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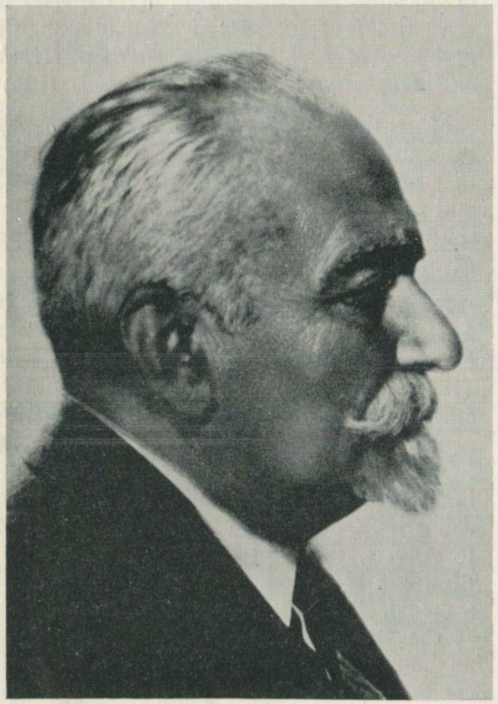
Emil G. Racovitza: Founder of Biospeology

by C. Motas

ABSTRACT—Emil Racovitza was born in Jassy, Rumania on November 15, 1868. He studied in Paris receiving his Masters Degree in Science in 1896. From 1897 to 1899 he was naturalist on the *Belgica* Antarctic Expedition. In 1905 he began biological studies in the caves of the Pyrenees. These studies, in co-operation with Jeannel and Chappuis continued for 25 years. In 1906 Racovitza founded *Biospeologica,* a journal devoted to cavern biology. In 1910 he was appointed professor of Biology at the University of Cluj and in 1929-30 was Rector of the university. Racovitza was an ardent conservationist and was greatly interested in furthering national parks on a world wide basis. He died on November 19, 1947.



Emil G. Racovitza 1868-1947
(Photo by Kino Service, Cluj)

Emil G. Racovitza was the first Rumanian explorer of the Antarctic and one of the founders of speleology. He created the first institute of speleology in the world and was one of the most brilliant and popular Rumanian writers.

He was born the son of a rich landowner on November 15, 1868, in Jassy, a town in the northeastern part of Rumania. In his youth he was active in the Social Democratic Party of Rumania, and in 1918 he divided amongst the peasants the estate he had inherited from his parents. He attended elementary and secondary school in his native town, having among other outstanding teachers the paleontologist Gr. Cobalescu and the great Rumanian prose writer Ion Creanga.

At the age of 19 Racovitza left for Paris, where he attended courses in the School of Anthropology and the Faculty of Sciences, at the same time studying law. In Paris he came under the influence of three of the most prominent zoologists of France, Henri de Lacaze-Duthiers, Georges Provot, and Yves Delage. While a student he was primarily interested in oceanography and especially in regard to marine worms, cephalopods, and crustaceans. He graduated in law in 1889, received the bachelors degree in natural sciences in 1891, and took his masters degree in 1896. His masters thesis, *The Cephalic Lobe and Encephalon of the Polychaete Annelids* (1896), brought him world renown.

Being recommended by Lacaze–Duthiers and the Belgian zoologist Edouard van Beneden, Racovitza was chosen as naturalist in the famous Antarctic expedition on the ship *Belgica* (1897-1899), whose promoter, organizer, and leader was the navy lieutenant Adrien de Gerlache de Gomery, at that time curator of the Museum of Natural History in Brussels. The expedition physician and anthropolist, Dr. Frederick Cook, of New York related his appointment as follows:

Special efforts were put to secure a competent zoologist, one who possessed essential qualities to a polar explorer, and this proved one of the greatest difficulties. Belgium and France were searched without avail, and finally Mr. Racovitza was found in Rumania. But he was doing military duty, and it was feared that the diplomatic arrangements essential for his release would be slow. However, he was luckily freed at once to join the growing family of pioneers.

Apart from Cook and Racovitza, the ship's crew (19 persons) included the artillery lieutenant Georges Lacointe, second commander of the ship and Director of the Belgian Astronomical Observatory; Roald Amundsen, the famous Norwegian explorer, First Lieutenant, who in 1912 was to reach the South Pole; Henryk Arctowski, of the meteorological service of the Belgian Observatory and his assistant Anton Dobrowolski; and the artillery lieutenant Emile Danco.

The *Belgica* sailed from Anvers in August, 1897, following the routes of Cook, Bellingshausen, Weddell, Dumont d'Urville, Wilkes, Ross, and other well-known navigators to West Antarctica. They fought hurricanes and rough seas, which swallowed two of their companions (Danco and the Norwegian sailor Carl Wiencke), discovering new lands, straits, capes, bays and islands, and accomplishing their outstanding scientific mission, whose results surpassed by far any previous Antarctic expedition. They wrote a page of immortal glory in the history of navigation, being the first men to spend a polar night in the Antarctic, completely isolated from the rest of the world. The geographical features of the newly discovered countries, the geological and tectonic structure, the glaciation and Antarctic climate, the oceanography of the explored seas, and especially the Antarctic fauna and flora, were described in Racovitza's report, "General Results of the Belgian Antarctic Expedition" (in Cook, Through the First Antarctic Night, 1900). He was a careful and competent observer of whales:

The latest and most accurate observer of the life of whales is, of course, E. Racovitza, who, as a zoologist of the Belgian expedition to the South Pole has studied them day by day. It is he who teaches us that each species has its own particular customs which are wholly different even from those of the kindred species, thus every species is recognizable from afar by its movements and way of breathing and sinking. (Heck and Hilzheimer, Brehm's Tierleben, 1915)

More than 70 papers were written by biologists all over the world, describing the new material which Racovitza had collected and compiling faunal and floral lists of the south polar area and the southern countries of South America.

Racovitza's voyage aboard the *Belgica* is a striking parallel to Darwin's famous journey around the world in the *Beagle* (1831-1836). Both men, as youthful naturalists, were afforded an outstanding opportunity to familiarize themselves with the fauna, flora, and geology of a region strikingly different from their own native countries. On the day of the *Belgica's* return to Anvers, the expedition received an enthusiastic reception. Racovitza was awarded a medal, and in 1900 was elected a member of the Geographical Society of Anvers and an honorary fellow of the Belgian Zoological Society. Back in France, he was appointed assistant director of the Arago Laboratory at Banyuls-sur-Mer, founded by Lacaze-Duthiers. It was here, in the summer of 1901, that an incident occurred which definitely changed the trend of his scientific preoccupations, and led to his great achievements in the study of cavernicoles.

On the invitation of the Spanish professor Odon de Buen, whom he had met in Paris, Racovitza visited the famous *Cueva del Drach* on the Island of Majorca. Here he discovered a small, blind, non-pigmented crustacean, the object of his first speleological paper (1905). This discovery was decisive for his future career. From then, the problem of the adaptation of animals to life in caves never left his mind. The heroic, yet brief, activity as a polar explorer was followed by a longer and more fruitful endeavor entirely devoted to speleology.

In 1905 Racovitza took to exploring caves in the Pyrenees, together with a young protege, Rene Jeannel, now honorary professor at the Museum of Natural History in Paris and one of the most prominent biospeleologists and coleopterists. They were accompanied on their trips by Racovitza's wife Helene (nee Boucard), whom he had met in Paris. This research work, requiring the aptitudes of both biologist and sportsman, together with the encouraging results he obtained, induced Racovitza to create, together with Jeannel, the important publication *Biospeologica* (1906), a supplement to the review *Archives de Zoologie Experimentale et Generale,* which had been founded and edited by Lacaze-Duthiers. With Jeannel, he embarked upon a vast program of biological investigations which was to take them into more than a thousand caves in Europe and North Africa.

In one of his classical works, *Essay on Biospeological Problems,* (1907), Racovitza pointed out the importance and the extent of the subterranean realm, established his working schedule, and examined the fundamental problems of speleology. It is in this paper that he proposed the term *speology,* a simpler and more euphonic term to be used in place of *speleology,* which had been introduced by Emile Riviere in 1894. Today both terms are in use.*

On February 1, 1920, Racovitza was appointed professor of biology at the University of Cluj, located in northwestern Rumania. He persuaded Jeannel to come to Rumania and undertook to explore the caves of Transylvania. Later on they were joined by P. A. Chappuis, the Swiss authority on copepods, and Valer Puscariu.

In his *Essay on Biospeological Problems,* Racovitza considers the fauna of caves as a heterogeneous mixture of forms differing as a result of their origin, degree of organization, and epoch of migration into the subterranean realm. He divided cavernicoles into three categories according to their more or less pronounced tendency toward subterranean life following but greatly improving the classification of Schiodte and Schiner: (1) *troglobites,* living exclusively in caves, having undergone radical changes which render them incapable of living elsewhere; (2) *troglophiles,* living and reproducing in caves, but often found on the surface; and (3) *trogloxenes,* which do not live their entire life cycle in caves, but must return to the surface at intervals, usually for food. Racovitza considered the "subterranean domain", which included not only accessible caves but all habitable crevices and inaccessible solutional cavities beneath the earth, as a veritable museum of old forms, relics from different epochs, a refuge where these true "living fossils" were obliged to take shelter, owing to change in climate and other conditions of life on the surface. Some biologists (e.g. Packard, Verhoeff) concluded that, since caves do not possess abundant sources of food for their inhabitants, cave animals are consequently small. Racovitza and Jeannel, on the other hand, showed that there are parts of the subterranean domain where food is abundant, and others where it is scarce. Food sources, principally organic detritus carried underground by water or the guano of bats, are sufficient to enable cave animals to live a normal life. As to their size, cave forms do not differ appreciably from their relatives living at the surface.

In order to reach valuable conclusions in biospeleology, Racovitza believed that one should proceed from a detailed study of species to the groups to which they belong,

* Ed. note — The term *speleology* now in common American use has been used in this paper except in specific titles.

and to their affinities, origins, and biology. This point of view demands an extensive —rather than intensive—study of the fauna of many caves. Following this line, joined by Jeannel, Chappuis, and Puscariu, and helped by Fage, Breuil, Winkler, Leruth, and others, Racovitza explored more than 1400 caves in France, Spain, Italy, North Africa, Jugoslavia, Turkey, Rumania, and the United States of America. From these caves he accumulated a vast collection of cavernicoles, comprising some 200,000 specimens which are preserved at the Institute of Speology in Cluj and which so far have not yet been completely studied. Various groups of animals included in this huge collection are still subjects of different studies at present.

Alone at the beginning, then in cooperation with Jeannel, Racovitza published the monumental work, *Enumeration of Caves Visited* (1904-1927), including a series of seven speleological monographs, covering 6200 pages, in *Biospeologica*. In this same periodical he published three zoological monographs: *Terrestrial Isopods* (1907, 1908), *Spheromids and Revision of the Monolistrini* (1910), and *Cirolanids* (1912). These studies and a series of papers entitled *Notes on Isopods* (1919, 1923, 1924, 1925) published in *Biospeologica* total more than 800 pages, with more than 1000 figures drawn by Racovitza.

Racovitza was a skillful artist, and his drawings are clear and expressive. He left witty sketches representing comical scenes on board the *Belgica* and satirical portraits of some of his mates from the Antarctic expedition.

He accumulated long experience as editor of scientific periodicals. For 46 years he served as coeditor for *Archives de Zoologie Experimentale et Generale,* first with Lacaze-Duthiers and G. Pruvot, then with Pruvot and Octave Duboscq, and later on with L. Fage. At Cluj he founded the Society of Sciences, whose president he was until his death, and in the *Bulletin* of the Society he published some preliminary notes on new cave isopods (*Asellus and Stenasellus*) and on some new, interesting relict cave isopods from *Slavonia* (*Microlistra spinosa* and *M. spinosissima*). In the *Bulletin de la Faculte des Sciences de Cluj* was printed Racovitza's most interesting study in physical speleology: *Observations on the natural ice cave of Scarisoara* (1926), in which he minutely presented studies of the structure and way of formation of the ice stalactites and stalagmites in this wonderful grotto in the Aúpseni Mountains of western Transylvania.

Racovitza also founded the *Travaux de l'Institut de Speologie de Cluj,* a collection of papers of his own and of those of his coworkers which had not been published in *Biospeologica*. By 1947 nine volumes had been issued. Soon, with the aid of the Ministry of Education, to which the Institute for Speology of Bucharest is attached, we hope to publish the tenth volume and further to continue the great work of our predecessor in the years that lie ahead.

In the brief but most valuable book *Speology* (1927), issued in the Rumanian language, and the result of twenty years of sustained subterranean research work, Racovitza resumed the discussion of the fundamental problems of the young science to which he had so greatly contributed. He revised some of his previous ideas concerning life conditions in the subterranean environment, which he no longer considered uniform and constant, and the density of species and individuals, which he no longer considered scarce. He again raised the problem of relics and expressed the opinion that descriptive observation alone cannot solve the fundamental problem of adaptation, proposing a wider use of the experimental method. In his opinion, it is easier to conduct good experiments in caves, where relatively stable conditions are less likely to induce serious errors in the results than in surface laboratories. Today, in Europe, speleological research work has surpassed the simple descriptive stage and is in the experimental stage. New cave laboratories have been set up such as the laboratory at Moulis (France), directed by Professor A. Vandel.

Racovitza was not only a passionate and indefatigable searcher and a great naturalist, but also a brilliant teacher, who used to fascinate his audience with his interesting and vivacious lectures. In his pupils he instilled a passion for research work.

All his works, including *Speology,* and particularly his book *Evolution and Its Problems* (in Rumanian), clearly show that Racovitza was a confirmed follower of Lamarck's principles; yet he did not wholly comply with the great naturalist's formula "the function creates the organ," his own opinion being "the function re-adapts the pre-existing organ." He did not deny the importance of natural selection, but emphasized Lamarckian factors, and thus belonged to the Neolamarckian school of the American paleontologist E. D. Cope and the American Zoologist and biospeleologist A. S. Packard. He was opposed to the concept of random variation, but believed with Th. Eimer that evolution is orthogenetic and with the Belgian paleontologist L. Dollo that it is irreversible. He bluntly refuted the theories of August Weismann, founder of the Neodarwinian theory.

Racovitza was one of the founders of the phylogenetic or evolutionist taxonomy; according to him, systematics should not confine itself to denominating the actual morphological characteristics, but should take into account all changes undergone by these characteristics in space, together with the changes that took place in time. The identity of a species and its place among the other species could be established only by making use of the morphology, geography, and phylogeny of this species. Species should not be conceived in a simple manner as local entities, but should be considered in historical and geographic perspective. He tried to replace the static, fixed, notion of species by the dynamic, evolutionary notion of "phyletic line." According to Racovitza, taxonomy has the task of discovering the "lines" formed by homogeneous, directly related elements and thus give a good interpretation of structure, function, and the direction of evolution. "Taxonomy," he said, "is only applied phylogeny."

Racovitza considered geographical isolation to be of primary importance in the evolution of species. His definition, "The species is an isolated colony of related individuals" indicates his attachment to the ideas of Moritz Wagner. In a well-known study, Maurice Caullery emphasized the importance of Racovitza's argument for the theory of speciation by geographic isolation:

The studies concerning cavern fauna, particularly those done by Racovitza and Jeannel, made obvious the importance of segregation. The segregation of true cavernicoles is absolute in each authonomous system of caverns. A detailed study of a group, for instance of the Silphidae (Coleoptera) belonging to the subfamily Bathysciinae, show the neighboring, yet independent caverns are inhabited by distinct species, whereas caverns pertaining to the same group and in communication with one another have the same inhabitants. It is significant that in a given area amidst a series of populated caves there are some which are deserted; either their inhabitants died off or they could not be replaced. It is speology which shows the differentiation into special forms in each independent cave, i.e., in each case of segregation. (*Caullery,* 1931, *p.* 352-353).

The fundamental contributions of Racovitza to speleology were substantial, indeed. But underground explorations, life in conditions of great humidity, sleep under a tent in the middle of mountain forests, and all the physical strains required by such work, had taken their toll. His last collecting trip took him to a cave in the Bihor Mountains. The entrance slope was steep, and the climb out was exhausting. Before he reached the entrance he suffered a fainting fit, and his days in the field were finished. From now on Jeannel and Chappuis had to organize and lead the expeditions.

In 1920 Racovitza had been appointed fellow of the Rumanian Academy, and in 1929 and 1930 he served as president. From 1922-26 he was senator of the Cluj University and rector from 1929-1930. Because of his long accumulated experience in the French educational system and his lofty moral authority he was often consulted in problems regarding the organization of instruction in secondary schools and universities. He submitted several projects for the reorganization of the educational system, but unfortunately they were never adopted. He promoted the tourist industry in Transylvania, encouraging the development of commercial caves, and founded a touristic society which boasted a large membership.

