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The Society is a non-profit organization of men and women interested in the study of caves, karst and allied phenomena. It is chartered under the law of the District of Columbia.

The Society serves as a central agency for the collection, preservation, and dissemination of information relating to speleology. It also seeks the preservation of the fauna, minerals, and natural beauty of all caverns through proper conservation practices.

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Published twice a year; Editor: William E. Davies, 125 W. Greenway Blvd., Falls Church, Va., Assistant Editors: Nancy G. Rogers, 2026 Key Blvd., Apt. 640, Arlington, Va.; Dr. William R. Halliday, 1117 56th. N., Seattle, Washington; Thomas C. Barr, Jr., Department of Biology, Tennessee Polytechnic Institute, Cookeville, Tennessee.

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THE NATIONAL SPELEOLOGICAL SOCIETY
203 VIRGINIA HILLS AVE.
ALEXANDRIA, VIRGINIA

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Speleology in Japan

by EITARO TAKAHASI and MICHIHIRO KAWANO;
introduction by WILLIAM R. HALLIDAY

Speleology in Japan is a relatively young undertaking. Post-war studies of cave and karst are centralized in the Japanese Association for Scientific Research of Caves and Underground Water and in the Japanese Association for Quaternary Research. Limestone is not extensive in Japan and occurs in several, small, isolated regions. Limestone caves and karst features are well developed. Typical of such development is the Akiyoshi Plateau, a limestone karst region 15 km long, 7 km wide at the south end of Honshu. Five caves, over 1,000 feet long, are in the area along with 19 smaller ones. Karrenfelder, dolines, and pits are well developed on the plateau.

Since there seem to be only two references to Japanese caves in the entire American speleological literature, American cavers may be excused for vagueness about the nature of caves and speleology in Japan. Envisioning travel posters of the volcanic cone of Mt. Fuji, overlooking picturequely rugged coasts, the average American caver would be led to expect lava caves in the mountains, and littoral (“sea”) caves on the shore. However, such a concept is quite incorrect. The geology of Japan is highly complex and the islands possess excellent limestone caverns, well-developed karst topography, and a considerable number of active speleologists.

There are, of course, some lava tubes in Japan. 10 to 20 of them are on the northern and northwestern flank of Mt. Fuji, in gently inclined Quaternary basalt flows. They are in a national park, in the Fuji-Five Lakes area. At least three of them are glaciers. Most of them are quite short by American standards. Although he has been told of a longer tube west of Mt. Fuji, Professor Hisashi Kuno, of the Geological Institute of Tokyo University, who might well be termed a vulcanospeleologist, reports that the others are about 300 to 600 feet long. The three best known caves in this group are Bat Cave, Fukagu Wind Cave and Fuji Wind Cave.

Littoral caves are numerous in Japan. Some of them are of unexpected size. One of the two commercially-developed “sea caves” on the resort island of Enoshima, near Kamakura, is almost 500 feet long. Other littoral caves are mentioned in the official guidebook prepared by the Japan Travel Bureau.

Professor Kuno reports that there is some thin bedded Mesozoic limestone in Japan, but that almost all Japanese limestone caverns are in more massive Paleozoic limestones (Figure 1): the largest limestone area in Japan is the cavernous Akiyoshi Plateau, 7 by 15 kilometers in size. The limestone caves of the Akiyoshi Plateau described in the second part of this paper serve as an admirable introduction to Japanese speleology. Other limestone caves are scattered quite widely over the large islands of Honshu, Shikoku, Kyushu. Probably there are caves on Hokkaido since there is at least one speleologist located on that island (Dell'Oca 1955). Irinizu Caverns, Nippara Cavern, Ryugado Cave and the Furen Caves, as well as Akiyoshi Cave, are described in the Japan Travel Bureau Guidebook. As in several of the caves of the Akiyoshi plateau, the cavern near Kou, northwest of Tochigi, contained many bones of Pleistocene mammals.

Two other Japanese caves are worthy of brief mention. Taya Caves (Great Cave) at Ofuna, south of Yokohama, seems to be a catacomb dug in soft sandstone. At Shiobara, in Tochigi Prefecture, there is a cave in a hot spring terrace.

For the average American caver visiting Japan, the easiest Japanese limestone cavern...
The Akiyoshi Plateau is the largest limestone area in Japan. It is situated near the southwestern tip of the island of Honshu (Figure 2). In this plateau, limestone caves are found in abundance, including the famous Akiyoshi Cave, visited by about 500,000 travelers every year. The area is reached by motorbus from the Ogori Railroad Station, about 50 km east of Shimono-seki, on the Sanyio Railroad line between Kobe and Shimonoseki.

The Akiyoshi limestone mass occupies an extensive area in the central part of the Nagato mountainland. It is about 15 km in length from east-northeast to west-southwest, and is about 7 km in breadth. Geological studies of the Akiyoshi limestone were carried out about thirty years ago by the late Dr. Y. Ozawa (1925, 1925) of Tokyo University and by Professor R. Toriyama (1954a, b, 1958) of Kyushu University in recent years. The geological age of the limestone as determined by coral and fusulinid fossils is Middle Carboniferous to Upper Permian.

Speleological surveys of the four major limestone caves of this area were made by the late Professor S. Sato (1928) of the Tokyo College of Education, and were reported in 1928. Some of the caves were studied by the present writers in 1956 (Takahasi and Kawano 1957). At that time, we collected abundant mammalian and other Pleistocene fossils from the cave deposits. The fossils are now under study and description by Professor T. Shikama of the Yokohama National University. In that survey, we were helped by many persons, especially with the mapping of the caves. We are indebted to Mr. Ichiro Eto of Akiyoshi village for his help, and to Mr. Goro Okafuji of the Ohmine High School, for allowing the use of his photographs. In 1956, some of the caves were surveyed by...
the members of the Japanese Association of Scientific Research on Caves and Ground Water (1957). In 1957, some of the caves were studied by Dr. H. Coiffait of the University of Toulouse, France, in cooperation with the members of the Association. The writers express their most sincere thanks to Professor H. Fujimoto of the Tokyo University of Education, through whom arrangements for the publication of this paper were made.

Scientific University of Toulouse, France, in cooperation were studied by Dr. H. Coiffait of the Water (1957). In 1957, some of the cave the member of the Japanese Society of Tokyo whom arrangement for the publication of thank to

LARGE LIMESTONE CAVES

AKIYOSHI CAVE (Akiyoshi-do) - Akiyoshi Cave is situated in the polje called Hirotani of Syucho, at the southern foot of the Akiyoshi Plateau. Akiyoshi Cave is the most famous and largest cave in the Akiyoshi district, and also the largest in Japan. This cave was designated a Natural Monument in 1922. From the mouth inward for about 1 km, the cave is electrically lighted for visitors. In 1956, an elevator was installed in the cave, so that it is now possible to ascend to the karstic Akiyoshi Plateau, 80 meters above the cave. The floor of Akiyoshi Cave is probably at the level of the water table and an underground stream flows freely on the floor. (Figure 3). At the mouth, it forms falls several meters high. Because of this the Akiyoshi Cave was formerly called Taki-ana (Cascade Cave).

In the main cave (Figure 4), one can go along the stream to a pool called Kogafuchi (Lyre Pool), 2 km from the entrance. On the way, about 1 km from the mouth, there is a side passage called Kurotani (Black Abyss). The ceiling height averages 20 meters, and that of the highest part is 40 meters. The width of the cave averages 20 meters, and that of the broadest part is 90 meters. The mouth of the cave opens toward the east, and is 26 meters high and 14 meters wide. The first 50 meters of the cave runs toward the west, but the main passage of the cave is north-south. By going towards the north along the stream for about 900 meters, the visitor passes the main points of interest of the cave en route to Senjojiki (Thousand Mat Room). These features include Rokujizo (Six Buddha), a group of large and beautiful stalagmites; Hyakumaizara (Hundred Dishes), a group of gours (rimstone deposits) which look like many dishes arranged side by side and in a step-like fashion (Figure 5); Donai-Fuji (Subterranean Fuji) which is a cone of accumulated fallen boulders and blocks, reaching to the ceiling, cemented and covered by flowstone. Other points of interest include Chichimachi (Thousand Paddyfields), another large group of gours; Kaza-zukusi (Umbrellas on Show), a group of stalactites; and two large columns known as Daikokubashira (King’s Post), and Ohgobashira (Golden Pillar). The latter is 10 meters from Senjojiki. It is the most famous and largest calcareous column in this cave, with a diameter of 8 meters and a height of 28 meters.

At Nagabuti (Long Pool), 100 meters from the entrance, is a platform-like terrace on the east wall of the cave, 14 meters above the stream. There are potholes and gravels on the surface of the platform. Another terrace-like platform, on the same level, is at a terrace consisting of sand and gravel cemented by calcareous matter, called Takan-sanji (Dress-circle). On the roof of this passage, there are noteworthy fissures running north-south parallel to the direction of the passage. The terraces and fissures are of interest in considering the origin of the cave.

From Senjojiki, the main cave extends about 700 meters toward the northeast to Kohogafuchi. Between these two points, the stream separates from the main cave. In this area, there are many fallen boulders and the passage is narrower. If one goes toward the northwest through a narrow passage and ascends a steep slope called Sarusuberi (Monkey Slip), a fissure cavern is seen, the Kurotani branch of the cave. The Kurotani branch extends north-northwest for 150 meters from Sarusuberi, then turns west-northwest and becomes broader, but ends after another 50 meters.

Akiyoshi Cave has layers of sand and gravel in several sections, but these deposits have not been excavated and properly studied since the cave is a Natural Monument. Dr. N. Naora of the Waseda University has reported that the mammalian fossil Megaloceros was collected from this cave.

The entrance of this cave is at the southwestern foot of the Shishide Plateau, northeast of the Akiyoshi Plateau proper. It was formerly called Akano-ana or Nagai-ki-do.

Kagekiyo Cave penetrates the Shishide Plateau and is a continuation of Misumada Cave which is situated on the northeastern side of that plateau. The water of the Misumada is being drained into Misumada Cave, flowing underground for a distance of 2.5 km to emerge from Kagekiyo Cave. One can pass through from Kagekiyo Cave to Misumada Cave only in an extremely dry season.
The entrance of Kagekiyo Cave is 26 meters high and 22 meters wide. It faces southward. The cave trends north-east for 2 km, then turns northwest. At a farther distance of 500 meters, Misumada Cave is reached. From the entrance to Sainokawara (River Styx), 1 km from the mouth of the cave, the ceiling height averages 14 meters and the width, 18 meters. Beyond the neighborhood of Sainokawara, the ceiling gradually becomes low. The entrance to Taisho Cave opens to the north under a cliff. There are actually two entrances several meters apart. The mouth of the east opening is 8 meters high and 9 meters wide. That of the west opening is 13 meters high and 15 meters wide. The two are connected in the interior. At a chamber called Ushikakushi (Cattle Hideout). This chamber is connected with a chamber called Jigoku (Hades). The Jigoku chamber has some branches to a complicated system of lateral passages and aven.

