BULLETIN

OF THE

NATIONAL SPELEOLOGICAL SOCIETY

VOLUME TWENTY-ONE PART TWO

Contents:

JULY 1959

THE NATIONAL SPELEOLOGICAL SOCIETY was organized in 1940. It has members throughout the United States and many members in other countries. The Society is associated with the American Association for the Advancement of Science.

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.

THE AFFAIRS of the Society are controlled by an elected Board of Governors. The Board appoints national officers. Technical affairs of the Society are administered by a Research Committee of recognized specialists in professional fields.

LIBRARY: An extensive library on speleological subjects is maintained by the Society. Material is available on loan to NSS members at a nominal charge to defray the cost of handling.

OFFICERS FOR 1959-1960: Brother G. Nicholas, F. S. C., *President;* Donald N. Cournoyer, *Vice President (Administration)*; Thomas C. Barr, Jr., *Vice President (Publications)*; George W. Moore, *Vice President (Research)*; Donald F. Black, *Vice President (Organization)*; Mrs. Barbara C. Munson, *Treasurer*.

BULLETIN
of
THE NATIONAL SPELEOLOGICAL SOCIETY

VOLUME 21, PART 2 **JULY, 1959**

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 36th. N., Seattle, Washington; Thomas C. Barr, Jr., Department of Biology, Tennessee Polytechnic Institute, Cookeville, Tennessee.

Inquiries relating to the publishing of manuscripts in the BULLETIN should be addressed to the editor or assistant editor.

PUBLICATIONS include the BULLETIN published twice a year, the NEWS appearing monthly, and the OCCASIONAL PAPERS. All members receive the BULLETIN and the NEWS.

Office Address:
THE NATIONAL SPELEOLOGICAL SOCIETY
203 VIRGINIA HILLS AVE.
ALEXANDRIA, VIRGINIA

Membership dues in effect January 1, 1959:

Family Associate	$ 2	Sustaining	$ 14
Associate	$ 4	Institutional	$ 10
Regular	$ 7	Life	$140

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 picturesquely ragged 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 *glacieres.* 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 Eno Shima, 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). Irimizu 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 Kozu', 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

Figure 1
Limestone areas of Japan.

to tour is Nippara Cave, 30 miles northwest of Tokyo in Chichibu National Park; this cave is quite small and lacking in speleothems. It is reached by bus from Hikawa on the Ome Railroad line which begins at Tachikawa, a Tokyo suburb. Akiyoshi Cave is equally easy to reach for persons who are able to visit the western end of Honshu.

There are two organizations in Japan concerned with speleology. The Japanese Association for Scientific Research of Caves and Underground Water has its headquarters in the Zoological Institute, Faculty of Science, Kyoto University, Sakyo-ku, Kyoto City. Its President is Masuzo Uyeno who is Professor of Zoology at Kyoto University. Although the Association is made up chiefly of zoologists its interest covers the whole field of speleology. Much of the information on Japanese caves is on file at the Association. Several reports, in Japanese, have been published but the Association has not established a periodical.

The Japanese Association for Quaternary Research includes many members interested in palaeontology and geology of caves. Its headquarters are in the National Scientific Museum of Japan, Ueno Park, Tokyo City. The President is H. Yabe, Professor Emeritus of Geology, Tohuku University, Sendai City. Dr. H. Ozaki, Geologist of the National Scientific Museum of Japan is Secretary. A periodical *The Quaternary Research* is published; the first issue was in 1957. Papers in this journal are in Japanese or English and cover geology, palaeontology, archaeology, climatology and geography of the Quaternary. Professor T. Shikama of the Geological Institute of Yokohama National University, Yokohama City is a leading geologist and palaeontologist of the Association.

Except for data in the guidebook of the Japan Travel Bureau, two distinguished Japanese geologists, Professors Hisashi Kuno and Haruyoshi Fujimoto, supplied the information and maps for much of this introduction. Professor Takahasi furnished the details on the organization of speleology in Japan.

LIMESTONE CAVES OF THE AKIYOSHI PLATEAU OF JAPAN

by EITARO TAKAHASI and MICHIHIRO KAWANO

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 Shimonoseki, on the Sanyo 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 (1923, 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

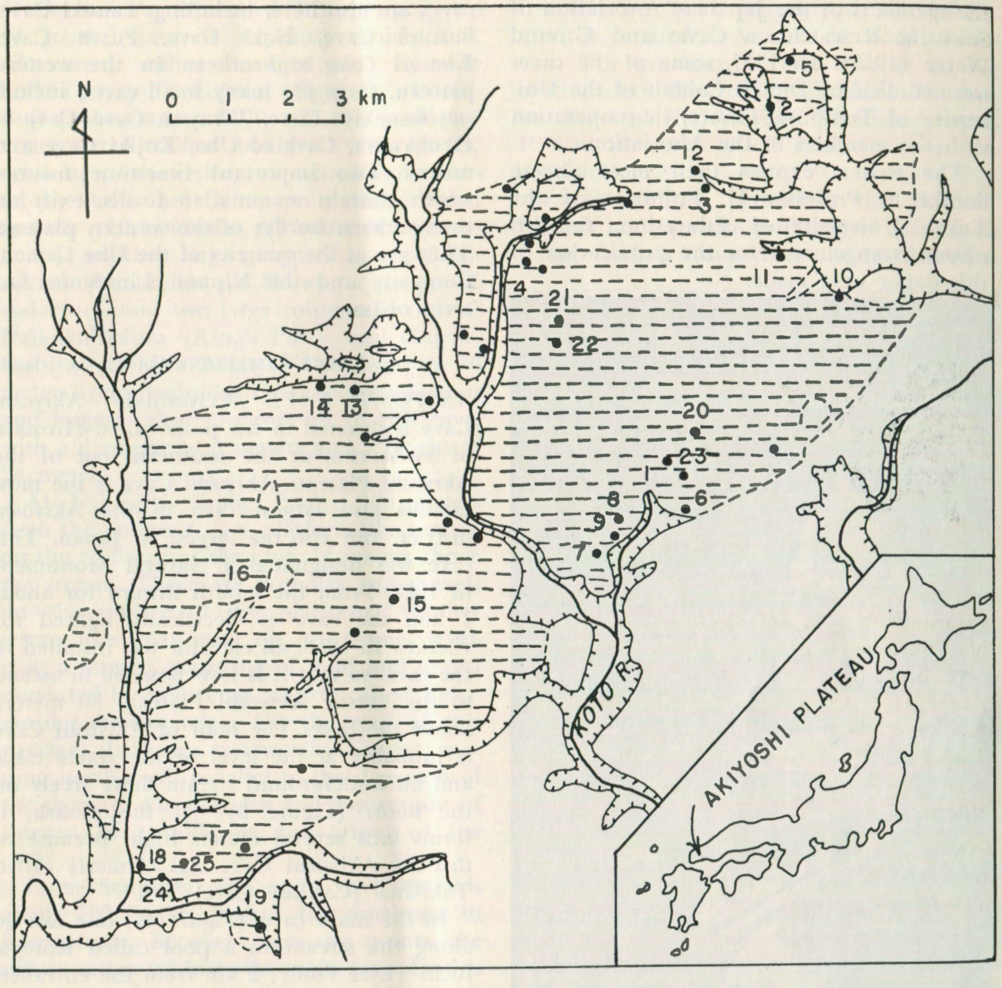

Figure 2
Map of the main caves and fissure deposits in the Akiyoshi district. Dashed lines indicate limestone region. Black dots are localities of main caves. 1. Akiyoshi Cave 2. Kagekiyo Cave 3. Taisho Cave 4. Nakao Cave 5. Misumada Cave 6. Kcmori Cave 7. Cave of Awaya 8. Upper Cave of Mizushima 9. Cave of Mizushima 10. Hakugyo Cave 11. Ryuogu Cave 12. Cave of Oba 13. Kanekiyo Cave 14. Teratama Cave 15. Cave of Uba 16. Cave of Maruyama 18. Kojiki Cave 19. Cave of Maguraji 20. Tanuki Cave 21. Suzume Cave 22. Naki Cave 23. Fusen Cave 24. Limestone quarry of the Ube Cement Co. (fissure deposit). 25. Limestone quarry of the Nippon Sekkai Co. (fissure deposit).

limestone caves of this area were made by the late Professor D. 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.

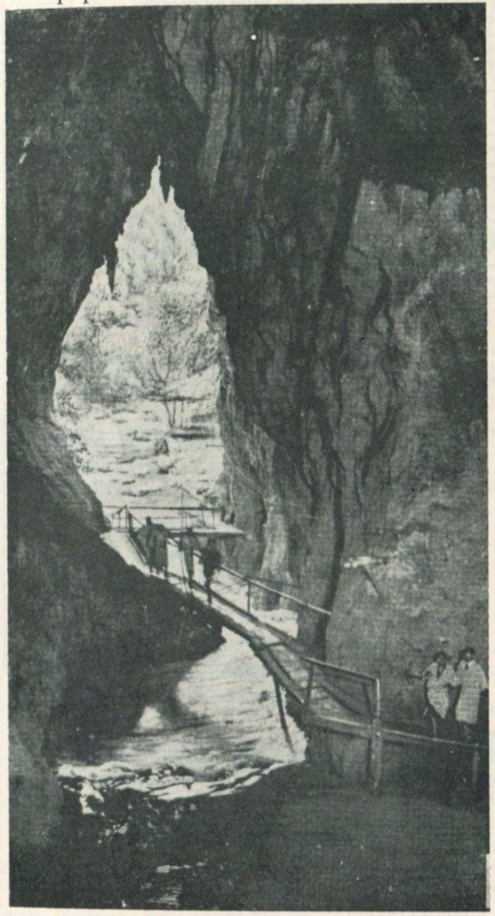

Figure 3
Entrance to Akiyoshi Cave.