Being a genuine naturalist and lover of nature, he was an indefatigable militant for the protection of nature. In *Natural Monuments: A Contribution to the Study of Natural Reserves and National Parks* (1937) he summarized his ideas about "the science of natural monuments" and suggested ways of implementing through laws and regulations the protection of fauna and flora, natural resources, and of species in danger of extinction in their normal habitat. Of the United States he wrote: "This great nation can be proud of the initiative in the drive for the protection of nature ... She possesses the oldest National Parks. In addition to the best qualified men, the boldest managers, and the most educated public opinion, she possesses the most vast, best organized, and finest resources."

For his scientific attainments, the University of Lyon awarded Racovitza, in 1923, the degree of *Doctor honoris causa.* He was a fellow of numerous scientific societies, among them the Academy of Medicine of Paris, the Zoological Society of France, the Council for the Improvement of the Oceanographic Institute of Paris, the Zoological Society of London, the Belgian Society for Natural Sciences, the Paris Society of Biology, the Anvers Society of Geography, the Paris Society of Speology, the Junta de Ciencias Naturales of Barcelona, the Society of Physicians and Naturalists of Jassy, the Bucharest Academy of Medicine, and the Bucharest Society of Geography and Geology.

Racovitza's wife gave him three sons: Rene (1908), Jean (1910-1936), and Andre (1911). The last was the only one to study natural sciences, and is a distinguished mycologist.

On November 19, 1947, Emil Racovitza died at the age of 79, and was buried at Cluj, with national honors, on November 21. Eleven years after his death (December 10, 1958) the University of Cluj erected in front of the Institute for Speology a brass monument in his memory. It represents Racovitza with a skull of the cave bear, Ursus spelaeus, in his hand.

The Rumanian Academy of Sciences will soon publish the selected works of the great Rumanian scientist and patriot who considered progress, democracy, and peace the supreme aims of mankind, and who had such great faith in science and the scientific method that he concluded his wonderful lecture on speleology (1926) with the words: "The question of questions is not *'to be or not to be'* but *'to know or not to know'* ".

Director, Emil G. Racovitza
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Notes on the Caves of Jamaica

by William B. White and J. Robert Dunn

Abstract—Forty-nine caves have been reported on the Island of Jamaica. Fourteen of these were investigated in 1957. Cave patterns in the tropical climate of Jamaica are similar to those of temperate climates. The skylight and ceiling pockets are very common features. Calcite is the most common cave mineral and is present chiefly as massive dripstone deposits, often eroded by bat urine. Hydroxy-apatite is also present. Kegalkarst and Türmkarst are developed in Jamaica. The former is extensive and occurs in "Cockpit" country. Doline Karst is also extensive. Several poljes are developed in Jamaica.

Introduction

In June 1957 seven members of the Pittsburgh Chapter of the N. S. S. spent two weeks on the Island of Jamaica making a cursory investigation of the caves and the karst.*

Travel on the island was by rented car. The roads are narrow but passable. For the first four days the group based its operations in Mandeville while exploring caves along the south coast and then moved to St. Ann's Bay for the remainder of the work. It was impractical to camp out. Hotel rates were reasonable and it was found convenient to base at a hotel and to travel to the various caving regions each day. However, the combination of roads and topography were such that trips of more than 50 miles were not easily undertaken.

Jamaica is a south central member of the island arc that makes up the Greater Antilles in the Caribbean Sea. The island is roughly 40 miles wide and 150 miles long. Northward it is separated from Cuba by the Bartlett Trough, a down-faulted block 90 miles wide and over 3000 fathoms deep. To the East is 100 miles of open sea separating Jamaica from Haiti. Since 1655 Jamaica has been a colony of Great Britain. The combination of British laws, the English language, and a thriving tourist trade make conditions for cave hunting by Americans much superior to those in other Caribbean localities. The people in the back country speak a patois of English, Spanish, and Carib, which with a little practice is easy to understand and thus one seldom has difficulty obtaining directions and information. The economic level in the back country is rather low and one can hire local people to carry caving gear through the cockpit country for a very reasonable fee.

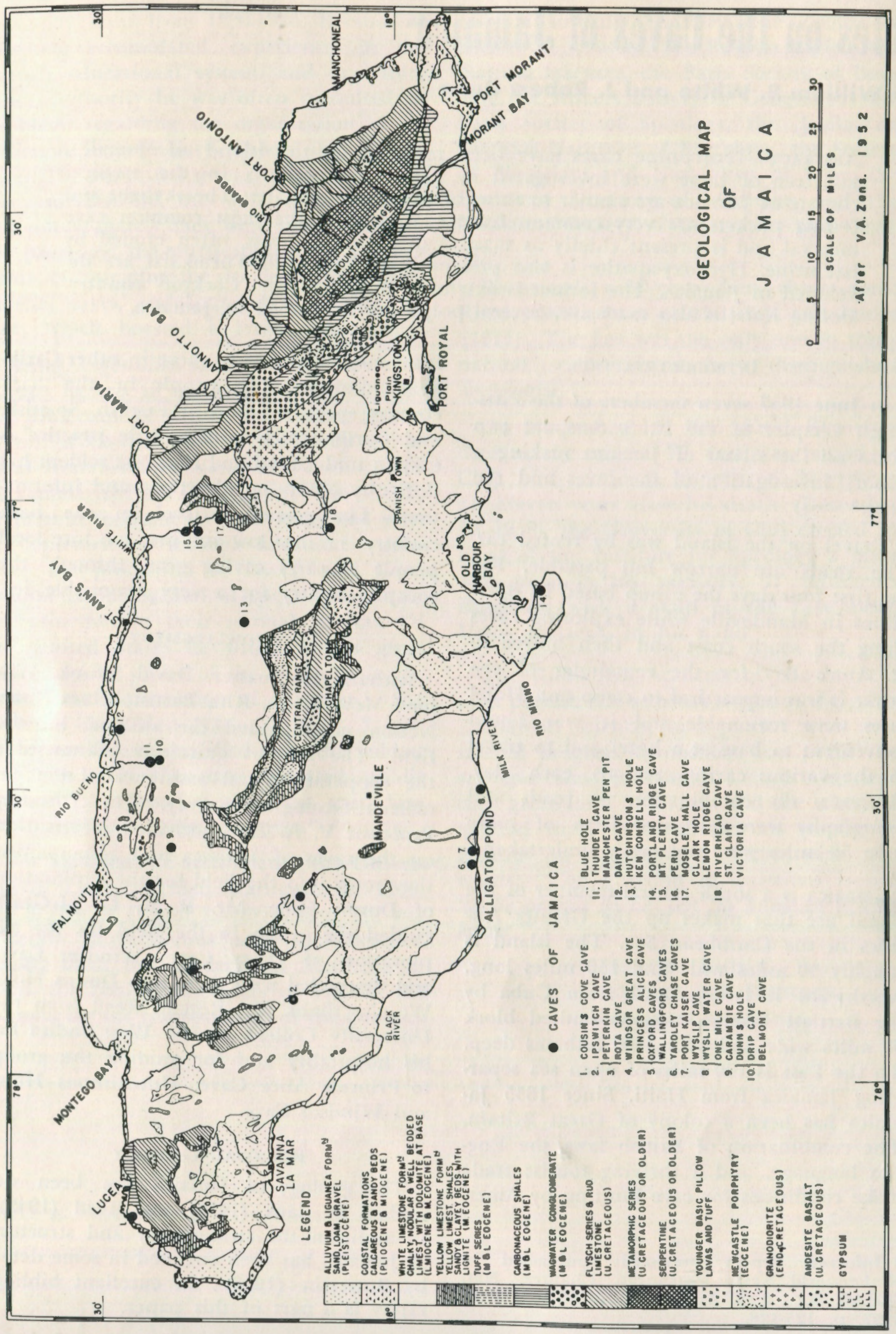
* Informal report previously published in Netherworld News, Pittsburgh Chapter, Nat. Speleol. Soc., v. 5, Aug., 1957, p. 92-103; Sept. 1957, p. 125-128.

Acknowledgment

Richard Hoffmaster, David Strunk, William McWilliams, Rita Battistoli, and Lucy Nelson accompanied the authors in the field. The authors gratefully acknowledge the cooperation and assistance of the Jamaican Geological Survey. The Director, Professor V. A. Zans, provided information on the caves of Jamaica and accompanied the group into the field for the exploration of Dunns Hole. Mr. B. R. G. McGrath guided the group in the field for the exploration of Dairy Cave, Windsor Cave, and descended with them into Dunns Hole. We also thank Mr. Ronald Read from the University College of the West Indies for his hospitality and for guiding the group to Princess Alice Cave, Hutchinsons Hole, and Windsor Cave.

Regional Geology

The geology of Jamaica has been described by Zans (1956) and Reed (1949). In addition the stratigraphy and structure of Jamaica has been outlined in some detail by Butterlin (1956); an excellent bibliography is a part of this paper.



The Island of Jamaica is composed of three main physiographic provinces. These are the interior mountain ranges, the dissected and karsted limestone plateaus, and the coastal plain.

The interior mountain ranges are made up of rocks of the basal complex and constitute the core of the island. For the most part, they are Pretertiary igneous and metamorphic rocks (fig. 1). The interior mountains form the highest parts of the island, reaching a maximum elevation at Blue Mountain summit of 7402 feet. The Central Range of mountains in the interior of the island are an important factor in cave development because they form the drainage divide separating the north and south flowing streams. The upthrown block of the Central Range has been referred to in hydrology studies as the Central Inlier.

The Coastal Plain is composed of alluvial sands, gravels, and loams. They extend inland for as much as several miles to the base of the limestone hills. The lower reaches of the river valleys and the floors of the deep interior valleys have much the same composition as the Coastal Plain.

The upland plateaus are the most interesting to the speleologist. These plateaus are a great belt of limestones surrounding the Central Inlier at an elevation ranging from 1500 to 3000 feet. They are composed for the most part of the White Limestone of Oligocene age underlain by the Yellow Limestone of Middle Eocene age. These limestones are folded into broad anticlines and synclines whose main axes trend east-west. The limestone terrain is broken at many points by major faults which also trend east-west, roughly paralleling the old tectonic lines of the archipelago.

Most of the caves on the island are formed in the White Limestone formation. It occupies about one-half of the surface of Jamaica with a thickness up to 2000 feet. It varies from chalky to hard and massive and at the base it grades locally into the Yellow Limestone The chalky limestone is believed to be a marine facies of the White Limestone and is referred to as the Montpelier beds. The White limestone in the central part of the Island is hard and massive. The solubility, massiveness, and well developed joints of the White Limestone have been major factors in the development of the Jamaican karst topography.

Karst

Jamaica has been cited as classical example of a tropical karst since the work of Danes in 1914. More recently Lehmann (1954) described the karst features of Jamaica and their significance in the karst development in the humid tropics. Sweeting (1956, 1958) examined the ground water problem of the island and also reviewed the literature on Jamaican Karst. A general study by Doerr and Hay (1957) examines the karstlands from a geographical viewpoint. Most of the work in the above papers deals with the surficial aspects of karst, particularly with respect to climatic influence and the morphology of the landforms. A brief summary based largely on the literature but backed by personal observations is presented below.

Lehmann distinguishes two main types of tropical karst. *Kegalkarst* (cone karst) is that in which the major landform is a tapering cone or conical hill of limestone. Separating the hills are large dolines (called cockpits in Jamaica). The individual cones may be 20 to 400 feet high and about a quarter of a mile in diameter at the base. The cockpits vary in depth from 100 feet to as much as 700 feet below the average elevation. Kegalkarst usually has a surface of limestone pinnacles (spitzkarren) with relief of 2 to 15 feet. The larger pinnacles themselves are often covered with many tiny pinnacles which come to needle sharp points.

Türmkarst (tower karst) describes an area characterized by isolated towers of limestone separated by realtively flat land usually with an alluvial cover. The towers may reach a height of 600 feet. Other examples are the *mogotes* of Cuba and the *pepino hills* of Puerto Rico. Although intermediate forms are to be found, it is uncertain whether the kegalkarst and türmkarst represent different stages in landform development, whether they reflect slightly different climatic conditions, or whether, as Monroe (1960) has suggested for the karst of Puerto Rico, they reflect differences in lithology.

According to Sweeting kegalkarst is the most extensive in Jamaica. It makes up the Cockpit Country and in a degraded form, the Dry Harbour Mountains and a number of other areas. The kegalkarst is developed only in the massive White Limestone. It has a "gerictete karst" pattern or rectilinear alignment which is prominent on aerial photographs. This pattern indicates that the depressions between the cones are strongly joint or fault controlled. The cockpit Country is an area about 30 miles wide and 50 miles long lying on the high limestone plateau between Stewart Town in the north and Maroon Town in the south. No roads traverse this part of the island and it is nearly impenetrable. Sweeting (1958) has plotted an altimeter traverse which shows great variation in elevation in a regular sinusoidal fashion.

Türmkarst is not common. It is found along the Duanvale fault zone in the northern part of the island and in the interior valleys in the central part of the island. Only in a very few places are really spectacular towers developed. Areas of degraded tower karst are even more rare.

A doline karst is formed on much of the Yellow Limestone. Because of the different lithology the Yellow Limestone terrain looks more like the sinkhole plains of United States. Many caverns are also found in the Yellow Limestone, especially in the vicinity of Maroon Town.

Some poljes occur in Jamaica. These are large alluvial-floored karst valleys, completely surrounded by limestone hills. Streams which flow on the floor of the polje exit along underground routes. Two of the largest and best known poljes are the Queen of Spains Valley and the Cave River Valley.

In much of Jamaica the major karst landforms are covered with extensive karren. The karren of the Cockpit Country has already been mentioned. Along the south coast even more intense karren were observed. The relief of the pinnacles here was as great as 25 feet. The ridge overlooking the south coast near Allegator Pond rises about 1500 feet above the sea and is apparently entirely covered with karren. Near One Mile Cave it was possible to travel hundreds of feet along gullies and slots at the bottom to the karren, the surface being 20 feet overhead. Small pockets hollowed out in the bottom resembled small caves.

The problem of water supply in karst terrain is one of considerable importance since the people are often very short of a water supply. Zans (1952) and Sweeting (1956) have discussed the ground water problem in Jamaica.

There are very few rivers in the limestone country. Along the north coast are many short rivers such as White River, Dunns River, Roaring River, Rio Bueno, and the Martha Brae River. Their sources are springs draining the Cockpit Country. A number of rivers sink in the interior valleys, flow under the limestone and appear at one of these springs. Sweeting suggests that the usual concept of a water table does not exist in such an area and introduces the concept of a "karst basis" which marks a rough level at which ground water is circulating. The karst basis is determined by the contact between the White and Yellow limestone under the Cockpit Country and thus the water is circulating hundreds of feet below the limestone plateau.

A fairly well defined drainage divide runs the length of the island from Garlands in the west, south of the center of the Cockpit Country and the Dry Harbour Mountains through the Mount Diablo District to Guys Hill in the east. The drainage of the southern part of the Cockpit Country resurges from a series of rises that form the headwaters of the Black River. Princess Alice Cave follows the route of one of these subterranean tributaries. From the northwestern part the drainage converges at Deeside Rise and Boiling Spring at the

Figure 2
Main stream passage of Princess Alice Cave. The stream is an underground tributary to the Coffee River.

headwaters of the Martha Brae. The drainage from the northeastern Cockpit Country and much of the interior valleys converges on Dornock Head (Blue Hole) to form the Rio Bueno. Cave River sinks in one of the interior valleys and follows an underground course for 13 miles to Dornock Head. The Eastern Dry Harbour Mountains and the Pedro district drainages converge in a number of springs along the North Coast to head Dunns River, the White River, and Roaring River. A sketch showing these drainage lines is given by Sweeting (1956). It should be noted that most of these drainage lines are highly theorteical. No. fluoresecein tests have been made to check the course of the water. Likewise, there have been no apparent serious attempts to penetrate the cavern systems which probably underlie these limestone areas. In one interesting experiment sugar mill waste and John Crow Beans were dumped into a sink and found by smell 8 miles away.

Caves

Jamaica has a reputation for being permeated with caves but few have been described in detail. Zans (1956) reports that 244 caves have been noted by the Jamaican Geological Survey. It is not known how many of these have been explored or what size they are. About a dozen caves are well known on the island. They were mentioned briefly by Zans and a brief description of the same caves was given to the authors by Jamaican Tourist Bureau. Zans (1953, 1954) has reported the Moseley Hall Cave and the St. Clair Cave in detail. Sweeting (1958) published a map of Windsor Cave along with a brief description. Jamaican Caves for which at least a name has appeared in the literature are shown in Table 1. Most of the caves in this table were plotted as accurately as possible on the topographic map of Jamaica* and then transferred to the geologic map (fig. 1) that appears in this article.

