BULLETIN THIRTEEN

NATIONAL SPELEOLOGICAL SOCIETY

Affiliated with the American Association for the Advancement of Science

IN THIS ISSUE . . .

Accurate and informative articles on caves including

TECHNIQUES FOR DATING CAVE DEPOSITS

CAVES AND ROCKSHELTERS IN SOUTHWESTERN ASIA

THE CAVE SALAMANDERS OF CALIFORNIA

MECHANICS OF CAVERN BREAKDOWN

WYANDOTTE CAVERN

AN ENGINEER INSPECTS THE RIGGING

REPORT ON THE TITUS CANYON EXPEDITION

SOUTHWESTERN CAVES AS BOOKS OF HISTORY

AND OTHERS

DECEMBER 1951

BULLETIN THIRTEEN

Published by THE NATIONAL SPELEOLOGICAL SOCIETY
To stimulate interest in caves and to record the findings of explorers and scientists within and outside the Society

IN THIS ISSUE, December, 1951

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THE NATIONAL SPELEOLOGICAL SOCIETY was organized in 1940. It now has members scattered throughout the United States, and also has many members in foreign countries.

THE SOCIETY is a non-profit organization of men and women interested in the study and exploration of caves and allied phenomena. It is chartered under the law of the District of Columbia. Its energies are devoted to the unlocking of the secrets of the world underground.

THE SOCIETY serves as a central agency for the collection, preservation and publication of scientific, historical and legendary information relating to Speleology. It arouses interest in the discovery of new caves and encourages the preservation of the natural beauty of all caverns.

THE AFFAIRS of the Society are controlled by a Board of Governors. The Board appoints the national officers. The Board also approves committee chairmen —who are chosen not only for their proved ability in a particular field, but also for their activity in the work of the Society.

LOCAL SECTIONS of the Society are called Grottoes. They serve to stimulate and coordinate activity and increase the interest, enjoyment and productiveness of caving.

LIBRARY: An excellent speleological library is owned by the Society and is being constantly enlarged. Items on hand may be borrowed by NSS members. Extensive collections of cave maps, photographs and slides are being gathered and are available on a loan basis.

Membership helps to support the publications, special investigations, and the operation of the Society.

Associate	$ 3	Institutional	$10
Regular	$ 5	Life	$75
Sustaining	$10		

PUBLICATIONS include the BULLETIN published at least once a year, and the NEWS appearing monthly. All members receive the BULLETIN and the NEWS.

Preface to Bulletin Thirteen

The editor of this BULLETIN and the Society may well be proud of it. It shows unmistakably the broadening scope of the National Speleological Society. Its publications logically have become the clearing house for American speleological activities whether carried out at home or abroad.

As significant as the reports herein on cave studies in Iraq and Southwest Asia is the description of an expedition by NSS members to Titus Canyon. This is the first published report of a well organized, official activity. We hope that it will become the pattern for many more.

The Society's effort to keep its members informed of the latest scientific advances is exemplified in an up-to-the-minute review of the current work on dating cave deposits.

Vital information from the field of engineering is applied to speleological problems in two articles designed to increase both the safety factor and the enjoyment of cave exploring.

Other articles of high caliber round out the BULLETIN, making it one of the most important yet published. The next BULLETIN, already underway, is expected in mid-1952. Considerable progress is being made also on the next regional bulletin, due in 1953.

Readers of the BULLETIN should not overlook the interesting and valuable articles which appear in the monthly NEWS. In the last four years, a total of 278 pages have appeared. Due to the larger and more condensed nature of the NEWS page a great amount of copy can be handled—the equivalent of a 200-page bulletin each year. While much of this material admittedly is of temporary interest, an impressive proportion of the articles is of lasting value. An index to these major articles and reports is planned.

At the last annual meeting the growing importance of the Society's publication program was recognized by the election of a vice-president in charge of publications. In addition to the BULLETIN and the NEWS, the Society this year published "Palaces Under the Earth," a directory of commercial caves. Underway are two extremely ambitious projects, a "Handbook of Speleology" and a "Bibliography of Speleology, 1750 - 1950." Both are in relatively advanced stages of preparation.

The Society expresses its gratitude to its editors and contributors.

CHARLES E. MOHR,
President

December 1, 1951
Greenwich, Conn.

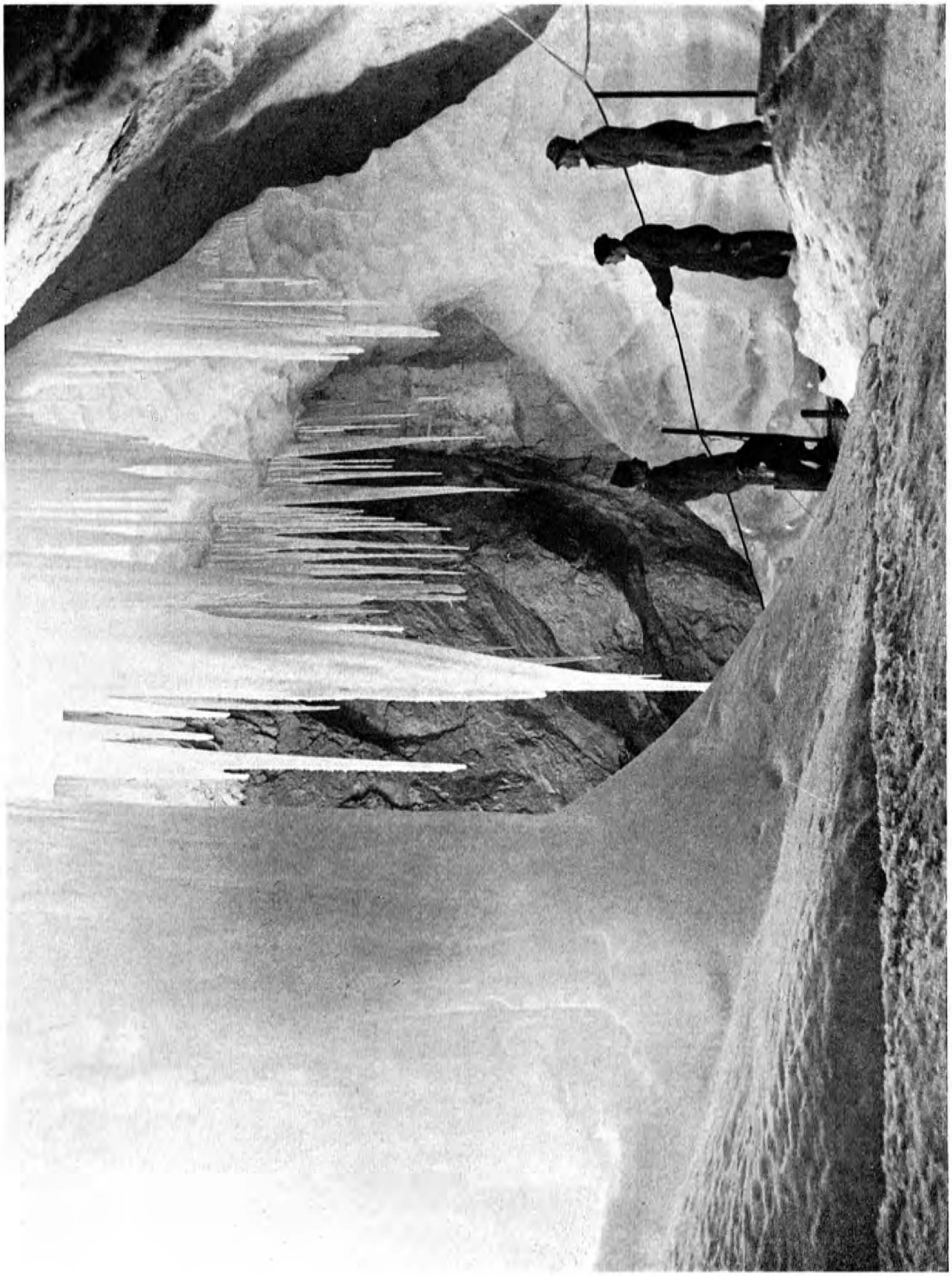


Photo by Gustav Abel, Salzburg, Austria

Eisriesenwelt, Das Eistor; at the Tennengebirge in Austria. The Ice Gate of the Eisriesenwelt Cave. This beautiful photograph was chosen for our frontispiece from a group of 14 entries of Gustav Abel of Salzburg, Austria, submitted to the 1951 Photographic Salon of the National Speleological Society.

Techniques for Dating Cave Deposits

By IVAN T. SANDERSON
Zoologist

All photos by American Museum of Natural History, New York

The coming of man to North America, long believed to have taken place a mere 35,000 years ago, has probably been pushed back into time far beyond that figure by new discoveries and advances in the techniques of dating archaeological finds. The methods for dating artifacts are described herein in a manner which makes complicated technical procedures easily grasped by the average reader.

There are several well-established methods for dating geological and archaeological specimens; among which five are of outstanding significance to speleology — namely, the statistical analysis of radioactive carbon 14 content, flourine-analysis, varve-clay layer counts, tree-ring counts, and spore-analysis. Each may be applied either in general or in special cases to the dating of cave deposits. The extent to which these techniques have been applied to cave material is as yet regrettably small, and an endless task awaits speleologists in this field. Before reviewing what has been attempted or accomplished, it would be well to describe briefly the bases upon which the five specific techniques mentioned above are founded.

The radiocarbon method is probably of first importance to speleology. The basis of this technique is that the half-life of carbon-14 is 5,568 plus or minus 30 years, which allows accurate dating—though it cannot be too strongly stressed that this is only on a *statistical basis*—of material up to about 25,000 years of age. This is far more comprehensive than any previously devised methods—and much more precise, be it noted—for dating late quaternary deposits and their contained human artifacts.

As a result of the constant press stories and articles in scientific and popular magazines which have appeared during the last few months it has become well known to geologists, archaeologists, and speleologists that all plant and animal matter contains, during life, a fairly if not entirely constant amount of the carbon isotope number fourteen. This is caused by cosmic rays striking our atmosphere and being captured by the nitrogen. The resultant nucleus immediately disintegrates, throwing out a proton, which results in the formation of a carbon atom of atomic weight 14. These carbon atoms happen to be radioactive. They are ultimately again reduced to ordinary nitrogen of atomic weight 14 by the expulsion of an electron.

In the meantime, however, the radioactive carbon atoms enter into the carbon-dioxide content of the atmosphere and are absorbed by plant life along with their sister isotopes Carbon 12 and 13. As a result they become transferred to all terrestrial animal life because this is ultimately dependent upon plants for its growth and sustenance. The proportion of radiocarbon 14 to ordinary carbon 12 is of the order of 1×10^{-12} gm to a gram of carbon 12. When a plant or animal dies, absorption of radiocarbon ceases and the remains of said animal or plant, if preserved in any way, are not thereafter altered from this particular point of view unless *contaminated* by physical proximity to some secondary source of nuclear disturbance. Thus, any such remains may, by analysis of the proportion of their radioactive to non-radioactive carbon content, be dated with an accuracy that is dependent only upon the degree of refinement of the methods of analysis and the absence of contamination.

Dr. W. F. Libby of the Institute for Nuclear Studies of the University of Chicago solved both these problems and initiated this great advance and its practical application to historical, archaeological and geological researches. However, a warning should be sounded here, for it has been far too readily assumed—not only by the non-specialist—that this technique is absolutely precise and invariably infallible. This, alas, is far from the case. The method is entirely statistical, and the actual age of the material analyzed has almost as much bearing upon the degree of precision obtained in estimating its apparent age as does the care taken in the analysis and the liability to contamination. Dr. Libby, his co-workers, and others now entering this field with similar equipment do not and never have claimed the degree of precision that has often been attributed to their findings by both popular and by some scientific publications. Nevertheless, the method is an extraordinarily valuable advance in this most important field of research and has, as we shall see later, already resulted in a number of most remarkable discoveries.

The next two techniques that have been applied to the problem of prehistorical dating are flourine-analysis and varve-clay counts. The first is of a purely chemical nature and is applicable only within any one stratum or deposit. Being dependent upon the extent of *replacement* of matter, it is only of use in the determination of the age of fossils which it may be suspected are of older or younger age than the deposit in which they are found.

Fossils may be washed out of one stratum and deposited in another, newer sediment, at any time. Normally, such redeposits are obvious: a Liassic[1] ammonite in a Pliocene clay would be a striking and easily noted example. When, on the other hand, human bones such as the Piltdown skull and lower jaw and teeth, and mammoth-bone artifacts found along with them are washed out of one quaternary gravel and redeposited in another, it is impossible at first sight, to tell whether they were all derived from the same original stratum.

