-4393	jaw frag. w/ m1	P-31206
	Taxidea taxus				
		Bot 4	L-4394	frag. P4	P-31224
Order Chiroptera					
	bat				
		Kathy's Pit	L-4381	jaw with 2 teeth	P-31112
		Pink Solid	L-4393	2 Mx	P-31207
Order Insectivora, Family Soricidae					
	Sorex sp.				
		Kathy's Pit	L-4381	maxillary with P4-M2	P-31113
		Pink Solid	L-4393	mandible	P-31208
	Soricidae gen. et sp. indet.				
		LB6	L-4385	maxillary w/ M1-2	P-31152
Order Lagomorpha, Family Leporidae					
	Leporidae				
		LB2	L-4389	1 element	P-31176
	Lepus californicus				
		Kathy's Pit	L-4381	3 m, 3 M, humerus, distal radius, 3 lumbar vertebrae (last three cf.)	P-31115
		Pink Solid	L-4393	P3, mx	P-31209
	Lepus sp.				
		Kathy's Pit	L-4381	mx	P-31116
		Under Arch	L-4395	Mx, cheek tooth	P-31255

Appendix, continued.

Taxonomic group	Species	Locality	Location number	Elements	Accession number (NMMNH)
	Sylvilagus sp.				
		Kathy's Pit	L-4381	p3, humerus, 3 thoracic vertebrae	P-31117
		Kathy's Pit	L-4381	p3	P-31118
		LB5	L-4386		P-31157
		Bot 4	L-4394	M, cervical vertebra, cheek teeth	P-31228
Order Rodentia, Family Cricetidae, Subfamily Microtinae/Arvicolinae					
	Allophaiomys sp.				
		Tight Spot	L-4392	2 m1, 2 M3	P-31193
		Pink Solid	L-4393	advanced, mandible w/ m1-2, 23 m1, M3	P-31213
		Bot 4	L-4394	10 m1, 4 M3, M3, 4 mandibles w/ m1, m1, 2 m1, m1, M3	P-31235
		Under Arch	L-4395	m1, M3, m1, M1, M3(?), m2, 2 m1, 3 M3, m1, M3, mandible w/ m1-2, 3 m1, M2, 8 m1, 2 M3, frag. m1, 2 M3, M3, m1	P-31265
		recent	L-4396	advanced morphotype, m1, M3	P-31147
	Allophaiomys-Lemmiscus				
		Bot 4	L-4394	M3	P-31236
	Clethrionomys cf. *C. rutilus*				
		LB6	L-4385	M1	P-31154
		LB3	L-4388	2 mandibular frag. w/ m1 and m1-2, 2 M3, n=6+	P-31167
	Clethrionomys sp.				
		LB1	L-4390	M2	P-31195
	Lemmiscus curtatus (modern morph)				
		LB5	L-4386	m1	P-31159
	Lemmiscus curtatus (modern)				
		LB2	L-4389	M1	P-31128
	Lemmiscus curtatus (SAM morph)				
		Tight Spot	L-4392	m1, 2 modern morphotype m1, 4 M3	P-31194
		Pink Solid	L-4393	mand. w/ m1-2, 17 m1, (modern) 2 m1, 2 M3	P-31214
		Bot 4	L-4394	2 palates w/ teeth, 17 m1, 7 mandibles w/ teeth, 33 M3, 2 m1, 39 cheek teeth	P-31237
		Bot 4	L-4394	M3	P-31238
		Under Arch	L-4395	M3, 3 m1, 2 m2, 2 M1, 2 m3, 2 m1, 5 m1, M3, maxillary frag. w/ M1-2, 7 m1, mandible, 2 mandibles w/ m1, mandible w/	P-31267
		recent	L-4396	2 SAM m1, 2 advanced m1, 2 M3, m1,mandible w/o teeth, M3, 2 cheek teeth	P-31289
	Lemmiscus curtatus (SAM)				
		Under Arch	L-4395	m1, M3, m1, M3, maxillary frag. w/ M3, m1, m2, M2, frag. m1, 3 M3	P-31266
	Microtus cf. *M. californicus*				
		Kathy's Pit	L-4381	5 M, 4 M3, unworn m1, part m1, teeth, m1, M3, 3 teeth 2 m1, M3	P-31130
		Bot 4	L-4394	2 m1, M3	P-31240
	Microtus sp.				
		Kathy's Pit	L-4381	m1, M3 (Microtus?), M3, a cheek tooth	P-31131
		LB5	L-4386	m1, 2 M2, M3	P-31269
		LB2	L-4389	1 element	P-31178
		LB1	L-4390	M2	P-31186
		Pink Solid	L-4393	m1, M3	P-31133
	Mictomys kansasensis				
		LB4	L-4387	m1, m3, M3, M1, M1, m3	P-31162
		Pink Solid	L-4393	M3, part m1	P-31215
		Bot 4	L-4394	m1	P-31241
		Under Arch	L-4395	partial m1	P-31270
	Mictomys sp.				
		LB3	L-4388	m1	P-31168
		Tight Spot	L-4392	M1, Mx	P-31197
	Phenacomys cf. *P. intermedius*				
		recent	L-4396	m2	P-31287
	Phenacomys intermedius				
		Kathy's Pit	L-4381	incomplete m1	P-31123
	Phenacomys sp.				
		LB1	L-4390	M2	P-31185
	sp. indet.				
		Kathy's Pit	L-4381	2 teeth, 10 molars, 2 toothless mandibles	P-31129
		Tight Spot	L-4392	mandible w/ no teeth	P-31196
		Pink Solid	L-4393	many teeth	P-31148
		Bot 4	L-4394	mand. w/o teeth, many teeth	P-31239
		Under Arch	L-4395	miscellaneous elements	P-31268
Order Rodentia, Family Cricetidae, Subfamily Sigmodontinae					
	Neotoma cinerea				
		Bot 4	L-4394	m1, 2 partial m1	P-31229