It was found that prospecting for new caves in the tropics requires slow patient work. On the several excursions when the group attempted to find caves by themselves, the results were disappointing. Large roomy openings were found to be only pockets extending a few dozen feet into

* 12 topographic maps on a scale of 1:50,000 with a contour interval of 250 feet covering the entire Island have been prepared by the Directorate of Colonial Surveys. They are available from the Department of Surveys, Kingston, Jamaica.

TABLE 1

CAVES OF JAMAICA

Cave Name	*Town*	*Parish*	*Reference*
Bat Hole Cave	Chesterfield	St. Ann	5
Belmont Cave	Stewart Town	Trelawny	3
Bloxburg Cave		St. Andrew	8
Carambi Cave	Burnt Hill	Trelawny	2, 5
Clark Hole Cave	Ewarton	St. Catherine	1
Cousin's Cove Cave	Cousin's Cove	Hanover	5
Dairy Cave	Discovery Bay	St. Ann	2, 3, 5, 7
Dallas Castle Cave		St. Andrew	8
Drip Cave	Stewart Town	Trelawny	3
Dunn's Hole	Stewart Town	St. Ann	3
Ferry Cave	Ferry	St. Catherine	7
Goat Island Cave	Old Harbour Bay	St. Catherine	8
Hutchinson's Hole	Edinburg Castle	St. Ann	3, 8
Ipswitch Cave	Ipswitch	St. Elizabeth	2
Ken Connell Hole	Edinburgh Castle	St. Ann	3
Lemon Ridge Cave	Ewarton	St. Catherine	1
Long Mile Cave	Windsor	Trelawny	7
Moseley Hall Cave	Blackstonedge	St. Ann	4, 8
Manchester Pen	Stewart Town	St. Ann	3
Mt. Plenty Cave	Mt. Plenty	St. Ann	5
One Mile Cave	Alligator Pond	St. Elizabeth	3
Oxford Cave	Auctembeddie	Manchester	2, 5
Peru Cave	Goshen	St. Ann	5
Peterkin Cave	Maroon Town	St. James	2
Port Kaiser Cave	Port Kaiser	St. Elizabeth	3
Portland Ridge Cave	Portland Ridge	Claredon	2, 5, 7
Princess Alice Cave	Auchtembeddie	St. Elizabeth	3
River Head Cave	Ewarton	St. Catherine	2
Rota Cave	Maroon Town	St. James	5
Seven River Cave	Cambridge	St. James	8
Sheep Pen Cave	Windsor	Trelawny	7
St. Clair Cave	Ewarton	St. Catherine	1
Thunder Cave	Stewart Town	St. Ann	3
Victoria Cave	Ewarton	St. Catherine	1
Windsor Great Cave	Sherwood Content	Trelawny	2, 3, 5, 8
Wallingford Cave	Balaclava	St. Elizabeth	5
Wyslip Cave	Alligator Pond	St. Elizabeth	3
Wyslip Water Cave	Alligator Pond	St. Elizabeth	3
Yardley Chase Cave	Yardley Chase	St. Elizabeth	5, 6

NOTES

Ten additional caves are mentioned by Olley but are unnamed and poorly located.

Referencess

1. Zans, 1954
2. Personal communication from Jamaican Tourist Bureau, 1957
3. Results of this investigation
4. Zans, 1953
5. Zans, 1956
6. Manuscript in possession of Jamaican Geological Survey, kindly shown to us by Professor Zans.
7. Williams, 1952, 1922
8. Olley, 1953

the limestone. Entrances to significant caves are often narrow slits far from the roads and completely obscured by brush. There are undoubtly many new caves to be found, but to systematically scout them cockpit by cockpit would be a very long and difficult job.

The following is a description of the caves in the order in which they were visited on this trip. Fourteen caves were explored in the available time of which 5 are small caves of very little significance. The names used are the best local names available and in most cases were obtained either from the Geological Survey or from natives in the immediate vicinity.

Princess Alice Cave—At the village of Auchtembeddie near Balaclava the Coffee River forms from two streams which flow out of a ridge. The north branch flows through the explored length of Princess Alice Cave and resurges near the entrance. The west branch is reputed to flow from a cave also. The cave was discovered by Mr. Ronald Read and other speleologists of the University College of the West Indies.

A trail leads upstream high on the bank and at a very obscure point one descends the bank through the bush to a small crack. Just inside, the cave widens into a large room which forms the beginning of a spacious gallery. A few hundred yards farther one must climb over breakdown and descend to the level of the river on the other side.

For a considerable distance one wades knee-deep in the river through a gallery 20 feet wide and 20 feet high (fig. 2). The ceiling is decorated with numerous small stalactites. Upon reaching a large fallen travertine mass lying in the water, one may climb up the left wall about 10 feet and go through a dripstone lined fissure into another room above river level. This room is decorated with speleothems of a pure white color.

Figure 3
Dripstone partially eroded by bat excrement in Windsor Great Cave. The figure is B.R.G. McGrath of the Jamaican Geological Survey.

The speleothem gallery connects shortly with the underground river which for the next quarter of a mile flows over very severe karren. The relief of the karren varies from 2 to 3 feet. The tops of the pinnacles are jagged and lie about a foot under water. At the end of the karren passage the roof is low (3 feet) and one is forced to crawl over the karren into a narrow sewer passage where the water is too deep to touch bottom.

The deep water passage is effectively blocked within a few hundred feet by massive breakdown but a small chimney leads upward 25 feet into a large room at the top of the breakdown pile. It has the appearance of a collapse dome. The chamber is 40 feet wide and nearly as high. White dripstone abundantly covers the walls and ceiling.

From this chamber a roomy passage leads down over the breakdown into the stream channel again. A short distance up the stream course a large and very fresh looking breakdown again blocks the passage. This pile of large block breakdown is perhaps 50 feet high and extends to the ceiling. However, by climbing, it is possible to find several passages through the large blocks. Several large blocks were found with active stalactites growing from the rock at angles of 45°. These were of the soda straw type and on some a tiny stem was found resuming the vertical direction. This obviously recent growth and the freshness of the breakdown prompted a careful search of the literature. The following was found: "On 1st March, 1957, Jamaica was shaken by the most destructive earthquake experienced for 50 years . . . . The Earthquake shock attained intensity 9 on the modified Mercalli scale in part of western Jamaica, decreasing to about intensity 4 in the eastern parts. A report with isoseismal map was prepared".* Beyond the breakdown the cave continues upstream as an elliptical cross-section passage 40 feet wide and 30 feet high. We followed it for about 500 yards and then were forced to return because of lack of time.

Princess Alice Cave is a single large gallery with no known side passages. It generally has dimensions of 20 to 30 feet in cross-section. The section varies from a collapsed elliptical arch in some places to high canyon passage in others. It is at least 1 mile from the entrance to the point of farthest exploration. The cave is well decorated with the common varieties of speleothems and some unusual hollow calcite bubbles up to 1 inch in diameter were noticed on the walls. There are black coatings on the walls and ceilings and in low stream passages. The stalactites are black which leads one to suspect that the stream often rises and backs up in the cave. The floor is commonly composed of sand containing a fair percentage of magnetite. Throughout much of the cave, the stream is running on smooth bedrock or through karren.

Port Kaiser Cave—On the north bank of the railroad about 1 mile east of Port Kaiser is a small shelter cave 30 feet wide by 30 feet high and 150 feet long. It opens in the center of the railroad cut. There are a number of dripstone speleothems but these are dry and inactive. The cave is very dry and completely lighted by daylight. The cave is apparently in the Yellow Limestone.

Wyslip Cave—Wyslip Cave is located in the bush about 200 feet north of the South Coastal Road just west of milestone 51. A large opening gives access to a single room 100 feet long and 20 feet high with its main axis trending 230° magnetic. The floor slopes gently downward and is covered with breakdown. At the lower end of the room is a shallow pool with a dripstone column in the middle of it. There are no obvious continuations. The cave is a pocket cave — common in areas of intense karstification. It is very similar to many small solution pockets in Yucatan.

Wyslip Water Cave—Wyslip Water Cave is situated directly on the bank of the South Coastal Road about one quarter of a mile east of Wyslip Cave. It is a single channel, about 5 feet high and 8 feet wide, trending north for 75 feet. The floor is covered with several feet of brackish water which the local people use for drinking. There are no speleothems and no side passages.

One Mile Cave—One Mile Cave is the largest of a group of shelter caves just west of milestone 50 on the South Coastal Road. It is 60 feet long and trends to the north. There are other shelters nearby which are much smaller. This appears to be merely a

* Progress report on Overseas Geological Surveys 1956-1957: Jamaica Overseas Geology and Mineral Resources, Rpt. 7, p. 315 (1959).

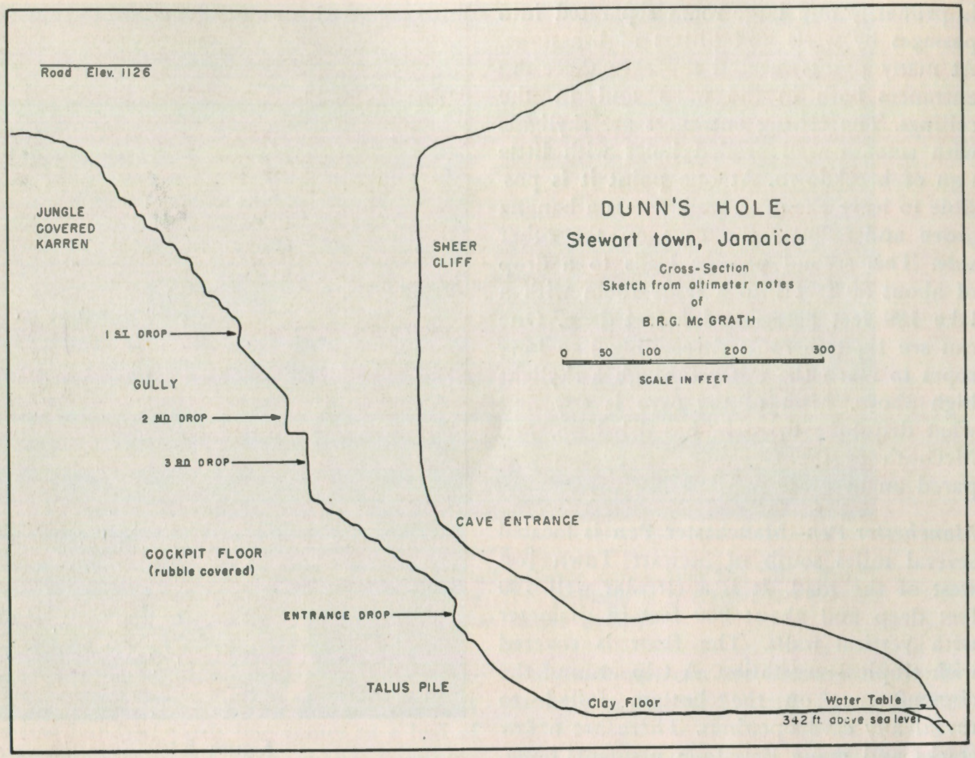


Figure 4
Profile sketch of Dunn's Hole

solution pocket developed in the bottom of an intense karren.

Hutchinsons Hole—Hutchinsons Hole is a vertical shaft nearly 250 feet deep located 800 feet due south of milestone 8 near Edinburg Castle. The pit has a characteristic fluted wall and is nearly uniform in cross-section from top to bottom. Descent was made via ladder to within 40 feet of the floor but it was impossible to determine from that height the existance of any possible cave passage. The floor appears to be smooth gravel with one possible gallery going back under the entrance chimney. This was one of two genuine dome pits seen in Jamaica.

A local legend claims that the former owner of Edinburgh Castle, a Mr. Hutchinson, used to shoot people he didn't like and throw their bodies into the hole which bears his name.

Ken Connell Hole—Ken Connell Hole is located about a quarter of a mile to the east of Hutchinsons Hole. The entrance is a low slit 3 feet high and 10 feet wide under a ledge just over the bank of the road. Just inside one descends about 20 feet over a series of small drops and then enters a narrow sinuous passage 1 to 3 feet wide and 10 feet high. This passage continues gradually downward for about 800 feet where it opens into a medium sized room. The floor is covered with a thick layer of guano and a few bats were observed in the room. The walls of the passage are well decorated with dripstone.

Dairy Cave—Dairy Cave is located about 100 yards south of the Coastal Highway about 1 mile west of Discovery Bay. The cave is developed along the bedding plane and is said to be 3000 feet wide by 6000 feet long. The ceilings average 6 to 10 feet. The cave is primarily one large room separated into passages by walls and pillars of limestone. At many points around the cave there are entrances both in the walls and in the ceilings. The ceiling entrances are skylights with smooth well eroded holes with little sign of breakdown. At one point it is possible to leave the cave, walk across a banana grove and re-enter the cave on the other side. This second passage leads to a drop of about 50 feet into a large room with a lake 100 feet across and 5 feet deep. One can see fig tree roots descending like long ropes to reach the water through a skylight high above. Most of the cave is dry and what dripstone there is, has dried up. Mr. McGrath of the Geologic Survey has prepared an accurate map of this cave.

Manchester Pen—Manchester Pen is located several miles south of Stewart Town just west of the road. It is a circular well 100 feet deep and about 200 feet in diameter with vertical walls. The floor is covered with tropical vegetation. A trip around the circumference on the bottom failed to reveal any cave openings. There are a few cracks and many limestone pendants hanging from an undercut ledge about 10 feet from the floor of the pit (the "Decken Karren" of Lehmann).

Drip Cave—Drip Cave is located at the side of a polje in a small limestone ledge. It has a walk-in entrance opening into a big room with a floor sloping steeply downward over breakdown. From the bottom the main gallery leads to the right as a passage 30 feet wide by 15 feet high. It continues for several hundred feet through a forest of small cylindrical stalagmites to a smaller room where the passage splits. To the right there is a drop to a lower level which parallels the left hand fork and meets it in a large room at the end of the cave. The upper level comes out on a ledge which goes around the room and the lower level opens into the bottom of the room. The cave has large colonies of bats which have covered the floors with guano to a depth of several feet. The cave is well decorated but the speleothems are rotting away from bat drippings.

Figure 5
Stalagmite in Dunn's Hole

Belmont Cave—Belmont Cave is a large dome pit cave located S 70° W 150 feet from Drip Cave. The entrance is of walking height and brings one into a short passage leading to the side of a dome pit. At the top of the 90 foot dome is a small skylight. The bottom is about 30 feet below the ledge. It was not descended because of lack of time. There appear to be two passages leading off from the bottom.

Thunder Cave—Thunder Cave is a 150 foot long tube, 8 feet in diameter, with smooth walls. It is 50 feet above the road 300 yards west of milepost 59 on the Stewart Town-Brownstown pike. A few bats were seen in the cave.

Windsor Great Cave—Windsor Great Cave is located on the Windsor Estate near Sherwood Content 10 miles south of Falmouth. The entrance may be found by following a crude trail left by guano miners for several hundred yards. Just inside the cave opens

Figure 6
Scalloped walls and ceiling of arched passage connecting the "Big Yard" with rear portions of Windsor Cave. This passage is a constricted portion of an otherwise larger gallery.

into a large gallery decorated with stalactites. Most of these are rather dirty. After a few hundred yards one comes to a hill of breakdown covered with guano swarming with gnats. On the other side of this hill the passage opens to 100+ feet wide and 50+ feet high with a beautifully arched ceiling (map in Sweeting, 1958). It continues this way for several hundred yards. At the end of the Big Yard, the cave narrows and speleothems occur. There are great clusters of small broom handle stalagmites and a profusion of stalactites from the ceiling (fig. 3). The cave forks near this point and the left passage is reported to lead to even more beautiful gallery. The right hand passage leads a short distance to a 40 foot drop. This was rigged over the mud and a descent was made to a lower level. By climbing over a cluster of black stained stalagmites one could look into a deeper pit and a lower level. The intermediate level was followed to a lake. It is reported by the University College speleologists that the cave is 1½ miles long and has several entrances.

Dunns Hole—Dunns Hole is a giant cockpit several miles south of Stewart Town. From the road one can see the top of the limestone escarpment. Starting down through a field brings one to the edge of a steep descent through vines and brush. By hacking a trail it is possible to get into a deep erosion gully in the side of the pit and descend a considerable distance without the use of ropes. There is a 40 foot drop which can be descended on a log and rigged with a rope. From the bottom of this drop one can again descend a steep trail to the top of a double pitch of total depth of about 150 feet. The bottom of this drop is the bottom of the cockpit but not the bottom of the cave. Across the rubble-covered bottom of the sink near the cave entrance is another 100 feet of drop. At the entrance is another 50 foot vertical drop which can be rigged with a rope. This brings one inside the cave from which he can descend again over talus to the floor. The total drop from the floor of the cave to the lip of the pit as measured by Mr. McGrath with a survey altimeter is 765 feet (fig. 4).