In certain places and at certain times, however, flourine compounds—notably, flourapatite—of specifically detectable nature may enter into the list of minerals replacing the bones or other materials being fossilized. The rate at which such materials are replaced, or the amount of such flourine compounds available vary from place to place. Thus, it is possible to tell by analysis of the proportional content of these compounds whether one fossil found in any bed is of similar age to any others associated with it. The method has been applied to the various bones associated with and including the specimen of the ape-man known as *Eoanthropus* discovered by Dawson at Piltdown in England, and as a result its previously claimed age has had to be very considerably reduced because the analysis showed much lower flourine concentration in the fossilized bones of the ape-man than in the associated fossils. In other words, this skull was a later intrusion into the gravel bed from which it was dug, probably through having lain in—or possibly even having been buried in—a pocket sunk from above into that deposit.

Reconstruction of skull of Piltdown man.

Lower jaw of Eoanthropus.

[1] The oldest division in the European Jurassic system.

The study of varved clays, which was originally initiated in Sweden by glaciologists, is a mechanical rather than chemical method of calculating past time. The melting of a glacier foot or front, especially in a confined fjord or valley, proceeds much more rapidly under summer suns than during the extended northern winter. The water resulting from the melting ice carries with it a certain amount of very fine sediment derived from the grinding action of the moving morainic material contained within the glacier. The fine sediment remains in suspension in the water for a long time and is thus carried out into the still waters of the lakes that usually lie below the glaciers; it is there slowly deposited. The result is a deposit of clay made up of a continuous succession of layers that alternate in thickness according to the seasons. Slight variations in texture and color between the alternate layers, deposited in summer and winter respectively, make it possible to count the actual number of years that the process has been going on and thus to date precisely any included fossils or other foreign bodies that may be found therein.

Varves may often be found in caves, not only because of the presence of a local ice front, but also because of pronounced seasonal variations in rainfall. Their presence has often been overlooked by the excavators of cave deposits for the very simple reasons that they do not look for them and the artificial lights used are not bright enough to reveal them. When found they may be exceptionally valuable, especially in the tropics or in other areas where there is a pronounced seasonal variation in precipitation. In a cave in Trinidad the author made a very rough count back to 700 years in a small side pocket, in order to try to date a surprisingly fresh-looking potsherd that occurred at a depth of just over three feet. Where cave deposits run up to 20 feet in depth without noticeable stratification, a varve count might produce some surprising results.

The two remaining methods mentioned previously for dating the record of the past are of a biological nature and are only applicable to the post-glacial era. Seasonal variation is also detectable in tree rings, and in some cases the extent of variation therein recorded is so great, because of the sensitivity of the tree to the day climate, that specific years of drought, flood or other catastrophes may be detected. When this is done, tree trunks of various ages may, when analyzed, be linked together by temporal overlap with a high degree of certainty in any one area, thus giving us an extended picture both of past climatic history and of the age of the trunks themselves, together with any associated remains found deposited with them. Such deposits sometimes occur in caves, especially in sink holes near their mouths or at the bottom of a complete roof cave-in.

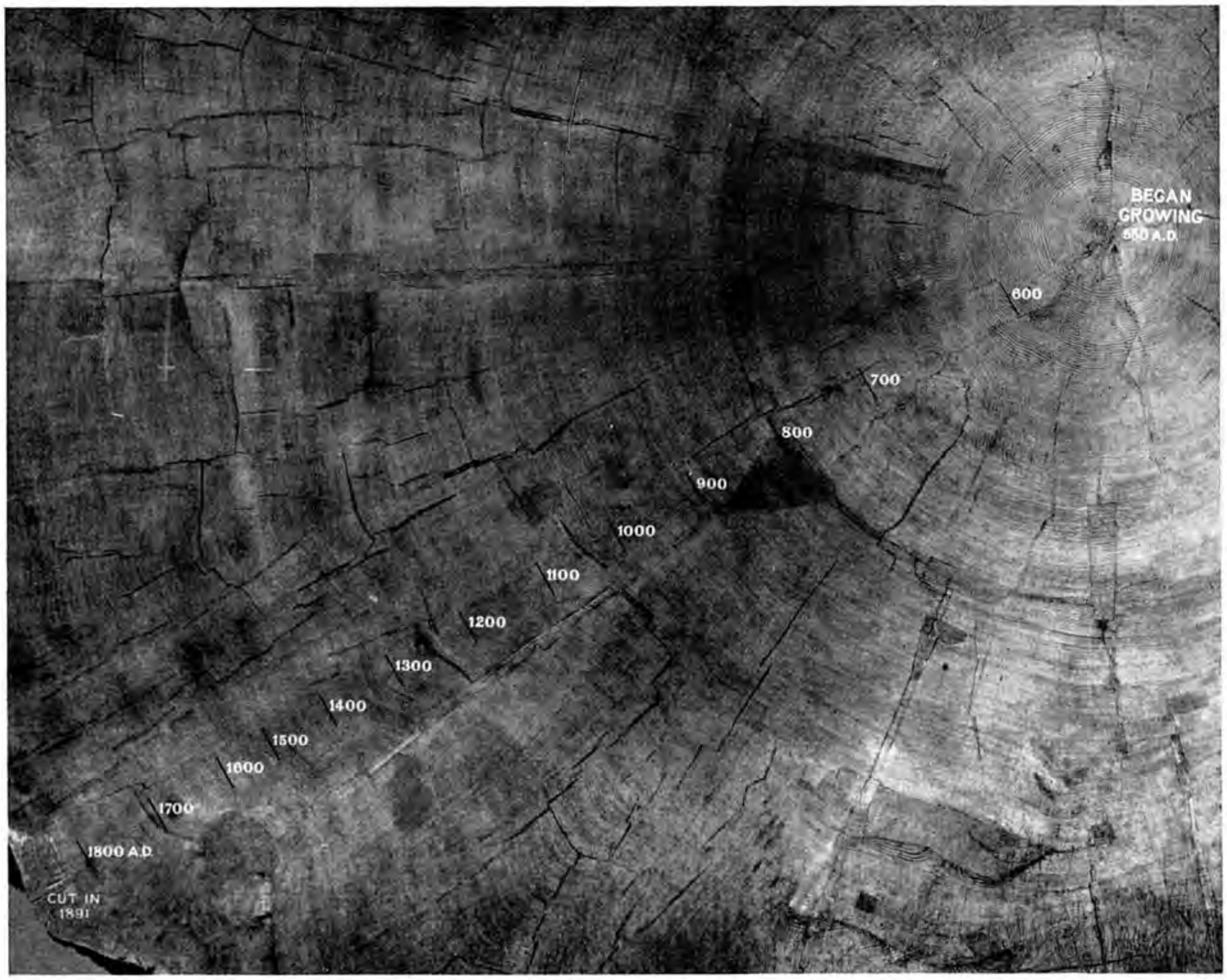
The last method that requires special mention here has now been developed to such a high degree of complexity that it has warranted the establishment of a separate department of scienific research known as *Palynology*. This, in simpler terms, means *pollen analysis*.

Pollen analysis, as employed today, was first developed by the Swedish geologist, Lennart von Post. There are two great modern works that may be consulted by anyone wishing to pursue such studies and it is a field that would repay the speleologist. The method is based upon the fact that the pollen grains of flowering plants and even the spores of lower plant forms are of incredible variety, though specifically of constant appearance, when examined microscopically. These forms and patterns have a high specific value to the systematist and ecologist, and now that enormous collections of type-specimens have been built up, the parent plants may be identified very readily and rapidly. Moreover, pollen and spores are exceedingly durable, outlasting almost everything else—except molluscan shells—if buried in suitable deposits which vary from acid peat bogs to alkaline cave deposits. The vast majority of pollen grains are, of course, normally destroyed, but enough fall upon bodies of water, swamps, and bogs in the bottom deposits of which they may be preserved, especially if oxygen is deficient therein, as in anaerobic muds on many lake bottoms.

Analysis of the specific grains found in a large variety of post-glacial deposits has now been completed, and as a result an extraordinarily detailed picture has been constructed of the changing vegetational cover of the land surface, the climatic variations that caused these changes, and consequently, of the comparative ages of various deposits or facies of deposits. The final objective of palynology is to survey the entire land surface of the earth with a view to cataloguing all existing types of pollen grains and spores, and identifying their parent plants, then recording the incidence, proportional amount, and spatial distribution of all such pollens and spores in surface deposits, and, finally, extending this analysis as far back as possible into the past. In doing this some workers have already stepped over into the realm of wholly fossilized spores and grains which opens up the possibility of extending the chronology back hundreds of millions of years.

The method is of potential value to speleology, especially in flood streams or where large cave mouths are open to winds but protected from direct rain. Sometimes fine material such as pollen grains may be preserved in such places alone, the entire surrounding territory being either too dry, too moist, or otherwise chemically unsuitable for their preservation. It is certainly a possibility that should no longer be neglected.

The result of these techniques is that we have now gained a very much clearer and truer picture of the past history of our earth and more especially of the glacial and post-glacial periods. Of course these newer techniques have been combined with the more ordinary and much less spectacular though reliable methods for dating the past that have been used by geologists and archaeologists since those sciences were first formulated and practically applied. Moreover, since the establishment of the radiocarbon technique, some great surprises have come to light necessitating an almost complete



Tree rings as shown by close-up of *Sequoia Washingtonii*.

reorientation of our previously established ideas of chronology. This is particularly true in the field of North American archaeology.

Until recently it had become an accepted maxim that man entered this continent only after the last retreat of the ice cap, that this took place 35,000 years ago, that he came exclusively from eastern Asia by way of Alaska, and that even the earliest traces of his handicraft were of almost recent date. This concept was first shaken by the discovery of human artifacts associated with the dung of an extinct giant ground sloth in Gypsum Cave in Nevada. Then, in

Reconstruction of giant ground sloth.

Peruvian coastal regions, ever deeper layers of culture came to light; these obviously required much greater periods of time for their accumulation, deposit and replacement than had previously been assigned to them in the accepted chronology of American man. Also de Terra in Mexico claimed an age of 11,000 years for the amerindian-type skull which he named Tepexpan Man. At the same time a large number of people, both amateur and professional, claimed ages that were sometimes positively enormous for certain Northern American cultures such as that of the makers of the famous *Folsom Points*, a most distinct form of notched stone spear head found in the West.

The radiocarbon method has, on the one hand, greatly reduced many of these estimates down to proper size, but it has also provided some astonishing and most unexpected support for those who claim a great age for man on this continent. For instance, Tepexpan Man's age has, according to this analysis, been reduced to 4,200 years, which strongly supports the theory that he was either buried in a much older deposit by his relatives, or fell into a hole at death. On the other hand, charcoal from certain camp-sites in Ohio proved to be 6,400 years old. But further surprises followed.

Material from mound-burials in Kentucky, and wood from an ancient fish-weir found in the mud under Boston during reclamation projects turned out to be over 5,000 years old. Objects from Crater Lake gave an age of 6,500 years, those from a South Dakota campsite, 7,000 years, and a pair of woven fiber sandals found in a cave in Oregon proved to be at least 9,000 years old. The first analysis of material of the age of the Folsom points gave an antiquity of only 4,300 years, but further more exhaustive tests have proved this to have been in error, and 9,900 years is now given as a minimum age for this culture. But older still is the so-called Llano Culture of the plains of New Mexico which is now estimated at 10,000 years, while the dung of the sloth mentioned above as having been associated with human

Folsom arrow points, Folsom, New Mexico

remains in Gypsum Cave, Nevada, is certainly 10,500 years old.

These findings would be interesting in themselves, and would considerably extend the

Sandal made of unsplit yucca blades, Grand Gulch, New Mexico.

history of American man, but they take on an entirely different significance in view of another discovery brought to light by the radiocarbon method. This is the unquestionable fact that the ice-cap started to retreat from Wisconsin only 11,500 years ago and *not*, as previously claimed, 35,000 years ago. This can only mean that man, and perhaps semi-civilized man was living in the Americas during and presumably *before* the last ice advance.