The Ushikakushi chamber is also connected by a gallery-like passage to a larger chamber called Gokuraku (Paradise). The Gokuraku chamber is the main room of the Taisho Cave. It is 220 meters long, 10 to 20 meters wide and 10 meters high. It trends N20W. There are also several side caverns. At the roof or lateral wall, there are interesting fissures which strike N20W and dip 50 degrees north. These fissures appear to have been related to the origin of the cave.

The walls of the Gokuraku chamber are ornamented with stalactites, stalagmites and flowstone. Deposition is still active. This chamber also contains pools or ponds. Flat stalagmites resembling lotus leaves (sheaf-stone) are found at a pond called Hasuike (Lotus Pond). In the pond, cave pearls also exist in large numbers. NAKAO CAVE (Nakao-do) — Nakao Cave is situated in Aokage, Shu­ho­cho, at the top of Mt. Nakao in the northwestern part of the Akiyoshi Plateau. This cave was found in 1921, and was designated a Natural Monument in 1923. The interior of this cave is not huge, but it contains interesting stalactites, stalagmites and other calcareous deposits. This cave opens at the bottom of the north wall of a funnel-like hollow, 30 meters in diameter. The cave descends from south to north with a steeply sloping entrance passage. At a depth of 10 meters is a chamber. Ascending a slope through a narrow, cavernous passage, a large chamber called Okuno-do (Inner Shrine) is reached. This large gallery-like chamber is more than 160 meters in length. It averages 12 meters in height and 2 meters wide. In this chamber there are several kinds of stalactites, stalagmites and other calcareous deposits.

The length of Nakao Cave is 860 meters. The vertical entrance chamber is a fossil pororo into which water poured in ancient times.

**Small Limestone Caves**

Akiyoshi Cave, Kagekiyo Cave, Taisho Cave and Nakao Cave, as mentioned above, are large limestone caves and have been designated as Natural Monuments. The other limestone caves of the Akiyoshi Plateau, described below, are small and have not been studied in detail. Their interiors, however, have been known by the people of the neighborhood since ancient times.

KOMORI CAVE (Komori-ana) — This is a small cave situated in Hirono of Shuhcho. It is at the southwestern foot of the Akiyoshi Plateau, 500 meters from Akiyoshi Cave. An upper and a lower opening are connected in the interior. Mammalian fossils were once collected from the cave deposits.

CAVE OF AWAYA (Awayano-ana) — This cave is situated in Sowa of Akiyoshi, Shu­ho­cho. The mouth of this cave opens at the cliff, north of Sowa. The length of the cave is 20 meters, the height is 5 to 10 meters and the width is 4 to 8 meters. The cave descends at a slope of about 25 degrees. This cave is situated in the area of the Akiyoshi Plateau. It is 800 meters southwest of Akiyoshi Cave. It is 20 meters long, 1 to 3 meters high and 7 to 10 meters wide. It is a horizontal cave.

CAVE OF MIZUSHIMA (Mizushimanano-ana) — This cave is 100 meters west of the Upper Cave of Mizushima. It consists of two passages connected by an aven. It is 20 meters long. The ceiling height is 3 to 8 feet, and the width varies from one to 5 meters.

HAKUGYO CAVE (Hakugyo-do) — This cave is situated in South of Yokono of Akago, Mito-cho. Hakugyo Cave as now known consists solely of several poros, but it is thought that they empty into a large cave. Normally, the surface drainage pours into this system, but during an extremely wet season, water sometimes gushes back out. On these occasions, fish come out of the cave. The name Hakugyo is derived from the report that there are discolored, white fish in the cave.

RYUGU CAVE (Ryugu-do) — This cave is situated in Ueyama of Akago, Mito-cho. An underground stream emerges from this cave. Although its interior is thought to be large, it has not yet been surveyed.

**Cave of Oba (Obaga-ana) —** This cave is situated in Sayama of Akago, Mito-cho. It is 600 meters northwest of Taisho Cave, and its entrance is on the northern slope of Mt. Managatake. The mouth of the cave is 7 meters high and 9 meters wide. The cave is about 38 meters long.

KANEKYO CAVE (Kanekyo-do) — This cave is situated in Kanekyo of Katada in Beppu, Shu­ho­cho. The mouth of this cave opens to the north and is on the northern slope of the western plateau. The entrance is 8 meters wide and 4 meters high. In some places it descends at a slope of 30 to 40 degrees. Its floor is covered with mud.

**TERAYAMA CAVE (Terayama-do) —** This cave is situated on the northern slope of the western plateau in Beppu, Shu­ho­cho. It is 1 km west of Kanekyo Cave. The dome-shaped mouth of the cave is 7 meters wide and 4 meters high. The cave descends at a slope of about 30 degrees for about 25 meters to a large chamber about 20 meters high. This chamber is about 20 meters wide, 10 meters north-west, and 30 meters wide from north to south. On the floor are black-brown mud deposits.

The cave divides into two branches, one extending toward the northwest and the other toward the west. The former is 75 meters long. The other extension passes west for a distance, then turns northwest and becomes narrow.

**CAVE OF UBA (Ubagana-ana) —** This cave opens toward the east at the dolina of Iwanaga Plateau, Shu­ho­cho. The mouth of this cave is 20 meters wide, 4 meters high, and is dome-shaped. The cave is 250 meters long. It is formed along the contact between limestone and slate. The cave descends to...
ward the west. Fifty meters from the mouth, there is an exposure of silt. From this point, the cave turns toward the southwest and descends at a slope of 30 to 40 degrees.

CAVE OF IRIMI (Irimino-ana) — This cave is situated in Irimi of Omine-machi, Mine City. It is about 200 meters long, 0.5 to 15 meters high and 0.5 to 15 meters wide. A river usually flows into this cave, and the mouth is so narrow that only one man can pass through at a time. There is a river beach consisting of gravel and clay in the interior.

CAVE OF MARUYAMA (Maruyamano-ana) — This cave is situated in Maruyama of Isamachi, Mine City. It is on the slope of the plateau. The mouth is 2 meters high and 4 meters wide. The cave descends at a moderate slope for about 50 meters and has a pit in the interior.

KOJIKI CAVE (Kojiki-ana) — This cave is situated in Yoshimori of Omine-machi, Mine City. It is only 10 meters long, but consists of two caverns at different levels. The average ceiling height is 4 to 6 meters and the width is 5 to 7 meters. The floor is covered with flowstone and mud. Deposits 5 to 10 cm beneath the flowstone floor have yielded shells of the fresh-water gastropod *Semisulcospira*. Bones of fossil mammals and freshwater fish have also been found.

CAVE OF MAGURAJI (Magurajino-ana) — This cave is situated in Maguraji of Isamachi, Mine City. The cave is about 150 meters long, 1 to 10 meters high and 1 to 10 meters wide. It slopes downward in two steps. Underground streams and pools are present, and much mud is accumulating in the cave. From deposits 10 meters beyond the entrance, an abundance of bones of extinct small mammals and reptiles were collected.

LIMESTONE CAVES SURVEYED IN 1956

TANUKI CAVE (Tanuki-ana) — This cave is situated on the southeastern part of the Akiyoshi Plateau, 1/5 km northeast of the mouth of Akiyoshi Cave. Its mouth opens on the western slope of Mt. Minami, and is surrounded by trees.

The mouth of the cave is 3 meters wide and 1 meter high. The cave is about 15 meters long, 2 to 3 meters wide and 3 to 5 meters high. It descends at a slope of about 15 degrees at first, but the far interior is almost horizontal. The slope is covered with limestone boulders, and the horizontal part is floored with deposits of clay. Only a few patches of calcareous deposits are present on the walls, and few stalagmites are present.

The clay deposits at the rear of the cave are 1 meter in thickness, with thicker deposits mainly of clay mixed with boulders. Mammalian fossils of *Nyctereutes*, *Meles*, *Cervus*, etc. have been excavated here.

SUZUME CAVE (Surome-ana) — This cave is situated a little west of the center of the Akiyoshi Plateau, in the forest. It is about 3 km north-northwest of Akiyoshi Cave.

The mouth of this cave is in the shape of an arch 17 meters wide and 5 meters high. On the ceiling of the entrance, a remarkable fault breccia zone is seen extending inward. It is probably closely related to the origin of the cave.

Suzume Cave descends 415E at about 30 degrees. The slope length is about 20 meters. The width is 10 to 15 meters, and the height is 4 to 5 meters. The lower end of the cave is horizontal, and has a chamber 6 meters long and 7 meters wide; a short distance beyond the chamber the passage is constructed.

The walls of the cave have few deposits of flowstone, but stalactites and stalagmites are present in the far interior portion. The floor at the entrance is covered with clay, but the floor of the middle of the cave is covered with limestone blocks, some of which are more than 20 cm in diameter. The floor at the bottom of the cave is covered with a thick deposit of clay, such that bedrock was not reached after considerable excavation. From this clay, shells of the fossil land gastropods *Gyraulus*, and *Tyannophardusa*, the fresh-water gastropod *Georisia* and others were collected.

NAKII CAVE (Naki-ana) — Naki Cave is 0.3 km south of Suzume Cave and 50 meters higher than that cave. It also is in the forest. The irregular mouth of the cave opens toward the east. It is 10 meters wide, and 3 to 5 meters high. The cave slopes downward toward the west at an angle of 30 degrees.

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At a point 17 meters from the entrance is a large chamber which trends north-south. It is about 30 meters, 20 meters wide and 10 to 20 meters high. The floor of the entrance and the west side of the large chamber are covered with clay, but most of the large chamber is covered with breakdown. With the exception of the southwestern wall of the chamber, the walls of the cave have no flowstone. Stalagmites, bacon-like sheets, and travertine deposits are present on the wall and floor at the southwestern end of the chamber. Two fissures are in the ceiling, and coincide with the direction of the cave. They appear to be related to its formation. Mammalian fossils of *Meles*, and shells of the gastropods *Gyraulus* and *Georisia* were collected from the same deposits.

FUSEN CAVE (Fusen-ana) — This cave is situated in the forest in the southern part of the Akiyoshi Plateau, 800 meters east-northeast of Akiyoshi Cave. Its main chamber was found by three young men from Hirotani in 1954, who reported that there were some fossil bones of mammals in it. In the same year, Dr. T. Shikama, I. Eto, and one of the writers (Kawano), entered the cave under their guidance and collected mammalian fossils of *Megalocerus*, *Cervus*, *Nyctereutes*, and others. In 1955, G. Okafuji collected in the cave; in 1956, the writer surveyed the cave and collected fossils in cooperation with I. Eto, G. Okafuji and four others, *Palaeoloxodon aomoriensis* and other fossil mammals were found.