The entrance to the cave is 80 feet high by 40 feet wide. The entrance passage gradually widens into the main cave room which is at least 200 feet wide, 500 feet

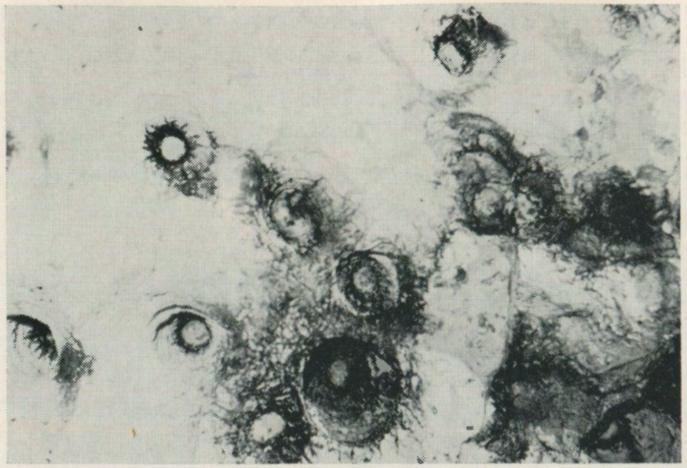


Figure 7
Solution pockets in the ceiling of Dairy Cave

long, and 100 feet high. The floor is smooth clay which is nearly level. To the left the clay is very sticky and hard to walk through. At the back of the room the floor descends to the water level of a small pool which may represent a water table. The room is devoid of speleothems except for some stalactites on the ceiling and one giant stalagmite 12 feet high and 5 feet in diameter near the right hand wall (fig. 5). Dunns Hole is probably the deepest pit in Jamaica.

Cave Features And Patterns

Patterns—It is not possible with the limited data available to attempt a systematic classification of the caves of Jamaica but it is possible to show some of the patterns that have developed in a tropical environment.

"Solution Pocket caves" are exemplified by the small caves described from the South Coast. They have no definite pattern or obvious connection with subterranean drainage network. In general they are small chambers with walls often marked by spongework and solution pockets. They are apparently phreatic chambers formed from a local zone of saturation and may simply mark a region of greater solubility in the limestone.

Hutchinsons Hole and Belmont Caves are domepits in Pohl's (1955) sense of the word. They have vertical walls with strongly incised vertical flutes and some bedding plane grooving. Hutchinsons Hole is more or less elliptical in cross-section throughout its 250 foot depth. Belmont Cave is more irregular and tends to narrow near the top. The top is domed and it intersects the surface only in a small skylight near the center. Its actual opening thus appears to be fortuitous rather than an integral part of its development. Domepits perhaps form in a tropical climate without the presence of a resistant caprock although the topographic relations are more or less those suggested by Pohl.

Dairy Cave is the only example of a network pattern visited by the writers. It is an extreme example of high connectivity and yet no special lithologic control is obvious.

The large caves of Jamaica appear to be single passages with little or no branching. They have the appearance of being segments of drainage channels formerly occupied completely by streams. The course of the channel is seldom straight and the widths vary to form wide rooms and narrow channels within the same passage. This is shown by the map of Windsor Cave (Sweeting, 1958). It is interesting to note that in the same cave the large chambers

have relatively smooth walls while the constricted parts of the passage are scalloped indicating the passage of water with considerable velocity (fig. 6). Princess Alice Cave has an active stream and shows evidence of flooding. Sweeting (1958) emphasized that a water table as such does not exist in the Cockpit Country but that one could think of the "karst basis" which would mark the level at which ground water was circulating. Both Sweeting and Zans (1954) have emphasized the role of flood-waters in the origin of these long drainage tubes. However, observation in Princess Alice Cave by the writers indicates that in the present stage of activity, flood-waters are simply depositing detrital fill. High water lines on speleothems are indicated by clay and debris. The speleothems show some signs of resolution but have not been destroyed. Although the channel is obviously completely water-filled at times, the presence of a clay coating and speleothems indicates that these waters are not a particularly effective enlarging agent. The free surface stream occupying the passage in drier seasons flows on some stretches of bedrock floor but through much of its length it is perched on detrital fill and thus cannot be effective in enlarging the passage. In contrast, the bedrock walls, particularly of Windsor Cave, show scalloping and grooving — indicating high velocity flow with the tunnel completely submerged for a considerable period of time. Thus the elongate caves of Jamaica would appear (at least with a casual examination) to be the product of sub-water table streams in the shallow phreatic zone in the manner suggested by Davies (1960). The effect of the floodwaters following the shallow phreatic stage is simply to add detrital fill, which takes place with the contemporaneous growth of speleothems.

Features—A common feature in Jamaican caves is the ceiling pocket, such as occur in large numbers in Dairy Cave (fig. 7). They are characteristically circular with a diameter of 1 to 3 feet and a depth of ½ to 2 feet. They are seemingly identical in form to the ceiling pockets described by Bretz. Bats are commonly found roosting in the

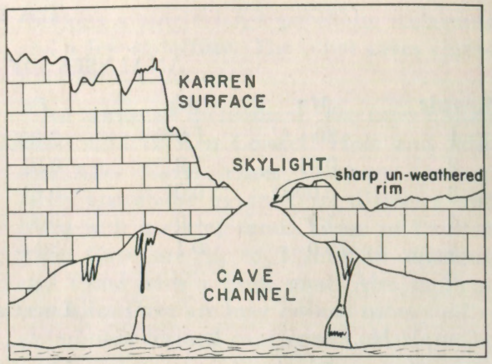


Figure 8
Sketch showing the relation of a skylight with overlying karren and underlying cave passage.

pockets and they are usually found with small piles of guano on the floor beneath. This has lead Zans (1953) to suggest that the pockets are formed from the urine of the bats being directed upward against the ceiling and dissolving the limestone. King-Webster and Kenny (1958) reports similar bell-shaped cavities in the caves of Trinidad but attribute most of the erosion to the actions of bat claws. While many of the pockets are stained brown and are associated with bat roosts and guano, they do not seem to differ significantly from the ceiling pockets of humid temperate climates and thus it would appear likely that the effect of the bats is merely to modify an already existing feature. The crucial case — a pocket dissolved in ceiling travertine — was not observed by the writers.

The "Skylight" is a feature common to many caves in tropical climates and deserves some additional comment. A skylight is an aperture in the cavern ceiling to the surface characterized by an even sharp-edged rim (fig. 8). They are more or less circular and show little evidence of collapse playing a part in their origin. They were observed in Dairy Cave and Belmont Cave. The writers have seen similar features in Yucatan, Venezuela, and Haiti. They are not common in a humid temperate karst. It is suggested that under tropical weathering conditions where a soil cover is not formed, surface erosion of the limestone takes place

TABLE 2

ANALYSES OF CAVE MINERALS

Sample	Mn	Mg	Fe	Al	Ti	Si
1	30+%	1.0%	3.0%	30+%	0.3%	3.0%
2	0.01	1.0	0.01	–	–	–
3	0.0003	0.01	0.01	–	–	–
4	3.0	1.0	0.3	1.0	–	0.3
5	10.0	0.1	30+	1.0	1.0	1.0

Sample No.	Location
1	Coating from stream pebbles of Windsor Cave
2	Pure white speleothem from Princess Alice Cave
3	Typical stalactite from main stream passage of Princess Alice Cave
4	Black stalactite near stream in Princess Alice Cave
5	Black mammary wall deposit from Princess Alice Cave

without deep penetration into joints and fractures and when the wasting land surface intersects the underlying cave, the limestone remains firm and supports the rim of the skylight. In contrast, in temperate climates where a thick soil cover exists weathering is deep and when the surface approaches the cave, the weakening of the rock by solution along joints causes collapse resulting in a collapse sink.

Mineralogy

Minerals—Secondary calcite in the form of dripstone was noted in nearly every cave visited. Fractured surfaces frequently show a grain structure ranging in size from 2mm. to more than 25 mm. in monocrystalline speleothems. The crystals are white and growth rings are not apparent indicating uniform deposition. In many of the caves visited the dripstone appeared either dead or dormant.

Neither aragonite nor gypsum was observed. X-ray diffraction analysis of five samples of crystalline material proved all of the samples to be calcite and did not reveal the presence of aragonite. In addition emission spectrographic analysis of the same five samples failed to show the presence of either strontium or barium, which is commonly associated with aragonite in cave deposits.

A shiny black deposit is located in Princess Alice Cave. It appears as a "flowstone" cascade 10 feet wide and 6 to 8 feet long situated 6 feet above stream level. It has a mammary surface. When mammalae are broken, liquid mud oozes out. Analysis by emission spectroscopy shows the deposit to be principally iron oxide containing about 10% manganese. X-ray diffraction analysis shows no evidence of crystal structure.

In Windsor Great Cave stalagmites are found which have been almost eroded away to give a soft yellow crumbly deposit. Portions of these deposits prove to be the mineral hydroxyapatite:

$$Ca_4\,(CaOH)\,(PO_4)_3$$

The black coating of the stream pebbles in Windsor Cave was found to consist of an equal mixture of manganese and aluminum oxides.

It is apparent that bats may greatly alter the structure and appearance of speleothems. In most of the caves visited there were large colonies of bats and consequently the floor at places was covered with massive deposits of guano, sometime covering speleothems to the extent that they barely protruded through it. In portions of Drip Cave the guano reaches a thickness of 10 feet and in Ken Connell Hole the back room contains 6 feet of guano. Where there is continually dripping water, it forms a black fluid that seems to deteriorate the dripstone. The result is that some stalagmites have softened almost to the core and will crumble on touch. A stalagmite in Drip Cave which was 3 inches in diameter initially has rotted to within ½ inch of its center. The outer layers could easily be scraped off with the fingernail and this soft material proved to be principally calcite. Apparently the attack by the excrement did not alter the basic chemical composition of the stalagmite. A sample was analyzed for water soluble nitrogen (urea, nitrates, and nitrites) by a micro-kjeldahl technique and was found to contain 0.02% water soluble nitrogen. A brittle solidified guano sample from Ken Connell Hole was examined by X-ray diffraction and found to be calcified.

The results of some analyses of Jamaican cave deposits are shown in Table 2. Analysis was made by emission spectrograph by a fast semi-quantitative method. Values are only precise to the nearest third of an order of magnitude.

Speleothems—Few speleothems showing external crystal faces were found. Flowstone and dripstone are the only classes of speleothems commonly present. However, a few of the botryoidal class were found in Princess Alice Cave and Ken Connell Hole.

Dripstone is abundant in Princess Alice Cave. Stalactites tend to be pure white and coarse-grained. A few noted were internally monocrystalline. In upper levels, out of reach of floodwater, tapering stalactites are forming. Stalagmites are not common but fluted cylindrical forms occur on the walls. In Drip Cave and Windsor Cave tapered stalactites grow in profusion in places nearly blocking the passageways. Cylindrical or "broomhandle" stalagmites are the most common form. They are buff-colored or mud-brown and often show etching either by guano or resolution. The cores are generally white and more coarsely crystalline indicating that initial speleothem growth took place under different conditions than prevail now, at a time when there were no bats in the caves and possibly before the present entrances were opened. Dunns Hole contains a single large parabolic stalagmite and a few stalactites. The other caves visited were poorly decorated.

An unusual speleothem, the cave blister, was found in Ken Connell Hole and Princess Alice Cave. Those in Ken Connell Hole are about ½ inch in diameter and filled with a clayey sand. Those in Princess Alice Cave are ¼ to 1 inch in diameter and filled with a fluid mud. Also in Princess Alice Cave are long hollow tubes similar to bubbles, formed over cracks in the walls.

Status Of Speleology In Jamaica

At the time of this visit in 1957, there were two groups studying caves in Jamaica. The Jamaican Geological Survey has an economic interest in the caves because of the phosphate and guano deposits and because of the possibility of adding commercial caves to Jamaica's tourist attractions. V. A. Zans, the director, has compiled lists of known caves and located them on a master map of the island. As fast as feasible the caves are visited and guano reserves estimated. B.R.G. McGrath, of the Survey has been preparing a series of precise surveys and detailed reports of important caves but few of these have been published.

A cave exploring group was informally organized among faculty members of the University College of the West Indies in Kingston. Under the leadership of Ronald Read, of the Department of Mathematics, they have concentrated on locating and exploring new caves. A number of finds had been made by 1957 of which Princess Alice Cave was the most outstanding. They work in cooperation with the Geological Survey.

Despite the excellent progress of the Geological Survey and the work done informally by cavers, many caves and cave systems remain to be explored and surveyed. Mapping of active cave systems and drainage networks would contribute much to the understanding of Jamaican karst hydrography.

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The Caves of Guatemala

by Russell H. Gurnee

Abstract—Exploration was made in 1960 of the Alta Cuchumatanes, a plateau north the Sierra Madre in Guatemala. Exploration for caves was also done on the Plain of Peten. The plateau averages 10,000 feet high and is one of the highest karst areas. Several large caves, including Languin were explored. At Semuc a natural bridge formed of travertine 200 feet across and 50 to 60 feet thick spans the Cababon River for 1600 feet.

Six members of the National Speleological Society visited Guatemala in June 1959 on a reconnaissance of the cavernous areas of the country to map and collect data on as many caves as possible.

Guatemala is composed of five physical regions:

1. Pacific coastal plains
2. Volcanic mountains — Sierra Madre
3. Plateaus north of the Sierra Madre (Highlands)
4. Mountains of the Atlantic versant (Midlands)
5. Plain of Peten (Lowlands)

The reconnaissance covered only the three cavernous regions; namely, the Highlands, Midlands and Lowlands. Ten caves were visited in these areas—three of them of major importance in size.

Highlands

Geology — The highlands of Guatemala occupy almost half of the land area in a broad east-west belt across the country. Volcanism near the end of the Cretaceous period built seven enormous volcanoes and covered most of the highlands with thick, fertile volcanic ash. During mountain building processes, a single block (horst) of limestone was thrust up at the northern edge of this mountain range. This east-west, southward facing block rises to an altitude of more than 13,000 feet—higher than the volcanoes except Tajumulco (13,814).

Around the margins of the horst, the relief heights above the Rio Negro are from 3,000 to 5,000 feet.

The horst, called Alto Cuchumatancs, stands as one of the most impressive non-volcanic mountain areas in Central America. The uplands of this block are smoothly rolling with sinks, karst topography and caves. At an average elevation of 10,000 feet, the caves are about 40°F, and reports of local people tell of ice caves in this 1200 square mile area.

Midlands

Geology — Alta Verapaz is located on the north slope of the east-west mountain ranges of Guatemala. This slope was produced by step and block faulting during the Pliocene period leaving a series of broad, plateau-like terraces from 8,000 feet in the Sierra de Chuacus to 1,000 feet in the Peten.

The underlying Paleozoic granites and schists are covered by beds of Carboniferous limestone, Cretaceous clay, sandstone, conglomerate and a series of limestone beds. The humid climate erodes these limestones quickly and most of the karst area of Alta Verapaz has reached full maturity. The Rio Cabon and Cahabon (the same river) drains most of the central plateau. Several rivers, including the Rio Lanquin and Rio Tyalihux, with underground sources feed this system.

In the area between Coban and Lanquin, countless sinks, limestone outcroppings (Karren) and swallow holes are visible from the road. The valleys are steep and the local relief is as great as 1,500 feet.

Caves — The caves of Alta Verapaz were studied as far back as 1900, when Dr. Karl Sapper made a map showing their location (fig. 2). Sapper provided the most extensive description of Lanquin Cave, the best known cave in the region.

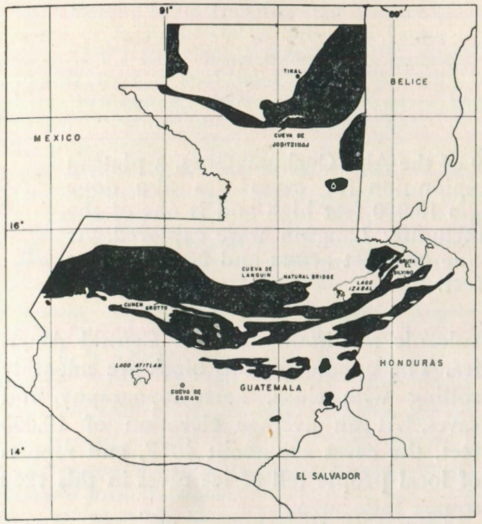

Figure 1
Limestone regions of Guatemala. From U. S. Geological Survey Bulletin 1034.