As demonstrated by Brooks, Alaska and Siberia were not covered by the northern ice caps because of their geographical position and absence of the necessary precipitation, factors that play such a major part in glacial periods. Nevertheless an enormous belt of territory was so covered from the Pacific to the Atlantic seaboards and extending down to Long Island in the east, St. Louis in the center, and the mid-Rockies in the west. The thousand years between the beginning of the retreat in Wisconsin (9,500 B.C.) and the appearance of man with the giant sloth in the Gypsum cave (8,500 B.C.) is not enough for immigration via the Aleutians and Alaska, particularly because the ice sheets did not just melt away instantly, but took at least this period to retreat north and break up into west, central, and eastern caps which alone would allow human migrations from north to south.

Thus man was here before the last glacial advance. But how long was he here? At present we have no satisfactory data to work upon, but there has been one serious, though admittedly startling, claim made.

In a gravel pit near Frederick, Oklahoma, there has been found a large assortment of flint and other stone implements of fairly well-advanced human workmanship. They are intimately and apparently inextricably associated with sundry extinct animals—species of elephants, camels, and large, lion-like cats—that existed during the first inter-glacial period, 750,000 years ago. The age of these deposits is hotly debated, but the protagonists and critics are about equally matched and the former number among their ranks several outstandingly conservative geologists and palaeontologists. The question is at present without concrete answer, but should the artifacts prove to be of the same age as the animal remains—something that the radiocarbon method cannot help us to determine—we will be confronted with the challenge of filling in some 740,000 years of human history in North America. In this the speleologist will of necessity play the outstanding role because it is almost exclusively in cave deposits that it

A glacier front, Untergabelhorn, Switzerland.

will be worthwhile searching for the evidence.

There is really only slight reason for doubting the possibility that man may have been present in America since pre-glacial times, because continuing researches in the Old World are constantly pushing human history backward, and the age of Chellean and Acheulian cultures in Europe, and their equivalents in East Africa and Southeast Asia are already comparable in age to the Oklahoma finds, or even older. So far we have not looked intensively enough in this country for something that we have been conditioned not to expect, while Europeans have done so for something that they always believed must exist. The oldest remains of American man that have been actually dated have been found in our caves and it is in caves that we must search for further evidence, and every method at our disposal should be used, notably the five techniques specifically mentioned in this article.

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Southwestern Caves as Books of History

By M. R. HARRINGTON

Curator, Southwest Museum, Los Angeles, California

All photos by Southwest Museum, Los Angeles, California

The tremendous assistance which the speleologist can give to the archaeologist in supplying the missing chapters in our history of man on this continent is dramatically portrayed in this very informative article. Described herein is a potential field of interest for all cavers that could yield exciting and valuable results. We should accept its challenge.

It was a nice little dry cave, as such places go. It faced southeast, if I recall, and the river was just around the corner; I would not mind camping there myself. But who, except an archeologist, would ever guess its 8 by 12 foot floor might contain a real historical record that could be read by the trained eye?

It did not look very tidy, however, when I first ran across it during my work in the Moapa Valley, Nevada. Busy packrats had cluttered up the floor with all kinds of sticks and bits of cactus. But among them I spied traces of man! Not very ancient, I fear, but still part of the cave's story. Mixed with the packrat junk lay charred sticks, ashes, a worn-out pair of shoes, some chicken bones, three tin cans and one whiskey bottle (empty). I studied these specimens

Entrance to Gypsum Cave, near Las Vegas, Nevada, with the author, M. R. Harrington.

as an archaeologist should. Part of a label remained on one can; it had contained baked beans. The second was obviously a sardine can; the third, somewhat larger than the first, was smoked on the outside and contained a few coffee grounds. The last occupants of the cave had belonged to the Modern American culture —that much was indisputable fact. As a theory, since the railroad was near, I guessed that they had been members of the Hobo or Bindle-Stiff tribe.

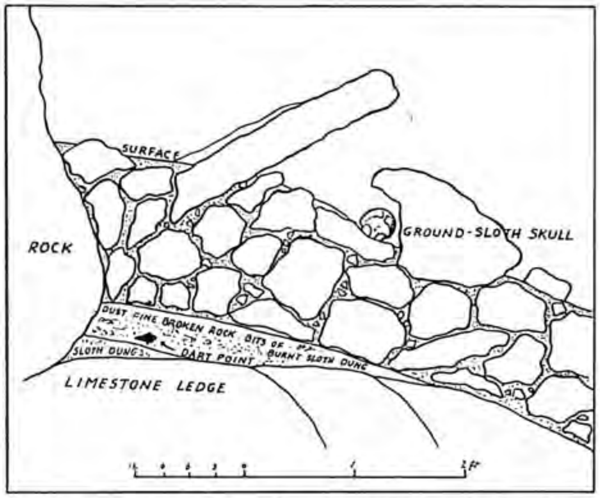
I cleared away this mess and dug deeper. Soon I struck a dusty layer containing dry rushes and grass, some partly burned, the relics of somebody's bed. In one spot ashes and char-

Inside the entrance to Gypsum Cave, Nevada, showing cribbing needed in test pit. In this pit pieces of painted wooden dart shafts were found in a layer below one containing sloth dung, above which was another with relics of a later period.

coal showed the one-time location of a camp fire; mixed through the rubbish were deer bones split for the marrow and quids of cooked mescal fiber that had been vigorously chewed. There were also some fragments of coarse dark-brown pottery, some scraps of worn-out baskets, a few bits of home-made fiber string, a couple of small triangular arrowheads made of obsidian, a broken cane arrow. Evidently the Southern Paiute Indians had used the cave before our hobo friends.

Below this, if I remember correctly, came a layer of plain dirt that was quite compact, and contained no trace of human occupation. Naturally I thought it might be the bottom, but to make sure I dug through it. Good thing I did!

Underneath it were more ashes and charcoal, and quite a lot of broken pottery, some from a white jar, some from a red bowl, both tastefully decorated in black. There was also a small stemmed arrowhead, a few stone beads, scattered animal bones, some diminutive corn cobs, a mano stone for grinding corn. Without anything else, the pottery told me that Early Pueblo Indians had preceeded the Paiutes.



Section showing where the stone dart point lay in a layer beneath that containing the ground sloth skull in Gypsum Cave, Nevada.

But that was not all; deeper still lay still another bed of charcoal and ashes, with animal bones split for the marrow, a few more corn cobs, several large stone points for javelins or darts, and some fragments of a gray pottery bowl with rather crude patterns composed of thin black lines and dots—clearly the work of a people called "Late Basketmakers" by archeologists—and probably more than 1,300 years old! This layer rested on the rock bottom of the cave; consequently, unless they themselves had cleaned out older deposits before moving in, the Late Basketmaker family were the cave's first human occupants.

When I finished my digging I realized that in this one little cave I had found a record of four different peoples who had lived in what is now southern Nevada from 500 or 600 A.D. onward. And not only that, in each case I had found some of the characteristic things each people had used, even hints as to their favorite foods.

Of course without training and experience I would not have been able to identify the peoples by their products; without reading I would not have known the age, for instance, of the Late Basketmakers, which has been worked out by the famous tree-ring method—from the late 400's to the late 600's A.D.

Apparently these Late Basketmakers had used the cave during the early part of their period, because the large points indicated that they were still using javelins or darts hurled with the spear-thrower known as *atlatl* to archeologists, which they later abandoned in favor of the bow and arrow.

A side light is thrown on the period when this occurred by another cave near Lovelock, Nevada, explored by the University of California and the Museum of the American Indian, Heye Foundation. Here was found one layer containing both dart-points and arrowheads, while the deposits above contained only arrowheads and those below only dart-points. Evidently there was one period when both were being used, after which the less efficient atlatl was discarded.

Perhaps some cave, some time, will produce evidence to tell us WHO introduced the bow

Expedition Secretary, Mrs. Bertha Parker Cody, points to spot where she found ground sloth skull in Gypsum Cave, Nevada.

and arrow into the southwest. We know that epoch-making event probably occurred between 400 and 500 A.D.—possibly a little earlier. We also know that the bow and arrow was not invented here, for we find no early stages of development. It arrived in perfected form.

The little cave in the Moapa valley could not be called important; but others have been found in Nevada that gave us real information —for instance, Gypsum Cave near Las Vegas, explored by the Southwest Museum in collaboration with the California Institute of Technology and the Carnegie Institution of Washington. This cave furnished evidence to support a fact which had been disputed. Previously various clues had been found showing that man had arrived in America before the strange animals of the Ice Age had become extinct, but some archeologists would not accept the idea.

In one room of Gypsum Cave we found a very deep dry deposit in which the lower levels were composed mainly of the dung of the ground-sloth, a large Ice Age animal long since extinct. Buried in this were two fireplaces, a stone knife or scraper and some sticks which had been cut with stone implements. Above the dung layer was a thick deposit of rock fall and dry cave debris barren of human indications; then near the top a succession of Basketmaker, Early Pueblo and finally Paiute layers similar to

Skull of ground sloth found in Gypsum Cave beneath a slab in a stratum above another containing a stone dart point.

that we saw in the little Moapa Valley cave. Tests made by the new Carbon 14 method show the ground sloth dung, in which the older human traces were imbedded, to be between 8,000 and 10,000 years old!

Still another good record was found in Etna Cave, near Caliente, Nevada, explored under the direction of its discoverer, Mr. S. M. Wheeler, one time archeologist for the Nevada State Park Commission. Here the lowest layer of all contained, among other human traces, a dart point of early type; the next layer above yielded dart points of Gypsum Cave type, and along with them the dung of an extinct American

Ground sloth claw, dart point and wooden dart foreshaft from Gypsum Cave, Nevada.

horse. Above this again was an Early Basketmaker layer, then a Late Basketmaker; then Early Pueblo and finally Paiute.

A still more outstanding record appeared in Ventana Cave in southern Arizona, explored by the University of Arizona and the Arizona State Museum, under the direction of Dr. Emil W. Haury. This yielded relics of human life from an early period when man hunted animals now extinct through various geologic changes as the centuries rolled on, up to the modern tribes of the region. The final report of this important project has recently been published.

Perhaps the most important of all is Sandia Cave in New Mexico, explored under the direction of Dr. Frank G. Hibben of the State University—important in that it demonstrably carries the historical record farther back than any other cave thus far reported. Here the soft upper layer contained potery fragments and other articles left by Pueblo Indians, some of them quite modern. Below this lay a hard stony crust which effectually sealed off the lower deposits. Breaking through this a layer was encountered, more or less hardened into breccia, again containing signs of human occupation. The people responsible for it were identified by their peculiar dart points as belonging to the

"Folsom" group—an early culture well known to American archeologists and before this discovery the oldest to be defined. This layer also contained the bones of extinct horse, camel, bison, mammoth and ground sloth, evidently hunted and eaten by the people.

But that was not all. The Folsom layer rested upon a barren deposit of yellow ochre, laid down in some remote wet period when the cave stood unoccupied; under this again lay an even older human deposit containing fireplaces, various stone implements and the bones of extinct horse, bison, camel, mastodon and mammoth. The one-shouldered spear or dart-points found in this deposit are entirely different from the Folsom, very distinctive and unlike those produced by any ancient American people previously known. They do however resemble certain points of the Solutrean division of the European Paleolithic period—but there is probably no connection.

Occasional one-shouldered points of this form had previously been picked up in various places, especially in the southwestern states, but until the Sandia Cave find their age and associations were not known.

The late Dr. Kirk Bryan of Harvard University considered the yellow ochre in Sandia Cave to have been deposited during the last advance of the glacial ice, dated approximately at 25,000 years ago, and of course the makers of the one-shouldered points lived in the cave before the ochre was laid down. Whether this estimate is correct or not the fact remains that the ancient culture, now named "Sandia" from the place of its discovery, is the oldest thus far defined in North America.

Caves may furnish some surprising information. Before the recent excavations in Bat Cave, New Mexico, made by Harvard University under the direction of Dr. Herbert W. Dick, it was thought that the growing of corn was introduced into the southwest by the Early Basketmakers, about the beginning of the Christian Era. From discoveries made in this cave it appears that corn was grown in what is now New Mexico perhaps 4000 years ago. Even more interesting to students is the fact that corn went through a progressive development in this region, starting with a variety that combined pop and pod corn, without husks, the oldest and most primitive type of corn known. Later examples show a regular increase in size of cobs and kernels as time went on.

It is plain that caves containing human deposits should be treated with respect, and that their excavation should be left to skilled hands and to those alone; to eyes that can read these priceless and unique records of the past. Dry caves are especially valuable, because in them everything may be preserved, down to fiber, hair and even feathers, for literally thousands of years—as in the tombs of Egypt. Once disturbed the layers laid down throughout the ages lose their value—can no longer be read. If you locate one of these precious "books of history" don't mangle or destroy its irreplaceable leaves. Notify some reliable museum or university—then volunteer to help them dig if you wish.