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Fusen Cave has a complicated pattern, with vertical chambers, a large inner chamber and connecting lateral passages (Figure 6). The mouth of the cave is a nearly vertical opening 2 to 3 meters in diameter. At a point several meters down, the steeply sloping entrance pit opens into the top of a vertical chamber 10 meters high.

From the bottom of the first vertical chamber, a sloping passage extends 80E for 17 meters, turns south, and descends 7 or 8 meters. This passage opens on the north wall of another domed chamber 10 meters above the floor. The part of the passage which trends 80E is 2.4 meters wide and 6 meters high. The north-south passage is 1.5 meters wide and 2 meters high. In the first vertical chamber there is a side passage and a pit. The floor of that chamber is covered with breakdown.

The second vertical chamber is ellipsoid in shape. Its ceiling height is 15 meters; it is 13 meters long and 6 meters wide at the center. There is a thick deposit of red-brown clay on the floor. There is one pit in the main part of the chamber, and two others in a side passage entered at the southeast end of this chamber.

From the western wall of this chamber, a passage 17 meters long and about 1 meter in diameter continues to a third vertical chamber which it intersects at a point about 5 meters above the floor. One section of the connecting passage, however, is only about 30 cm wide, making penetration difficult.

The third vertical chamber is 7 meters in diameter and 20 meters high. The western part of its floor is covered with breakdown; the remainder has a deposit of thick, red-brown clay 3 meters thick. There is a pit at the south end.

At a height of 15 meters on the western wall is the opening of a passage which extends to the large inner chamber. This passage is 2 to 4 meters wide and 1.5 meters high. At a point about 8 meters from the third vertical chamber, this passage opens into the inner chamber. This ellipsoidal chamber measures 44 by 23 meters. It has a domed roof with a ceiling height about 10 meters.

Many stalactites are on the ceiling and walls of the northwest side of the inner chamber; beautiful stalagmites are also present here (Figures 7, 8). Breakdown covers most of the floor although a red-brown clay is exposed near the walls. A cone of guano 60 cm high has accumulated on the floor.

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The National Speleological Society

Lava Beds National Monument is located in extreme northern central California in Siskiyu and Modoc counties. The northern boundary is twelve miles south of the Oregon state line. The monument covers 46,238.69 acres (Figure 1).

The area was set aside in 1925 by presidential proclamation to create the Lava Beds National Monument. The United States Forest Service administered the area as a part of Modoc National Forest until 1933 when the National Park Service assumed responsibility. During the later 1920's roads, stairways, and cave trails were started to make this unique area available to the public.

The earliest human history of the monument is in the petroglyphs or carved symbols and in the pictographs or painted symbols. These apparently existed before white men recorded trips to the west as the Indians encountered in these trips made no mention of these paintings and carvings in their folklore.

The old Fort Hall Trail and parts of the Oregon Trail wound their way around the northern section of the Lava Beds. When Kit Carson and John Fremont visited the area it was known as the "Dark and Bloody Ground of the Pacific" as emigrants were extremely exposed to Indian attack here.

The most significant historical event in the monument was the Modoc Indian War of 1872-1873. This war was the only major Indian engagement in California and has the dubious distinction of being the only Indian war in which an United States Army general (General E. R. S. Canby, the peace commissioner) was killed.

The first cave discovered by white men in the area received its name from bear paws nailed on an old ponderosa pine. Trappers working the area in the early 1880's killed a bear in their camp near a large butte. This butte was named Bear Paw, and the two nearby caves Little Bear Paw and Big Bear Paw. Years later the settlers remember seeing the paws nailed on the pine tree. In the later 1880's nearby settlers ranged cattle and sheep over the country and utilized the only available water which was found within the caves.

About this time the valley settlers started using the area as a picnic ground. They would load up their wagons with youngsters and the makings for ice cream and stop at the Bear Paw Ice Caves. Ice chipped from the cave deposits made the ice cream. No
one worried about the cause and preservation of the huge ice pendants. They were just something to give off a musical tinkle as the picknickers tossed rocks.

By the 1890's several men had settled in the Lava Beds area. Ernest Heppe, a remittance man from England, set up his camp near the southwest corner of the present day monument. His name was given to Heppes Cave and Heppe Lava Chimney located near his camp. Birds and other wild animals drink from the crystal-clear pool of water below the natural arch in Heppes Cave. The ice beneath the water is solid the year round.

To the east, near Caldwells Butte, is the tumbled-down cabin of Caldwell, an early sheep man. To the south of his cabin is Caldwells Ice Cave (Figure 2). At one time he supplied his sheep troughs with water from the caves.

Early visitors named many of the caves from first impressions. One man in particular, J. D. Howard of Klamath Falls, Oregon, became interested and would spend days and weeks walking from one rift to another in search of caves. Seeing a bobcat run into an entrance, he named that cave Wildcat; another had an inclined entrance, so he called it Incline Cave. He had a great deal to do with marking and measuring the caves.

and several others first mapped Catacombs, a cave well-named because of its similarity in complexity to the Catacombs of Rome.

Of the 293 caves known to exist in the Monument, approximately 190 have been explored. When winter temperatures fall below zero, lava cracks, collapsed trenches, and even innocent-looking rock piles “smoke” and steam from the condensation of warm air emerging from the caves. During Civilian Conservation Corps days, one man was assigned to drive up and down Monument roads or walk a cross-country, exploring the “smokes” during subzero weather. Today his calling cards—small weathered lath sticks—are found throughout the area. Some of the caves will never be entered by man, unless some hardy individual pulls away the entrance-blocking debris. Not all the Monument caves, however, have entrance-blocking openings. The caves made available to the public today are generally entered through lava trenches which are collapsed portion of old lava tubes.

**WITHIN THE CAVES — FLOOR FORMATIONS**

It is not monotonous, as one would think, to visit so many caves in the same area, for all are distinct in floor, ceiling or wall development. Many unique formations are built up in the floors by the varying rates of cooling and rates of flow of the old lava flows. Where the lava was quite fluid and rate very slow, pavement-like floors indicate partial cooling with frequent changes of flow level. As cooling progressed inward from the edge, varying widths of terraces were created.
Valentine Cave presents various examples of rates of flow level cooling. Just inside the entrance are found curving-like structures several feet above the floor line and encircling the walls (Figure 3). Farther in the cave there is a large terrace-like ledge. However, the finest terrace development is found in Lower Caldwell Cave. Here, terraces, ten to fifteen feet in width line the walls. At the center is a depressed, gutter-like formation.

In Golden Dome Cave, the large loppy ridges of the floor indicate flow movement after the floor surface was nearly complete. Likewise, the delicate rippled surface in Catacombs was caused by partial completion of the floor when the flow resumed, dragging the surface downstream. The surface resembles those found in marsh mud flats.

The crinkler-like surface of many cave floors was caused by gases frothing out to the surface as the magma cooled (Figure 4). A majority of cavern floors with this type of surface are slightly rounded and separated from the walls by low gutters known as contraction valleys. As the lava cooled it contracted, leaving cracks in nearly every type of floor formation. These cracks vary from paper width to several inches across, with unlimited depths.

During the time the floors were being formed, parts of the ceiling often dropped and were carried along with the flow. Such picturesque island, imbedded in the floor, is found in Golden Dome Cave.

### Within the Caves — Ceilings and Walls

Temperature, viscosity and fluctuating supply of magma have made the ceiling and wall decorations of the caverns. As the magma drained away from the crust, solidification on the interior began. In caves where cooling progressed with a constant lowering of temperature, a glaze developed. When the gas temperature fluctuated, this glaze remelted and created unique formations.

In many places drip pendants were formed. These resemble small icicles. Their size depends on the viscosity and the temperatures of the gases during development. More viscous lava and higher temperature produced the more massive pendants. Thin, rapidly cooling glaze developed the smaller pendants, such as are found throughout the caves near Indian Well. In White Lace Cave the pendants are shaped like rose thorns with a globular tip, while in Catacombs, Golden Dome Cave and others, they taper uniformly.

Where drip pendants were created in frothy lava, highly charged with gases, the pendants are in uneven clusters, and are less highly developed than the freely flowing glaze pendants. Protection of these fine drip pendants is a serious problem in the National Monument.

Often, however, drip pendants were not formed. In many caves, the glaze sagged around the ceiling protuberances and down the walls, creating flow ridges of varying depths and widths; in such cases drip pendants did not form. The vertical ridges which are narrow ($\frac{1}{4}$" to $\frac{5}{8}$") and project from $\frac{1}{2}$" to $\frac{5}{2}$" from the wall are defined as projecting ribs (1). Where the glaze flowed rapidly, with gradual slowing, wrinkled ripple marks similar to those on the floors were created. It appears as the too-thin cake frosting of an amateur baker. The wrinkled flow ridges of Hercules Leg Cave are excellent examples.

Evidence of the passage of more than one flow through a single cavern is clearly shown by laminations of the walls. Apparently, the "welding" of the built-up glaze gave way, and the lava of the upper flow pulled away from the original crust. This occurred in Merrill's Ice Cave. Here, too, there are variations in color—a dark gray inner wall of basalt contrasting to an outer reddened wall.

The lava caves in the older flows, such as Post Office Cave, Craig Cave, Fossil Cave, and Guano Bridge, have ceilings that resemble the rough limestone quarry tunnels of the Middle West. Here the original ceiling has fallen. Often the weight, crushed lower tunnels, thereby enlarging the caverns. The weakness of the ceiling, acting upon frost and by contraction, brought on the collapse. An excellent example of this is Skull Cave which contained at one time three or more lava tubes in tiered formation. A series of collapses broke down the separating ceilings creating a channel-like cave with the rubble deposited on the ceiling of the lowest tube. Thus, the entrance to Skull Cave is two stories high—98 feet; four hundred feet from the entrance it is three stories high, and a fourth tube lies beneath the rubble. At the stairway leading to the ice floor of the cave this history of change within the caves is shown by the natural bridges, which are remnants of the old ceilings.

It is difficult to find continuous level tubes in the area of the National Monument. Caves located in the same flow are generally separated by lava trenches. In others, the walls and ceiling gradually meet, terminating the cave. Here the outflow of lava was blocked and began solidification before it could push on. In other caves the outflowing lava melted its way through walls and ceilings of nearby tubes. Pouring through these holes, the last remnants of magma cooled into cascades. Nearly every cave open to the public has at least one of these features. The tubes seem to be pouring out a never-ending supply of "cake batter".

The dome-like rooms found in some caves were formed by gas pressure belting out the upper crust of the tube. The gold ceiling domes of Golden Dome Cave show the effect of a weakened crust and tremendous gas pressure. Many of the interlacing caverns of Catacombs present unique structures. The water-like opening in one of the formations, with its broken floor plates radiating around a hole which leads to a lower tube, is the result of a weakened floor collapsing into a partial vacuum.