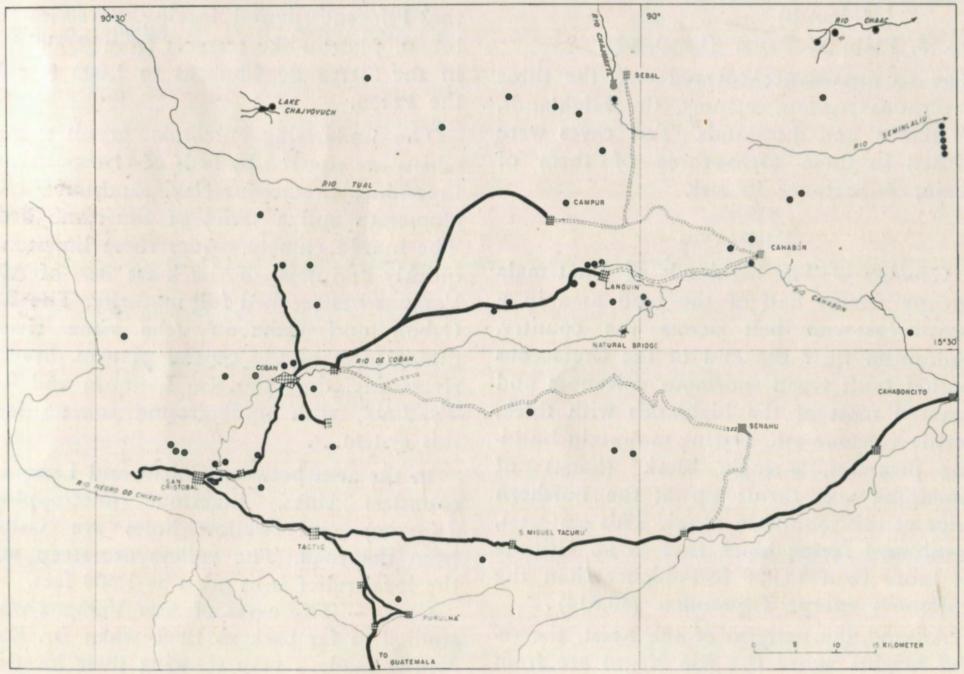

Figure 2
Caves of Alta Verapaz, Guatemala. Roads shown by solid lines, jeep tracks by dashed lines. Dots indicate caves.

Lanquin Cave — (15° 35′ N; 90° 03′ W). This is the most publicized cave in Guatemala. Its huge rooms and enormous river passages were only partly explored on the reconnaissance. However, a sketch map was prepared of this first portion of the cave (fig. 3), and a film record was made of an authentic Indian ritual within the cave.

In addition to the early explorations of Sapper, more recent explorations have been made by Jose Storek of Guatemala, Robert Vergnes of France, and Arnold Meyers of Canada (1958).

The cave is located at the foot of a limestone ridge 1.4 kilometers west of the town of Lanquin just off the road to Coban. The upper, dry entrance leads to a series of large rooms 30 to 60 feet high filled with massive formations. The lower entrance is the source of the Lanquin River which discharges an estimated 625 gallons per second

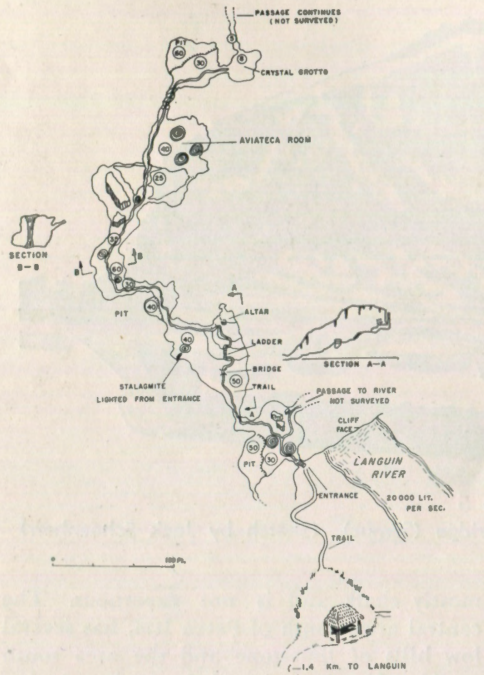

Figure 3
La Gruta Languin, Alta Verapaz, Guatemala. Survey by Gurnee and Limeres, June 2, 1959.

as a fully developed river. The Lanquin River, originating from underground sources, drains possibly 400 square kilometers of land west of Lanquin and the ultimate limit of exploration of this system is not known at present as many other caves probably connect with this system.

Traveling from Coban to Lanquin, one passes through an area of limestone with evidence of the presence of tremendous caverns. Dolinas, sink holes, swallow holes and tziguans are on every side.

Natural Bridge (Semuc). 15° 30′ N.; 90° 01″ W.). About 8 kilometers southeast of the town of Lanquin is a natural bridge crossing the Cahabon River. This remarkable structure is composed of travertine, the natural calcium carbonate deposit of a small stream which has slowly built up crustations of calcite until it completely spans the Cahabon River, 200 feet across and 1,600 feet long.

This bridge, which is 50 to 60 feet thick, carries the small stream which has formed it and also enormous rimstone pools of beautifully clear blue-green water. These pools are impounded by dams of calcite, some of which are 12 feet high and 100 feet long (fig. 4). The growth of this bridge is believed to be caused by algae in the water which cause the calcium carbonate to be precipitated at a very fast rate.

The Cahabon River is funnelled into a gorge at this point and plunges beneath the bridge for 1600 feet and reappears as a rushing resurgence (fig. 5). In dry seasons it is said to be possible to traverse this tunnel on foot, but in rainy seasons the river flows over the bridge. When we were there, it was impossible to pass under due to the flow of water in the river.

Although difficult to reach, requiring a strenuous climb, this is a truly remarkable natural phenomenon, unique in Guatemala and perhaps in the world.

Cunen Grotto — (15° 22′ N.; 91° 00′ W.). This grotto is not actually a true cave but a cliff which has developed into an overhang by deposition of calcareous sinter and

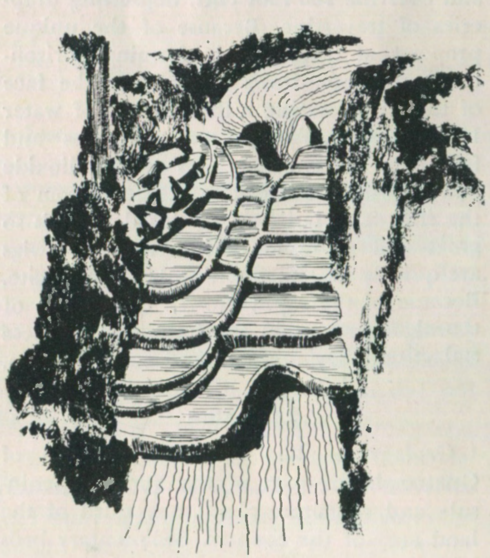

Figure 4
Rimstone pools, Natural Bridge (Semuc). (Sketch by Jack Schoenherr)

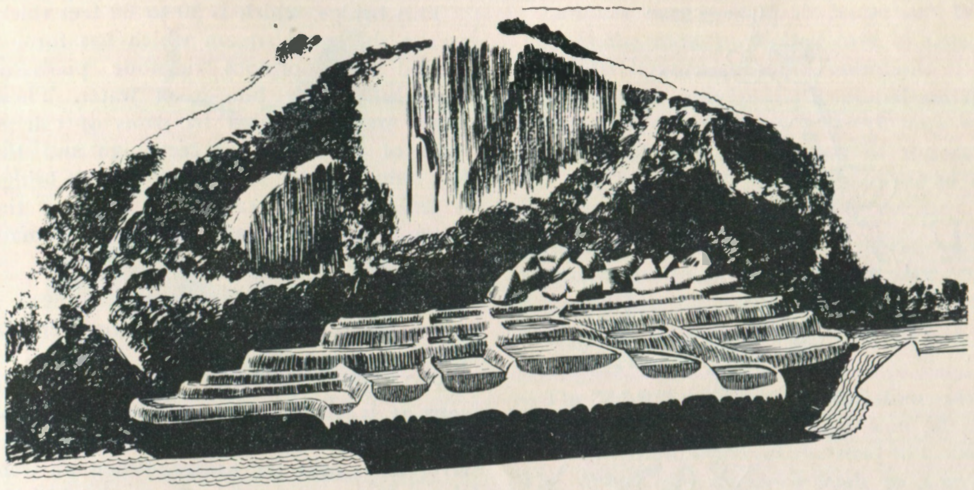

Figure 5
Cahabon River flowing beneath the Natural Bridge (Semuc). (Sketch by Jack Schoenherr)

was formed in the same manner as Natural Bridge. The grotto is festooned with stalactites. Several small springs flow from the south side of a limestone ridge 4 kilometers west of the village of Cunen. These springs evidently are saturated with calcium carbonate, as the water flows down the slope and over the 100 foot cliff, depositing draperies of travertine. Because of the unique property of travertine in forming horizontal dams, water flows evenly over the face of the cliff, creating a thin shower of water 150 feet long. As the water ripples and falls over the edge, it loses carbon dioxide and deposits more calcite at the bottom of the cliff. The build-up of this deposit is so great and so rapid that leaves and twigs are quickly encrusted with a layer of calcite. Because of the rapid growth or because of the algae present in the formation of these stalactites, they are soft and easily broken.

Lowlands

Geology — The northern lowlands of Guatemala are part of the Yucatan peninsula and constitute about one third of the land area of the country. Sedimentary beds laid down in the Mesozoic and Cenozoic periods are largely horizontal in this region. The northernmost part of the Peten is mostly chalk and is not cavernous. The central area, south of Peten Itza, has several low hills of limestone and the area south to Alta Verapaz viewed from the air has "cockpit" country karst as found in Jamaica, Cuba and Puerto Rico. This area is now most easily accessible by air, and travel on the ground is restricted to horses and foot.

Caves — Yucatan has been noted for its caves and descriptions of them go back as far as the late 1500's. Pre-Columbian Indians and later the Spaniard Conquistadores investigated the caves and described them.

Jobitzinaj Cave — (16° 52′ N., 89° 53′ W.). Three kilometers directly south of Flores at the end of a trail cut through the jungle is one of Guatemala's most beautiful caves. The entrance, about 15 feet in diameter, leads directly into large decorated chambers dissolved out of highly fractured limestone. The cave is formed in a series of inter-connecting rooms, very confusing to traverse and difficult to map (fig. 6). The most spectacular room occurs 1600 feet from the entrance, where the ceiling of the cave collapsed leaving a chamber 150 feet in diameter and over 100 feet high. The apex of the room is pierced by an opening to the sky, which forms an entrance for a colony of thousands of bats.

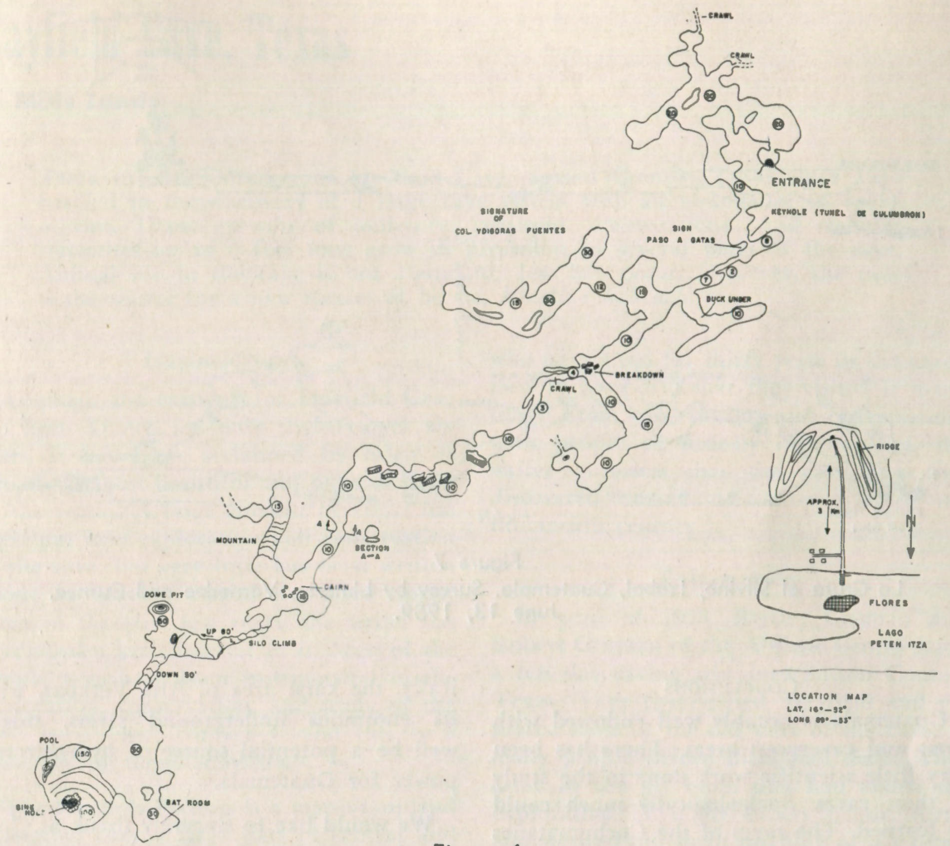

Figure 6
La Cueva Jobitzinaj, Flores, Guatemala. Survey by Limeres and Gurnee, June 17, 1959.

This cave is so accessible that many tourists and local people have explored and left initials and names throughout. One room half-way back on the route covered contains the signature of the President of Guatemala, Colonel Ydigoras Fuentes, who wrote it on the cavern wall 21 years ago when he was Governor of Peten. Only the main route of the cave was traversed and mapped. Undoubtedly other passages exist and can be explored and mapped.

Silvino Cave — (15° 35′ N.; 88° 45′ W.). This cave, located on the Guatemala-Puerto Barrios highway at kilometer mark 256, is the most accessible cave visited in Guatemala. The entrance was discovered while excavating the road bed for the highway, and exploration of the cave seems to be thorough.

Jose Storek, who explored the cave several years before the new entrance was discovered, had gained access through the stream entrance. The local Indians had entered for many years to catch the catfish in the pools at the rear of the cave. The accompanying map (fig. 7) shows the main body of the dry cave from the highway entrance. From this survey it is remarkable that the road-building operation did not break into the cave at other places.

This beautiful little cave has commercial possibilities, as it is safe, easily traversed and convenient to reach. Immediate steps should be taken, however, to preserve the formations from vandals, as many of the speleothems in easy reach of the path have been broken off.

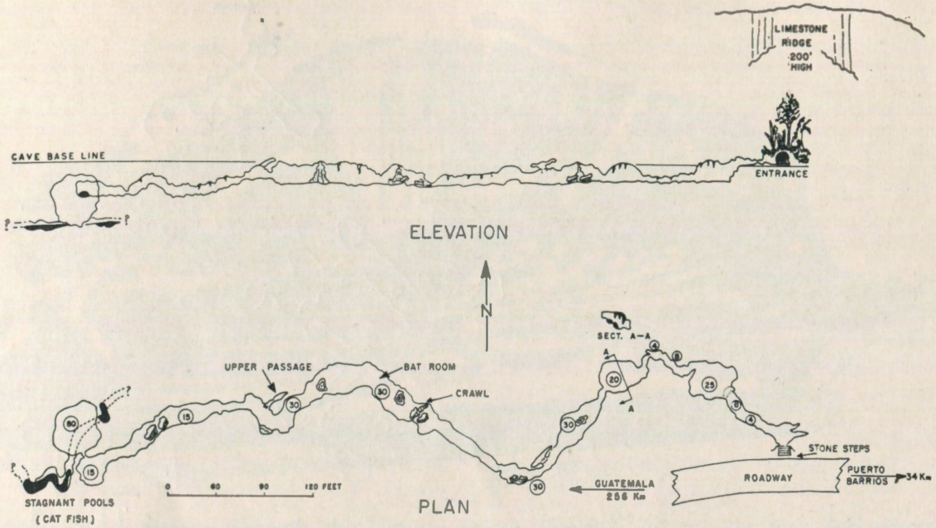

Figure 7

La Gruta el Silvino, Izabal, Guatemala. Survey by Limeres, Varnedoe and Gurnee, June 13, 1959.

Conclusions

Guatemala is notably well endowed with karst and cavernous areas. There has been very little scientific work done in the study of these caves. Speleologically much could be learned. The caves of the Cuchumatanes mountains, located at 10,000 feet elevation, are some of the highest known limestone caves in the western hemisphere. Economically, the karst area of Alta Verapaz, with its enormous underground rivers, might well be a potential source of hydroelectric power for Guatemala.

We would like to sincerely thank Sr. Jose Storek, geologist, of Guatemala City, who supplied us with information, instructions and guided us in our study of this area.

Mayfield Cave, Texas

by Mills Tandy

*A*BSTRACT——Exploration of Mayfield Cave, Sutton County, Texas since 1955 has led to the discovery of a large cave system with an abundance of speleothems. Dense growths of helictites, coralloid encrustations, and tabular stalactites up to 6 feet long grow in profusion in several parts of the cave. Animal life in the cave is not abundant; few bats occur. However, the cave is the source for a new species of beetle, *Rhadine babcocki*.