The Akiyoshi Plateau is divided topographically by a tributary of the Koto River into east and west parts. In the eastern plateau are four giant caves, designated as Natural Monuments: Akiyoshi, Taisho, Kagekiyo and Nakao Caves. Many smaller caves are also here, including Tanuki Cave, Suzumi Cave, Naki Cave, Fusen Cave, Komori Cave and others. In the western plateau, there are many small caves, including Kanekiyo Cave, Terayma Cave, Cave of Okugawara, Cave of Uba, Kojiki Cave and others. Two important limestone fissures, which contain mammalian fossils, exist on the southern border of the western plateau. They are at the quarries of the Ube Cement Company and the Nippon Limestone factories of Isa.

Large Limestone Caves

AKIYOSHI CAVE (Akiyoshi-do)—Akiyoshi Cave is situated in the polje called Hirotani of Syuho-cho, 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 Kotogafuchi (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 Chimachida (Thousand Paddy-fields), another large group of gours; Kasazukusi (Umbrellas on Show), a group of stalactites; and two large columns known as Daikokubashira (King's Post), and Ohgonbashira (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 Takasanjiki (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 Kotogafuchi. 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.

KAGEKIYO CAVE (Kagekiyo-do)—Kagekiyo Cave is situated at Sayama of Akago, Mito-cho. The entrance of this cave is at the southwestern foot of the Shishide Plateau, northeast of the Akiyoshi Pleateau proper. It was formerly called Akano-ana or Nagaiki-do.

Kagekiyo Cave penetrates the Shishide Plateau and is a continuation of Misumada Cave which is situated on the northeastern

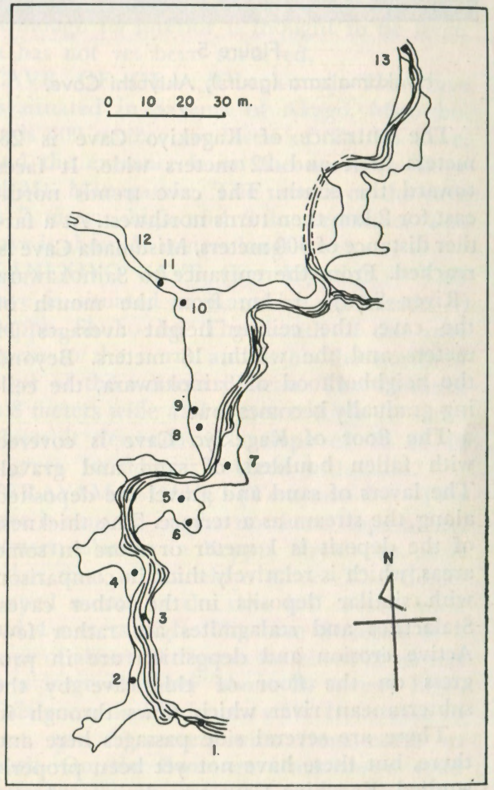

Figure 4

Map of Akiyoshi Cave, 1. Mouth of Cave, 2. Rokujizo, 3. Nagabuti, 4. Hyakumaizara, 5. Donai-Fuji, 6. Chimachida, 7. Kasazukushi, 8. Daikokubashira, 9. Senjojiki, 10. Ohgonbashira, 11. Sarusuberi, 12. Kurotani, 13. Kotogafuchi.

side of that plateau. The water of the Misumada River pours 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.

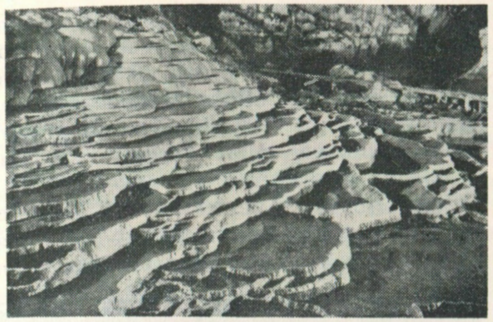

Figure 5
Hyakumaizara (gours), Akiyoshi Cave.

The entrance of Kagekiyo Cave is 26 meters high and 22 meters wide. It faces toward the south. The cave trends northeast 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 floor of Kagekiyo Cave is covered with fallen boulders of sand and gravel. The layers of sand and gravel are deposited along the stream as a terrace. The thickness of the deposit is 1 meter or more in some areas, which is relatively thick in comparison with similar deposits in the other caves. Stalactites and stalagmites are rather few. Active erosion and deposition are in progress on the floor of this cave by the subterranean river which flows through it.

There are several side passages here and there, but these have not yet been properly studied. Kagekiyo Cave was designated as a Natural Monument in 1923.

TAISHO CAVE (Taisho-do)—This cave is situated at Sayama of Akago, Mito-cho, at the foot of the northern slope of Mt. Managatake in the northern part of the Akiyoshi Plateau, 2 km southwest of Kagekiyo Cave. It was designated as a Natural Monument in 1923.

Taisho Cave is the third largest of the Akiyoshi Caves. The large interior chamber was found in 1921. The form of this cave is cubical and irregular. Side caverns at different levels are connected by avens and form a multibranched cave. These have not yet been surveyed. No underground stream is visible, but running water is said to be audible at the bottom of one pit.

The entrance to Taisho Cave opens toward 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 avens.

The Ushikakushi chamber is also connected by a gallery-like passage to a large 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 the 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 (shelfstone) are found at a pond called Hasuike (Lotus Pond). In this pond, cave pearls also exist in large numbers.

NAKAO CAVE (Nakao-do)—Nakao Cave is situated in Aokage, Shuho-cho, 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 360 meters. The vertical entrance chamber is a fossil ponor 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 Hirotani of Shuhu-cho. 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.

UPPER CAVE OF MIZUSHIMA (Mizushimanoueno-ana)—This cave is also situated in Sowa of Akiyoshi, Shuho-cho, on the slopes of the Akiyoshi Plateau. It is 800 meters southwest of Akiyoshi Cave. It is 20 meters long, 1 to 3 meters high and 1 to 7 meters wide. It is a horizontal cave.

CAVE OF MIZUSHIMA (Mizushimano-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 south of Yokono of Akago, Mito-cho. Hakugyo Cave as now known consists solely of several ponors, 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 case 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 the 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.

KANEKIYO CAVE (Kanekiyo-do) — This cave is situated in Kanekiyo of Katada in Beppu, Shuho-cho. 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, Shuho-cho. It is 1 km west of Kanekiyo 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 room is 23 meters wide from east to 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 passage extends west for 25 meters, then turns northwest and becomes narrow.

CAVE OF UBA (Ubaga-ana)—This cave opens toward the east at the dolina of Iwanaga Plateau, Shuho-cho. 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-

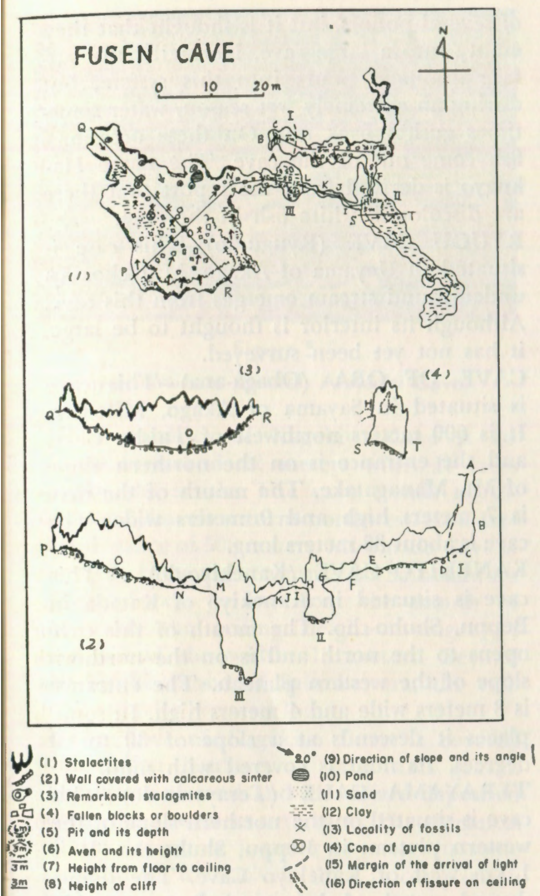

Figure 6
Map of Fusen Cave, (1) Plan of cave, (2), (3), (4) Profiles.

ward the west. Fifty meters from the mouth, there is an exposure of slate. 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 13 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 Yoshinori 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 Isa-Machi, Mine City. The cave is about 150 meters long, 1 to 10 meters high and 1 to 10 meters high. 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 (Suzume-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.