There are many, probably thousands, of such caves, still unexplored, in the Southwest, waiting to tell their story. Smoked ceilings, deep floor deposits, chips of flinty stone on the dump running down the bank outside,—all are among the clues that prehistoric men have left a record inside. Rather shallow caves were preferred, or areas near the entrance in large ones, in most but not all cases. It should be considered not only a pleasure, but a privilege, for every Spelunker to locate and report all he can of them.

Caves and Rockshelters in Southwestern Asia

By HENRY FIELD

Research Fellow, Harvard University

During the past twenty-five years a systematic search has been made in order to establish the antiquity of man in Southwestern Asia. The author, a renowned archaeologist, herewith presents some of the details in this productive quest among the ruins of ancient cultures. This article, and the companion piece following, show dramatically the important part which caves play in this fascinating field of research.

In Southwestern Asia, ranging from southwestern Sinai to eastern Afghanistan and from the Caucasus to the Arabian Sea, flourished one of the great civilizations. Here was the birthplace of writing, law-making, astronomy and scientific research. From this soil sprang two of the great religions, Christianity and Islam.

Man has lived here in caves or rockshelters for at least 50,000 years. Our interest in these natural shelters lies in their human occupation rather than from a geological aspect. Hence we shall concentrate mainly on those which have thrown light on man and his cultures from modern times back into the mists of antiquity.

Several groups of cave-dwellers today live in this area: (a) Bedouins at Es Salt (No. 4) near the road from Amman to Jerusalem in Jordan; (b) Chaldeans near Al Qosh (No. 12) in northern Iraq; and (c) the Shihu, a wild tribe near Ras al-Kheima (No. 26) beside the Persian Gulf on the Trucial Oman Coast.

Caves have long sheltered Bedouin raiders and lawbreakers. One of the largest is Mukamin al-Walaj (No. 9) in western Iraq. With a small entrance this sinkhole is reported to be able to hide 1,000 horsemen; abundant water is available. In 1934 at the western end of Jebel Sinjar we crawled into a small cave (No. 11). Recent Arab pottery, including blackened lamps, were embedded in the muddy floor. In Kurdistan (Anatolia, Iraq and Iran) and Luristan the hundreds of limestone caves have sheltered shepherds and those who through the centuries have feared the local governments.

In Biblical times there are several examples of the use of caves: (a) "And Lot went up out of Zoar and dwelt in the mountain, and his two daughters with him; for he feared to dwell in Zoar: and he dwelt in a cave, he and his two daughters" (Gen. XIX, 30); (b) Abraham and Sarah, Isaac and Rebekah and Leah were buried in a cave (Gen. XLIX, 29-32); (c) when the Philistines attacked in great strength the Israelites hid in caves (I Sam. XIII, 6); (d) David escaped to the cave of Adullam (No. 3), which became a rallying point (I Sam. XXII, 1); and Elijah received the word of the Lord in a cave in Horeb (I Kings XIX, 8-9).

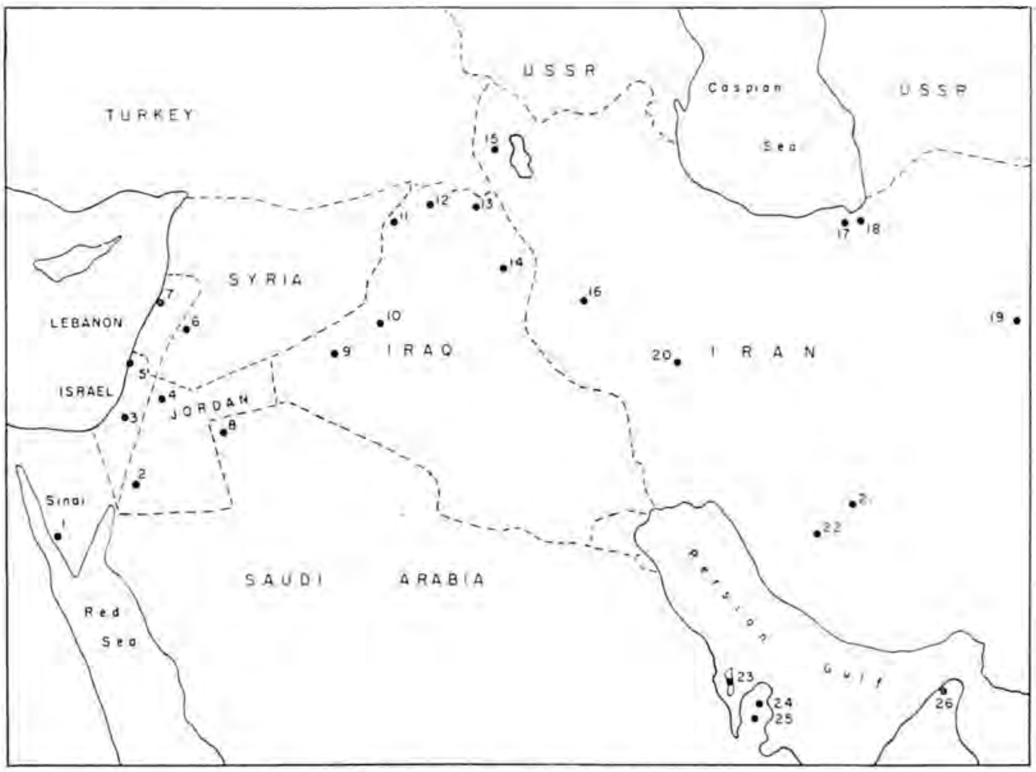
The ancient Egyptians sheltered in a small limestone cave on the northern side of the Wadi Khraiza, a tributary of the Wadi Feiran (No. 1). Here in 1948 we found a large basalt pounder of the type used by the ancient Egyptian miners on their way to Serabit el-Khadem or to the turquoise mines in the nearby Wadi Muqattab. Chalcolithic implements lay on the surface. Fresh camel and sheep tracks on the sandy approaches proved recent temporary occupation by Bedouin shepherds. This place must have served as a shelter from the Chalcolithic period to the twentieth century.

At Petra (No. 2) the Nabateans lived, worshipped and were buried in the rock-cut, multihued sandstone. At Athlit on Mount Carmel (No. 5) a series of skeletons of the Old Stone Age and their cultures and associated fauna were excavated. The thickness of the deposit indicated a long occupation by these ancient hunters. Near En Nebk (Nebek) (No. 6) in Syria excavations in Yabroud rockshelter identified forty-five cultural levels, ranging from Acheulean to Neolithic. Northward near Tripoli in Lebanon Upper Paleolithic deposits have been found associated with stag, gazelle and wolf bones. The honeycomb caves at Nahr el-Kelb (No. 7) have been explored for many years. Evidence of ancient and relatively modern occupations were found.

On the eastern slope of Tell el-Hibr in northwestern Saudi Arabia, Don Holm, Aramco geologist, guided me to a small rockshelter (No. 8) wherein lay a Bedouin skeleton. Nearby we collected a fine series of large Nummulites. Thousands of honey-colored flints, many flaked by prehistoric man, were strewn on the summit and slopes of Tell el-Hibr.

Moving eastward we come to several sinkholes or pot-holes near Haditha (No. 10) on the Euphrates in Iraq.

During the Peabody Museum-Harvard Expedition to the Near East in April, 1950, Dennis Batten of the Iraq Petroleum Company guided me to one of these potholes. The circular depression was about 250 ft. across. Climbing down about thirty feet we entered a small, narrow tunnel by wriggling headfirst over a very rocky slope. Once inside we were able to stand up in a low chamber. Dennis' headlight swept onto the pale face of his bride, Bernice. Until that moment I had not realized this was her first experience in speleology. The cave was dry and musty and an evil stench permeated everything.



CAVES AND ROCKSHELTERS IN SOUTHWESTERN ASIA

1. Wadi Feiran, Sinai.
2. Petra, Jordan.
3. Cave of Adullam, Israel.
4. Es-Salt, Jordan.
5. Mt. Carmel, Israel.
6. En-Nebk (Nebek), Syria.
7. Nahr el-Kelb, Lebanon.
8. Tell el-Hibr, Saudi Arabia.
9. Mukaimin al-Walaj, Iraq.
10. Haditha, Iraq.
11. Jebel Sinjar, Iraq.
12. Al Qosh, Iraq.
13. Jebel Baradost, Iraq.
14. Hazar Merd and Zarzi near Sulaimaniya, Iraq.
15. Tamtama near Urmia (Rezaiyeh), Iran.
16. Bisitun (Behistun), Iran.
17. Belt Cave (Ghar-i-Kamarband) near Behshahr, Iran.
18. Hotu Cave, southeast corner of Caspian, Iran.
19. Khunik Rockshelter, south Khurasan, Iran.
20. Khurrumabad, Iran.
21. Near Persepolis, Iran.
22. Lake Maharlu near Shiraz, Iran.
23. Jebel ed-Dukhan, Bahrain Island.
24. Al Duhail, Qatar Peninsula.
25. Midway between Dukhan and Umm Said, Qatar Peninsula.
26. Ras al-Kheima, Trucial Oman Coast.

My flashlight picked out a hunk of raw meat near my right foot. Bernice shuddered. We moved cautiously ahead into the earth. Now we were surrounded by hundreds, if not thousands, of animal bones. Here lay skulls and long bones of camels, horses, hyenas, foxes, jackals, sheep and goats. Far inside we came to a fork. To the right the vault was covered with bats hanging head down. As we disturbed them, they flew pell-mell, squeaking madly. We cornered them in a low chamber. The walls were black with bats. Suddenly with a wild rush they came toward us. They hit us in the face as they flew panic-stricken past our flashlights. Dennis, like Horatio of old, swung a butterfly net backwards and forwards above his head. This was an eerie picture with strange shadows flickering on the walls. After it was over we picked up twenty-seven victims felled by the thrashing white net. These have been identified by Colin Sanborn at Chicago Natural History Museum as six male and twenty-one females of *Rhinopoma cystops cystops*, a new species to be recorded in Iraq, but previously known from Egypt and Palestine. However, Bernice was found crouching in a corner with her hands clasped tightly over her hair. She seemed to be enjoying the bat hunt even less than she would the skull chase which was just around the corner. Yusuf put the poor little bats into a bag and we started down the other passage.

A drip from the roof disturbed the utter silence. In the mud below were large pad marks. We were in a wolf's den. Without comment Dennis and I each picked up a camel's thigh bone as a weapon. We advanced slowly and cautiously deeper into the cave until we reached a narrow path leading up into a small tunnel. Here the pad marks had beaten a track in the fine dust. My hand tightened around the upraised camel femur. As the light flashed into the tunnel I expected to see a pair of eyes glowing as coals. The tunnel was empty. Was the wolf or his mate in their lair just around the corner? We did not venture to crawl in to see.

Back in the outer chamber we began to hunt for human remains. I found a lower jaw with the molars showing considerable wear. Dennis, lying full-length into a sloping crevice, spotted a skull which had rolled into the deepest point. We began to clear a space through a pile of animal long bones and earth. Bernice watched with fascination as she held the flashlight for the diggers. With our hands and geological hammers this was slow work. Bernice whispered, "I've never touched a human skull before, but I can wriggle in there far easier than you or Dennis." With her sylphlike figure, this was obviously true. A few minutes later Bernice crawled headfirst down the narrow tunnel. Her right fingers almost touched the skull. A little more was cleared out. This time by pushing and wriggling like a snake Bernice removed the skull delicately and dragged it slowly back to our willing hands. It proved to be a middle-aged male of local Bedouin type. Did a wolf decapitate a body and drag this skull into its den? Was this possible or was there another explanation? We still do not know.

During the next hour we found six more fragmentary human skulls and three mandibles. Scrambling upward through the entrance, each carrying a skull in either hand, was hard work. The air outside was refreshing indeed after two hours inside that smelly cave. Another day we returned with duffel bags to collect a representative series of animal bones and eight more human skulls for study at Harvard.

Our next speleological venture was high on Jebel Baradost (No. 13) in northeastern Iraq. In this phase of the expedition we were working coöperatively with the Iraq Department of Antiquities, *Sayyid* Fuad Safar being their representative. Five cars carried us and our equipment to Havdian village at the foot of the mountain. We walked and rode for five hours up a narrow, rocky trail. One of the "sure-footed mountain ponies" slipped and fell twenty feet to a ledge. Fortunately, he was only carrying some bedrolls. Seeing this we all dismounted and walked for a time without comment. We arrived panting and footsore outside Dian Cave. Snowbanks covered the slopes for we were at 3,500 feet. Jebel Baradost stands near the Iraq-Iran-Turkish frontiers. We were surrounded by snow-capped mountains and huge limestone peaks. Our purpose was to dig trial trenches to search for ancient human habitation in this cave.