Many of the walls have broken gas bubbles. Gas, building up behind a hardened crust, ruptured the wall. Often the molten material cascaded over the lips of the bubble and resolidified into pendants, such as found in Hercules Leg Cave.

### Cave Color

Lava coral is common in many of the caves. Its short, thick, crinkler-like formations appear to be studded with blunt tapered spines, generally less than one inch long and radiating from a central mass. The vitreous luster of the coral is thought to be due to the section in color due to this formation. In Fern Cave, a sulfur-stained variation festoons the contraction cracks. In other caves, such as Golden Dome, it is stained frost white by calcium carbonate compounds. Formation of the coating of the coral is believed to be the result of ground moisture brought to the spines by capillary action. Evaporation then builds the delicate portion.

Reds, browns and grays of the lichen-covered rocks at cave entrances are open invitations to visitors. Soft green moss has followed to the end of the light rays within the caves. Beyond this fringe are other colorations. Oxides of iron provide most of the colorations within the rocks; the black and light gray basalt contrasted to the red.
stained lava gravel. Many of the surface stains are produced by calcium carbonate precipitated from ground moisture. Nearly every cave has these types of colorations. Notable for uniqueness are the sulphur compound deposits clinging like gold crystals to the ceilings of Golden Dome. Because of condensation small droplets of water add sparkle to each rock surface in the lantern light.

**Lava Chimneys**

Other unique formations in the Lava Beds offer opportunities. No one has explored the volcanic necks of Fleener Chimneys, although some years ago a lantern-carrying line was dropped down one 18 inch gas orifice nearly 100 feet before obstructions were encountered. Adjacent to Fleener Chimneys, near the head of the Hot Creek flow, are many shallow caves which have been visited by very few people. Although visited by more people, the Thomas-Wright Chimney group is outstanding for its volcanic story. In one location it is possible to walk beneath the chimney and look upward to see the sky.

Schollendoms differ from the lava tube caves in size and shape, and are large cavities created by trapped gases. Later, the conning crust cracked, exposing the cavities. These caves are seldom more than fifteen or twenty feet in depth. Wind-blown dust has partially filled the lava cracks, building natural paths through them. Schollendoms were used by the Modocs as natural forts during the battle in 1872.

**Archeology**

At Fern Cave the ten-foot circular entrance opens directly onto the low fern-covered mound ten feet below. To the south of the mound is a large vaulted room with a gently sloping floor. At the wall are pictographs (Figure 5). Archeological reconnaissance was carried out here by National Park Service crews in 1935. The shallow test trenches dug in the debris mound directly beneath the entrance revealed evidence of man's occupation. The water worn pebbles found among the charcoal in the test trenches were probably from water-fowl gizzards. Stone awls and obsidian chips indicate a simple way of life. No pottery or vessels for storage of food or water were found. It is probable that the inhabitants of the cave were nomadic, living off the land. These people did not create a culture with architectural trends nor cultivate crops because everything was readily available throughout the year. The layered charcoal deposits with alternate layers of soil accumulations from the ceiling and wind-blown dust indicate intermittent use of the cave.

The wave cut caves of the Petroglyph Point, located northeast of Fern Cave, were investigated by University of Oregon representatives in 1940. Apparently, the caves were used by historic Indians. The water-washed pumice and other debris indicate that one cave was used continuously and the other for an occasional burial at a time when Tule Lake was at a lower, less fluctuation level. Had the caves been used by prehistoric Indians nearly all of the occupational material would have been washed away by wave action of the lake when it stood at a higher level.

North wave cut caves are the Indian carvings on a wall of cemented volcanic ash of an old volcano. When the old Tule Lake completely surrounded the petroglyph volcano, wave action on the western edge created a nearly vertical wall of approximately 200 feet. It is believed that Indians, standing on their canoes, scratched the petroglyphs into the soft walls. Other Indian writings are found in Symbol Bridge and Painted Cave. These are pictographs like those of Fern Cave.

Caving in the Lava Beds National Monument has been made popular by the building of access roads and by the installation of self-guiding trails and stairways within certain caves. Gasoline lanterns are provided free of charge by the National Park Service. Guide Service is not provided. Local residents, during the hot summer months, find in the caves a cool, welcome afternoon. Even throughout the fall and winter they return again and again. Many prefer a trip to the Lava Beds caves to the more extensive trip to beautiful Crater Lake National Park. Even the Scout Troops utilize the area, combining overnight stays in Indian Well campground with caving explorations. Approximately forty caves have been made accessible to the touring public and bring caving enjoyment to approximately 60,000 visitors each year.

Information on many of the caves of the Monument was supplied by Superintendant Don C. Fisher, Lava Beds National Monument; his aid is gratefully acknowledged. Photographs were supplied by J. H. Swartzlow, Dr. William R. Halliday, Seattle, Washington and the University of California.

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**GEOLOGY OF LAVA BEDS NATIONAL MONUMENT**

**by Richard T. Gale**

The monument is entirely covered with volcanic rocks. The Medicine Lake Highlands to the south are the center of the regional volcanic activity which started about thirty-five million years ago.

The oldest rock in the monument is the rhyolitic-pumice tuffs (Lewis and Anderson 1936) with which the Indian petroglyphs are associated. These may be Early Tertiary (Swartzlow 1934).

The main flow which covers the monument is the Modoc Basalt. Flow, Late Pleistocene or Early Recent in age. This flow originated in the Medicine Lake Highlands and has not been weathered or subjected to erosion in any degree. In texture this flow is fine granular to glassy, but is not obsidian. It is about half plagioclase feldspar and half pyroxene and basic glass. However, olivine is found in abundance, some...
The olivine basalts along the fault scarp at the northwest end of the monument are Early Pleistocene or possibly Late Pliocene. These flows, which probably average over one hundred feet in total thickness, underlie much of the Modoc basalt flow.

To the northwest of the monument are a series of steep faults in the olivine basalt. These extend into the monument and such volcanic structures as craters, cinder cones, and spatter cones or chimneys are apparently developed along extensions of these faults (Lewis and Anderson 1936). The extreme northeastern corner of the monument is a horst cutting the tuffs. There are several other faults along the northern boundary of the monument which are associated with the graven that Tule Lake occupies immediately to the north of Lava Beds (Swartzlow 1934).

In Fossil Cave there are remains of camel and mastodon but unfortunately these cannot be of much help in determining the age of the Modoc basalt flow. The mastodon lived in modern times as high as twenty percent. Small amounts of iron oxide are common (Lewis and Anderson 1936).

The oldest flow is the Juniper Butte flow, which is estimated to be up to 60,000 years old. Later flows from Caldwell, Hippo, Schonchin, Mammoth Crest, and Glass Mountain built up successive layers covering much of the older flows. The flows branched out from central sources; secondary flows developed where gas pressure or molten magma broke through contraction cracks in cooling lava to form large secondary (toy) fields. As a consequence many lava tubes cross at right angles on different levels. Cascades of lava in tubes may also reflect action of the secondary flows.

The youngest flows in the monument are perhaps five hundred years old. These are the Devils Homestead Flow in the northwestern part of the monument and the Black Flow (the largest lava flow in the monument) partly in the southwestern corner of Lava Beds. Black Flow has few caves; Devils Flow has many "miniature" caves, few of which have been explored. These flows support only scant vegetation in isolated pockets where pumice has collected. This pumice indicates that there has been volcanic activity since the flows. Indeed, Glass Mountain, a mass of obsidian about six miles south of the monument, is supposed to contain a steam vent on its northern slope.

LAVA TUBES

There are about three hundred lava tubes or caves in the monument and most of them have several characteristics in common. The tubes are normally much longer than they are wide, are circular to oval in cross section, have low (up to ten feet high) ceilings, straight main passages, and the floors tilt along the general slope of the terrain (Figure 6). The tubes were probably formed in the following manner. As the lava flowed out from the various cinder buttes and spatter cones it began to cool on the outer edges which soon solidified into rock. Beneath this cooling crust the lava was still molten and fluid. The force of gravity and gas pressure pushed the fluid lava onward leaving a tube sealed at both ends. Access to the tunnel was brought about by the collapse of the roof. In a few caves, such as Hercules Leg Cave, the entrances may have been blown out by gas pressure. Usually collapse formed two caves, one upgrade toward the source of lava and one downgrade, toward the end of the rift or trench. If the collapse occurred in two adjoining areas and the debris did not fill the tube, a natural bridge resulted (Figure 7). There are more than twenty such bridges, the best known being Symbol Bridge, which contains the Indian pictographs.

Cave floors exhibit a variety of shapes and forms. Since molten lava is a fluid, the flow encountered obstacles similar to those encountered by streams and rivers. Several caves, notably Valentine Cave, Golden Dome Cave, and Lava Brook Cave, exhibit such common stream features as rapids, falls, and eddy currents, well preserved in the basalt. This occurs mainly when the lava is highly fluid, swiftly moving, and is accompanied by rapid cooling. Smooth floors, as in Catacombs Cave, have resulted from slowly cooling lava flows within the tubes. If, on the other hand, the flow was highly charged with gases, steam or water vapor, rough cinder-like floors, as in Silver Cave, are produced. As the lava tubes, still filled with moving molten lava, began to drain, curious wall formations were left. Shelves were formed by rapid cooling of the lava as the flow "hesitated." If the flow was stationary for a long enough period, the entire surface hardened or "froze," forming a lava tube. Some caves, namely Crystal Cave, have several well-defined levels.

In places the hot gases above the lava remelted the ceiling and wall crusts, allowing them to drip and flow downward forming drip pendants (Fern Cave) or "lava-cicles." Another feature, lava "coral" (Swartzlow and Keller), is found only in caves in which the crust that formed the ceiling is broken into shards or fragments. The coral forms by the deposition of calcite along the shards of basalt. The calcite is present in the ground water in the form of calcium carbonate probably originating in the weathering of plagioclase feldspars and the pyroxenes. Some of the deposits produce...
a branching effect which greatly resembles coral. The best displays of this coral are in White Lace Cave, Hercules Leg Cave, and Valentine Cave. (Swartzlow and Keller 1937).

ICE CAVES

About one hundred caves in the monument contain ice or water or both. The water is thought to be of meteoric origin which percolated downward through the porous basalt to the lower levels of the caves (Swartzlow 1935). If the lower ends of the cave are sealed to prevent seepage, a sufficient quantity may collect to form ice.

According to Harrington (1934), the angle of the sun’s rays is a fairly uniform factor in the formation of ice in caves. As the various ice caves in the monument face in all directions, this factor cannot be used in theory postulation of Lava Beds.