Figure 7
Bacon-like stalactites and stalagmites, north wall of the large chamber in Fusen 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 S45E at about 30 degrees. The slope length is about 20 meters. The width is 10 to 13 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 *Tyannophaedusa*, the fresh-water gastropod *Georissa* and others were collected.

NAKI 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.

Figure 8
Stalactites and stalagmites, part of the large chamber in Fusen Cave.

At a point 17 meters from the entrance is a large chamber which trends northwest-southeast. 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 *Georissa* were collected from the clay 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 *Megaloceras, Cervus, Nyctereutes*, and others. In 1955, G. Okafuji collected in the cave; in 1956, the writers surveyed the cave and collected fossils in cooperation with I. Eto, G.. Okafuji and four others. *Palaeoloxodon aomoriensis* and other fossil mammals were found.

Figure 9
Karrenfelder, Akiyoshi Plateau.

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 S80E 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 S80E 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 ellipsoidal 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.

Geological Institute
Yamaguchi University
Yamaguchi, Japan

REFERENCES

Dell'Oca, Salvatore, 1955 Entita' del Movimento Speleologico nel Mondo: Rassegna Speleologica Italiana, vol. 7, no. 1-2, June, pg. 16.

Ozawa, Y. 1923 Stratigraphic studies of the Upper Paleozoic Chichibu System including the Akiyoshi limestone: Jour. Geol. Soc. Japan, vol. 30, no. 357.

——— 1925 Paleontological and stratigraphic studies on the Permo-Carboniferous limestones of Nagato; Part II, Paleontology: Jour. Coll. Sci., Imp. Univ. Tokyo, vol. 14, art. 6.

Sato, D. 1928, Karst of Akiyoshi Plateau: Reports of the Natural Monuments, Section of Geology and Mineralogy, no. 3.

Takahasi, E. and Kawano, M. 1957 Reports on the survey of Tanuki-ana, Suzume-ana, Naki-ana and Fusen-ana in the Akiyoshi Plateau: Reports on the Scientific Survey of Akiyoshi Plateau, Board of Education, Yamaguchi Prefecture.

Toriyama, R. 1954a Geology of Akiyoshi, Part I. Studies of Akiyoshi Limestone Group: Mem. Fac. Sci., Kyushu Univ., Ser. D, Geology, vol. 4, no. 1.

Toriyama, R. 1954b Geology of Akiyoshi, Part II. Stratigraphy of the non-calcareous groups developed around the Akiyoshi Limestone group: Mem. Fac. Sci., Kyushu Univ., Ser. D, Geology, vol. 5, no. 1.

Toriyama, R. 1958 Geology of Akiyoshi, Part III. Fusulinids of Akiyoshi: Mem. Fac. Sci., Kyushu Univ., Ser. D., Geology, vol. 7.

Japanese Association of Scientific Research of Caves and Ground Water 1957 Brief report on synthetic study of Japanese caves, I. Akiyoshi District: Biological Institute, Kyoto Univ.

The Land of the Burnt Out Fires
Lava Beds National Monument, California

by RAYMOND G. KNOX

With notes on geology and cave life by RICHARD T. GALE

Lava Beds National Monument encompasses part of the largest pseudokarst area in the United States. In its 46,238 acres are 293 lava tubes and caves. The tubes are up to 98 feet in diameter, and up to a mile long; several are multilevel. Floors of the large tubes have uniform slope; many have a rough clinker floor. Access to the tubes is through collapse sinks. Seven major caves in the monument contain ice that lasts throughout the year. Pleistocene fossils as well as archeological material have been recovered from the caves. Historically the lava fields are known as the site of the Modoc Indian war 1872-1873 when the Indians made use of the pseudokarst features for strong defense emplacements.

Lava Beds National Monument is located in extreme northern central California in Siskiyou 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 bear 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

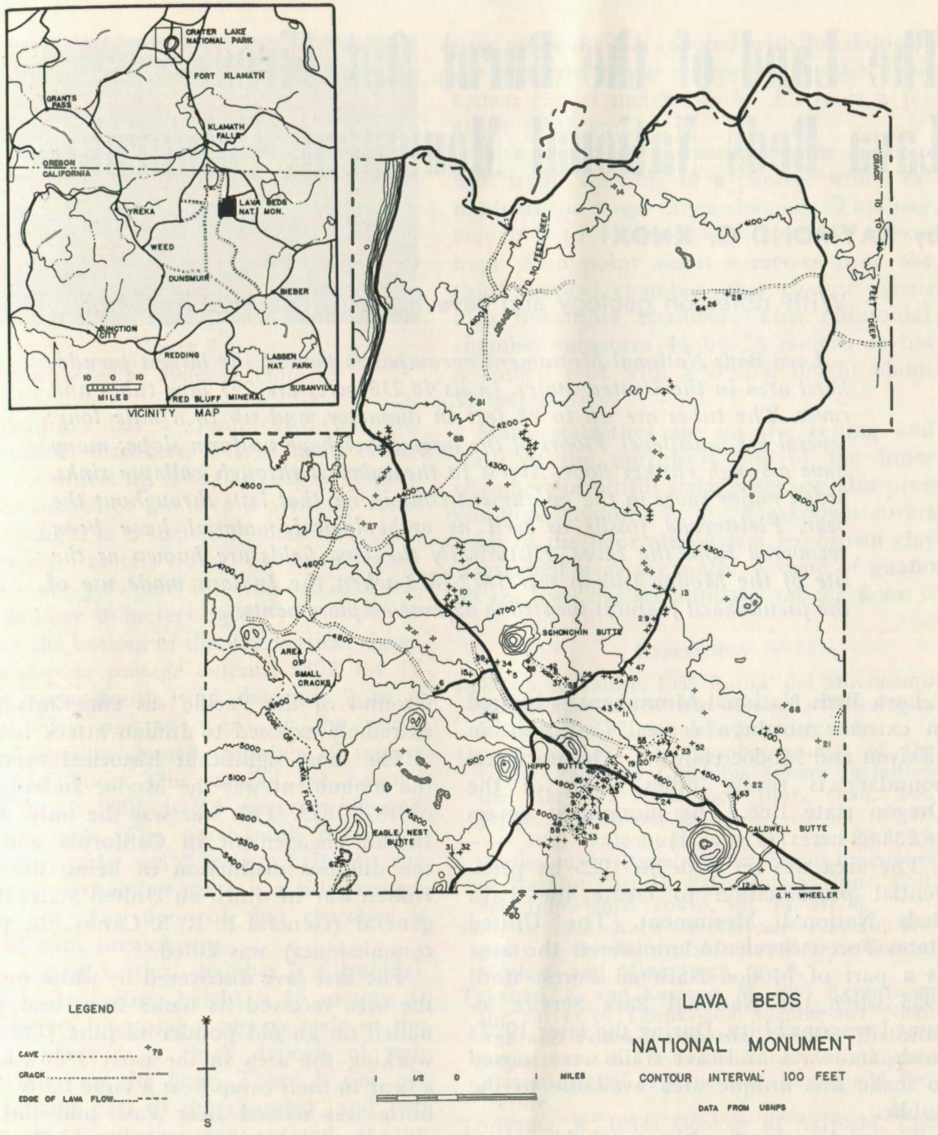

Figure 1

Map of Lava Beds National Monument

Major caves of Lava Beds National Monument

1. Angleworm, 2. Arch, 3. Balcony, 4. Bat, 5. Beaconlight, 6. Bearpaw, 7. Berthas Cupboard, 8. Big Painted, 9. Blue Grotto, 10. Boulevard, 11. Bowers, 12. Caldwell Ice, 13. Captain Jacks Ice, 14. Captain Jacks, 15. Castle, 16. Catacombs, 17. Chest, 18. Compound Bridge, 19. Coopers, 20. Cox Ice, 21. Craig, 22. Crawfish, 23. Dragon Head, 24. Dynamite, 25. Fern, 26. Flat Arch, 27. Fleener Chimneys, 28. Fossil, 29. Frozen River, 30. Garden Bridge 31. Heppe, 32. Heppe Chimney, 33. Hercules Leg, 34. Igloo, 35. Incline Cavern, 36. Indian Well, 37. Irish Bridge, 38. Juniper, 39. Kirk White's, 40. Labyrinth no. 1, 41. Labyrinth no. 2, 42. Little Painted, 43. Lost Pinnacle, 44. Mahogany, 45. Maze, 46. Mushpot, 47. North Bend, 48. Ovis Bridge, 49. Post Office, 50. Rock, 51. Ross Chimneys, 52. Schonchin, 53. Sentinel, 54. Ship Cavern, 55. Silver, 56. Skull, 57. Stinking, 58. Sunshine, 59. Symbol Bridge, 60. Tecnor, 61. Trapper, 62. Upper Ice, 63. Valentine, 64. Wedding Cake, 65. White Lace, 66. Wild Cat, 67. Winemas Chimneys, 68. Wright Chimneys.

one worried about the cause and preservation of the huge ice pendents. They were just something to give off a musical tingle as the picnickers 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. he 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 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 obstructed openings. The caves made available to the public today are generally entered through

Photo by William R. Halliday

Figure 2

Entrance to Lower Caldwell Cave.