We were quite a party, thirty-three of us altogether, including: Robb White, my brother-in-law as photographer; Dennis Batten, speleologist; Fuad Safar, pottery specialist; fourteen Assyrians and fourteen Kurds from Havdian; two mounted police as escort; and horses and donkeys, the pack animals. Sentries were posted day and night for these mountains harbor bandits. During the night we often heard shots ringing out across the valley. At these moments we were glad to be able to muster sixteen rifles. We each slept with a rifle at our side.

For a week we lived in the open on army cots outside Dian Cave. The trench became so deep that we had to proceed by 3 ft. steps down until virgin rock was reached at 14 feet 6 inches. Pottery, animal bones and a few flints were found. Fuad Safar identified the pottery as similar to that from Uruk, Hassuna and other famous ancient sites in Mesopotamia attributed to about 3,000-5,000 B. C. During this time Dennis Batten and Robb White explored every meter of the interior of the cave. The walls were too rough for prehistoric cave paintings or engravings. There were two pitches, one of twenty feet and another of thirty feet. The floor of the lower chamber contained a large pool of water. Another small sounding was made in the interior; a similar cultural sequence was found together with animal bones washed down.

We moved to Pastun Cave, half an hour's walk across the mountain. This was a much larger cave with giant stalactites and stalagmites. Two soundings were also made down to virgin rock, again at a depth of 14 feet 6 inches. We found many hearths, pottery, flints and a beautiful necklace of thirty-five cylindrical terra cotta beads. These soundings proved for the first time that hunters and nomads inhabited caves in Kurdistan for the past 7,000 or more years.

We climbed to the peak of Jebel Baradost (No. 13). The air was fresh and cold. We saw ibex tracks beside breath-taking precipices. To the north were the snow-capped peaks of southeastern Anatolia, but Mt. Ararat was just too far to be seen through the Zeiss glasses. On the eastern side rose the Persian peaks. Standing on a rock out of view of the rest of the party I felt that deep thrill inside which comes only to mountaineers alone with nature. . . .

At the foot of Jebel Baradost we examined Havdian rockshelter. Here on the scree slope Fuad and I found hundreds of microlithic flint implements indicating occupation by men of the Stone Age. The Rowandiz area has many caves worthy of exploration and trial trenches.

We drove south to Erbil (anc. Arbela) and Kirkuk and eastward to Chemchemal, where we were told about a gigantic cave called Mamlaha in mountains about twenty miles east. A roaring torrent following heavy rains made the track from Chemchemal to Mamlaha impassable.

Kurdistan from Rowandiz through Aqra to Sulaimaniya (No. 14) and Penjwin has many caves and rockshelters, the majority of them unexplored or unexamined for traces of ancient human habitation. However, Hazar Merd and Zarzi near Sulaimaniya were excavated by Miss Dorothy Garrod, who found Paleolithic implements *in situ*.

Moving eastward on this survey lies Iran or Persia. The mountains of Kurdistan and Luristan on the west contain hundreds, if not thousands, of rockshelters and caves. Last year I searched for stone implements in three rockshelters in the Khurrumabad area (No. 20). At Konji typologically Paleolithic flint implements were found at a depth of eight feet. This was the first time Stone Age implements were excavated in Luristan.

In 1934 Dr. Donald McCown and I found microlithic flint implements on a scree slope outside a small rockshelter beside Lake Maharlu (No. 22) near Shiraz. Dr. Ernst Herzfeld described to me a large, unexplored cave (No. 21) about three hours by horseback east of Persepolis, ancient capital of Persia founded by Darius I (521-486 B. C.). To the south and east across to Kuh-i-Taftan no prehistorian has searched for Paleolithic man and his cultures. Excavations have been made in five caves by Dr. Carleton S. Coon of the University Museum of the University of Pennsylvania:

(a) Tamtama, 13 miles northeast of Rezaiyeh, at 5,000 feet (No. 15). A few animal bones and one Neanderthaloid femur were found associated with 23 crude implements and cherty flakes.

(b) Bisitun (anc. Behistun), 30 miles east of Kermanshah, at 4,500 feet (No. 16). About 1,100 implements and many animal bones were unearthed.

(c) Belt Cave (Ghar-i-Kamarband), 5 miles west of Behshahr, about 120 feet above the Caspian (No. 17). An Upper Mesolithic female skull (aet. 12) was found associated with flint implements and animal bones.

(d) Khunik rockshelter in southern Khurasan (No. 19). Patinated Mousterian implements lay on the surface. Early Islamic pottery was excavated. Evidence of an earthquake was recorded.

(e) At Hotu Cave (No. 18) at the southeastern end of the Caspian he found in May, 1951, three skeletons of *Homo iranicus*, their flint implements and animal bones. This is a most important discovery in Southwestern Asia, for we now have for the first time prehistoric skeletons midway between Mt. Carmel and the Neanderthaloid child's skeleton from Teshik-Tash rockshelter near Tashkent in Soviet Central Asia.

In the Persian Gulf on Bahrain Island Mr. T. G. Bibby and I examined two small rockshelters (No. 23) on Jebel ed-Dukhan (450 ft.). Some recent sherds were collected on the scree slopes.

In the center of the Qatar Peninsula midway between Dukhan and Umm Said, we climbed to the bottom of a 90 ft. sinkhole (No. 25) with a pool of water at the bottom. No traces of ancient human occupation were found. At Al Duhail, northwest of Doha, we found animal bones and some human remains in another sinkhole (No. 24). This material was very similar to that from near Haditha (No. 10) in Iraq. The animal bones are now being identified at Harvard.

Other significant areas worth careful investigation for caves and rockshelters are the Red Sea coast from Aqaba to the northern fringe of the great Rub'al-Khali sands, in the mountains of Oman and along the Hadhramaut, Aden and into the Yemen.

Speleological reconnaissance [1] in Southwestern Asia has already thrown light on the earliest inhabitants of this region, their many cultures and the animals they hunted for food. As a result many lacunae are being filled in the great historical mosaic on the crossroads of the three continents of Asia, Africa and Europe.

[1] For references *see* Carleton S. Coon, "Cave explorations in Iran, 1949," University Museum Monograph, Philadelphia; *Archaeology*, vol. 4, No. 2, pp. 116-118; and Henry Field, "Contributions to the Anthropology of Iran," Field Museum of Natural History, 1939, also "Reconnaissance in Southwestern Asia," *Southwestern Journal of Anthropology*, vol. 7, No. 1, pp. 86-102, 1951 and "Reconnaissance in Saudi Arabia," *Journal* of the Royal Central Asian Society, vol. 38, pts. 2-3, pp. 185-197, 1951.

Cave Exploration on Jebel Baradost, Iraq

By DENNIS J. BATTEN

Civil Engineer, Iraq Petroleum Company

During the spring of 1950 Dr. Henry Field, who was then leading the Peabody Museum-Harvard University Expedition, invited me to join him in his search for prehistoric man in the caves of Kurdistan. That I accepted with alacrity need hardly be mentioned, and I would like to here record my appreciation of his offer and thank him for his kindness, good humor and generosity during our period of association. Dr. Field concluded that early men, when migrating from the north, used the passes through the mountains of Anatolia and Kurdistan as easy access routes to the fertile lowlands of the Middle East. His supposition that Rowandiz Gorge had at some time been one of these migratory routes was correct: this was I think the pointer he used in choosing Mount Baradost as a field of activity.

Many caves on the south and east faces of Jebel Baradost were visited, but Dr. Field finally selected two caves, Dian and Pastun, as being most likely to yield the evidence he sought. A camp site was therefore chosen outside Dian Cave. Dr. Field, Robb White, *Sayyid* Fuad Safar, and myself explored both caves.

While the remainder of the party were allotted the tasks which best suited their particular talents, I as an amateur potholer (I prefer the term rather than that of Speleologist) was given the task of making a quick survey of the caves.

Since this survey was made with the aid of a 50 ft. tape and a 6 ft. flexible rule, inaccuracies are bound to have occurred. By means of two torches, one from each leg of the cave, the convergence angle was measured at the intersection of the light beams.

ESHKAFTA DIAN

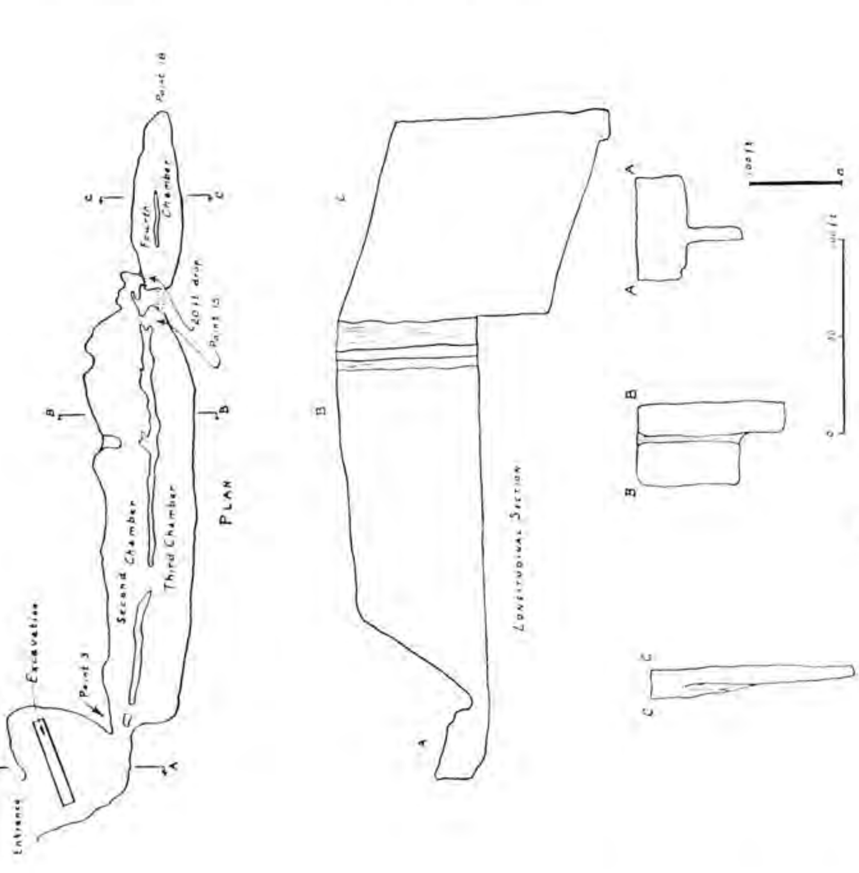
Eshkafta Dian[1] (Hawdian or Havdian) lies approximately 1,000 ft. from the summit of Jebel Baradost. The cave entrance faces east and overlooks a snow water drainage valley running almost north-south down the southern face of the mountain. A small spring lies about 100 yards south and above the cave.

This cave, which is of Cretaceous limestone, appears to be both a solution and an erosion cave. Accurate identification has not been made, but the neighboring Bekhme limestone has been identified as Campanian Maestrichian (Upper Cretaceous). Bekhme Gorge lies northwest of Jebel Baradost.