Introduction

Although the existence of Mayfield Cave has been known for only slightly over six years, it has been acclaimed by many as one of the most beautiful and unusual caves in the world. A large amount of effort has been put into exploration and conservation of the cave, but very little has been written about it. Having visited the cave many times in the past few years, the writer has developed a keen interest in it. Most of the people who have been instrumental in the exploration, conservation, and study of the cave have been contacted, and this is a summary of these activities.

The Edwards Plateau is a massive upland extending over a large part of central and southwestern Texas. On the south and east the plateau descends to the low flatlands of Texas over the maturely eroded Balcones Escarpment, which decreases in height from 1500 feet at Del Rio near the Rio Grande to less than 100 feet north of Austin (200 miles northeast of Del Rio). Along the escarpment, where the thick strata of limestone are exposed and highly dissected, numerous caves occur, ranging in size from small pits and shelters to gigantic cavern systems.

Mayfield Cave, located in west-central Sutton County, is one of the most extensive of these cavern systems, and is considered to be the most beautiful because of the many varieties of unusual speleothems found throughout the newly discovered portion of the cave.

The exact time of discovery of the old portion of the cave is not known. Residents who have lived for thirty years in the cave's locality have said that they visited it many times. From observations and conversations with people of near-by communities, the writer estimates that the cave was first discovered during the latter part of the nineteenth century.

Exploration

In June of 1955, Bartley Crisman and Robert Crisman of the Abilene Grotto made a ten day caving trip into Sutton County, Texas. They first visited Mayfield and explored most of the old part of the cave, as many people before them had done. They came to the pit room that had ended the exploration of many others before them, and noticed the small opening of a passage in the far side of the pit. After carefully investigating the walls of the pit, they decided that they could go no further.

The location and description of Mayfield Cave was given to the Dallas Speleological Society and it is to the members of this group (Claude Head, Daniel Sheffield, Jack Prince, Jack Allen, Peter Cobb, and Allen Cain) that the full credit for the discovery of the new part of Mayfield Cave must be given. On Labor Day weekend of 1955, this group made a trip into the Edwards-Sutton County area. .A part of one morning and a great part of an afternoon were spent exploring the old part of Mayfield cave. On this trip Prince tried to scale the west wall of the Pit Room in order to gain access to the northern passages plainly visible from there. He was unsuccessful in his attempts to hook a rope in the rocks there, and so abandoned this line of attack.

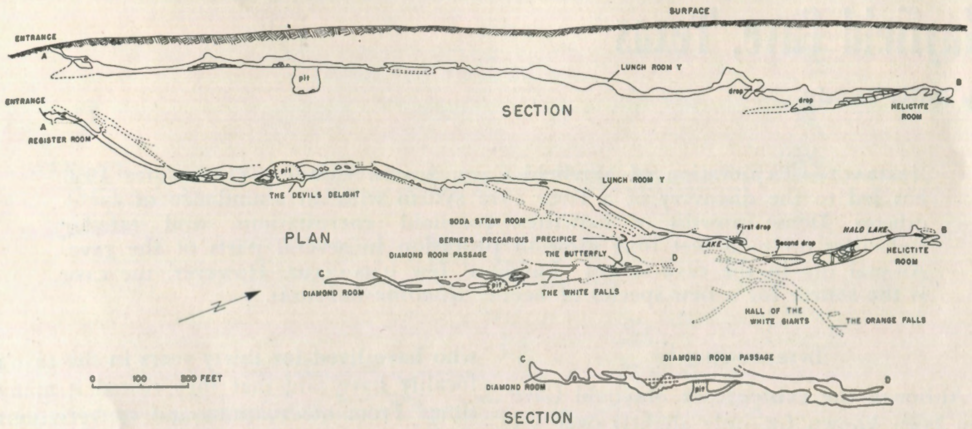

Figure 1

Map of Mayfield Cave. Surveyed by Calvin Perryman, W. T. Perryman, Ralph Perryman, Jack Burch and Don Shupe, January 9, 1959. The Diamond Room is also known as the Rhombic Crystal Room and the Diamond Room Passage is also referred to as the East Wing.

He then attacked it from the top—the now famous ledge—and inched his way across the ledge, to the comparative safety of the other side. After he had determined that the passage appeared to continue, the rest of the group inched their way across the "devil's delight."

After about an hour and a half of exploration of the West Passage, the group reached a 10 foot drop connecting with the Lake Room and because of fatigue they terminated their explorations at this point. After this numerous trips were made to the cave and its vast extent and beauty were revealed (Table I).

Geological Aspects

In solution caves, at least three related phases of development are recognized: (1) In the first phase, openings are developed by solution and are integrated to form cavern passages. (2) The second phase involves the filling of these passages with clay, silt, sand, or gravel, the source of which is the surface soils or rock in the vicinity of the cave. At times these deposits of cave earth accumulate to such an extent that they completely fill the primitive passages of the cave. (3) The third stage is a reverse of the second and results in the partial removal of the earth fill by streams flowing in the cave. These active streams also modify and enlarge the primitive passages. Simultaneously, the reopened passages receive deposits of calcite or other minerals that are carried through the rocks in solution to form speleothems.

While these three phases of development are recognized by most scientists, there are two schools of thought as to the timing and position of each phase. Some believe that the three stages occur simultaneously at or near the top of the ground water (Swinnerton 1932). Davis (1930), Bretz (1942), and others have postulated that the first and second phases occur in the phreatic zone well below the top of the water table, and the third phase occurs in the vadose zone.

Davies (1960) states that the fills are a result of alternate vadose and phreatic conditions in which active subterranean streams deposit sand and gravel when the water table is low and fine silt and clay when the water table is high and phreatic conditions exist. Such alternations would occur as the phreatic stage of excavation drew to a close, and uplift of the cavern passages began.

Mayfield Cave appears to have developed along the lines set forth by Davis and

TABLE I

Date	Party	Extent of Exploration
Oct. 1955	Dallas Speleo. Soc.	West Passage and Helictite Room
Nov. 1955	Dallas & Abilene Grottoes	Hall of the White Giants and East Wing
Dec. 1955	Dallas & Abilene Grottoes	East Wing and Rhombic Room
Jan. & Feb. 1956	Dallas & Abilene Grottoes	Lake below War Club Room and Petes Passage
Easter, 1956	Univ. Texas Grotto	Helictite Room
June 1956	Univ. Texas Grotto	Mapping
July 1956	Univ. Texas Grotto	Mapping
January 1959	Ardmore, Okla. Grotto	Mapping

Bretz. Networks of passages and irregular solution pockets in the cave's walls—characteristics of caves formed according to their theory—are common in Mayfield.

It is thought that the stage of cavern fill is of minor importance in the formation of Mayfield Cave. This stage may have been completely absent. A type of clay can be found in isolated spots in the cave today, but this clay is much different from the limestone soils of the surface above the cave. If extensive clay fills were present in the cave's lower passages, they would not be visible because secondary calcite formations cover many of the cave's walls and floors. Recent soil fills are present in some of the cave's upper levels.

There are horizontal passages on several different levels in Mayfield Cave. The limestone in which Mayfield Cave was formed is flat-bedded and it has not been determined whether these levels are due to successive solution horizons directly below the water table, or solution of more soluble beds.

The age of caverns is still a problem. Caves, obviously, are younger than the rock that encloses them, and older than the deposits that fill them. The limestone in which Mayfield Cave is located belongs to the Comanche series of Cretaceous age. Of the fossil remains of prehistoric vertebrates which have been found in Texas' caves, none have been dated older than Pleistocene age. This scant evidence places the date of origin of Mayfield Cave as pre-Pleistocene — post Cretaceous.

Undobutedly, the most outstanding feature of Mayfield Cave is the beautiful display of rare and varied types of speleothems. The helictites of Mayfield Cave are abundant and well developed. The entire wall of one side of the Helictite Room is completely covered with masses of crystal clear helictites that are up to twelve inches long and average about one-fourth inch in diameter. Giant helictites protrude from the floor of the room at an angle of forty-five degrees, and measure up to twenty-four inches in height.

Semkin (1957) said that there is fairly conclusive evidence that the helictites in the Helictite Room of Mayfield Cave were formed under water because no helictites are found above a certain level, which is an old water level. Mason (1957) comments on this by pointing out that it is generally believed that helictites are formed in the

Figure 2
Big Room of Mayfield Cave

Figure 3
Helictite Room in Mayfield Cave. (Photo by Jim Papadakis)

Figure 4
The snake dance

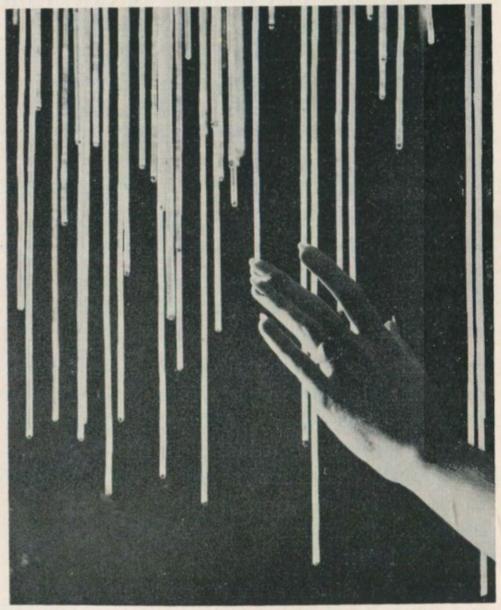

Figure 5
Soda Straws

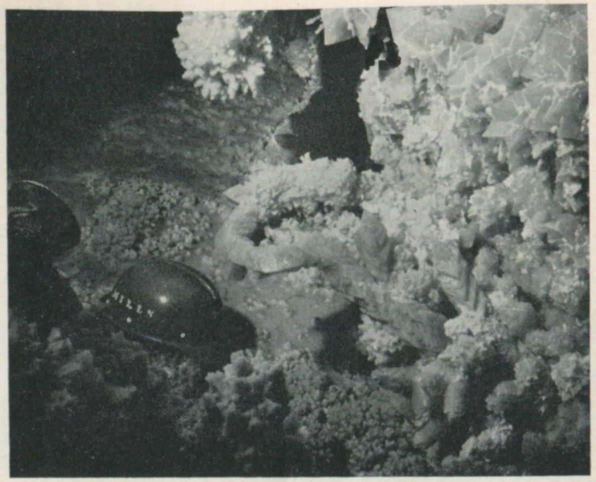

Figure 6
Helictites of rhombohedral crystals. (Photo by Moore)

air, and that the shapes displayed could not be formed under water. Moore's (1954) explanation of helictites based on internal arrangement of crystals is probably the most applicable theory to those in Mayfield Cave.

Great areas of the ceilings, floors and walls of passages in the cave are covered with beautiful coralloids which, upon close examination, show definite crystal structure. The colors of these speleothems range from pure white to rust red. These formations are believed to be sub-aqueous. "Christmas trees" up to three or four feet in height have been formed by the deposition of the coralloids on stalagmites.. Odd stalactites have been found that are wider at the bottom than at the top, and they were also formed in this manner. Although coralloids are not particularly rare speleothems, the size, color, and fragility of the ones in Mayfield Cave make them outstanding.

Far back in one of the remotest areas of the cave are some of the cave's most unusual and beautiful formations. In what was once a rimstone pool are giant rhombohedral crystals of calcite. These crystals are orange and the sides of some measure up to 3 inches. In one place, the crystals have grown together in the shape of a horseshoe. This horseshoe and many of the cave's other speleothems appear to have gone through several stages of alternate submersion and exposure to air and are composed of mineral structures of both aerogenic and subaqueous origin. The successive lowerings and raisings of the water level in the cave have occurred in the cave's third stage of development, and are not directly related to the initial solution development of the cave.

Tubular stalactites (soda straws) in Mayfield Cave are crystal clear, and their average length is about two feet, though some reach over six feet. They are so delicate that they vibrate rapidly when they are breathed upon.

The relative humidity is 100 percent throughout Mayfield cave. The temperature remains steady at 72° Fahrenheit throughout the year.

BIOLOGICAL OBSERVATIONS

Bats—From all indications, there has been only one bat colony in Mayfield Cave, and this was present in the spring of 1956. At that time, Baker (personal communication) observed a small group of about two hundred *Myotis*, with young, that had taken up a position over the ledge in the Pit Room. They evidently had been there for only a short time as the accumulated guano

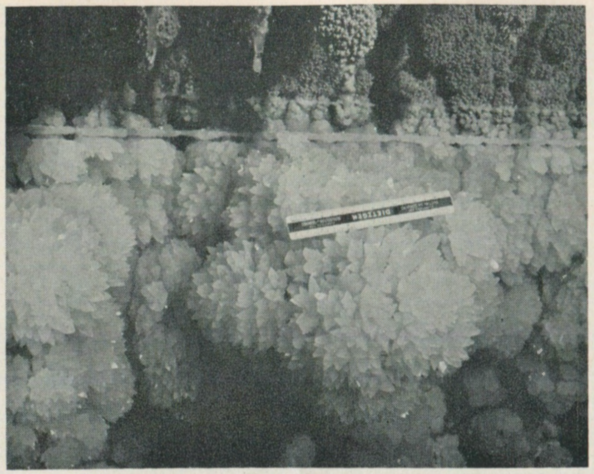

Figure 7
Calcite along a rimstone pool

beneath them was very slight. An interesting point was that while speleologists were setting up their ladders on the other side of the pit, the bats became excited and began flying around. One of the young bats was dropped by its mother and remained on the floor of the cave during the cavers' ladder operations. Upon the explorers' return, Baker noticed that the young bat was gone, the mother having evidently picked it up while they were in the back of the cave. There are no other guano deposits in the cave, and it is doubtful that bats inhabited the cave in great numbers.

The writer has observed a few isolated bats in the upper tunnel leading from the Pit Room to the entrance, but he has never seen a group of any size in the cave. A wire screen has been placed on the entrance gate so that bats will not get into the new part of the cave and ruin its beauty with guano deposits.

Other Mammals—One unsolved mystery has puzzled speleologists since the new part of the cave was entered. Throughout the cave numerous droppings of live raccoons, *Procyon lotor,* or ringtailed cats, *Bassariscus astutus,* have been found. Bones of raccoons have also been found in the upper levels of the cave. They could not have gotten there by coming through the entrance that is now known; so it is thought that there must be another entrance. Much time has been spent searching for this entrance both in the cave and on the surface, without avail.

Insects—"Cave Crickets," or "Camel Crickets," belonging to the genus *Ceuthophilus,* are the most numerous of the insects in Mayfield Cave. Some black bestles with a recurved carapace, belonging to the family Tenebrionidae, have also been observed in the cave.

Recent biological investigations in the cave have revealed several interesting insects which were not known to inhabit the cave prior to 1959. One is a carabid beetle of the genus *Rhadine.* This beetle lives only in caves, and it was described as a new species, *Rhadine babcocki,* in 1959 by Thomas C. Barr, Jr. Another interesting find is a rare milliped of the genus *Cambala.* This milliped, also, lives only in caves. Biologists suspect that other new species will be found when Mayfield Cave is more thoroughly investigated.

Conservation

Through the years, many people have visited the old part of Mayfield Cave, and their visits are much in evidence. In a small chamber in the bottom of the Pit Room, there were once many beautiful formations. Now, in many places, only the broken stubs of former stalagmites and stalactites can be seen. Stalagmites up to eight inches in diameter have been broken off, and supposedly, carried out by some thoughtless person. Certain steps have been taken by the owner and members of the National Speleological Society in Texas to prevent such destruction from coming to the new part of the cave. Soon after the new section of the cave was discovered, a locked iron gate was installed over the entrance. The beauty, rarity, and fragility of the cave's speleothems require that visits to the cave be held to a minimum. Too much traffic would destroy many of these formations. Mr. Mayfield has been most co-operative, and it was through agreement with him that this policy was adopted.

A new register was placed in the main passage of the cave, a short distance from the entrance, by the Conservation Committee of the Texas Regional Association of the NSS in the summer of 1957. The register is accompanied by a sign on which the preamble for cave conservation of the Texas Region is stated.

"Take nothing but pictures!
Leave nothing but footprints!"