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 flow rate very slow, pavement-like floors similar to those in Boulevard Cave were created. Slow cooling with a constant level made a very smooth floor. The terrace or cornice-like formations of nearby Balcony Cave indicate partial cooling with frequent changes of flow level. As cooling progressed inward from the edge, varying widths of terraces were created.

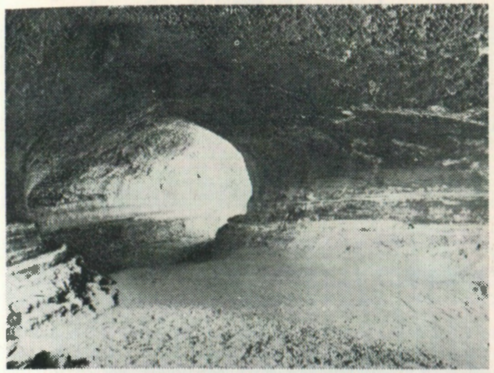

Figure 3
Valentine Cave, curb and terrace along walls mark a former lava level.

Valentine Cave presents varied examples of rates of flow level cooling. Just inside the entrance are found curbing-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 certain walls. At the center is a depressed, gutter-like formation.

In Golden Dome Cave, the large ropy 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 ripples resemble those found in marsh mud flats.

The clinker-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 a 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 (¼″ to ¾″) and project ½″ to 1½″ from the wall are defined as projecting ribs. 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.

Photo by Eastman's Studio

Figure 4
Clinker surfaced gutter with a lava terrace bordering it.

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 whole sections of wall pulled away from the original crust. This occurred in Merrills Ice Cave. Here, too, there are variations in color–a dark gray inner wall of basalt contrasting to an outer redstained 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, acted upon by 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 tubes.

It is difficult to find continuous single 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 belling 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 crater-like opening in one of the side passages, 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, clinker-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 opal. Variations in color enhance this formation. In Fern Cave, a sulphur-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 portions.

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 redstained 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.

Photo by Eastman's Studio

Figure 5

Fern Cave, pictographs.

Cave Atmosphere

Atmospheric pressure changes, as well as temperature fluctuations, cause movement of air within the caves. Of lesser importance is the effect of wind entering one entrance and passing out another. In only a few caves is the latter possible as the majority have a single restricted entrance. The greatest air exchange in the caves occurs during the winter months. The cold heavier air displaces the lighter warmer air of summer trapped in the caves. Atmospheric breathing, the result of changing air pressure either drawing air into caves or forcing it out, accounts for most of the air exchange during the warm months. Because the interior of the cave is insulated from solar heat air temperatures are approximately 15 to 25 degrees cooler than outside air temperatures. Even during August one finds Merrill Ice Cave uncomfortable without a light jacket. Crystal Cave has a below-freezing temperature the year round.

Fern Cave, with a circular opening in the ground crust, is protected to a certain degree from wind currents. During the winter months the sun's angle allows some rays to create a warm micro-climate near the entrance. Here the warm, moisture-laden air rising from the cave condenses above the opening producing the humid conditions necessary for coastal ferns.

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 Homestead 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 confining 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. On both walls 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 fluctuating 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 of 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 in 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 haunt. 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 Superintendent Don C. Fisher, Lava Beds National Monument; his aid is gratefully acknowledged. Photographs were supplied by J. H. Eastman, Eastman Studio, Susanville, California, Dr. William R. Halliday, Seattle, Washington and the University of California.

References

Anderson, Sumner M., Lewis, J. Volney, 1936 Lava Beds National Monument, Outline of Geology: unpublished manuscript.

Crouch, J. Carlisle, 1935 Preliminary archeological reconnaissance, Lava Beds National Monument: unpublished manuscript.

Cressman, L. S., 1940 Report of archeological reconnaissance, Lava Beds National Monument: unpublished manuscript.

Howard, J. D., Personal diary of the Lava Beds: unpublished manuscript.

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 ryholitic-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, sometimes as high as twenty percent. Small amounts of iron oxide are common (Lewis and Anderson 1936).

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 step 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 into modern times and the exact time of the camel's disappearance from this area has not been determined. Only a rough estimate of the age of the flow is possible; it is thought to be between twenty thousand and sixty thousand years old (Lewis and Anderson 1936).

The oldest flow is the Juniper Butte flow, which is estimated to be up to 60,000 years. Later flows from Caldwell, Hippo, Schonchin, Mammoth Crater 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 confining 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.

* There is a difference in terminology in referring to lava flows. It has been the custom to refer to lineal vents of the flows as rifts. Stearns (1928) suggests that trench is a better word, as rift is commonly used to refer to a fault structure.

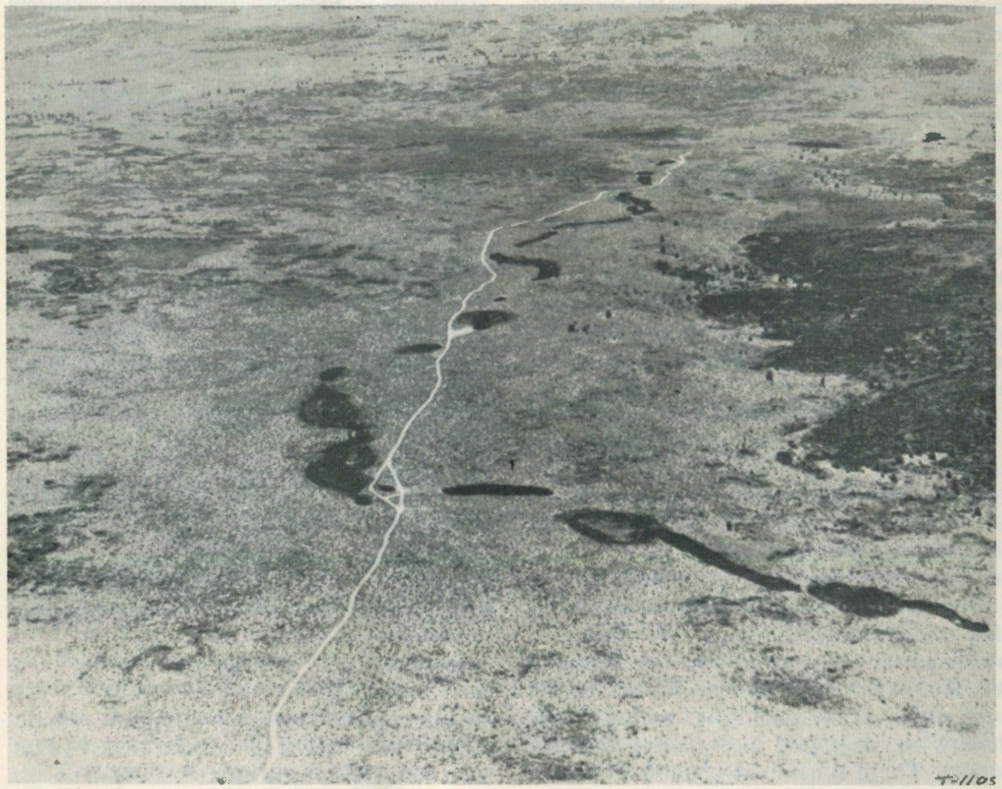

Photo by Eastman's Studio

Figure 6

Aerial view of a portion of Lava Beds National Monument. Sinuous dark areas along road are trenches. Dark area on right is the Schonchin Lava Flow.

Cave floors exhibit a variey 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 two level cave. 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 "lavacicles." 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 exceptionally 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 considerable 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.

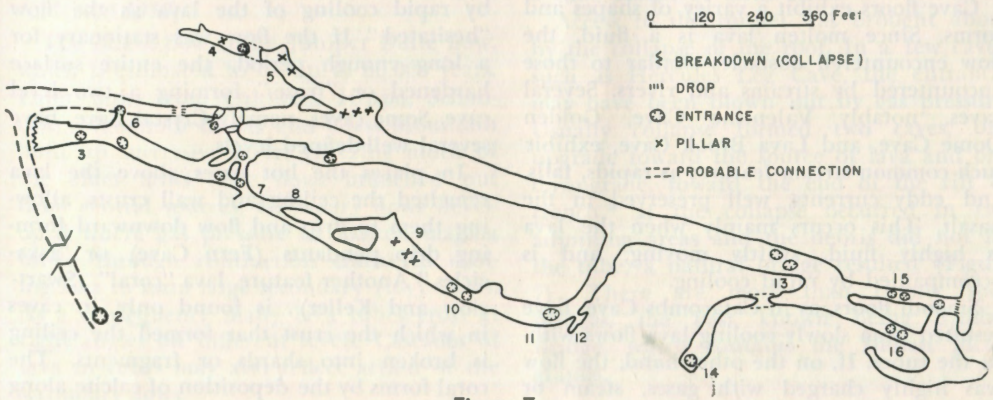

Figure 7
Map of a lava tube complex; modified from S. D. Howard's map 1920. (1) Natural Bridge, (2) Sentinel Cave, (3) Juniper Cave, (4) Sunshine Cave, (5) The Witches Chamber, (6) Hercules Leg Cave, (7) Blue Grotto Cave, (8) Pop Corn Chamber, (9) Balcony Chamber, (10) Golden Dome Cave, (11) Mitertyte Cave, (12) Pool of water, (13) Lava Brook Cave, (14) Muspot Cave, (15) Thunderbolt Cave, (16) Labyrinth Cave.