Another factor which does not hold is that air circulation through rock fissures is an important factor in the formation of ice. If air circulated through fissures in the summer, the ice would be warmed sufficiently to melt, in most cases probably totally. There is a minor amount of atmospheric circulation through rock fissures in a very few ice caves in the monument, but in the great majority there is no noticeable circulation (Swartzlow 1935).

The explanation of ice caves centers around the fact that there is active circulation of air in winter but comparatively little circulation in the summer months. The density of surface air increases in winter, and will tend to seek lower levels. This effectively pushes out the warm air that may be in these lower levels. This cycle repeats until the lower end of the cave is below the freezing point of water. Ice may then form from the water that has previously collected there or that seeps after the freezing temperature has been established.

During the hot summer months, the air is heated and expands, tending to rise in the atmosphere. As the colder air is lower in the lava tube, there is very little air circulation in the cave in the summer. A person may note the usually tremendous difference of air temperature when entering ice caves in the summer. This "buffer zone" is usually confined to the entrance and there may be as much as forty degrees of temperature change in a few vertical feet.

Another factor in ice caves formed in porous basalt is the dead air spaces in these basaltic rocks. These spaces act as an insulator surrounding the ice, helping to prevent the ice from melting in summer.

In most ice caves the ice does not change much in volume throughout the summer. Ice is known to be greatly reduced or disappear from some caves during an exceptional long dry period, but generally returns when normal precipitation is again the standard. For example, Heppe Cave contained ice in the summer of 1956 and 1958 but not in 1957. The rainfall and snowfall of 1956 and early 1957 was considerably below normal. As the precipitation in 1958 has been well above normal, Heppe Cave should have a greater volume of ice in 1959 than there is at present.

The following caves are the best and most well-known ice caves in the monument. The direction that the entrance faces has been included to illustrate the fact that the angle of the sun’s rays is not an important factor in the formation of ice caves in Lava Beds.

CRYSTAL CAVE. Crystal Cave contains the most beautiful and spectacular display of ice in the monument. The entrance is a vertical descent of 20 feet. The cave is in five levels. Inside the entrance, which faces east, a solid sheet of ice covers the wall and floors. This ice is remarkably clear, as rock fragments can be seen up to depths of ten or more feet. Farther westward are three tremendous ice pendants, twenty feet high and four to six feet thick (Figure 8). Portions of these are almost transparent. In the lowest level of Crystal Cave there is a large lagoon of ice, about five feet thick and twenty feet square. A tunnel about two feet high leads completely through the ice. This tunnel apparently has been in the ice since 1936 (Lewis and Anderson 1956). The most beautiful ice formations in Crystal Cave are the ice crystals. Portions of the cave are completely covered with these crystals, which range in size up to one inch in width and are found in groups which are six inches in diameter. The crystals are hexagonal in shape and sparkle with a brilliant luster in lamplight. Another form of crystal exists in the lower level and are formed into ribbons, looking very similar to translucent gypsum flowers. Unfortunately, there are only two of these ribbons remaining, the other having been vandalized. Crystal Cave contains more ice than any other cave in the monument.

FROZEN RIVER CAVE. Frozen River Cave, which faces southwest, has a tremendous mass of ice. The ice chamber is about one hundred feet below the surface. The ice is several hundred feet in length and about five to six feet thick. It is covered by a thin pool of water.

MERRILL ICE CAVE. This cave, which was formerly Bearpaw Ice Cave, faces north. The ice in this cave is similar to a frozen river, fifteen feet wide and four hundred feet long. The middle of the ice river contains a fifteen foot deep pit, into which the ice cascades.

COXS ICE CAVE. Coxs Ice Caves faces southwest and contains a dome room about fifty feet square full of ice. As in Frozen River Cave, two inches of water covers the ice.

SKULL CAVE. The ice chamber in Skull Cave (the entrance faces west) is about one hundred and fifty feet below the surface. The ice is similar to that in Merrill Ice Cave.

* Editors Note — Raymond G. Knox, in November 1949 found one of the ice formations in Crystal Cave entirely covered to a depth of one quarter to one half inch with a deposit of gypsum. The gypsum was sampled and proved to be 98% pure. A month later the same formation contained only crystal-clear ice.
WHITE LACE CAVE. The entrance to White Lace Cave faces northeast and the ice is in small thin patches scattered throughout the tube.

HEPPE CAVE. Heph Cave, one of the few ice caves with two entrances, faces west and east. The ice in Heph Cave is covered by a pool of water two to three feet deep. The floor of this cave is composed of collapse from a tube and the ice is formed in a low depression in this breakdown.

Cave Life

Plant life in the lava tubes is limited to lichens growing in the sunlit areas of the caves, with the exception of Fern Cave. As its name suggests, Fern Cave contains a luxuriant growth of ferns in the entrance, flourishing in spite of the semi-desert conditions.

The vertebrate animal life of the tubes does not remain permanently underground. The most common mammal observed in the caves is, of course, the bat. In Blue Grotto Cave, Long-Eared bats (Corynorhinus alatus) are fairly common. The western Pipistrellus has been observed in Cox Ice Cave, Sentinel Cave, and Juniper Ice Cave. It is thought that perhaps a variety of Myotis also occurs in the monument caves. Bat Cave contains guano ten feet thick and was said to house over three million bats at one time (K. A. Murray and J. D. Howard personal communication).

Wood rats nests are seen in almost every cave. Bobcats have been reported in the Caldwell Caves, and a pika or cony has been seen in the entrance to Thunderbolt Cave. Purple Martins roost in the entrance to Fossil Cave. Dragonshead Cave and Skull Cave have yielded the skulls of a now extinct bighorn sheep. Antelope skulls have also been found in Skull Cave and Coyote Cave was named for the coyote that was found in it. Gopher snakes, attracted by toads and mice in Fern Cave, startled many visitors who were conducted through this cave.

The Indians knew and probably occupied certain caves, as the pictographs suggest. These are found in Big Painted Cave, Little Painted Cave, and Ship Cavern (all located in approximately the same area). Two human skeletons are said to have been found in Skull Cave, which is quite near the three above caves.

Fossil Cave, in the northeastern part of the monument, has been named for several fossils found in the lava tube. It has recently been suggested that perhaps the lava flow uncovered the fossils, rather than burying them (K. S. Murray and J. D. Howard personal communication). The first fossils were found in 1931 and included two teeth (upper and lower molars) of a camel (Camelops sp.), portions of two teeth and a part of a lower jaw of a young mastodon (Mammuthus americanus), and a tooth of a carnivore. These fossils are in the Museum of Paleontology at the University of California (Lewis and Anderson 1986).

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Food and Drink

There are many instances recorded in literature concerning speleology where some well-intentioned person used a large amount of fluorescein dye to trace a disappearing stream. The dye emerged in some village's water supply, turning it completely green for a period of time. Needless to say, in those locations where the villagers knew the source of the dye, the speleologist and cave explorer was no longer welcome. This excess use of dye to determine the flow pattern and emergence of a disappearing stream is not necessary if proper evaluation of stream tracing methods is made.

Origin and Character of Openings in Limestone

There are many instances recorded in literature concerning speleology where some well-intentioned person used a large amount of fluorescein dye to trace a disappearing stream. The dye emerged in some village's water supply, turning it completely green for a period of time. Needless to say, in those locations where the villagers knew the source of the dye, the speleologist and cave explorer was no longer welcome. This excess use of dye to determine the flow pattern and emergence of a disappearing stream is not necessary if proper evaluation of stream tracing methods is made.

Inorganic chemicals, dyes, bacteria, and radioactive elements were found to have been used to determine speed and path of flow of ground water in limestone. Considering the peculiarities of water flow through limestone and the equipment available to the average speleologist, the following methods of stream tracing are recommended:

1. If it is necessary to know only if two streams in a limestone area are connected, the Dunn method is recommended. This method employs the detection of fluorescein in the stream by use of adsorbent carbon. The dye is then leached from the charcoal by ethyl alcohol solution containing 5% potassium hydroxide.

2. If it is necessary to know also the speed of flow, a variation of Slichter's method is recommended. This method employs the detection of ions in the water by the increase in electrical conductivity as the ions pass the site of suspected emergence. Slichter recommends ammonium chloride be used as the tracer.

The bed as it passing through a stave. Because of the compactness of limestone, the ground water is initially restricted to the fractures, joints, and bedding planes. Such openings in limestone permit the movement of water down to the water table and along, under the water table to some spring on the surface.

In percolating down through the soil layer, the water dissolves carbon dioxide, or carbonic acid, and certain organic acids derived from decaying vegetation in the soil. As limestone, and dolomite to a lesser degree, are slightly soluble in these weak acid solutions, portions of the rock are removed along the fractures, joints, and bedding planes. In the vadose or aerated zone, ground water movement downward is controlled mainly by gravity. This results in widening of the initial openings; in addition vertical movement in the vadose zone results in the development of fissures and shafts. These shafts may show on the surface as dolines or solution sinks. The sinks are rounded, shallow depressions and develop from the surface debris and soil being transported into the fissure or shaft by water. Solution sinks should be differentiated from...
the arrival of a salt is detected electrically. Several small wells are driven into the water bearing material in such a manner that the water moves from the upgradient well towards one or more of the down-gradient wells. The movement of the salt from the upgradient well to the down-gradient well is observed by means of an electric circuit that utilizes the conductivity of ground water. As the salt moves toward the lower well the conductivity of the water increases. Another electric circuit within each down-gradient well is used for detecting the time of arrival of the salt. The amount of current that will flow in this circuit depends on the conductivity of the water in the well and is observed by measuring the current that will flow between the electrodes, one in the well and the other in the well casing. The rate of movement of the salt as well as the rate of movement of the ground water is computed from the time elapsing between the introduction of the salt in the central or upgradient well and its detection in a well located down-gradient. Slichter found by experiment that ammonium chloride (NH₄Cl) was a satisfactory salt for this method. Figure 3 is a diagram of the electrical circuit. Figure 4 is a graph obtained from data in a test run by Slichter.

**Dye Trackers**

Dyes have been used extensively in underground water tracing because of their detectability when diluted to low concentrations. They work well in cavernous strata where the flow is rapid and the short duration of exposure prevents much chemical reaction between the rocks and the dye.

Visible detection — A sufficient quantity of dye is placed in a stream or well to permit visible detection at the possible resurgences. A person is then stationed at each possible resurgence to watch for the dyed water. The time the dye was added and the time the dye appeared at the resurgence is noted. From this data it is possible to calculate approximately how much time is required for water to flow between the two sites. Table 1 lists three common dyes used and the concentrations which can be detected by sight.