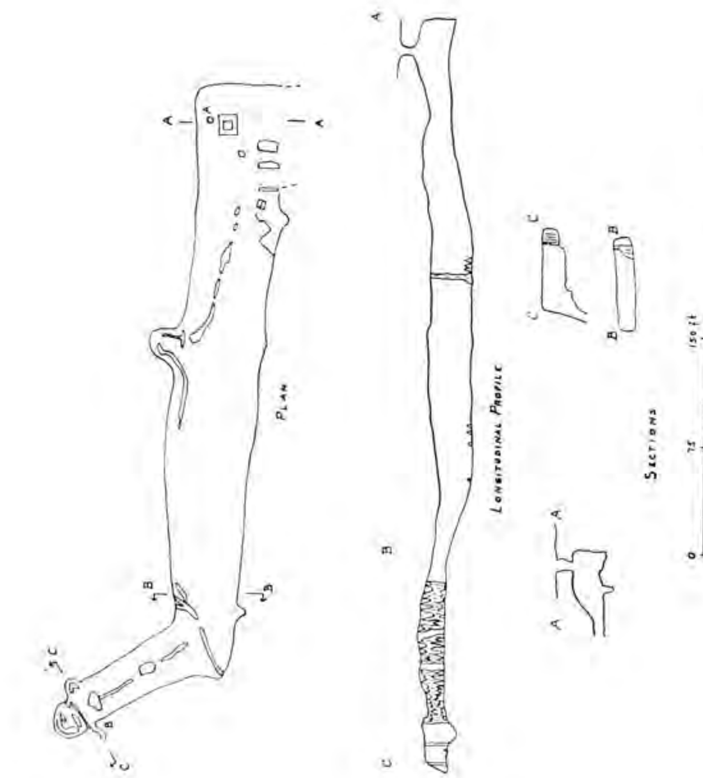
From observation of the cave position in respect to the snow water drainage valley, it has been inferred that the formation of the cave and valley was taking place while the bed of the valley was level with the cave entrance. The dip of the strata gave the infiltrating water a southwesterly direction. When the valley bed became lower than that of cave level, the formation by erosion undoubtedly ceased. Surface water infiltration has been responsible for the stalagmatic formation, but it is improbable that any great changes have taken place since the main water flow was directed into a different channel.

From observation of roof and walls it was deduced that the cave is both a solution and erosion cave. The flat roof and the shapes and sizes of the material composing the scree leads to this belief. Unfortunately, the facets that would have made identification easier have been obscured by false walls and observation of the original angles of facets and roof becomes impossible. All roof and wall joints have been obscured by a heavy limestone glazing to such an extent that it has been almost impossible to reconstruct in imagination the original cave shape, with the exception of the implication

[1] A. M. Hamilton in his "Road through Kurdistan" mentions Eshkafta Hawdian calling it the "Cave of the Wind." At no time during our occupation of it was even the slightest breath of wind felt inside the cave. Dr. Field puts forward an ingenious theory: The cave is known locally under two names, Dian and Hawdian; Hawdian or Havdian being the nearest village. Dr. Field presumed that Hamilton gave the Kurdish noun an Arabic translation and finally resolved it in English as "The Cave of the Wind.'



Map of Dian Cave.



Map of Pastun, Cave of the Pillars.

that the three levels of the cave were originally one cavern under one roof.

The cave entrance has been partially blocked by man to afford greater protection for himself and his animals. That the cave has been habited by man at intervals over a lengthy period is borne out by the thickness of the open hearth levels. In general, the entrance is dry, although some water drips from the roof in isolated spots but in insufficient quantity to make the cave uninhabitable.

From trial trenches it was established that the original scree slope floor dips at the same angle as the adjoining strata. The roof is clear and free of cracks and joints. Progress in the first chamber is easy for the most part, and can be made with a slight bending of the body. From there on, however, it is necessary to crawl. Previous excavation here increased the head room. Moving into Chamber No. 2, one is faced with a passage widening at the extremity with a vertical wall on the left hand and a stalagmatic wall on the right. With the formation of the latter came the retention behind the wall of foreign material with a corresponding rise in floor level. In addition, the retention of infiltrating water has both levelled and glazed the floor. Examination of the floor showed the sandwiching of foreign material and glazing. The vertical pitches shown are not original portions of the cave formation but can be considered faces of the stalagmitic walls. Accurate observation of the roof and floor points were impossible because of limestone glazing and the false wall.

The slight pitch to Chamber No. 3 can be easily negotiated, the effect being more of a tunnel than a chamber. Some low stalagmites rise from the floor. These encrustations are wide-based and mushroom in shape; some are basin-topped and contain good drinking water. The latter I take to be stalagmites caused by filling up of flukes in the original scree slope.

A tunnel leads from Chamber No. 3 to Chamber No. 4. The tunnel, which appears to have been recently excavated, drops vertically about ten feet, where it takes a 90° turn; full-length crawling is necessary to negotiate the remainder of the tunnel. In Chamber No. 4, although none of the original scree slope is visible, the limestone glazing and stalagmites have not entirely obliterated the shape of the slope. One short stalagmatic wall has begun to take shape but at no point has it attained more than ten feet. The lowest point in the cave, is the water retaining level of the cave.

Dian Cave undoubtedly continues beyond this point, although it is not at the moment apparent. However, when nature decides to break down the walls now dividing the caves, further exploration should be possible. It is thought that the cave extension, if any, will be in a southwesterly direction.

ESHKAFTA PASTUN

Eshkafta Pastun proved to be the larger of the two caves. Erosion played a great part in the formation of Pastun, as is apparent from a glance at the ground plan. The water entry at Point A would at first appear to be from the surface. This I do not believe to be true.

The northeastern corner of the cave wall shows many water entries of various levels from roof to floor; each water entry at one time corresponded to cave floor level. Some water is at the present infiltrating through the strata but it is apparent that Point B is now only a water outlet during spring flooding and carries away only the water that infiltrates through the roof of the chamber.

The floor in the main chamber consists of material foreign to the cave being in the majority open hearth ash, and broken pottery. Evidence of man's search for potash from among the ash are apparent in many places. Spoor of bear, pig and wolf were seen, although none challenged our temporary occupation rights.

The size of the cave and the simplicity of its structure still puzzles me. To date I have been unable to form an opinion as to its origin and formation. Pastun Cave shows a general tendency to a southwesterly direction as does Dian Cave. The dip of the strata appears to be responsible.

The archeological finds [1] included Hassuna, Al Ubaid and Uruk ware as well as animal bones and from the lowest stratum in Pastun, a human femur blackened by fire.

[1] *See* Fuad Safar, "Pottery from Caves of Baradost," *Sumer*, vol. 6, No. 2, pp. 118-123, Baghdad, 1950; and Henry Field, "Reconnaissance in Southwestern Asia," *Southwestern Journal of Anthropology*, vol. 7, No. 1, pp. 86-102, 1951.

AN ENGINEER INSPECTS THE RIGGING

G. ALEXANDER ROBERTSON

All drawings by Grace Riddell Lundin

More than thirty years' experience in accident prevention, most of which has been spent in industrial operations, qualifies the author of this article to speak with authority. His work entailed rescue techniques, artificial resuscitation, first aid, the use of ropes, slings, lifts, hoists, scaffolding, ladders, block and tackle, boatswains' chairs and other types of construction and rigging. In view of the ever increasing number of persons exploring wild caves, this article is a timely one to give them sound advice.

On nearly every caving expedition some safety practice is violated, and usually when the exploration involves rope work, the violation is flagrant. Presented herewith are suggestions based on explorations of a considerable number of caves and years of technical experience and sound engineering practice. Every one of them has good grounds for support. Most of the reasons will be evident, even to the novice. It is also hoped that the reasons will be evident to that growing number of inexperienced and over-confident spelunkers who have been lucky enough to lower a companion into a cave and pull him out alive, and have thereafter considered themselves competent cave riggers.

Some of these suggestions may, at first glance, appear to be radical; others probably cannot always be followed, for there is hardly any such thing as an absolutely perfect safety rule. Some, no doubt, will be met with such belligerent retorts as:—"I have been caving for years without following these rules and have never been hurt!" Surely such an attitude is just as illogical as the remarks of a "jay walker" who, when cautioned against crossing a busy street between intersections, definitely replies "I've been crossing where I pleased all my life and I've never been hit."

To that group of cavers whose constant aim is not to make SAFETY a *probability*, but who continually strive to make ACCIDENTS an *impossibility*, this article is dedicated.

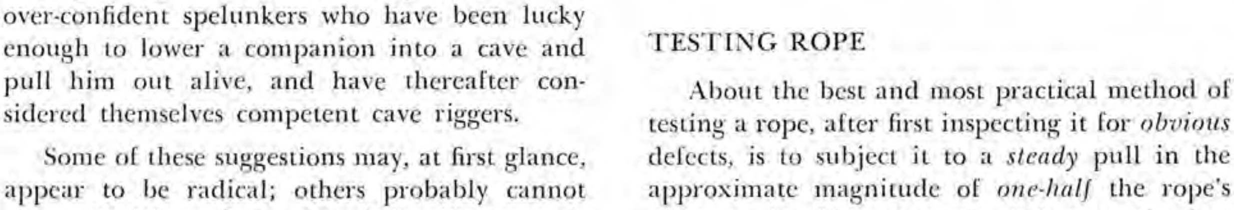
ROPE

Always use a line (cable or rope) that is of adequate size for the job, and that is in good condition. Inspect and test *every* rope *before* it is used, *on each trip*. The often-heard saying that "testing a rope weakens it" is sheer nonsense.

TESTING ROPE

About the best and most practical method of testing a rope, after first inspecting it for *obvious* defects, is to subject it to a *steady* pull in the approximate magnitude of *one-half* the rope's ultimate breaking strength (when new). Any rope that fails in this test (half-life) should be discarded as it will no longer possess the required factor of safety to meet emergencies.

One of the simplest tests is that of tying one end of rope to a tree about three feet above its base and having the necessary number of persons pull on the other end in a *steady* "tug of war" fashion, keeping the rope three feet above ground. When pulled in this manner, on a level grassy surface, the strain or pull on the rope will average about 75 per cent of the *total* weight of those pulling.



Pull on rope equals about three-fourths total weight of people pulling.

MAIN LINES

For the main raising and lowering line in vertical caves, a 5/8 *inch manila* rope is recommended. Its weight is approximately 13 pounds per 100 feet, yet it has an average breaking strength of 4000 pounds when new, or a "half-life" *factor of safety of ten to one* for a 200-pound man. *Sisal* rope may be used, but is only three-fourths as strong as manila and is more susceptible to injury from moisture. *Never use a factor of safety of less than five to one.* Six or seven to one is greatly to be preferred.

SAFETY LINES

A safety line, as the name implies, is a line used to "safety" a person climbing *by his own effort* (such as on a rope ladder, hand-over-hand, rope loop, etc.). A 1/2*-inch manila* rope is sufficiently strong for this purpose. It weighs about 7.3 pounds per 100 feet and, when new, has an average breaking strength of 2400 pounds or a "half-life" of 1200 pounds. *Never* use a "safety line" on a person when he is being raised or lowered on a "main line." It not only is *worthless* and *confusing* but highly conducive to accidents by becoming fouled, and it may become a real *hazard* by loosening rocks that might fall and strike the caver.

CARE OF ROPE

Do not jerk a rope when it is *kinked*—it tends to weaken it, and thereafter it may cause it to break under a moderate pull.

Never subject a rope to a *sudden jerk* of any great magnitude; its strength may be permanently reduced. The author has seen sight-seers lowered into deep caves by virtually dropping them almost as fast as in a free fall, only to be jerked to a sudden stop about 15 feet from the bottom by snubbing the top end of the rope around a tree. The strain on the rope was terrific, and why it did not break and result in a serious accident will forever remain a mystery, for surely it could not be attributed to the use of any judgement or common sense on the part of the person responsible for the rigging. What a price could have been paid, just to give someone a *thrill!*

Never use a rope when it is *frozen*—the fibers are then quite brittle and the rope may break even under a very light load. This is especially applicable to those who do caving and camping in the fall and winter and leave their ropes outdoors at night. Thaw the rope by warming it *slowly*—excessive heat also ruins rope.

Do not drag a rope on the ground any more than is absolutely necessary. It not only wears the outer fibers, but it picks up grit that may work in and cut the inner ones. If rope becomes caked with mud and sand, it is advisable to wash it with clean water, but *without soap*. A large galvanized wash tub, filled with water, is excellent for this purpose and accommodates comfortably about 50 feet of 5/8-inch rope at a time. Shake the rope around violently and a majority of the dirt and grit will become loosened and fall to the bottom of the tub.

Wet rope should be *dried promptly and thoroughly*. One of the best methods is to hang it on a *wooden* rack in a garage, so that air may circulate freely through it. Never leave a wet rope in a bag or other closed space, especially in warm weather, as it will almost certainly mildew. Although this greatly weakens it, there may be no marked difference in appearance.

If, on the contrary, the weather is very hot and dry, as prevails in certain sections of the United States, it may be advisable to wet the rope before using. A wet rope is *stronger* than a dry one.

Avoid bending rope over sharp corners while under load. It not only cuts the fibers on the *under* side, but, by excessive tension, it breaks those on the *outer* side as well.

Never store ropes on the *floor* of basements and garages. Aside from the danger of excessive dampness that is usually present, they are there accessible to pets. Animal feces and urine are ruinous to rope, and it is an established fact that next to the street corner fire plug, there is nothing so attractive to Fido as a coil of cave rope.