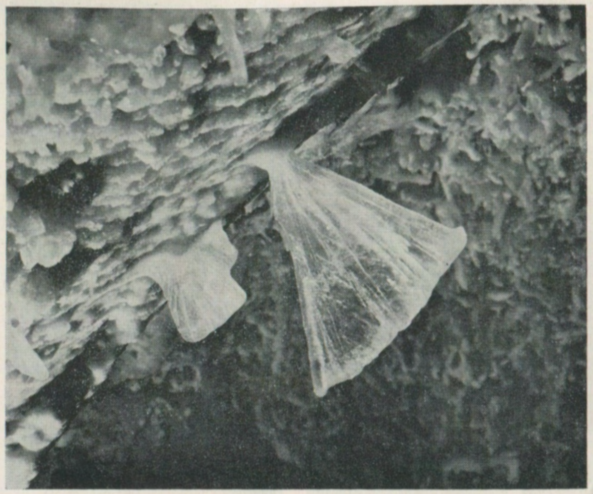

Figure 8
Fishtail speleothem

Acknowledgements

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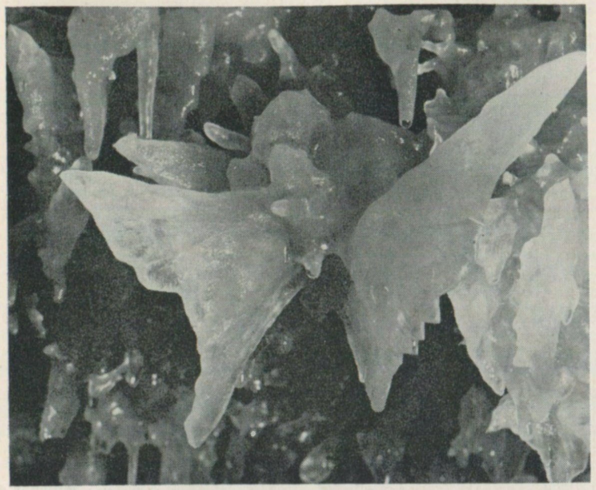

Figure 9
The Butterfly

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Figure 10
Coralloids

Figure 11
Helictite Room

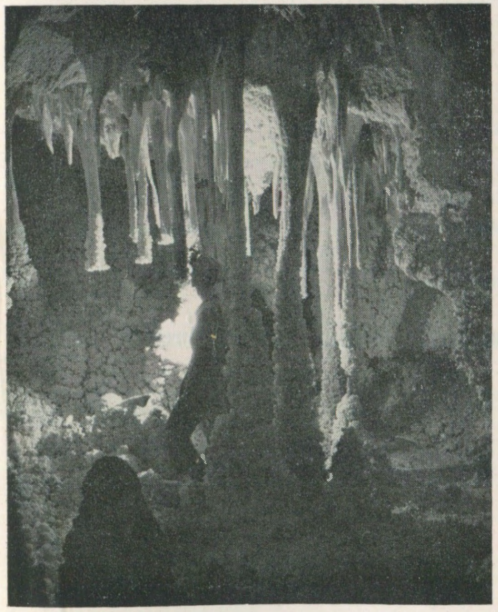

Figure 12
The Hall of the White Giants

Figure 13
Helictites and coralloids

The Accuracy of Cave Survey

by Heinz T. Schwinge

ABSTRACT—Cave maps are with few exceptions based on seemingly crude surveys with compass and tape, performed by volunteers during their spare time. Questions concerning the accuracy of such maps arise often, but are difficult to answer. By use of acknowledged methods of statistics for an estimate of the accuracy of simple cave surveys, it is evident that accuracy depends primarily on precise reading of angles; measurement of distance between stations can be made with some latitude without seriously impairing the accuracy of the survey. A compass and tape survey should have all points within a circle of error with a radius 0.55% of the length of the survey line. The radius of a circle of error for transit and tape is 0.14%.

INTRODUCTION

Based on accepted standards of engineering, almost all cave surveys are of low order accuracy. This is to be expected as such surveys are made under adverse conditions, in darkness, under great physical exertion, in limited space without the benefit of horizon or landmarks, and with relatively crude instruments. It is customary in surveying to close the survey line by returning on a different route to the point of origin and to consider the deviation as a measure of the accuracy. This method can be used in cave survey only for caves with more than one entrance. For most caves, an acceptable similar procedure would be to measure twice, once on the way into the cave and a second time independently on the way out. However, considering that cave survey is a voluntary effort generally performed in leisure time of an individual, time for such duplication is seldom available.

The accuracy of crude cave surveys with tape and compass can be determined and some ground rules can be developed that will enhance results obtained by concentrating on the measurements which are most decisive for the accuracy.

THEORY

A typical three-dimensional survey line of a cave is shown in Figure 1. The measured distances between the survey points are $a_1, a_2, a_3, \ldots, a_n$; the angles between the survey line and the positive X—axis (generally magnetic north when using compass) are

$$\alpha_1,\ \alpha_2,\ \alpha_3, \cdots \alpha_n;$$

the angles between the survey line and the horizontal are

$$\beta_1,\ \beta_2,\ \beta_3, \cdots \beta_n.$$

The coordinates of the n^{th} point of the survey can be computed from the measured data:

$$x_n = \sum_{k=1}^{n} a_k \cos\alpha_k \cos\beta_k \qquad (1)$$

$$y_n = \sum_{k=1}^{n} a_k \sin\alpha_k \cos\beta_k \qquad (2)$$

$$z_n = \sum_{k=1}^{n} a_k \sin\beta_k \qquad (3)$$

Assuming that the a_k, α_k and β_k data contain accidental errors only, that the error distribution is normal and is σ_{a_k}, σ_{α_k} and σ_{β_k}, the errors in x_n, y_n and z_n can be computed.* Yule and Kendall (1950) and Baule (1943) have shown that the standard deviation of a value p which is determined from measurements of data $t_1, t_2, t_3, \ldots\ldots, t_n$ and a function

$$p = F\,(t_1, t_2, t_3, \ldots\ldots, t_m) \qquad (4)$$

can be computed according to

$$\sigma_p^2 = \sum_{m=1}^{m}\left(\frac{\partial F}{\partial t_m}\sigma_{t_m}\right)^2 \qquad (5)$$

The coordinates of the n^{th} point of the survey are according to equation (1), (2) and (3) functions of the measured a_k, α_k, and β_k :

$$X_n = f\,(a_1, a_2, a_3, \cdots a_n;\ \alpha_1, \alpha_2, \alpha_3, \cdots \alpha_n;\ \beta_1, \beta_2, \beta_3, \cdots \beta_n) \qquad (1a)$$

$$Y_n = g\,(a_1, a_2, a_3, \cdots a_n;\ \alpha_1, \alpha_2, \alpha_3, \cdots \alpha_n;\ \beta_1, \beta_2, \beta_3, \cdots \beta_n) \qquad (2a)$$

$$Z_n = h\,(a_1, a_2, a_3, \cdots a_n;\ \beta_1, \beta_2, \beta_3, \cdots \beta_n) \qquad (3a)$$

By applying equation (5) to equations (1), (2) and (3), it follows for the standard deviations of the coordinates:

$$\sigma_{x_n}^2 = \sum_{k=1}^{n}\left(\frac{\partial f}{\partial a_k}\sigma_{a_k}\right)^2 + \sum_{k=1}^{n}\left(\frac{\partial f}{\partial \alpha_k}\sigma_{\alpha_k}\right)^2 + \sum_{k=1}^{n}\left(\frac{\partial f}{\partial \beta_k}\sigma_{\beta_k}\right)^2 \qquad (6)$$

$$\sigma_{y_n}^2 = \sum_{k=1}^{n}\left(\frac{\partial g}{\partial a_k}\sigma_{a_k}\right)^2 + \sum_{k=1}^{n}\left(\frac{\partial g}{\partial \alpha_k}\sigma_{\alpha_k}\right)^2 + \sum_{k=1}^{n}\left(\frac{\partial g}{\partial \beta_k}\sigma_{\beta_k}\right)^2 \qquad (7)$$

$$\sigma_{z_n}^2 = \sum_{k=1}^{n}\left(\frac{\partial h}{\partial a_k}\sigma_{a_k}\right)^2 + \sum_{k=1}^{n}\left(\frac{\partial h}{\partial \beta_k}\sigma_{\beta_k}\right)^2 \qquad (8)$$

The partial differentials of equation (6), (7) and (8) can be computed:

$$\frac{\partial f}{\partial a_k} = \cos\alpha_k \cos\beta_k$$

$$\frac{\partial f}{\partial \alpha_k} = -a_k \sin\alpha_k \cos\beta_k$$

---

* σ = standard deviation

σ_r = error radius (in feet)

$$\frac{\partial f}{\partial \beta_k} = -a_k \cos\alpha_k \sin\beta_k$$

$$\frac{\partial g}{\partial a_k} = \sin\alpha_k \cos\beta_k$$

$$\frac{\partial g}{\partial \alpha_k} = a_k \cos\alpha_k \cos\beta_k$$

$$\frac{\partial g}{\partial \beta_k} = -a_k \sin\alpha_k \sin\beta_k$$

$$\frac{\partial h}{\partial a_k} = \sin\beta_k$$

$$\frac{\partial h}{\partial \beta_k} = a_k \cos\beta_k$$

It follows for the standard deviations of the coordinates of the n^{th} point of the survey:

$$\sigma^2_{x_n} = \sum_1^n (\cos\alpha_k \cos\beta_k \,\sigma_{a_k})^2 + \sum_1^n (a_k \sin\alpha_k \cos\beta_k \,\sigma_{\alpha_k})^2 + \sum_1^n (a_k \cos\alpha_k \sin\beta_k \,\sigma_{\beta_k})^2 \qquad (9)$$

$$\sigma^2_{y_n} = \sum_1^n (\sin\alpha_k \cos\beta_k \,\sigma_{a_k})^2 + \sum_1^n (a_k \cos\alpha_k \cos\beta_k \,\sigma_{\alpha_k})^2 + \sum_1^n (a_k \sin\alpha_k \sin\beta_k \,\sigma_{\beta_k})^2 \qquad (10)$$

$$\sigma^2_{z_n} = \sum_1^n (\sin\beta_k \,\sigma_{a_k})^2 + \sum_1^n (a_k \cos\beta_k \,\sigma_{\beta_k})^2 \qquad (11)$$

The α_k, β_k and a_k data in these equations are known as soon as a survey is completed. The σ_{α_k}, σ_{β_k} and σ_{a_k} values can be determined as RMS averages from repeated measurements of the same angle or distance. The equations (9), (10) and (11) therefore could be used to determine the accuracy of a survey; they are, however, not easy to apply and not feasible for further investigations. A few simplifications and reasonable assumptions which are permissable within the scope of this examination will make the equations more suitable for continued investigations and will lead to interesting conclusions.

In Figure 2 are the σ_{x_n}, σ_{y_n} and σ_{z_n} pictured around the n^{th} point of the survey. According to Johnson and Moris (1956) the probability for the point n lying inside the parallelepiped with the sides $\pm\sigma_{x_n}$, $\pm\sigma_{y_n}$ and $\pm\sigma_{z_n}$ is 68%. If the sides are assumed to be twice as large, the probability should be 95% and if we triple the sides to $\pm 3\sigma_{x_n}$, $\pm 3\sigma_{y_n}$ and $\pm 3\sigma_{z_n}$, the probability is 99.7%. Replacing the parallelepiped by a sphere with the radius σ_{r_n} according to

$$\sigma^2_{r_n} = \sigma^2_{x_n} + \sigma^2_{y_n} + \sigma^2_{z_n} \qquad (12)$$

and assuming

$$\sigma_{a_1} = \sigma_{a_2} = \cdots = \sigma_{a_n} = \sigma_a ,$$

$$\sigma_{\alpha_1} = \sigma_{\alpha_2} = \cdots = \sigma_{\alpha_n} = \sigma_\alpha ,$$

$$\text{and} \quad \sigma_{\beta_1} = \sigma_{\beta_2} = \cdots = \sigma_{\beta_n} = \sigma_\beta$$

equation (12) can be written:

$$\sigma^2_{r_n} = \sigma_a^2 \Big(\sum_1^n \cos^2\alpha_k \cos^2\beta_k + \sum_1^n \sin^2\alpha_k \cos^2\beta_k + \sum_1^n \sin^2\beta_k \Big)$$

$$+\, \sigma_\alpha^2 \Big(\sum_1^n a_k^2 \sin^2\alpha_k \cos^2\beta_k + \sum_1^n a_k^2 \cos^2\alpha_k \cos^2\beta_k \Big)$$

$$+\, \sigma_\beta^2 \Big(\sum_1^n a_k^2 \cos^2\alpha_k \sin^2\beta_k + \sum_1^n a_k^2 \sin^2\alpha_k \sin^2\beta_k + \sum_1^n a_k^2 \cos^2\beta_k \Big)$$

$$\sigma^2_{r_n} = n\sigma_a^2 + \sigma_\alpha^2 \sum_1^n a_k^2 \cos^2\beta_k + \sigma_\beta^2 \sum_1^n a_k^2 \qquad (13)$$

An upper and a lower bound for σ_{r_n} can now be established. Assuming a survey line is horizontal; all the cosines will be one and the upper bound will result:

$$\ulcorner\sigma^2_{r_n} = n\sigma_a^2 + (\sigma_\alpha^2 + \sigma_\beta^2) \sum_1^n a_k^2 \qquad (13a)$$

If the survey line is vertical, the cosines are all zero, resulting in the lower bound

$$\llcorner\sigma^2_{r_n} = n\sigma_a^2 + \sigma_\beta^2 \sum_1^n a_k^2 \qquad (13b)$$

Continuing the investigation with upper bound according to equation (13a) will mean that the error of the measurement may well be smaller, but will never be greater than the computed error. Further simplification, assuming

$$\sigma_\alpha = \sigma_\beta$$

and $a_1 = a_2 = a_3 = \ldots\ldots = a_n = a$
gives the very simple relation

$$\sigma^2_{r_n} = n(\sigma_a^2 + 2a^2\sigma_\alpha^2) \qquad (14)$$

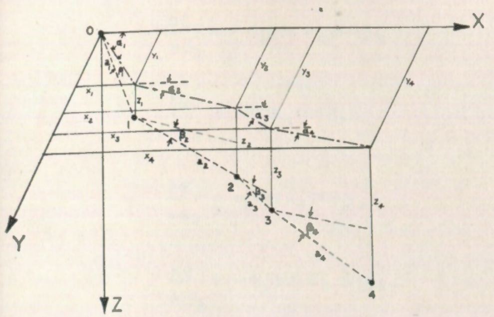

Figure 1

Three dimensional diagram of a survey line in a cave.

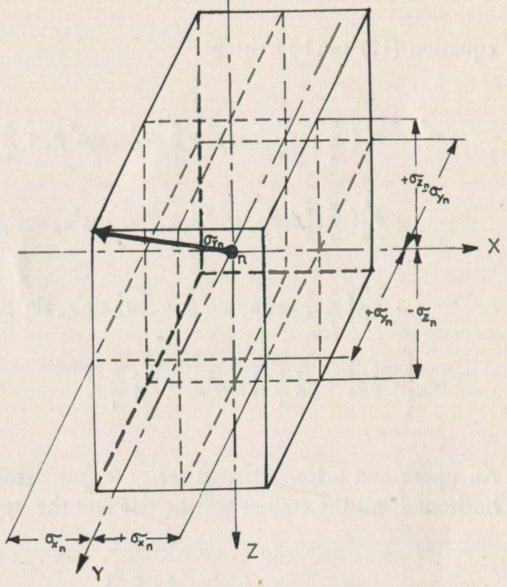

Figure 2

Error parallelepiped around the nth point of the survey. The probability that the point n lies truly inside the parallelepiped is 68%. The probability for the true point n lying inside the sphere with the radius around n is slightly higher.

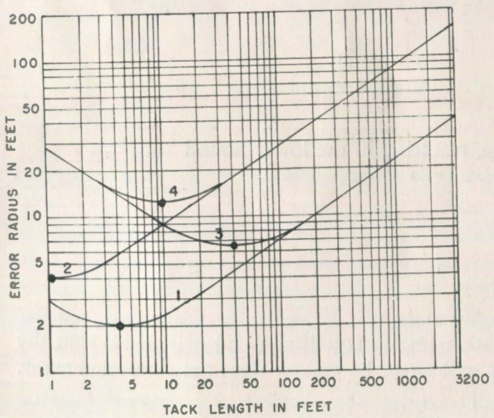

Figure 3

Error radius as a function of tack length for a total length of survey of 3200 feet. Curve 1 for transit and steel tape, curve 2 for compass and steel tape, curve 3 for transit and clothes line, curve 4 for compass and clothes line. Heavy dot indicates minimum.

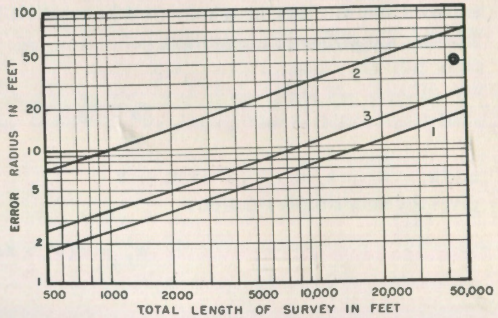

Figure 4

Error radius as a function of total length of survey for a tack of 40 feet. Curve 1 for transit and steel tape, curve 2 for compass and steel tape or clothes line, curve 3 for transit and clothes line.