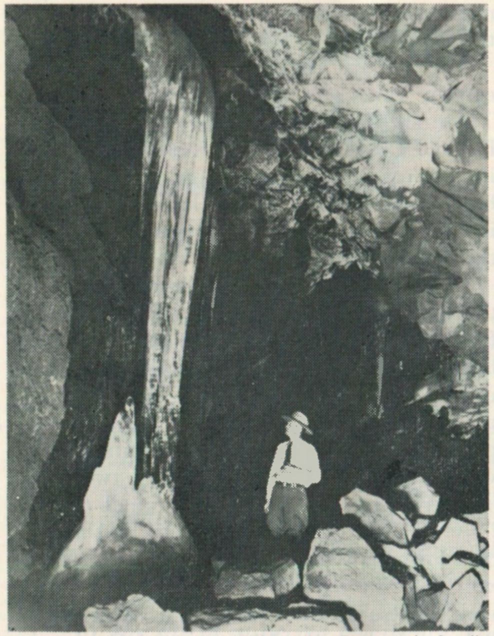

Photo by Eastman's Studio
Figure 8
Crystal Cave, ice pendant.

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 two 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 huge mound 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 1936). 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 transluscent 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. Heppe Cave, one of the very few ice caves with two entrances, faces west and east. The ice in Heppe 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 bats. In Blue Grotto Cave, Long-Eared bats (*Corynorhinus rafinesquii*) are fairly common. The western *Pipistrellus* has been observed in Coxs Ice Cave, Sentinel Cave, and Juniper 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 skelton of a 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 skeltons 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 molar) of a camel (*Camelops* sp?), portions of two teeth and a part of a lower jaw of a young mastodon (*Mammut americanum*), and a tooth of a carnivore. These fossils are in the Museúm of Paleontology at the University of California (Lewis and Anderson 1936).

University of Oklahoma
Norman, Oklahoma

References Cited

Harrington, E. R. 1934 The origin of ice caves: Jour. Geol., vol. 42, no. 4, May-June, pp. 433-436.

Lewis, J. V. and S. M. Anderson 1936 Lava Beds National Monument, Outline of geology.

Peacock, Martin A. 1931 The Modoc Lava Field, Northern California: Geographical Review, vol. 21, no. 2, April, pp. 259-275.

Powers, H. A. 1932 The lavas of the Modoc Lava Bed Quadrangle, California: Amer. Mineralogist, vol. 17, no. 7, July, pp. 253-294.

Stearns, H. T. 1928 Lava Beds National Monument: Bull. Geog., Soc., Philadelphia, vol. 26, no. 4, Oct., pp. 239-253.

Swartzlow, C. R. and W. D. Keller 1937 Coralloidal opal: Jour. Geol., vol. 45, no. 1 ,Jan.-Feb., pp. 101-108.

Swartzlow, C. R. 1935 Ice caves in northern California: Jour. Geol., vol. 43, no. 4, May-June, pp. 440-442.

Swartzlow, C. R. 1934 The Lava Beds National Monument: Compass, Sigma Gamma Epsilon, vol. 15, no. 1, November, pp. 17-24.

Evaluation of Ground Water Tracing Methods Used in Speleology

by JOHN L. HAAS, JR.

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 coconut charcoal. The dye is then leached from the charcoal by an 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.

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

Limestones and dolomites are generally very dense and do not appear to contain visible primary openings other than minute openings at bedding planes. The principal openings are secondary and consist of numerous fractures, joints, and a few faults which originate during uplift and folding of the strata.

In permeable sandstone and loose sands and gravels, the water filters through the bed as if passing through a sieve. 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, underneath 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 (NH_4Cl) 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 Tracers

Dyes have been used extensively in underground water tracing because of their detectibility 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.

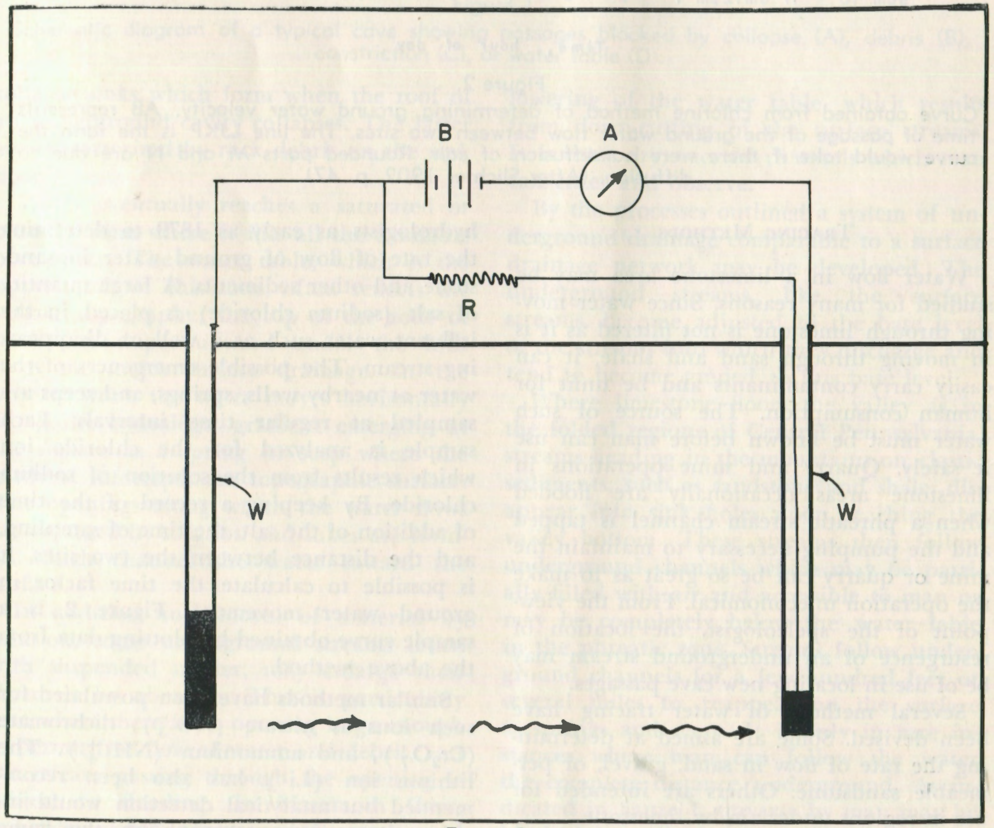

Figure 3
Diagram illustrating the electrical method of determining the horizontal velocity of ground water. The movement is suspected along the direction of arrow. The upstream well is charged with an electrolyte. The gradual motion of the electrolyte toward the lower well and its final arrival at that well are registered by the ammeter (A). B is the battery; R is a suitable resistance; and W is the well casing. (After Slichter 1902, p. 48)

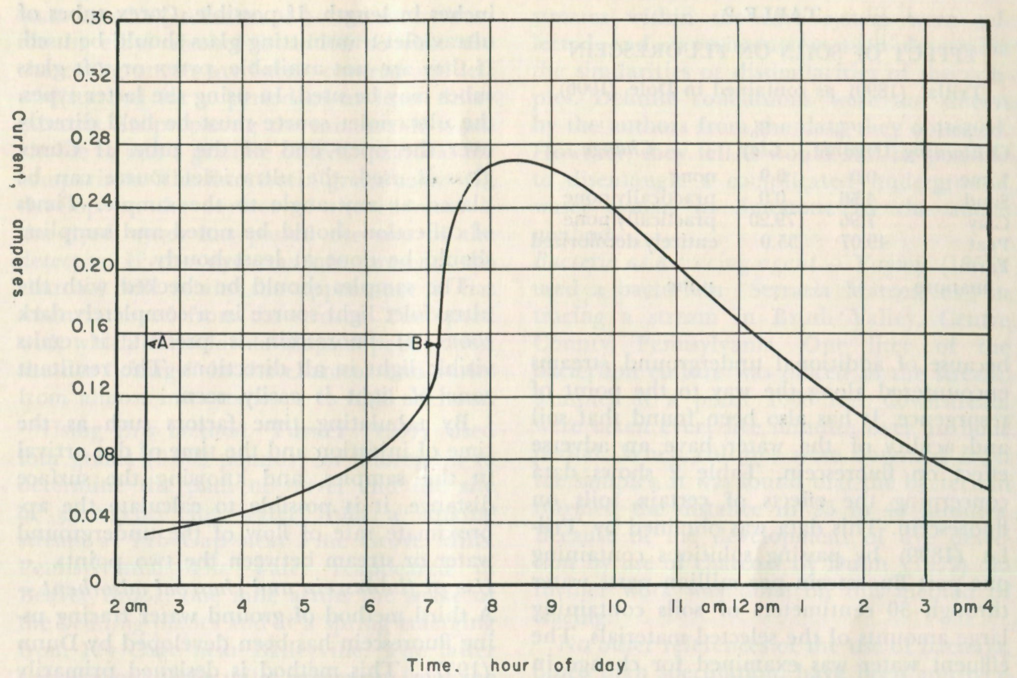

Figure 4
Curve obtained by electrical method of determining velocity. AB represents time of passage of electrolyte between wells. (After Slichter 1902, p. 49)