Since fluorescein is the dye most readily detected in low concentrations, this is the dye most often employed in this method. Fluorescein was used by the German hydrologists as early as 1877. In 1882 a French medical doctor, Dionis des Carrières used fluorescein to prove the origin of contaminated water during a severe typhoid epidemic at Auxerre, a city 85 miles southeast of Paris, France. Considerable laboratory and field work was accomplished with this dye by French geologists and hydrologists before it was even cited in literature in the United States by Dole in 1906.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Color</th>
<th>Dilution (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorescein</td>
<td>yellow-green</td>
<td>0.0042</td>
</tr>
<tr>
<td>Eosin</td>
<td>red</td>
<td>0.5</td>
</tr>
<tr>
<td>Aniline</td>
<td>red and green</td>
<td>1.0</td>
</tr>
</tbody>
</table>

In order to be sure of readily visible detection at an outlet, two to three pounds or more of dye is advised for every thousand gallons of water per minute of flow at the source. This would seem to be more dye than necessary, but it is necessary considering the dilution which the dye will undergo.
of measurement, Ken.


gallons of water per mile of underground
ciece. In dilution as low as one part


appearance of intense yellowish green. By use


of about one pound of dye per thousand
of thi property, it is possible to detect


or by minimizing the speed with which the color develops upon
the dye “charge” in the charcoal and varies


from almost instantaneous to half an hour.


By tabulating time factors such as the

time of injection and the time of dye arrival
in the samples, and knowing the surface
distance, it is possible to calculate the ap-
proximate rate of flow of the underground
water between the two points.


Use of fluorescein and charcoal adsorbent

A third method of ground water tracing us-
ing fluorescein has been developed by Dunn
(1950). This method is designed primarily for
tracing water in cavernous areas. It con-
sists of detection of fluorescein in water by
use of super adsorbent charcoal. The char-
coal picks up and retains the dye as the
dyed water passes the site of the charcoal.


Highly adsorbent coconut charcoal, 10 to
12 mesh, is wrapped in a piece of window
screening and supported in the flowing
water by use of a strong wire (a straightened
coat hanger is excellent). If the dye passes
the packet, it will be adsorbed and retained
by the charcoal. In the laboratory tests,
charcoal, in a stream of running water, re-
tained the dye for a period of six weeks.
(Dunn, personal communication).

A few granules of the charcoal can be re-
moved from the package at regular time in-
tervals and marked with an appropriate
sample number, or the packets may be left
undisturbed until the fluorescein dye has
had sufficient time to reach and pass the
site. The former will give data from which
to calculate when the dye passed the site.
The latter will only tell if the dye has passed
the site of the packets.


To determine if the dye has passed the
site, a few granules of the charcoal are
placed in a white porcelain dish. A small
quantity of 5% solution of potassium hydrox-
ide in ethyl alcohol is added so that the

charcoal granules are barely covered and left
undisturbed for a period of at least thirty
minutes. In preparing the mixture it is ad-
visable to add a granule of fresh charcoal for
comparison. The fluorescein green color will
develop on the surface of the charcoal if
the dyed water has passed the site of the
detector. If the dye was not present, the
charcoal will retain the appearance it has
when removed from the stream. The speed
with which the color develops upon
the dye “charge” in the charcoal and varies
from almost instantaneous to half an hour.


Using this method, Turner (1957) used
four grams (.009 pounds) of fluorescein to
determine the path of travel and the site
of emergence for water from a sinking
stream at Erb Gap near Pine Grove Mills,
Pennsylvania. The water reappeared in
Beaver Brook, one mile across the strike of
the bedding planes and at a spring emerging
from Fry Cave near Baileyville. The latter
site is about three miles from the vicinity
of Erb Gap along the strike of the strata. Since no regular sampling of the
charcoal was performed, only qualitative
results were obtained from this test. How-
ever the time which elapsed between place-
ment of the dye and the removal of the
packets was about 24 hours.


In another experiment, Turner also
found that 1.2 grams of fluorescein (.0026
pounds) could be detected in Spruce Creek
after a flow of 1.4 miles from the site of
addition.


The amount of dye recommended for use
with this method is about ten grams (or
.022 pounds) per thousand gallons of water
per minute per mile of probable under-
ground travel.


Bacteria

Bacteria and stream correlation -

In performing experiments on contamina-
tion of stream waters in the Milroy Cave
System, Milroy, Pennsylvania, Voysey and
Rumbaugh (1956) attempted to determine
if water traveling in the stream is related
to bacteria present. Samples of water from
the surface stream and three

strains within the cave system were col-
lected and experimented run to determine
the similarities or dissimilarities of the sam-
ples. Definite conclusions were not drawn
by the authors from the data they obtained.
However, they felt it would still be possible
to disentangle a complicated underground
water system in limestone by the above
method.


Bacteria as a tracing agent - Voysey (1957)
used a bacterium "Serratia Marcescens" in
tracing a stream in Brush Valley, Centre
County, Pennsylvania. One liter of this
bacterium culture was placed in the stream.
Samples at a point 1000 feet downstream
were taken every five minutes over an hour
period. When cultures were obtained
from the samples, it was found that the bacterium
traveled the distance in 35 to 40 minutes.
Because of the development of dye detec-
tion by use of charcoal by Dunn (1957) no
further work was done on this method of
tracking.


No other references of the use of bacteria,
other than speculation, have been uncover-
ed by this author.


Radioactive Tracers

Of late, radioactive tracers have been used by
petroleum geologists and hydrologists to
trace movement of liquids through a per-
miable medium such as sandstone and shale.


The common method is to introduce them
directly into the influent waters as a water-
soluble compound. Samples are collected at
the possible locations of emergence at re-
gular time intervals, usually every half hour,
de pending upon the distance of flow. Each
sample is checked with a geiger counter or
similar counting device. The resulting
values, in counts per minute, are plotted
against time of sampling on a graph. If the
radioactive tracer passes a point, it will show
up on the graph as a curve with a rather
fast rise to a rounded peak and a gradual
dropping off, approaching the normal count
of the stream asymptotically.


Radio-active - Several elements have been
used for this purpose. Salt of tracers such as
radioactive iodine-131 and bromine-82 may
be used without additional prepara-
tion. In water solution these are in the form
of anions and are seldom affected by the medium through which they pass.

This is not true of cations. Cations in solution will react with the clays and soils, remaining there, and through ion exchange will liberate other cations such as sodium and calcium. For this reason, little field work has been done with cations. Versene has been used in the laboratory to prevent ion exchange. Versene is the tetra-sodium salt of ethylenediamine tetra acetic acid. It will inactivate the normal ionic properties of almost all polyvalent cations to form with them a group of water soluble compounds known as chelates. A chelate consists of a large organic molecule surrounding the cation, completely blocking its ionic character. These compounds are extremely stable except in the presence of a cation which will form a more strongly chelated substance. The latter cations will replace the original cations, exposing them to adsorption by the nearby clay minerals. Therefore, cations chosen to be used as tracers should be capable of forming a stronger chelate than the cations present in the water being traced.

Of the cations present in ground waters, calcium forms the strongest chelate. In practice, the cation used must be capable of forming a stronger chelate than calcium ions at the pH value of the water being traced. In laboratory tests by Lacey and Laslagna (1956), 250 milliliters of aqueous solution containing 10 milligrams of versene and 2.5 microcuries of cobalt-60, ammonia, 124, and chromium-51 respectively, were passed through a quantity of crushed shale. The chelated cations passed through the shale without significant loss of concentration. When versene was not added to similar solutions, half or more of the cations remained, with the shale billigrams of versene and 2.5 microcuries of cobalt-60, ammonia, and chromium-51 respectively, were passed through a quantity of crushed shale. The chelated cations passed through the shale without significant loss of concentration. This indicates that it may be possible to use radioacive cations in groundwater tracing, but more data and field trials are necessary.

Tritium – Tritium (hydrogen-3) has been compounded with oxygen to form tritium water. Chemically it is the same as ordinary water, but there are several properties which differ slightly from common water. Among these are density, melting and boiling point, and the radioactivity of the tritium emits electrons or beta rays. Since the properties of tritium water are so nearly the same as common water, it is an excellent tracer of common water. The method used by Finkelstein et al. (1957) consisted of injecting 100 to 200 milliliters of tritium water with a specific activity of 10 to 20 microcuries per milliliter into a well in sandstone. Nearby wells were sampled and checked for any increase in beta decay over and above the normal count which the water from the well had previous to the experiments.

The experiments with tritium were successful. Ground water velocities between the recipient well and three other wells in the vicinity were determined. The three observed wells were about 120 degrees from each other with the recipient well at the focus of the angles. Velocities were found to be 40, 12, and 13 meters per day for this particular sandstone and locality.

**Evaluation of Methods**

### Standards

Carpenter et al. (1952) gave the following standards for an effective ground water tracer.

1. The tracer should be susceptible to quantitative determination in very low concentrations.
2. The tracer should be entirely absent or present only in very low, known concentrations in the water being traced.
3. It must not react with injected or displaced waters to form a precipitate.
4. It must not be absorbed or adsorbed by the permeable medium.
5. It must be cheap and readily available.

Kaufman and Orlöb (1956) added the above standard when it was introduced that the tracer must not in any way cause the soils or clays to coagulate and change the permeability of the medium. This occurs in shales and sandstones where an ionic substance, with its electrical charge, will cause the clays to collect and settle. The end result would be less resistance on the part of the medium to the water flow. In limestone, where the liquid does not follow small pores among the clay and sand grains, but travels through solution channels, there is little or no problem with use of such tracers.

Speleologists, interested in water tracing in limestone, usually are doing such as an avocation. The labor and equipment required, therefore, becomes an important item. It might be added, then, that further requirement is the ease and simplicity of employment of the method.

**Chemical analysis** — Common salt, sodium chloride, is a very inexpensive item. Present cost averages about $2.00 per 100 pounds. Use of salts of other ions is considerably more.

Use of cations, such as lithium and ammonium, in aqueous solution is not advised, mainly because of the loss of the ions through ion exchange with clays and soils. This loss can be overcome by increased concentration, but this adds to the expense.

The chief fault of this method lies in the labor and apparatus required. Once the tracer has been placed, a person must sample the suspected resurgences regularly. This is a full-time occupation for one person. It is necessary to sample at least hourly in order to detect the tracer. If the distance is shorter than one-half mile, sampling should be done more often.

A chemical laboratory usually is required for analysis of the tracer ions. This is not available to the average speleologist. Also required is a knowledge of quantitative or qualitative analysis procedures.

A mass spectograph or flame photometer is an expensive piece of equipment and usually not available to the person interested in water tracing. For this reason, use of lithium salts is prohibitive.

Use of salts in concentrations of more than 5000 ppm in the medium tested may be harmful to fauna both in the cave and in surface streams draining caves. This limits the amount of salts that can be used in tracing.

**Electrical conductivity** — Considering the long distances between the site of disappear ing streams and possible resurgences, the double circuit used by Slichter must be discarded. It is common for the two sites to be three to four miles apart.