No rope should ever be *discarded* or *left in or near a cave*. A discarded rope presents too great a temptation to the novice. All ropes that are condemned should be immediately destroyed by burning or cutting them into short unusable lengths.

SIZE OF WORKING GROUP

While a person can pull, when standing on level sodded ground, up to 85 or 88 per cent of his weight, it can be done for only a very short period of time.

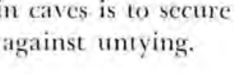
"Walking groups", pulling persons from vertical drops can never rely on being able to utilize more than one-half the total weight of group. If many persons must be pulled up and no relief is available, due to the fatigue factor 40 per cent of total weight is about all that should be relied upon.

Do not overlook the fact that "rope drag", or friction caused by the rope being pulled over projections inside a cave as well as over rocks and earth at the entrance, can easily supplement "live" load by 100 per cent or more. Indeed, it is not at all uncommon for a pull in excess of 300 pounds to be needed to raise a 150-pound person from a cave. This fact clearly demonstrates the need for a large factor of safety, not only for the rope but for manpower as well.

KNOTS

So much has been written about *how to tie* different knots that it is deemed unnecessary in this article to elaborate on that phase of rigging. There are, however, other aspects in their *use* that are equally important but often neglected. The cave rigger need not know many knots—five generally will suffice. They are:

a. *Half-Hitch*—A basic knot form, very seldom used alone, but often forming a part of other more complicated knots. Its main use in caves is to secure other working knots against untying.



b. *Flat or Reef*—Excellent in any case where the strain is from *within* (not applied to either *end* of rope). For example: A loop tied around a tree when it is desired to attach (with a shackle) a standing sheave block. *Never use* a *flat* knot when strain is to be put on either end of rope, as then it can slip and convert itself into two half-hitches—slip knots.

c. *Bowline*—Unexcelled for tying a loop in *end* of rope such as for a "safety line" around a person on a rope ladder.

d. *Bowline on a Bight*—Ideal for producing a loop along a rope (not at one end). As it is in reality *two* loops, it is recommended for the leg loops of the so-called "parachute harness" type of rig used for vertical drops.

e. *Sheet Bend*—Good for fastening two ropes together, especially if they are of different sizes.

A word of caution in the use of knots is in order. When strain is applied every knot "creeps" until it becomes set. Therefore, never tie a knot close to the end of a line. It may untie when strain is applied. Tie the knot at least 18 to 24 inches from the end.

Many types of knots that are stable when working in the open, are *subject to untying* if the knot catches on some obstruction. The bowline and sheet bend are notable examples. As such a danger *always* exists in caves, sufficient rope should be left when tying the "working" knot to put a couple of half-hitches around the line. This will safeguard the working knot from becoming untied.

BLOCK AND FALL .

Never use a traveling block (sheave) in a vertical cave drop to raise or lower anyone. The only possible excuse for using one is when the rope is too small or weak (and therefore has to be doubled) or when sufficient manpower is not available. Weighed against the potential accident hazard, however, neither excuse is valid.

The arguments against traveling blocks are:

a. If it is within reach of the caver it may cut off his fingers or at least severely injure his hand.

b. If placed too high to be reached by the caver it is then susceptible of becoming fouled on a projecting ledge, or even worse, in a crevice in a ledge. Being then out of reach of the caver, he would be unable to extricate it. The pulling party (generally out of sight of and out of hearing distance of the caver) upon feeling extra resistance would probably pull all the harder. This might easily result in breaking either the rope or the block or it might dislodge a portion of the ledge which could fall and strike caver who is pinioned immediately underneath. In any case such an accident could well be fatal.

c. In vertical drops ropes always twist or unwind to a certain extent. In cases where traveling blocks are used this causes the two ropes to be wrapped around each other thus fouling them and making them inoperable—a very common experience.

There is no way to remove *all* twist from a rope since one of the factors governing the amount of twist is *weight*. A rope that will *not* twist with a 100-pound girl *will* twist with a 200-pound man and vice versa.

Standing blocks can be put to excellent use both inside and outside caves:

a. As a means of *positioning* a drop over the *center* of an opening thereby eliminating the friction and wear on the rope that would be caused if it were pulled over the earth and rocks at the edge of the opening. Also, it lessens the tendency of the rope to loosen rocks which might fall and strike the caver on the rope) and others below.

b. As a means of *changing direction* of pull to facilitate easier handling—as for instance, when a block is secured to a tree so located near the cave entrance that the pulling party may hoist a caver by walking *down hill*—a very real help.

There are several rules that should be strictly adherred to in the selection of *sheave blocks:*

1. Never use a sheave that is too small in diameter for the rope. It not only requires considerably more work to operate but it greatly weakens the rope by excessively stretching the outer fibers passing around the sheave. A safe practice is to have all sheaves *eight times* as large in diameter as that of the rope. Example: A $5/8$-inch rope should use a five-inch sheave. Under no circumstances use one whose diameter is less than seven times that of the rope.

2. Never use a cheap or light sheave of the awning, toy, or window sash variety. A good five-inch block should not weigh more than five or six pounds—truly a small amount of weight when human safety is involved.

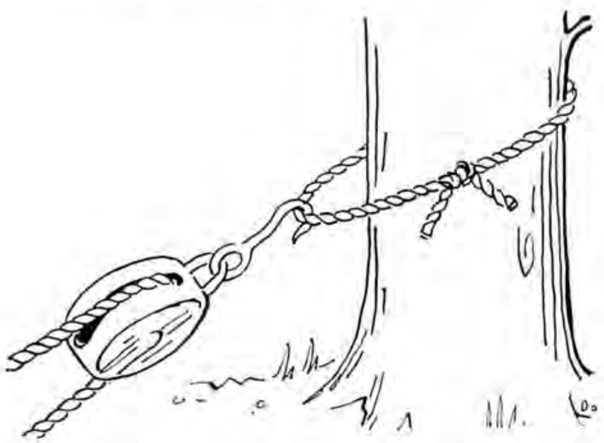
3. Never use any block except of the safety type—one that has a strong piece of metal across the lower side which will catch and hold the rope in the event that the sheave pin works out or wears in two. By using a good block of standard design and carefully inspecting and lubricating it before each use no trouble should be experienced on that score.

4. Never use a block that is equipped with a *hook*—in short *DO NOT USE HOOKS!* They are dangerous, time consuming, and even if the hooks are tied, they are still unfit for cave work. Remove all hooks from blocks and use *screw pin shackles* instead. They require only a fraction of the time needed for tying a hook, are far stronger and, above all, they *"stay put"*. When removing hooks from blocks they may generally be cut so as to leave the ring still attached. This ring is often large enough for the insertion of a shackle. If not, have a *reliable* welding shop forge and weld a ring at the top of every block. Do not have the rings welded (attached rigidly) to the block.

5. *Steel* blocks are superior to wooden ones. They will stand more abuse and are not affected by moisture. However, a good wooden block with steel shrouds (bands extending from top to bottom of block) should give good service if care is exercised in its use and it is not subjected to hard knocks which might break the wood. As to *size* of sheave: Since all ropes get *larger* with use it is advisable to get a block *one size larger* than the rope for which it is to be used. This reduces friction on sides of sheave and lessens wear on the rope.

SHACKLES

Screw pin shackles—not *loose* pin—are ideal for attaching sheave blocks to supporting ropes. The ½-inch size is recommended. They are large enough to accomodate all sizes of rope up to and including ¾-inch, and while they may appear small, they will support more than eight tons. To keep from bending rope too sharply at shackle the rope should be carried around a suitable sized thimble. Both shackle and thimble should be galvanized. The pin should be screwed up snug. If desired it can be locked by running a wire through the hole in the pin and around the body of the shackle.



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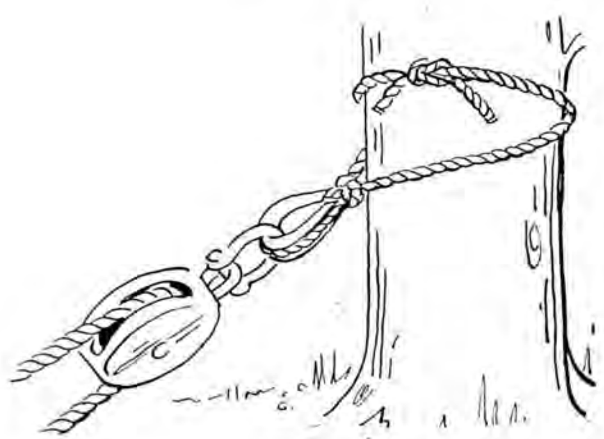

but THIS

LIGHTS

Never raise or lower a caver by a nonmetallic rope while his carbide lamp is burning unless rope is protected.

If the person on the rope has a good flashlight (which every caver should have) fastened to him by a strong cord to prevent dropping there will seldom, if ever, be need for another source of light during the descent.

For those who insist upon keeping a carbide lamp lit while being raised or lowered, the following suggestion is made:

Place a flexible metallic sleeve around the hoist line next to caver. This is extremely simple and efficient and consists merely of sliding a short section (about two feet long) of ¾-inch Greenfield flexible conduit over the hoist rope just above the chest knot. This may be purchased for a few cents from almost any

Greenfield flexible conduit protecting rope from flame of carbide lamp.

electrical contractor and makes the rope practically immune to damage from carbide lights. Before slipping the Greenfield tubing into position apply a couple of layers of friction tape to the rope for about three inches at points where *ends* of metallic sleeve will be. This will prevent injury to the rope. After the sleeve is in position apply another three-inch layer of tape at each end of it—one and one-half inches on sleeve and the same amount on rope. This is done to provide a smooth surface and to prevent grit from entering the space between the tubing and the rope.

The above precautions against flame apply equally to "safety lines" and "main lines."

"BOSUNS' " CHAIRS

"Bosuns' " chairs are safe for vertical drops in caves with ample-sized entrances, provided that previous exploration has revealed no intervening ledges. "Bosun" chairs permit a large group of people to be handled in a remarkably short time. They should, however, be so constructed that a caver *cannot possibly slip out of chair* if, perchance, it hangs on some obstacle and tilts or tips over.

ANCHORS AND MOORINGS

A line (cable or rope) that is made fast (tied) to an object *is never any more secure than the object to which it is tied.* This may sound elementary. It is an axiom of greatest importance, however, especially in cave rigging. Too often cave ladders have been tied and safety lines snubbed around stalagmites which were of ample proportions in themselves, but which close inspection would have shown to be *formed on top of a mud deposit.* Obviously such an object makes a dangerously insecure mooring. *Anchors should be inspected and tested as diligently as rope.*

The above treatise on cave rigging, while admittedly incomplete, is intended solely as a suggested guide to alert those who assume the responsibility for the safe conveyance in a cave of that most precious commodity—the human life—those who acknowledge the eternal truth that *Safety is an Art, not an Accident.*

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Origin and Development of "Positive" Water Catchment Basins, Carlsbad Caverns, New Mexico[1]

By DONALD M. BLACK

Ranger, National Park Service

OBSERVATIONS

Depressions which have, and do act as, catchment basins for water seemingly follow definite patterns of development. In origin they might develop as solution basins in the bed rock, as collapse dammed solution areas sealed with minerals or silt (fig. I), or as positive growing structures which build above the topography of the immediate area (figs. II, III). A careful search of much of the cavern has not revealed an indisputable solution catchment basin. A few basins are probably collapse dammed. The most common kind of catchment basin is the "positive" type.

[1] Approved for publication by the Director of the National Park Service.

POSITIVE BASINS

A positive basin is peculiar in that it is bounded on two or more sides by flow stone or "retaining dams" of crystalline carbonates. The maximum elevation of the water surface is controlled by the growth of these carbonate crystals across the areas of overflow. Overflow causes retaining dams to grow in height; in fact, without overflow, these dams will cease to grow. New dams develop when the water level is high enough to spill through other low places in the topography; each spillway eventually becomes dammed. Retaining dams are composed of two zones of growth, and no less than two types of carbonate crystals. The zone of growth in contact with the basin water (basin side) consists of massive, triangular, pyramidal crystals that radiate laterally (fig. II, A_1); back side of the dam is faced with layers of acicular crystals whose longest axis is normal to the slope of the dam (fig. II, A_2). Individual dams are often formed on formations that slope thirty or more degrees (fig. IV). Although the general trace of several adjacent retaining dams is concave toward the source of water (fig. II, C), the individual dams have a trace that is convex toward the source of water (fig. II, B).