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 Carrieres used fluorescein to prove the origin of contaminated water during a severe typhoid epedemic 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 1
DETECTABLE DILUTIONS OF SOME COMMON DYES IN PARTS PER MILLION (ppm)
Dole (1906) and Plummer (1945)

Substance	*Color*	*Dilution*
Fluorescein	yellow-green	0.0042
Eosin	red	0.5
Analine	red and green	1.0

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

TABLE 2

EFFECT OF SOILS ON FLUORESCEIN

Trillat (1899) as contained in Dole (1906)

Soil Containing	*% Organic*	*% Clay*	*Change*
Lime	0.0	6.9	none
Sand	4.56	0.0	practically none
Clay	7.96	79.20	practically none
Peat	49.07	35.0	entirely decolorized
Farm manure	—	—	none

because of additional underground streams encountered along the way to the point of resurgence. It has also been found that soil and acidity of the water have an adverse effect on fluorescein. Table 2 shows data concerning the effects of certain soils on fluorescein. This data was obtained by Trillat (1899) by passing solutions containing one part fluorescein per million parts water through 30 centimeters of soils containing large amounts of the selected materials. The effluent water was examined for change in color intensity and the results listed. It was noticed that sand, lime, clay materials, and ammonical organic matter had little effect on the color intensity of the fluorescein solution. However, peaty soils attacked the fluorescein and rendered it colorless.

In another experiment, Trillat found a color intensity decrease of about one-third when a solution was in contact with calcium carbonate for a period of 24 hours. In other work, fluorescein was found to be unaffected by free carbonic acid, but rendered colorless by acetic acid and mineral acids.

Use of fluorescein and ultraviolet light source — When exposed to a light strong in the ultraviolet wave lengths, fluorescein appears an intense yellowish green. By use of this property, it is possible to detect fluorescein in dilutions as low as one part in 40 billion. Using this property of fluorecein, Kent (1950) recommends a solution of about one pound of dye per thousand gallons of water per mile of underground travel. The dye is dissolved in a lye solution of water and then placed into the water being traced. Samples of water taken at expected emergences or springs are collected in test tubes one inch in diameter and 12 inches in length. If possible, Corex tubes of ultraviolet-transmitting glass should be used. If they are not available, pyrex or soft glass tubes may be used. In using the latter types, the ultraviolet source must be held directly over the open end of the tube. If Corex glass is used, the ultraviolet source can be placed at any angle to the sample. Times of collection should be noted and sampling should be done at least hourly.

The samples should be checked with the ultraviolet light source in a completely dark room. If fluorescein is present, it emits visible light in all directions. The resultant zone of light is easily seen.

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 approximate rate of flow of the underground water or stream between the two points.

Use of fluorescein and charcoal adsorbent — A third method of ground water tracing using fluorescein has been developed by Dunn (1957). This method is designed primarily for tracing water in cavernous areas. It consists of detection of fluorescein in water by use of super adsorbent charcoal. The charcoal 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, retained the dye for a period of six weeks. (Dunn, personal communication).

A few granules of the charcoal can be removed from the package at regular time intervals 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 packet.

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 hydroxide 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 advisable 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 depends upon the dye "charge" in the charcoal and varies from almost instantaneous to half an hour.

Using this method, Turner (1957) used four grams (0.009 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 southwest from the sink at 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. However the time which elapsed between placement 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 (0.0026 pounds) could be detected in Spruce Creek after a flow of 14.4 miles from the site of addition.

The amount of dye recommended for use with this method is about ten grams (or 0.022 pounds) per thousand gallons of water per minute per mile of probable underground travel.

Bacteria

Bacteria analysis and stream correlation — In performing experiments on contamination of stream waters in the Milroy Cave System, Milroy, Pennsylvania, Voysey and Rumbaugh (1956) attempted to determine if streams of water in the area were related by examining bacteria present. Samples of water from the surface stream and three streams within the cave system were collected and experiments run to determine the similarities or dissimilarities of the samples. 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 the 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 detection by use of charcoal by Dunn (1957) no further work was done on this method of tracing.

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

Radioactive Tracers

Of late, radioactive tracers have been used by petroleum geologists and hydrologists to trace movement of liquids through a permeable 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 regular time intervals, usually every half hour, depending 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-salt tracers — Several elements have been used for this purpose. Salts of tracers such as radioactive iodine-131 and bromine-82 may be used without additional preparation. 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 deLaguna (1956), 250 milliliters of aqueous solution containing 10 milligrams of versene and 2.5 microcuries of cobalt-60, antimony-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 within the shale bed through which the liquor was passed. This indicates that it may be possible to use radioactive 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 physical properties which differ slightly from common water. Among them 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 Finkelshtein *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 Orlob (1956) added to the above standards, one 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 a further requirement be 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 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 spectrograph or flame photometer is an expensive piece of equipment and usually not available to the people 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 disappearing 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-lye solution and another to sample the resurgence.

Use of fluorescein and charcoal adsorbent — Of the methods described in literature, this requires the least 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.

The person placing the charcoal packets in the stream should be instructed to place them in that portion of the stream where the velocity is greatest, unless this is impossible.

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.

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

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 prohibitive pricewise. 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.

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.

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.

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.

References

Carpenter, P. G., Morgan, T. D., and Parsons, E. D. 1952 Use of boron compounds as flood water tracers: Producer's Monthly, vol. 16, no. 10, pg. 12.

des Carrieres, D. 1882 Etiologie de l'epidemic typhoide qui a eclate a Auxerre en septembre 1882: Soc. Mid. des Hopitaux de Paris, Bul. et Mem., 2d ser., vol. 19, pp. 277-286.

Pennsylvania State University
University Park, Pennsylvania

Dole, R. B. 1906 Use of fluorescein in the study of underground waters: U. S. Geol. Survey, Water Supply Paper 160, pp. 73-85.

Dunn, J. R. 1957 Stream tracing: Mid-Appalachian Region, National Speleological Soc., Bull. 2, pg. 7.

Finkelshtein, Ya. B., Filonov, V. A., Soyfer, V. N., and Obukhova, M. P. 1957 Use of tritium as an indicator in the study of the dynamics of ground water: Proc. of Acad. Sci., USSR, Geol. Sci. Sect., vol. 116, no. 4, pg. 671, (Eng. translation by Consultants Bureau, pg. 867).

Kaufman, W. J. and Orlob, G. T. 1956 Measuring ground water movements with radioactive and chemical tracers: Amer. Water Works Assn. Jour., vol. 48, pp. 559-572.

Lacey, W. J., and deLaguna, W. 1956 Method of preparing radioactive cations for tracing ground water: Science, vol. 124, pg. 402.

Meinzer, O. E. 1934 The history and development of ground water hydrology: Wash. Acad. Sci. Jour., vol. 24, no. 1, pg. 25.

Meinzer, O. E. and Wenzel, L. K. 1942 Movement of ground water and its relation to head, permeability and storage: in Meinzer, O. E., *Hydrology*, Dover Publications, Inc., New York.

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

Slichter, C. S. 1902 The motions of underground waters: U. S. Geol. Survey, Water Supply Paper 67, pp. 48-51.

Trillat, A. 1899 Sur l'emploi des matieres colorantes pour la recherche de l'origine des sources et des eaux d'infiltration: Acad. Sci. Paris Comptes rendus, vol. 128, pp. 698-700.

Turner, T. D. 1957 Stream dyeing: Nittany Grotto Newsletter, National Speleological Soc., vol. 5, no. 8, pg. 11.

Turner, T. D. 1957 Stream tracing: Nittany Grotto Newsletter, National Speleological Soc., vol. 5, no. 9, pg. 1.

Voysey, B. 1957 *Serratia Marcescens*: Nittany Grotto Newsletter, National Speleological Soc., vol. 5, no. 8, pg. 18.

Voysey, B. and Rumbaugh, D. 1956 A bacteria analysis of Milroy Cave water: unpublished manuscript, Jan. 1, 1956.

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 caves, 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 (Giovannoli 1933, 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 (Cernosvitov 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 pheretimas, 6 diplocardias) to the Megascolecidae, 1 to the Sparganophilidae. Most of the worms that were identified as to species, 115 of 136 (Table 1) 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 exotics, as in many epigeal 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

* 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.

** 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. heimburgeri* and *welchi* are known only from the original descriptions. Little or nothing is known about the earthworms of large areas in the United States and Canada.

lacking as to adequacy of the sampling in any of the American caves. Castings do indicate earthworm activity but may be unrecognizable or even absent on the surface when some worms are present. Whether endemics have disappeared, during the last 26 or 27 years, in Weaver, Crystal and English caves and whether exotics subsequently have become established in any of the four caves from which only natives were secured, can be learned.