That portion of Slichter's circuit where the arrival of the tracer is detected by the increase in conductivity of the water can be retained. The cost of parts to build such an apparatus should not exceed $10.00. Again, it is required that a person be present at the emergence to record the ammeter readings at regular time intervals.

**Dye tracers, Visible detection** — Dyes are generally expensive items and cost $10.00 or more per pound when purchased from chemical supply houses. Since a considerable quantity of dye is needed to insure visible detection, this method can be expensive.

Again, it is necessary to have some person present at the resurgences to watch for the dyed water. High concentrations of dye may have an injurious effect on aquatic life in caves.

**Use of fluorescein and ultraviolet light source** — This method is less expensive than the visible detection method, but it is necessary to have a proper ultraviolet light source available. A procedure of sampling and indexing samples is necessary. The labor of at least one man during the test is required. Care must be taken to insure the samples do not become contaminated. This is best accomplished by having one person prepare and emplace the dye-lute solution and another to sample the resurgence.

**Use of fluorescein and charcoal adsorbent** — Of the methods described in literature, the most expensive requires a dye and packet of charcoal can be placed in their respective streams. The packets can then be picked up later at one's convenience. It is advisable not to allow them to remain in the stream much longer than two weeks.

The person placing the charcoal packets in the stream requires that the labor, equipment, and financial outlay. The dye and packets of charcoal can be placed in their respective streams. The packets can then be picked up later at one's convenience. It is advisable not to allow them to remain in the stream much longer than two weeks.

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**Bacteria** — Tracing streams by use of bacteria is not a simple matter. The method has not as yet been perfected. Both methods described require a knowledge of culture procedures. Also needed is the labor in preparing the cultures and the taking of samples.
Earthworms of North American Caves

by G. E. GATES

Twelve species of earthworms now have been reported from 23 caves in the United States. The samples hitherto available indicate that earthworm populations of eighteen caves are monospecific, bispecific and trispecific in five and three caves respectively, that exotic species only were present in 16 cases, native species in seven caves. Nearly 85 percent of the worms are exotic and of strains in which parthenogenesis is obligatory.

Three species of earthworms have been recorded hitherto from two caves in the United States (Giovanelli 1938, Gates 1954), one species from a cave in Puerto Rico (Gates 1937) and four from eight caves in Yucatan (Pickford 1938), a total of eight species from North America and the West Indies. Eight species have been found in English caves (Davies 1948) and nearly forty species have been recorded from European caves (Cernovitov 1939). Fourteen species of earthworms have been listed from mines in France but no records have been published hitherto for mines of North America.

Through the kindness of Dr. G. E. Pickford and of Dr. Fenner Chace, Jr., it is now possible to report the finding of several additional species in American caves as well as of one species in a mine. Also in the material turned over by Dr. Pickford is a single series from a continent for which there have been no cave records.

The author's thanks are extended to Dr. Pickford and to Dr. Chace for the opportunity of studying this material as well as for assistance rendered while the study was under way.

Sixteen species of earthworms belonging to eleven genera in three families are now known from North American caves. For the mainland United States the figures are eight genera and twelve species.

The earthworm fauna of North America, north of Mexico and east of the Pacific coastal strip, *comprises sixty species (Table 1).* Since 80 percent of them were not represented in collections hitherto available, a number of additions to the American cave list**, as well as to the mine list, can be expected.

Of the 173 cave and mine specimens that were identified as to family, 155 belong to the Lumbricidae, 17 (11 pheretimias, 6 diplocardias) to the Megascolecidae, 1 to the Sparganophilidae. Most of the worms that were identified as to species, 115 of 136 (Table I) or nearly 85 percent, are exotic. That proportion does not seem so surprising when it is recalled that 37 (over 60%) of the species in the area now under consideration became domiciled more or less widely after introduction by man, directly or indirectly, from Europe, tropical Africa, South Africa or southern South America, Central America or tropical South America, China and Japan. The same species could have been taken by man into caves if earth or compost of any sort was brought there - a small handful being sufficient for introduction of cocoons and somewhat larger clumps for adults. The exotic, as in many epigaeal areas, already may have replaced the natives, twenty or more years ago, in 16 of the 23 caves. However, most of the collections are small and information is incomplete.

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** Only nine of the 29 lumbricids in the table, *A. muldali* and *tuberculata, L. festivus,* and six species of *Bimastos* are unlisted from caves. *A. tuberculata may have been recorded from German caves as *A. caliginosa.* *A. muldali* has been found hitherto only at three sites, two in England and one in Michigan. *B. heinburgeri* and *vulcheri* are known only from the original descriptions. Little or nothing is known about the earthworms of large areas in the United States and Canada.

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1. Considering these facts, the speleologist is advised against use of this method.

2. Radioactive Tracers — Radioactive tracers are dangerous materials to handle. It is not known if the tracer will or will not end up in a domestic water system. In general, tracers are expensive to obtain, if they can be obtained at all. The equipment needed to detect the presence of radioactive tracers is also prohibitively expensive. The accurate information obtained from the use of radioactive tracers can be obtained by other less dangerous and less expensive means for the same amount of labor.

3. In tracing an underground stream in limestone, the method used will depend upon the information needed. The following recommendations are based on the economy and simplicity of the methods and the amount of labor involved.

4. If it is necessary to know only if two streams are connected by underground flow, Dunn's method is recommended. This method employs packets of charcoal to adsorb the dye from the water as the dye passes the site.

5. If it is desired to know also the speed of underground flow, Slichter's method is recommended with the variation noted in the evaluation. This method involves the detection of the tracer by the increase in electrical conductivity of the water as the tracer passes the site. The modification recommended is the elimination of the circuit which connects the site of injection with the site of resurgence of the electrolyte.

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References


Plummer, F. B. 1945 Tracing flow of fluids and gases beneath ground: Oil and Gas Jour., vol. 44, no. 20, pp. 141.


Vossey, B. 1957 *Serratia Marcescens:* Nittany Grotto Newsletter, National Speleological Soc., vol. 5, no. 8, pg. 16.


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*No records of earthworms in caves of the coastal strip have been found. The native fauna of the strip is quite different from that of the rest of the United States and Canada.*
However, in Maine, where all earthworms are exotic, the common species of ordinary soils (Gates, in MS) are, with one exception, those with obligatorily biparental reproduction. *E. roeselii*, with equally wide distribution, always provides smaller percentages of the populations. Other parthenogenetic forms, in such soils, are found but rarely. In sites with unusual amounts of organic matter, including compost and manure heaps, biparental forms usually constitute a large majority or all of the population. Rarely, *D. rubida* dominates but then most of the individuals are strains that mature and exchange sperms. Moreover, a single specimen of a sexual species also can find a new colony, if copulation is completed prior to transportation, for cocoons, after, the spermathecal battery has been charged with sperms, can be continued for some time. Even a single cocoon of an obligatory biparental species like *E. foetida* can give rise to a new colony because usually two to four of the embryos hatch. Accordingly, factors other than those previously postulated may prove to be of greater importance in establishment of cave colonies in spite of the preponderance of asexual individuals in the American samples, 115 (± 17) of the 156 specimens that were identified as to species.

The information now available as to American and European caves as well as mines indicates that *D. rubida*, regardless of method of reproduction, is of all species of earthworms living in cavernous areas, most nearly pre-adapted to a hypogean existence.

### Species from North American Caves

#### LUMBRICIDAE

*Allolobophora Eisen, 1874*

*Allolobophora chlorotica* (Savigny, 1826) Previously recorded from caves of Germany, Belgium, France, Hungary, England, and from mines in France. The species is of European origin and was brought to America by man. Reproduction is sexual and biparental.


#### TABLE I

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of specimens secured from caves</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lumbricidae</strong></td>
<td></td>
</tr>
<tr>
<td><em>Allolobophora</em></td>
<td></td>
</tr>
<tr>
<td><em>chlorotica</em></td>
<td>1</td>
</tr>
<tr>
<td><em>limicola</em></td>
<td>ES</td>
</tr>
<tr>
<td><em>longa</em></td>
<td>ES</td>
</tr>
<tr>
<td><em>mudali</em></td>
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</tr>
<tr>
<td><em>trapezdoides</em></td>
<td>EP</td>
</tr>
<tr>
<td><em>tuberculata</em></td>
<td>ES</td>
</tr>
<tr>
<td><em>turgida</em></td>
<td>ES</td>
</tr>
<tr>
<td><em>Bimastor</em></td>
<td></td>
</tr>
<tr>
<td><em>Heimburgeri</em></td>
<td>NP?</td>
</tr>
<tr>
<td><em>longicincta</em></td>
<td>NP?</td>
</tr>
<tr>
<td><em>palustris</em></td>
<td>NS</td>
</tr>
<tr>
<td><em>pares</em></td>
<td>ES</td>
</tr>
<tr>
<td><em>tumidus</em></td>
<td>NP?</td>
</tr>
<tr>
<td><em>welchi</em></td>
<td>NP?</td>
</tr>
<tr>
<td><em>Dendrobaena</em></td>
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</tr>
<tr>
<td><em>mammalis</em></td>
<td>EP</td>
</tr>
<tr>
<td><em>octaedra</em></td>
<td>ES</td>
</tr>
<tr>
<td><em>rubida</em></td>
<td>ES</td>
</tr>
<tr>
<td><em>Eisenia</em></td>
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</tr>
<tr>
<td><em>carolinensis</em></td>
<td>NS</td>
</tr>
<tr>
<td><em>foetida</em></td>
<td>ES</td>
</tr>
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<td><em>hottentii</em></td>
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<tr>
<td><em>lensbergii</em></td>
<td>NS</td>
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<tr>
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<td><em>tetraptera</em></td>
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<tr>
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<td><em>fettius</em></td>
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</tr>
<tr>
<td><em>Octlolaimus</em></td>
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</tr>
<tr>
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<tr>
<td><em>factum</em></td>
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<tr>
<td><em>Ocnerodrilus</em></td>
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<tr>
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<tr>
<td><em>Microcoleus</em></td>
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<tr>
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</tr>
<tr>
<td><em>Pherejeta</em></td>
<td>EP</td>
</tr>
<tr>
<td><em>agrestis</em></td>
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</tr>
<tr>
<td><em>bicinta</em></td>
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</tr>
<tr>
<td><em>californica</em></td>
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</tr>
<tr>
<td><em>diliformis</em></td>
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</tr>
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<td><em>haarvani</em></td>
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<tr>
<td><em>hilgardorfi</em></td>
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<td><em>kupferiti</em></td>
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<td><em>levi</em></td>
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<td><em>morrisi</em></td>
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<tr>
<td><em>rodiesi</em></td>
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<tr>
<td><em>Diplocardia</em></td>
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</tr>
<tr>
<td><em>sp.</em></td>
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</tr>
<tr>
<td><em>Sparganophilus</em></td>
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</tr>
<tr>
<td><em>sp.</em></td>
<td>N</td>
</tr>
<tr>
<td><em>Glossoscolecidae</em></td>
<td></td>
</tr>
<tr>
<td><em>Pontoscolex</em></td>
<td>corellanus</td>
</tr>
<tr>
<td><em>Eudrilus</em></td>
<td></td>
</tr>
<tr>
<td><em>Eudrilus</em></td>
<td>eugenii</td>
</tr>
<tr>
<td>E = exotic.</td>
<td>S</td>
</tr>
<tr>
<td>N = native.</td>
<td>P</td>
</tr>
<tr>
<td>J = reproduction</td>
<td>S?</td>
</tr>
<tr>
<td>= possibly sexual</td>
<td>unknown.</td>
</tr>
<tr>
<td>= possibly sexual but with facultative</td>
<td>parthenogenesis.</td>
</tr>
</tbody>
</table>
| SP = reproduction sexual but with option of parthenogenesis in some strains, parthenogenic only in others including those hitherto collected from American caves. | 1 Diplocardia requires considerable revision. Some of the species are dubious. To furnish a figure for the only recognized species in the eastern part of North America.