Appendix, continued.

Taxonomic group	Species	Locality	Location number	Elements	Accession number (NMMNH)
	Neotoma sp.				
		Kathy's Pit	L-4381	m2, m3, M1, unerupted molar frag., m1, m2, M2, M2	P-31119
		Tight Spot	L-4392	m2, M2	P-31189
		Pink Solid	L-4393	m2	P-31210
		recent	L-4396	unerupted tooth part	P-31284
	Peromyscus crinitus				
		recent	L-4396	m1, m2, M1, 2 mandibles w/o teeth	P-31285
	Peromyscus cf. *P. crinitus*				
		Tight Spot	L-4392	m2, mandible frag. w/ m1	P-31190
		Pink Solid	L-4393	mandible w/ m1-3	P-31211
	Peromyscus sp.				
		Kathy's Pit	L-4381	toothless maxillary	P-31122
		Bot 4	L-4394	maxillary w/ M1, mandible w/ m3, mandible w/ m1-3	P-31230
		recent	L-4396	M1	P-31286
	R*eithrodontomys megalotis*				
		Kathy's Pit	L-4381	M2, mandible w/ M1-3, mandible w/ M1, max w/ m2-3, max w? m2, 4 teeth	P-31124
		Bot 4	L-4394	maxillary frag. w/ M1, m2, mandible frag. w/ m1, mandible frag. w/ m1-2, maxillary frag. w/ M1-2, 14 cheek teeth	P-31231
	Reithrodontomys cf. *R. megalotis*				
		Under Arch	L-4395	M2, M3	P-31257
	Reithrodontomys sp.				
		Kathy's Pit	L-4381	m2, max w/ M1, max w/ M1-2, 6 molars, max w/ M1-2, m1, mand. w/ m1-2, m1	P-31125
		LB6	L-4385	M1	P-31166
		recent	L-4396	M2	P-31288
Order Rodentia, Family Erethizontidae					
	Erethizon sp.				
		Kathy's Pit	L-4381	molar, Mx, calcaneum	P-31126
		Under Arch	L-4395	incisors	P-31261
Order Rodentia, Family Geomyidae					
	gopher				
		LB2	L-4389	1 element	P-31177
	Thomomys sp.				
		Kathy's Pit	L-4381	2 p4, 2 M, p4, mx, 5 teeth, P4, 2 m1, [2 p4, 18 cheek teeth-stable isotopes, sacrificed]	P-31127
		LB5	L-4386	5 teeth	P-31158
		Tight Spot	L-4392	15 molars and p4s (sacrificed for stable isotopes)	P-31191
		Tight Spot	L-4392	2 p4	P-31192
		Pink Solid	L-4393	~90 teeth (15 sacrificed for stable isotopes)	P-31212
		Bot 4	L-4394	p4, mand. frag. w/ p4, m1, mand. w/ m2, mand. w/ p4, m1, 6 M, mand. w/ p4, 4 mand. w/o teeth, mand. w/ m1, mand. w/ p4	P-31234
		Under Arch	L-4395	cheek tooth, teeth, misc. elements, 2 p4	P-31263
Order Rodentia, Family Sciuridae					
	Cynomys ludovicianus				
		Kathy's Pit	L-4381	M3, m2	P-31132
		Bot 4	L-4394	M2, partial M3, mandible frag. w/ m2, 28 cheek teeth	P-31242