Introduction of exotics and especially of the Lubricidae, supposedly "a recently evolved and dominant group which possesses great power of adaptation to new surroundings" (Stephenson 1930, pg. 905), long has been thought to "cause" disappearance of the endemic earthworm fauna. The evidence usually cited in support of that thesis is presence of peregrine lumbricids and absence of endemics in several regions that were investigated early in the present century. At that time the earthworm habitats already had been disturbed by agricultural and other human activities for many years. If natives are haemerophobic, as now seems likely, they may have been destroyed by man before a competitive struggle with introduced earthworms could have gotten well under way. The exotics, still being transported to every quarter of the globe, certainly cannot be haemerophobic and many must be more or less haemerophilic. An ability to withstand, even to profit by, human activity now seems, especially for a score of lumbricids and a dozen pheretimas, to be much more significant than phylogenetic youth or unusual power of adaptation to new surroundings. If then hypogeal sites are less disturbed by man than the epigeal habitats of surrounding territory, information should be obtainable from some of our caves as to what really happens when introduced lumbricids meet native lumbricids, when peregrine megascolecids encounter endemic megascolecids, when exotic lumbricids meet exotic megascolecids and especially of *Pheretima,* the genus "which appears to have the power of conquering large territories and holding them for itself alone" (Stephenson 1930, pg. 673).

Parthenogenesis, more recently, has been thought to favor colonization of new areas. However, in Maine, where all earthworms are exotic, the common species of ordinary soils (Gates, in MS) are, with one exception, those with obligatory biparental reproduction. *E. rosea,* 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 of strains that mature and exchange sperm. Moreover, a single specimen of a sexual species also can found a new colony, if copulation is completed prior to transportation, for cocoon deposition, after the spermathecal battery has been charged with sperm, 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 (+1?) of the 136 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 hypogeal 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.

WEST VIRGINIA — Justice Arbuckle Cave, Lewisburg, March 11, 1931, 0-0-1. J. M. Valentine per G. E. Pickford.

TABLE I

EARTHWORM SPECIES OF CANADA AND UNITED STATES EAST OF THE PACIFIC COAST STRIP

Species			Number of specimens secured from caves
Lumbricidae			
Allolobophora	*chlorotica*	ES	1
	limicola	ES	
	longa	ES	
	muldali	ES?	
	trapezoides	EP	7
	tuberculata	ES	
	turgida	ES	3
Bimastos	*heimburgeri*	NP?	
	longicincta	NP?	
	palustris	NS	
	parvus	NP	
	tumidus	NP	14
	welchi	NP?	
	zeteki	NP	
Dendrobaena	*mammalis*	ES	
	octaedra	EP	
	rubida	ESP	45
Eisenia	*carolinensis*	NS	
	foetida	ES	10
	hortensis	ES	
	lonnbergi	NS	
	rosea	EP	28
Eiseniella	*tetraedra*	EP	
Lumbricus	*castaneus*	ES	
	festivus	ES	
	rubellus	ES	
	terrestris	ES	
Octolasium	*cyaneum*	EP	
	lacteum	EP	13
Ocnerodrilidae			
Ocnerodrilus	*occidentalis*	EP	
Megascolecidae			
Microscolex	*dubius*	EP	
	phosphoreus	EP	
Pheretima	*agrestis*	EP	
	bicinta	EP	
	californica	ES	
	diffringens	EP	8
	hawayana	ES	
	hilgendorfi	EP	
	hupeiensis	EP	
	levis	EP	
	morrisi	ES	
	rodericensis	ES	
Diplocardia	sp.[1]	NS	6
Sparganophilidae			
Sparganophilus	sp.[2]	N ?	1
Glossoscolecidae			
Pontoscolex	*corethrurus*	EP	
Eudrilidae			
Eudrilus	*eugeniae*	ES	

E = exotic.
N = native.
? = reproduction unknown.
S = reproduction sexual and biparental.
P = reproduction parthenogenetic.
S ? = possibly sexual but with facultative parthenogenesis
P? = possibly parthenogenetic.
SP = reproduction sexual but with option of parthenogenesis in some strains, parthenogenetic 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 use in the discussion fifteen are assumed to be good.

[2] *Sparganophilus eiseni,* for some time, has been the only recognized species in the eastern part of North America.

Allolobophora trapezoides (Duges, 1828)

A. trapezoides 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 Snedegar Cave, West Virginia, is damaged in a critical region and is not identifiable anatomically.

In a specimen from Snedegar 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 tumescences, enables identification.

ARKANSAS – Diamond Cave, south of Jasper, at spring, May 1, 1955, 0-0-1, Ottys 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, 1935, 0-0-1, J. M. Valentine per G. E. Pickford. Crystal Cave, Monteagle, March 4, 1932, 0-1-0, J. M. Valentine per G. E. Pickford; WEST VIRGINIA – Snedegar Cave, Pocahontas County, June 24, 1932, 3 specimens, A. M. Reese (U.S.N.M.)

Allolobophora turgida Eisen, 1873

Not previously recorded from caves. This species long has been confused with *trapezoides*. 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 *turgida*. 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, (?)-0-3, J. M. Valentine per G. E. Pickford. (Several unidentifiable juveniles may be of the same species).

Bimastos Moore, 1893

Bimastos tumidus (Eisen, 1874)

Male tumescences, conspicuous, confined to median half of *BC* in xv. Clitellum, on xxi-xxx (2 specimens from English Cave and 1 from Field Cave), (xxi?) xxii-xxx (2 from English Cave), xxii-xxix (2 from Wonder Cave), xxii-xxx (2 from English Cave, 1 each from Wonder, Gilly's, Crystal and Field Caves).

Gizzard muscularity extends only slightly behind insertion of septum 17/18. Extra-esophageal trunks, recognizable only in one worm, pass up to dorsal trunk in x. Hearts, all blood-filled, are present only in vii-xi (13 specimens). Male gonoducts sinuous just behind funnel septa, or loosely looped, or with one or two short loops bound closely together. Atrial glands prominent, in median half of *BC*, with transverse equatorial clefts, each half subdivided by a shallower transverse cleft in which septum 14/15 or 15/16 may have been inserted on the parietes. A slight glistening on male funnels and in male gonoducts of one worm may be due to presence of a very few mature sperm.

B. tumidus, which had not been recorded hitherto from caves, is one of the few lumbricids that are endemic in America. Method of reproduction is unknown but parthenogenesis is suspected.

VIRGINIA – Field Cave, Lebanon, August 1931, (1?)-1-2, J. M. Valentine per G. E. Pickford. (The juvenile, because of immaturity, is unidentifiable even generically. However, contra-indications to the suggested identification are lacking). Gillys Cave, Pennington Gap, August 1931, 0-0-1, J. M. Valentine per G. E. Pickford; TENNESSEE – Crystal Cave, Monteagle, March 4, 1932, 0-0-1, J. M. Valentine per G. E. Pickford; English Cave, Powell River, Cumberland Gap, March 14, 1932, 0-0-6, J. M. Valentine per G. E. Pickford; Wonder Cave, Monteagle, March 1932, 0-0-3, J. M. Valentine per G. E. Pickford.

Dendrobaena Eisen, 1874

Dendrobaena rubida (Savigny, 1826)

Helodrilus tenuis, Giovannoli, 1933, Amer. Midland Nat. 14, p. 622, Mammoth Cave, Kentucky.

Most of the adults probably are of an athecal morph (A) formerly known as *Bimastos tenuis* but are too soft to stand the handling required in determining presence or absence of spermathecal pores. Spermathecae are lacking in specimens from Alabama and Tennessee caves that were dissected. An exceptional specimen, from the coal mine, is of a thecal morph with a pair of spermathecae in x. Sperm had been matured sparsely in that worm. Brilliant iridescence on male funnels of an athecal worm from Dunbar's Cave indicated profuse maturation of sperm. Other dissected specimens probably are male sterile.

Previously recorded, often as *D. subrubicunda, Helodrilus* or *Bimastos constrictus* or *tenuis*, from caves of Germany, Belgium, France, Switzerland, Italy, Jugoslavia, Czechoslovakia, Hungary, Bulgaria, Greece, England, and from mines in France. Many more cave records of *D. rubida* have been published than for any other earthworm.

The species is of European origin and was brought to America by man.

Parthenogenesis is thought to be facultative in a thecal morph that usually has been known as *subrubicunda*. Reproduction may occasionally be sexual in individuals of bithecal and athecal morphs that still mature sperm profusely.