**BULLETIN** Volume 21, Part 2, July, 1959
**Allobophora trapezoïdes** (Duges, 1828)

* A. trapezoïdes long has been confused with other forms in a complex that has gone under the name of *caliginosa* and probably has been found in caves of some Mediterranean countries for which *caliginosa* has been reported.

The species is of European, very probably south European, origin and was brought to America by man, probably first by Spaniards after conquest of Mexico. Reproduction is parthenogenetic.

One of the specimens from Snedigar Cave, West Virginia, is damaged in a critical region and is not identifiable anatomically.

In a specimen from Snedigar Cave, male sterility, evidenced by absence of spermatozoal iridescence on male tunnels and by empty spermathecae in a worm with maximal clitellar tumescence, in conjunction with the genital tumescence, enables identification.

**ARKANSAS** — Diamond Cave, south of Jasper, at spring, May 1, 1955, 0-0-1, Ottes Sanders; KENTUCKY — Mammoth Cave, Cave City, August 28, 1941, 0-0-1, National Speleological Society (U.S.N.M.); TENNESSEE — Wash Lee Cave, Livingston, April 5, 1955, 0-0-1, J. M. Valentine per G. E. Pickford; Crystal Cave, Monticello, March 4, 1932, 0-0-1, J. M. Valentine per G. E. Pickford; WEST VIRGINIA — Snedigar Cave, Pocahontas County, June 24, 1932, 3 specimens, A. M. Reese (U.S.N.M.).

*Allobophora turda* Eisen, 1873

Not previously recorded from caves of this species. This long has been confused with *trapezoïdes*. Some of the records of *caliginosa* from German and English, if not of French and Belgian, caves quite possibly will be found, when specimens are reexamined, to be attributable to *turda*. The species is of European origin and was brought to America by man. Reproduction is sexual and biparental.

**WEST VIRGINIA** — Justice Arbuckles Cave, Lewisburg, March 11, 1931, (7) 0-3, J. M. Valentine per G. E. Pickford. (Several unidentifiable juveniles may be of the same species).
stream ca. one quarter mile from entrance, numerous castings on surface. July 19, 1951, 0-4-17, J. M. Valentine per G. E. Pickford ("This cave used by saltpetre workers in Civil War."). Cave, New York. July 26, 1941, 0-0-1, R. Kenk (U.S.N.M.).

Eiseniella Michaelisen, 1900
Eiseniella tetraedra (Savigny, 1826)

These specimens are of a morph which has male pores on xiii, an annular ciliated on xxi-xvii, tubercula pubertati between equators of xxiii and xxvi, spermathecal pores midway between D and M at 9/10-11. Genital tumescences include a-b setae of x, occasionally c-d of one or both sides of x. A short, unsegmented and unpigmented tail regenerates with terminal anus is present, in one specimen, at 37/38. Segment xxvii had lost all of its setae during post-amoebation reorganization and sites of follicle apertures no longer are recognizable.

These worms with ciliated at maximal tumescence but with empty spermathecae and no spermatogonal incidence on male funnels appear to be male sterile. E. tetraedra has been recorded previously from caves of Germany, Belgium, France, Switzerland, Italy, Yugoslavia, Hungary, Greece, Turkey, England, and France. The species is of European origin and was brought to America by man. It is known to be present in New England, New York and Pennsylvania west to Missouri and can be expected to turn up in caves of states where it occurs. Reproduction is parthenogenetic.

SOUTH AFRICA - Cango Caves, Czarne Skaeg, Cape Province. Two miles into caves, in damp earthy material", December 29, 1926, 11-1-9, G. E. Pickford.

Octolasion Oerley, 1885
Octolasion lacteum (Oerley, 1881)

Previously recorded from caves of France, Italy, Yugoslavia, Hungary, and from mines in France. Reproduction is parthenogenetic.


Lumbricidae gen. et sp.
MISSOURI - Onondaga Cave, Leasburg, June 7, 1938, 0-0-0, K. Dearolf (U.S.N.M.);
PENNSYLVANIA - Dragon Cave, Berks County, January 22, 1938, 0-0-0, K. Dearolf (U.S.N.M.);
Veiled Lady Cave, Center County, November 7, 1936, 1-0-0, K. Dearolf (U.S.N.M.);
VIRGINIA - Luray Cavern, Luray, "bottom levels", October 1, 1928, J. C. Bridwell (U.S.N.M.), possibly D. rubida.

MEGASCOLEIDAE
Balatendrillus Pickford, 1938
Balatendrillus pearsei Pickford, 1938
Balatendrillus pearsei Pickford 1938, Carnegie Inst. Washington Pub. No. 491, p. 79 (Gongora Cave, Oxtuztcb and San Isidor Cave, Merida, Yucatan.)

Eodrilus Michaelisen, 1907
Eodrilus oxkutzcabensis Pickford, 1938
Eodrilus oxkutzcabensis Pickford 1938, Carnegie Inst. Washington Pub. No. 491, p. 71 (First Cave on San Roque Road, Oxtuztcb and San Isidor Cave, Merida, Yucatan.)

This species, like B. pearsei, is known only from the original description.

Diplocardia Garman, 1888
Diplocardia sp.

EXTERNAL CHARACTERISTICS: Size, ca. 40 by 2 mm. Segments, 104, 109. Setae, present from ii, apparently not closely paired, ventral couple of xvii and xx penial, copulatory setae lacking. First dorsal pores at 12/13. Ciliated annular except on xviii where it is lacking ventrally, on xiii-xvii.

Spermathecal pores at or slightly lateral to D and at or just behind 6/7-8/9. Female pores anterior to a. Seminal grooves in AB on xviii-xx, male and prostatic pores, as well as any genital markings, unrecognizable.

INTERNAL ANATOMY: Gizzard in v-vi, Intestinal origin in xvii. Typhlosole well developed in postprostatic segments. Dorsal blood vessel, wherever recognizable, single. Hearts present in xii but none have been seen in xiii.

Holandric. Seminal vesicles present in ix (xii) and xii. Penisial follicles about half as long as prostatic ducts. Penial setae slender, sinuous ectally and there flattened (but not broadened) on two sides, gradually narrowing but not quite filamentous terminally. Ornamentation, ental to sinuosities, of several transverse irregularities. Spermathecal ducts widened entally. Diver­


ticum a small vertical disc with very short and very slender stalk passing to duct near ampulla.

REPRODUCTION: Male funnels have a brilliant spermatogonal incidence. Seminal chambers of spermatogonal diverticula appear to be indeterminate. Reproduction, since sperm are matured and exchanged in copulation, is assumed to be sexual and biparental.

REMARKS: These specimens are in an advanced stage of maceration, body wall except at ciliated almost glass-transparent. Even the gizzard wall is almost transparent but opacity of thickened cuticular lining enables recognition of gizzard locations. A fairly thick and high typhlosole is indicated by the structureless slime that can be seen, from the dorsal side, to separate the in­


testinal earth into two longitudinal masses.

Characters that would enable identification of species are not recognizable. The worms probably belong to a comminus group.

Diplocardia is known only from the United States and Mexico. The species, whatever it may be, then must be an en­


demic. No species of Diplocardia has been recorded from caves previously.

ALABAMA - Cathedral Caverns, Woodville, July 5, 1954, about 800 feet from en­


trance, 0-0-3, about 1500 feet from entrance, 0-0-3, B. E. Faust (U.S.N.M.).

Phremita Kimberg, 1866
Phremita diffirigens (Baird, 1869)

Several species of Phremita have been listed from cave in Japan (Ohfuchi, 1941) but diffirigens is recorded only from Ameri­


can caves. However, types of P. torii, from a Japanese cave, appear from the descrip­


tion to be only small and inornate variants of the present species.

P. diffirigens is of Asiatic origin and has been carried around the world by man. In the British Isles and in some parts of the United States, after 50-100 years, the species is still known only from greenhouses. Re­


production is parthenogenetic.

ALABAMA - Weaver Cave, Weaver, September 1941, 4-2-1, J. M. Valentine per G. E. Pickford. Three recently hatched juveniles may be of the same species.

Phremita rodensicus (Grube, 1879)

The Puerto Rican record is the only one from a cave.

The original home of rodensicus is still unknown but presence in greenhouses of England, Germany, Poland, Russia, Switzerland, and United States, as well as in Botani­


cal gardens at Rome and Prague, proves that the species has been widely transported by man. In natural habitats of the North American mainland the species has been reported only from Florida.

Reproduction is assumed, since sperm are matured and exchanged in copulation, to be sexual and biparental.

Dichogaster Beddard, 1888
Dichogaster affinis (Michaelisen, 1890)

Dichogaster bolawi (Michaelisen, 1891)

This species also has been recorded from the Siju Cave in the Garo Hills of Assam, India.

The original homes of affinis and bolawi are unknown though they presumably are in the tropical Americas or in Africa. Both species have been carried around the world by man.

Nothing is known about reproduction in either species. Sperm are matured in bolawi and have been found in the spermathecae but parthenogenesis (possibly facultative) would not be entirely unexpected.
SPARGANOPHILOIDAE

*Sparganophilus* Benham, 1892

*Sparganophilus* sp.

The worm is 148 mm long. The length is much greater than that of any other earthworm from caves of the United States. Immaturity obviates specific identification. The species is likely to be *S. eiseni* Smith, 1895, which is endemic in the United States. No species of *Sparganophilus* has been reported from caves hitherto.

ALABAMA – Weaver Cave, Weaver, September 1931, 0-1-0, J. M. Valentine per G. E. Pickford.

**References**