		Under Arch	L-4395	mandible frag. w/ m2-3	P-31271
	Cynomys sp.				
		Tight Spot	L-4392	M1, M2, maxillary frag. w/ M2	P-31198
		Pink Solid	L-4393	dp4, m2	P-31216
		Bot 4	L-4394	M2, molar frag., 3 teeth, 5 frag. of teeth	P-31243
		Under Arch	L-4395	p4, 3 upper teeth	P-31272
	Eutamias minimus				
		Kathy's Pit	L-4381	7 teeth	P-31135
	Sciurus aberti				
		LB6	L-4385	molar	P-31155
		LB3	L-4388	mandible frag. w/ p4, m1, 5 lowers, 4 uppers, n=11	P-31169
		LB2	L-4389	m1-2	P-31179
	Spermophilus lateralis				
		Pink Solid	L-4393	many teeth	P-31217
		Bot 4	L-4394	M3, M2, 3 mx, maxillary frag. w/ P2	P-31245
	Spermophilus cf. *S. leucurus*				
		LB3	L-4388	mandible frag. w/ p4, m1-2, n=4	P-31170
	Spermophilus tridecemlineatus				
		Tight Spot	L-4392	m2, M2, Mx	P-31199
		Pink Solid	L-4393	mand., many teeth	P-31140
		Bot 4	L-4394	m1, 30 cheek teeth	P-31246
		Under Arch	L-4395	m2	P-31277

Appendix, continued.

Taxonomic group	Species	Locality	Location number	Elements	Accession number (NMMNH)
	Spermophilus cf. *S. tridecemlineatus*				
		Kathy's Pit	L-4381	Mx	P-31136
	Spermophilus variegatus				
		Pink Solid	L-4393	many teeth	P-31218
		Bot 4	L-4394	astragalus, m2, Mx, m3, other elements, maxillary frag. w/ M2-3, 5 teeth	P-31247
		recent	L-4396	Mx	P-31291
	Spermophilus sp.				
		recent	L-4396	M3, small; large *Spermophilus* or *Cynomys*, m2	P-31290

Upcoming geologic meetings

Conference title	Dates	Location	Contact for more information
American Geophysical Union Fall Meeting	Dec. 15–19	San Francisco, CA	AGU Meetings Dept., (800) 966-2481 meetinginfo@agu.org
Symposium on Volcanoes and Volcanology in New Mexico	Feb. 17, 2001	New Mexico Museum of Natural History and Science Albuquerque, NM	L. S. Crumpler, NMMNHS 1801 Mountain Road NW Albuquerque, NM 87104 lcrumpler@nmmnh.state.nm.us fax: (505) 841-2866
New Mexico Geological Society Spring Meeting	Mar. 23, 2001	Macey Center NMIMT Socorro, NM	Brian Brister (505) 835-5378 bbrister@gis.nmt.edu
Rocky Mountain (53rd) and South-central (35th) Sections GSA Annual Meeting	Apr. 29–May 2, 2001	Sheraton Old Town Albuquerque, NM	John W. Geissman jgeissman@unm.edu (505) 277-3433