ALABAMA – Manitou Cave, Fort Payne, September 1931, 1-1-4, J. M. Valentine per G. E. Pickford; Weaver Cave, Weaver, September 1931, 0-1-1, J. M. Valentine per G. E Pickford; KENTUCKY – Mammoth Cave, Cave City, near "Minervas Dome", July 30, 1929, 0-3-0, L. Giovannoli (U.S.N.M.); near "Dead Sea", July 19, 1929, (?)-0-7, L. Giovannoli (U.S.N.M.). Several juveniles probably are of the same species as the adults with which they were found; Hidden River Cave, Horse Cave, June 26, 1937, 0-0-1, K. Dearolf (U.S.N.M.); MISSOURI – Fisher Cave, Meramec State Park, June 7, 1938, 0-2-2 (macerated), K. Dearolf (U.S.N.M.); PENNSYLVANIA – Veiled Lady Cave, Center County, November 27, 1936, 0-0-1, K. Dearolf (U.S.N.M.); TENNESSEE – English Cave, Powell River, Cumberland Gap, August 1931, (3?)-0-7, March 14, 1932, 0-0-3, J M. Valentine per G. E. Pickford; Dunbars Cave, Clarksville, April 9, 1935, 0-0-1, J. M. Valentine per G. E. Pickford; King Solomons Cave, Cumberland Gap, March 14, 1932, (?)-0-3, J. M. Valentine per G. E. Pickford; Indian Cave, near New Market, 1925, 2 specimens, J. D. Ives (U.S.N.M.); identified as *Helodrilus tenuis* by Frank Smith; PENNSYLVANIA (coal mine) – Pittston, on mine roof in mud, 1½ miles west of foot of No. 6 shaft, Pennsylvania Coal Co., July 1897, (?)-0-2, I. E. James (U.S.N.M.). Four juveniles may be of the same species as the adults.

Eisenia Malm, 1877

Eisenia foetida (Savigny, 1826)

Helodrilus foetidus, Giovannoli, 1933, Amer. Midland Nat. 14, p. 622, Mammoth Cave.

Previously reported from caves of Germany, France, Czechoslovakia, Jugoslavia, Russia, and England. The species is of European origin and was brought to America by man. Reproduction is biparental.

KENTUCKY – Mammoth Cave, Cave City, June 26, 1937, 2-3-0, K. Dearolf (U.S.N.M.); near "Minervas Dome" July 30, 1929, 2-3-0, L. Giovannoli (U.S.N.M. Two specimens, one of which had been halved anteriorly from the same tube, probably are not *foetida*.)

Eisenia rosea (Savigny, 1826)

These specimens have the characteristics that long were thought to distinguish a variety known as *macedonica*. All specimens that were dissected are of a thecal morph having large spermathecae filled, at maturity, with a white coagulum. Male sterility is indicated by absence of spermatozoal iridescence on male funnels and in spermathecae of individuals with maximal clitellar tumescence.

Previously recorded from caves of Germany, Belgium, France, Italy, Jugoslavia, Hungary, Czechoslovakia, Turkey, England. The species is of European origin and was brought to America by man since 1492. Reproduction is parthenogenetic.

KENTUCKY – Laurel Cave, Carter, June 25, 1937, (4?)-0-4, K. Dearolf (U.S.N.M.); VIRGINIA – Tawney's Cave, Newport. October 30, 1943, 0-0-2, H. W. Jackson (U.S.N.M.); in stiff clay soil in bank by stream *ca.* one quarter mile from entrance, numerous castings on surface, July 19, 1931, 0-4-17, J. M. Valentine per G. E. Pickford ("This cave used by saltpetre workers in Civil War.") Cave, Newport, July 26, 1941, 0-0-1, R. Kenk (U.S.N.M.).

Eiseniella Michaelsen, 1900

Eiseniella tetraedra (Savigny, 1826)

These specimens are of a morph which has male pores on xiii, an annular clitellum on xxii-xxvii, tubercula pubertatis between equators of xxiii and xxvi, spermathecal pores midway between *D* and mD at 9/10-10/11. Genital tumescences include *a-b* setae of x, occasionally *c-d* of one or both sides of x.

A short, unsegmented and unpigmented tail regenerate with terminal anus is present, in one specimen, at 37/38. Segment xxxvii had lost all of its setae during post-amputation reorganization and sites of follicle apertures no longer are recognizable.

These worms with clitellum at maximal tumescence but with empty spermathecae and no spermatozoal iridescence on male funnels appear to be male sterile.

E. tetraedra has been recorded previously from caves of Germany, Belgium, France, Switzerland, Italy, Jugoslavia, Hungary, Greece, Turkey, England. 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, Zwartbergen, Cape Province, "up to 1½ miles into caves, in damp earthy material", December 29, 1926, 11-1-9, G. E. Pickford.

Octolasium Oerley, 1885

Octolasium lacteum (Oerley, 1881)

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

TENNESSEE – Craighead Cave, Sweetwater, August 1931, 0-0-1, J. M. Valentine per G. E. Pickford; Dunbars Cave, Clarksville, April 9, 1915, 0-0-11, J. M. Valentine per G. E. Pickford; WEST VIRGINIA – Snedegars Cave, Pocahontas County, June 24, 1932, 0-0-1, A. M. Reese (U.S.N.M.).

Lumbricidae gen. et sp.

MISSOURI – Onondaga Cave, Leasburg, June 7, 1938, 3-0-0, K. Dearolf (U.S.N.M.); PENNSYLVANIA – Dragon Cave, Berks County, January 22, 1938, 3-0-0, 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.*

MEGASCOLECIDAE

Balanteodrilus Pickford, 1938

Balanteodrilus pearsei Pickford, 1938

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

Eodrilus Michaelsen, 1907

Eodrilus oxkutzcabensis Pickford, 1938

Eodrilus oxkutzcabensis Pickford 1938, Carnegie Inst. Washington Pub. No. 491, p. 71 (First Cave on San Roque Road, Oxkutzcab 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 couples of xviii and xx penial, copulatory setae lacking. First dorsal pores at 12/13. Clitellum annular except on xviii where it is lacking ventrally, on xiii-xviii.

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

INTERNAL ANATOMY: Gizzards 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 (xi?) and xii. Penisetal 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. Diverticulum a small vertical disc with very short and very slender stalk passing to duct near ampulla.

REPRODUCTION: Male funnels have a brilliant spermatozoal iridescence. Seminal chambers of spermathecal diverticula appear to be iridescent. 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 clitellum 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 intestinal earth into two longitudinal masses.

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

Diplocardia is known only from the United States and Mexico. The species, whatever it may be, then must be an endemic. No species of *Diplocardia* has been recorded from caves previously.

ALABAMA – Cathedral Caverns, Woodville, July 3, 1954, about 800 feet from entrance, 0-0-3, about 1500 feet from entrance, 0-0-3, B. E. Faust (U.S.N.M.).

Pheretima Kinberg, 1866

Pheretima diffringens (Baird, 1869)

Pheretima diffringens, Gates, 1954, Bull. Mus. Comp. Zool. Harvard College, 111, p. 227, Boone's Cave, North Carolina.

Several species of *Pheretima* have been listed from caves in Japan (Ohfuchi, 1941) but *diffringens* is recorded only from American caves. However, types of *P. torii,* from a Japanese cave, appear from the description to be only small and inornate variants of the present species.

P. diffringens 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. Reproduction is parthenogenetic.

ALABAMA – Weaver Cave, Weaver, September 1931, 4-2-1, J. M. Valentine per G. E. Pickford (three recently hatched juveniles may be of the same species.)

Pheretima rodericensis (Grube, 1879)

Pheretima rodericensis, Gates, 1937, Bull. Mus. Comp. Zool. Harvard College, 80, p. 365, cave 11 km. from Yauco, Puerto Rico.

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

The original home of *rodericensis* is still unknown but presence in greenhouses of England, Germany, Poland, Russia, Switzerland and United States, as well as in Botanical 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 (Michaelsen, 1890)

Dichogaster affinis, Pickford, 1938, Carnegie Inst. Washington Pub. No. 491, p. 95, Beleam Canche Cave, Chichen Itza and Muruztum Cave, Tizamin, Yucatan.

Dichogaster bolaui (Michaelsen, 1891)

Dichogaster bolaui, Pickford, 1938, Carnegie Inst. Washington Pub. No. 491, p. 95. Hoctun Cave, Hoctun, Yucatan.

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

The original homes of *affinis* and *bolaui* 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 *bolaui* and have been found in the spermathecae but parthenogenesis (possibly facultative) would not be entirely unexpected.

SPARGANOPHILIDAE

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

Cernosvitov, L. 1939 Études biospèologiques, X. Catalogues des oligochètes hypogés: Bull. Mus. Roy. Hist. Nat. Belgique, vol. 15, no. 22. pp. 1-92.

University of Maine
Orono, Maine

Davies, H. 1948 Earthworms from English caves: Cave Research Group Newsletter, No. 14.

Gates, G. E. 1937 The Genus *Pheretima* in North America: Bull. Mus. Comp. Zool. Harvard College, vol. 80, pp. 339-373.

Gates, G. E. 1954 Exotic earthworms of the United States: Bull. Mus. Comp. Zool. Harvard College, vol. 111, pp. 219-258.

Giovannoli, L. 1933 Invertebrate life of Mammoth and other neighboring caves: Amer. Midland Nat., Vol. 14, pp. 600-623.

Ohfuchi, S. 1941. The cavernicolous Oligochaeta of Japan: Sci. Rept. Tohoku Univ. Ser. 4, Biol., vol. 16, pp. 243-256.

Pickford, G. E. 1938 Earthworms in Yucatan caves: Carnegie Inst. Pub. no. 491, pp. 71-100.

Stephenson, J. 1930 The Oligochaeta: Oxford, Clarendon Press, xiii 978 pp.

BULLETIN
of
THE NATIONAL SPELEOLOGICAL SOCIETY

VOLUME 21 1959

CONTENTS