This equation permits investigation of the effect of tape length and measurement errors on the total errors of the survey. The optimum tape length for example can be determined, if the standard deviations of length and angle measurements are known. Assuming the total length of the survey to be constant equal to c, it follows

$$n = \frac{c}{a}$$

and from equation (14)

$$\sigma_{r_n}^2 = \frac{c}{a}\sigma_a^2 + 2ca\,\sigma_\alpha^2$$

$\sigma_{r_n}^2$ has a minimum or maximum, if

$$\frac{\partial \sigma_{r_n}}{\partial a} = 0 = -\frac{c}{a^2}\sigma_a^2 + 2c\,\sigma_\alpha^2$$

An extreme value of the tape length is therefore

$$a_{extr} = \frac{1}{\sqrt{2}}\frac{\sigma_a}{\sigma_\alpha} \qquad (15)$$

The second derivative

$$\frac{\partial^2 \sigma_{r_n}^2}{\partial a^2} = 2\frac{c}{a^3}\sigma_a^2$$

is always positive for positive values of a; equation (15) establishes the conditions for a minimum of σ_{r_n}.

Examples

A simple 50 foot tape made from a plastic coated clothes line and calibrated with a steel tape has an accuracy of 1 foot or better, if the graduation is in feet. The standard deviation will be around 0.5 foot. A steel tape graduated in inches has a standard deviation of 0.05 ft. A simple compass with attached magnifying glass will give with careful reading a standard deviation of 2°; a more expensive pocket transit which is much more difficult to use will result in a standard deviation of about 0.5°.

The optimum length of tape for four possible combinations: steel tape-transit, steel tape-compass, clothes line-transit, and clothes line-compass, can be computed from equation (15) (Table 1). The values shown in the table, with the exception of the clothes line-transit combination, are much smaller than the tape lengths commonly used in the survey of caves. The optimum tape length for the combination clothes line-compass for example is too small to be practical; a cave of 3200 feet length would require 320 tacks of the survey line—a difficult task for a weekend or a holiday. Fortunately, the minimum of the error radius as a function of tape length is very flat. Most survey

Angles measured with \ Length measured with	Steel tape $\sigma_a = 0.05$ ft.	Clothes Line $\sigma_a = 0.05$ ft.
Pocket transit and tripod $\sigma_a = 0.5°$	4.1 ft.	40.6 ft.
Compass $\sigma_a = 2.0°$	1.01 ft.	10.1 ft.

Table I.

Optimum tape length

groups use a tape length of 50 feet; the average tack length will then be around 40 feet. The error radii for this length do not differ greatly from those obtained with the optimum tape lengths with the exception of the steel tape-compass combination. The error radius as a function of tape length for a total length of survey of 3200 feet is shown in Figure 3. The error radius as a function of the total length of survey is plotted in Figure 4, assuming for all curves a tack length of 40 feet.

Discussion

As a basis of discussion a few error radii computed for an average tack length of 40 feet and a total length of survey of 3200 feet will be compared.

The best combination steel tape-transit gives an error radius of 4.4 feet or .14% of the length of survey. The next best combination clothes line-transit with an error radius of 6.3 feet or .20% is almost as good. The error radii for the combinations steel tape-compass and clothes line-compass are 17.7 feet (.55%) and 18.2 feet (.57%) respectively. It is apparent, that angle readings are much more critical than the length measurements. Any possible improvement of the accuracy of the angle measurements will benefit the overall accuracy much more than an improvement of the length readings. If for example the standard deviation σ_a can be lowered from 2° to 1°—a factor of one half—the error radius of the clothes line-compass combination would be improved from 18.2 feet to 13.3 feet. However, if the standard deviation σ_s is lowered from 0.5 feet to 0.05 feet—a factor of one tenth—by replacing the clothes line with a steel tape, the error radius changes very little from 18.2 feet to 17.7 feet.

The computed error radii are derived from standard deviations; their validity holds if the suppositions mentioned in the beginning of the theoretical part are not violated. Every effort should be made to avoid large systematic errors. Contrary to accidental errors, systematic errors inevitably accumulate causing large errors at the endpoint. Some sources of systematic errors are a tape, compass or transit not properly calibrated, the rounding off of readings always to one side, neglecting small slopes in an almost horizontal cave, and disregarding the paralax when reading instruments. The seemingly crude survey with tape and compass, commonly used for the mapping of caves, is surprisingly accurate, if the systematic errors are kept small.

Conclusions

The following ground rules for the survey of caves can be established:

a. Keep systematic errors small; otherwise, the total error at the end point of the survey will be large.
b. Use a tape with a maximum length of 50 feet for compass survey and 100 feet for transit survey.
c. Read distances to the nearest foot. Readings to the nearest inch are of advantage only in connection with tripod and transit.
d. Concentrate on the accurate reading of angles. An equivalent accuracy for angles is much more difficult to obtain than for length. A transit with tripod is better than a compass but much more cumbersome. A compass with fluid damping, magnifying lens and arresting button is better than a compass without these features.
e. Repeat measurements where precision is questionable.

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SHORTER CONTRIBUTIONS

Observations on Ice Caves as Heat Exchangers

by Paul M. Sturgess

ABSTRACT——An ice cavern near Le Fever Falls, New York has been studied since 1955 to determine the effect of convection currents in impounding cold air in caves and mines. The cavern at Le Fever is an abandoned cement mine with a volume of 9,000,000 cubic feet. In the lower portion of the mine temperatures were below freezing throughout the winter and rose to 41°F in late summer. Installation of louvres to allow flow of air into the cavern but not out resulted in a stabilized summer temperature of 38°F. without altering the winter temperatures.

Early in 1955 I became interested in the presence of ice in caves. From the Hudson River at Kingston, New York, up the Rondout Creek to Rosendale, lie millions of tons of limestone, the Rosendale deposit. This limestone was mined extensively for natural cement which was used to build the U. S. Capitol, the Brooklyn Bridge, and the base of the Statue of Liberty. The natural cement industry was at its peak around the turn of the century, and shortly after most of the mines were abandoned leaving vast man-made caverns. Some have filled with water, others are used for mushroom culture. In a few of them ice can be found in summer. Early in 1955 I became interested in this phenomena, and recalling a place on Highway 213 in Lawrenceville, between the villages of Rosendale and High Falls, where on hot days a torrent of cold air pours out across the road, I became interested in studying the part convection played in forming ice caves and mines. If convection occurred and the lowest passage of a cavern or mine connected at its level with the surface, it would let the cold air move out on a hot day, to be replaced, pound by pound, by warm summer air, entering the cavern at a higher elevation; in turn the warm air would become chilled by the cold rocks of the cavern, and continue to flow towards the lower exit. The flow can be demonstrated and observed by merely opening the door of a household refrigerator. The cold air falls out the bottom to be replaced by the warmer room air entering the top. It keeps flowing as long as the refrigerator surfaces are colder than the room temperature.

In winter, we would anticipate a reversal of air flow in the lowest passage. If the cave were warmer than the ambient air, it would be lighter and the cave would behave like a flue of a fireplace chimney, drawing cold air in at the bottom, heating it, and passing it out the top.

An obvious experiment presented itself. If a cave could form ice with the lowest passage open, how much colder would it get if a check damper were placed across the passage? For this purpose a check damper would have to be made of very light material, so that the slightest pressure of air entering the tunnel would push it open, but when air flow reversed, it would close and check the air flow.

A man-made cavern was located for such an experiment through the aid of Warren Knaust, Speleologist, and mushroom grower. Located at Le Fever Falls, its lowest adit is visible upstream from the bridge carrying the New York Thruway across the Rondout Creek. It can be seen by looking west between mileposts 84.1 and 84.2. This cavern (mine), now containing about 9,000,000 cubic feet of air space, was developed along two seams of cement rock, 1400 feet long, 22 feet wide and 160 feet deep, separated by a strata of unwanted

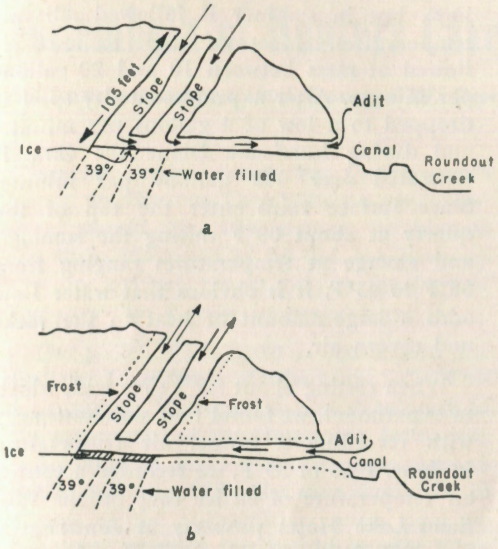

Figure 1
Profile of quarry at Le Fever Falls. Arrows indicate direction of air flow: (a) summer, (b) winter.

rock about ten feet thick. These drifts slope from the top of a mountain at an angle which averages about 45°, their upper rim forming the top of a "chimney" about 105 feet higher than the lowest adit which is also the drainage tunnel for the cave. The adit enters the mountain just above the old Delaware and Hudson Canal, along Rondout Creek, and runs about 535 feet before intersecting the drift in the natural cement. Cement was removed far below this level, but this part of the cavity has filled with water to the level of the bottom tunnel. Actual total volume of the cavern is unknown.

In one place in this cavern, above the water level, where seepage occurred, ice could be found year round. It was ideal for experimental purposes, as the vertical pitch of the cavern resulted in a strong draft at the adit. Temperature of air leaving the adit on June 1st, 1955 was 39° F. With a surface temperature of 95°F the volume of the air moving out of the cavern exceeded the equivalent of 1,000 tons of refrigeration. (fig. 1).

Permission was obtained from the custodians of this abandoned mine to install check dampers in the adit for experimental purposes (fig. 2). Installations was made during August of 1955. On hot days the individual louvres would vibrate strongly as they effectively held back the large mass of cold air that was blocked from moving past them. A barometer indicated a difference of 4 to 5 mm of mercury between the pressures on the louvres. As colder weather approached it was found that the temperature at which there was no movement of air in the tunnel occurred when the air temperature was about 5 degrees above that of the tunnel, indicating that there existed a temperature differential in the cavern of 10 degrees, being coldest at the bottom, and warmest at the top. The slightest breeze would make the louvres swing inward, as a venturi drop in pressure occurred at the top of the cavern.

On a crisp, sunny December morning when the temperature had dropped to 10°F I arrived at the mouth of the tunnel to find the brook frozen over and all the louvres swinging back and forth as the cold air entered the tunnel. While the direction of flow was as we had predicted, its force going in was far less than the force coming out in hot weather. We entered the cave by way of the bottom tunnel after the Christmas holidays of 1955 to find that the brooks at the far end of the tunnel had not yet frozen but on entering the cavern the temperature was much colder and the deep pools frozen with a 6 inch-thick clear, perfect sheet ice. Further observations during cold nights showed a strong breeze blowing down the drift showing that downdrafts had taken over and were refrigerating the rock walls of the cavern far greater than that possible by the small amount of air which was entering by way of the tunnel. Later the ice was covered by additional water from the surface, which flowed over it and froze into unclear mush ice.

Towards the end of winter the degree of cooling is limited by the millions of gallons of water entering and moving in the cavern. Since water is densest at 39°F, the water

Figure 2
Frame of aluminum check dampers that were installed in the adit of Le Fever Falls quarry. 8 frames were used to close off the adit.

under the sheet ice of the lake, away from the ice itself, it 39°F. It follows that the water in the lake and the mass of rock bordering it cannot be chilled much below this temperature by air brought in by convection currents. Although we obtained temperatures in the low twenties in parts of the cavern during the winter, the greater part of the cavern lies above a large source of heat at 39°F. A minimum temperature of 5°F was recorded at the bottom of the cavern when ambient temperature was — 20°F.

The temperature of the brook running out the adit was just above 32°F all winter long, but in summer it followed adit air temperatures. Most of the summer it flowed at rates between 10 and 20 gallons per minute. After a protracted dry spell it dropped to a low of 4 gallons per minute, and during hurricane Diane the flow is estimated over 400 gallons per minute. Since surface rains enter the top of the quarry at about 60°F during the summer, and emerge at temperatures ranging from 38°F to 43°F, it is obvious that water flow adds a large amount of heat to the rocks and cavern air.

When casting about for a cave with which to experiment, we found that simultaneously with recording a tunnel air temperature in June, 1955 of 39°F, we recorded a tunnel air temperature of an ice cave on the Williams Lake Hotel property at Binnewater, also 39°F. When our dampers were installed in the mine at Le Fever Falls in August, temperatures in both caverns had reached 41°F. Since the caverns are not identical, the use of the Williams Lake cave as a control for our experiment presents problems in correlation, but after 5 years of controlled air flow at Le Fever Falls cavern the temperature was 38½°F in this cavern on September 1, 1960, and that of the Williams Lake cavern, 43°F. The temperature difference of 4½°F was due, we surmise, solely to the effect of the dampers.

While sealing off of a part of the cavern did not result in lowering minimum temperatures it did indicate that the rocks contain a vast source of high temperature refrigeration. From our experiment it is apparent convection currents of winter air were responsible for cold conditions in ice caves, and that ice caves are effective traps for storing cold winter air the year round. Furthermore, it would be economically feasible to alter existing ice caverns or develop underground sites to trap cold winter air for use in large refrigerated installations involving little or no energy.

Collembola of Hunters Cave—Discussion

by James Hedges and George W. Darlan, Jr.

Several errors occur in Christiansen's paper on Hunters Cave*. In no way, however, should Mr. Christiansen be blamed for these inasmuch as he did not have access to a final report on the geology of the cave that is now in preparation.

On p. 59: "The cave is located—in the Galena Limestone (Ordovician),—". This is incorrect. Hunters Cave is developed in the upper part of the Hopkinton formation, a dolomite of Middle Silurian age. According to Scobey (1938), the cave should lie in a unit of the Alexandrian series, and on lithologic grounds this would be the Edgewood dolomite. However, fossil evidence indicates that the cave should be assigned to the Hopkinton. Hunters Cave lies near the crest of a high ridge, not reflected in Scobey's map, which no doubt accounts for the up-dip extension of the Hopkinton at this point.

Also on p. 59 "The 'Pit Room' —, resembling a huge drain." This may be misleading. There are two areas in the cave in which the floor is significantly lower than elsewhere, one of these areas being the Pit Room. There is a possibility that this room is the locus of a slump pit and, therefore, might be called a "drain". However, no mechanism to explain slumping is known; the floor here is virtually impervious and a small lake forms in wet weather; there is an old flowstone armor extending the length of one side of the pit; the room is probably the result of the coalescence of a three-dimensional network under phreatic conditions and some breakdown before the dome reached equilibrium. The possibility of slumping exists, but there is no present activity and no function as a "drain" at present.

Also on p. 59: "Silting in the cave seems to be rather rapid and in a short period of time, perhaps 10 to 20 years, considerable changes have been made in the traversable area." The only area in the cave which is now undergoing siltation or any sort of sedimentation is the area immediately surrounding the entrance sink. What little study has been made on the cave sediments indicates that the cave, away from the sinkhole entrance, is filled to a depth of many feet with clay, breakdown, and some silt and sand which are usually associated with blocks of breakdown included in the clay. In the Main Room, and the passages around the Flat Room and the sinkhole, there is some superficial soil and vegetable debris which has washed into the sinkhole. The age and origin of the sediments are not known. However, most, if not all, of the sediments away from the sinkhole are *not* stream-laid and are of much greater age than a mere 20 years.

Probably, the most recent date that clays could have been deposited under the still-water conditions indicated would be in the Middle Pleistocene, at the time of Kansan outwash (Kay and Apfel, 1929). Probably, the earliest date of their deposition would be during the Early or Middle Tertiary (Trowbridge, 1921). It is hoped that samples of the clay can be analyzed and some correlation made between them and samples of Pleistocene till or loess deposits, or with the non-soluble portion of the country rock. Because this clay blocks all known passages and lies against the cave walls at all points except those adjacent to the sinkhole, because the clay appears to be undisturbed from its initial deposition at a time when the cave was filled with water, and because this time probably could not have been more recent than Late Kansan, the assertion that silting is recent appears to be without basis.

* Christiansen, K., 1960, The collembola of Hunters Cave, Iowa: Nat. Speleol. Soc. Bull., v. 23, pt. 2, July, p. 59-70.

References

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Kay, G. F. and E. T. Apfel, 1929, The Pre-Illinoian Pleistocene geology of Iowa: Iowa Geol. Survey, Ann. Rpt., v. 34, p. 1-304.

Trowbridge, A. C., 1921, The erosional history of the Driftless Area: Univ. Iowa Studies in Nat. Hist., no. 40.