Positive basins formed by the converging of "aprons" of flowstone (fig. III) within narrow confining solution joints are responsible for many of the water levels seen in the Left Hand Tunnel. Where not confined between narrow solution joints, flowing water tends to build retaining dams to confine or impound water (fig. II, IV). This latter type is represented by the Mirror Lake, Longfellow's Bath Tub, and the Devil's Spring. Positive basins are responsible for the various types of "lily pads" which comprise an important part of the scenery of the Carlsbad Caverns.

J. H. Mackin and H. A. Coombs [1] recognized the existence of water basins in which they found cave pearls. The basins described by them would be considered flowstone sealed depressions and not the positive type basin.

[1] "An occurrence of 'cave pearls' in a mine in Idaho", Jour. Geol. pp. 58-65, vol. LIII, No. 1, Jan. 1945.

FIG. I

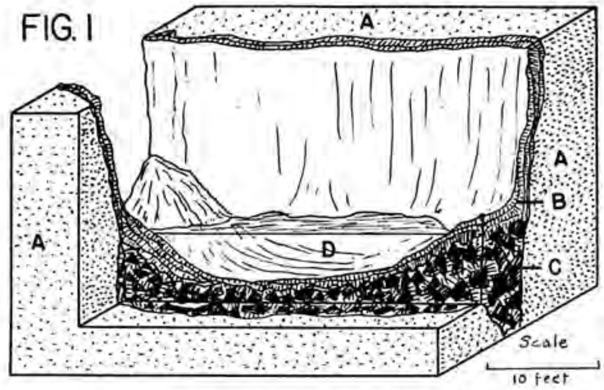

Fig. I—Collapse dammed solution joint sealed with flowstone. A, bed rock; B, flowstone; C, flowstone sealed rubble; D, water level.

FIG. II

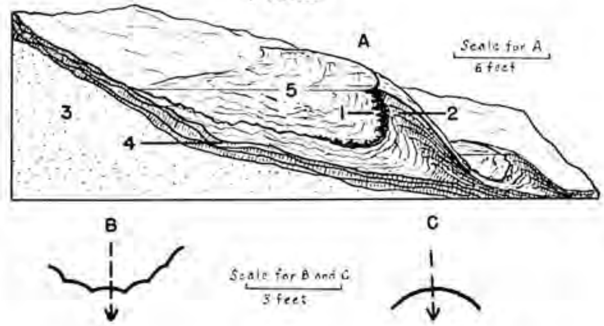

Fig. IIA—Retaining dams in cross section. 1, laterally growing, massive, triangular, pyramidal, carbonate crystals; 2, layers of acicular crystals with long axis normal to back slope of dam; 3, bed rock; 4, flowstone slope deposited prior to formation of retaining dams; 5, water level.

Fig. IIB—Trace of series of adjacent retaining dams; arrow indicates direction of overflow.

Fig. IIC—Trace of single retaining dam; arrow indicates direction of overflow.

FIG. III

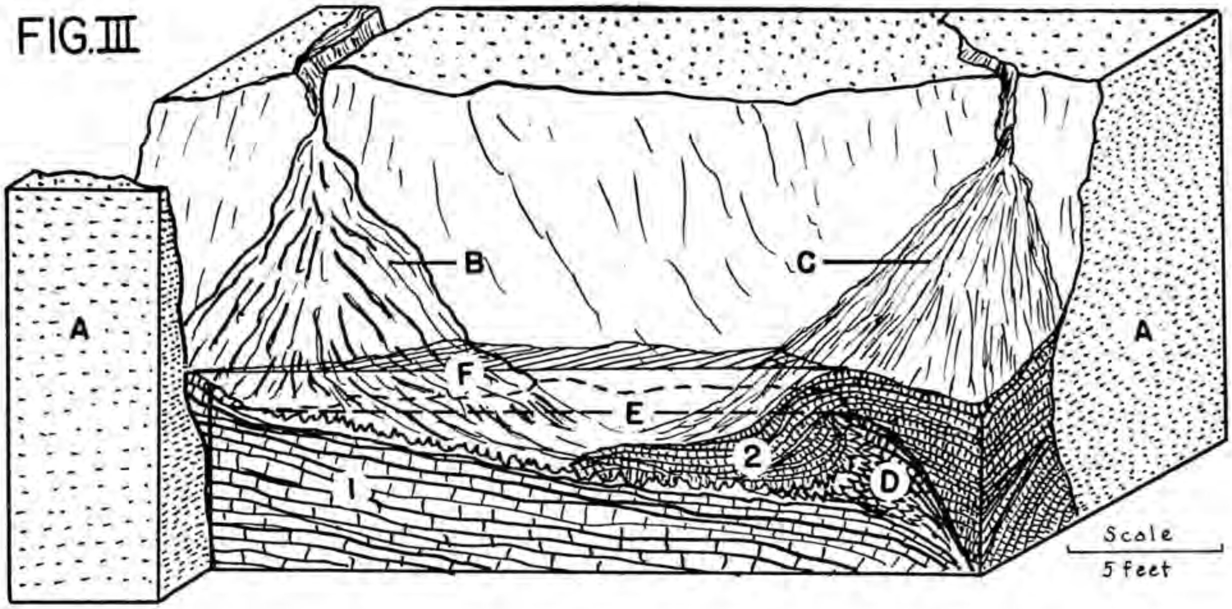

Fig. III—Solution joint dammed by two sources of flowstone: A, bed rock; B, oldest source of flowstone; 1, flank or apron of flowstone from source "B"; C, most recent source of flowstone; 2, apron or flank of flowstone from source "C"; D, old retaining dam on flank of "B"; E, old water level at height of retaining dam; F, new maximum water level due to building of flowstone from source "C". Water in basin retained by the old retaining dam completely disappeared before flank "2" could invade the basin.

FIG. IV

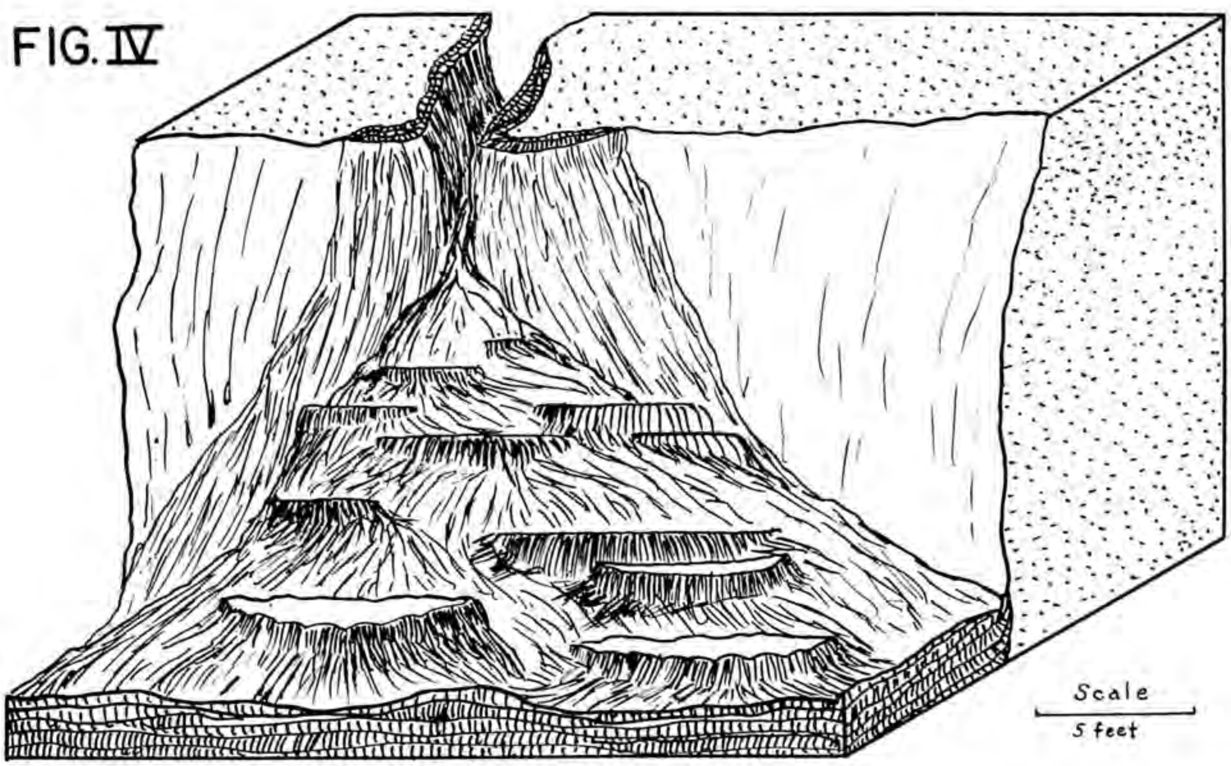

Fig. IV—Terracing of flowstone slope by retaining dams.

WYANDOTTE CAVERN

CLYDE A. MALOTT

Indiana University

(Published posthumously)

Dr. Malott herewith presents a scholarly history and description of one of America's most famous caverns, enlivened by his distinctly interesting literary style and authenticated by his years of personal experience in the Hoosier state. This paper, hitherto unpublished, was graciously given to the National Speleological Society by his family after his death on August 26, 1950.

Caves have long excited interest in Indiana, a state possessing an abundance of karst features. No area, however, has attracted visitors so early or continuously as Wyandotte cavern in southeastern Crawford County, some ten miles west of historic Corydon, the early Hoosier State Capital. This great cavern was discovered about the year 1800. It was exploited for its nitrous earth used in the manufacture of gun powder from about 1812 to 1818. The site of the cavern and some 4,000 acres of land were acquired by H. P. Rothrock from the U. S. Government in 1820, and the Rothrock family still retains the cavern and its environs of wooded hills.

The lure of the great cavern was at first rather local, but after 1850, when some inquisitive explorers discovered a passage leading into the lower levels composing the main part of the cavern system, word of its vast size and seemingly endless passages was spread afar, and the Rothrock family in self defense was compelled to open the cavern to the public and build an inn to care for the visitors who flocked to see the cavern with its wonders wrought in stone. It was visited in 1854 by H. C. Hovey, the famous cavern specialist, who prepared articles on the cavern for the *American Journal of Science and Arts*, the *New York Tribune* and the *Indianapolis Journal*. Hovey, like others, returned again and again, and in 1878 brought a special artist with him to prepare sketches of many interesting features of the cavern for *Scribner's Magazine* and for his book on *Celebrated American Caverns*. Detailed accounts of the cavern system were published in the Annual Reports of the Indiana Geological Survey by Collett in 1879 and by Blatchley in 1897, both of which are replete with information on the cavern.

Though the romantic name of Wyandotte was given to the cavern on behalf of the Indians who formerly were present in the region and who left abundant evidence of their visits in the great cavern, it appears unlikely that any of the Indians were of the Wyandotte tribe. These former inhabitants of the region left crude sledge-hammer stones in the cavern with which they quarried out a large section of the base of the gigantic "Pillar of the Constitution" in the older and upper gallery, and cut away quantities of flint stone from the roof section of the main gallery system 70 feet lower.

Wyandotte cavern is hollowed out of the thick limestone formations in the western section of the wide limestone terrain of southern Indiana where sinkholes, sinking streams, great up-welling springs and caverns abound, and where the high upland ridges are composed of sandstones and shales. Blue River and its immediate tributaries have deeply dissected the upland terrain into valleys and ridges with a relief exceeding 400 feet. The noisy riffling waters of Blue River near the cavern are 390 feet above sea level, while the adjacent sandstone ridges reach or exceed 800 feet in altitude. Wyandotte Inn and the nearby cavern entrance are located on the slopes reaching from the deeply-set river to the crests of the upland ridges. The view looking eastward from the Inn across Blue River valley is a magnificent one, and in the autumn, when the luxuriant summer foliage of forest green changes to brilliant hues, the view becomes one of marvelous beauty. State Highway 62, leading westward through the sinkhole country westward from Corydon and along the winding valley of Blue River, is an admirable work of engineering along and about the twisting valley sunk so deeply in the hilly terrain. It passes close by the great cavern and thence westerly through the most rugged and picturesque country in southern Indiana.

The more readily available portion of the cavern system has been developed into an easy route of travel for sight-seeing visitors, while the remote portion is open to the more adventurous cavern visitors who wish to extend their time and endurance in the great subterranean passages that lead into the unmapped and unexplored sections of the system. The regular trip with guide service through the more diversified section of Wyandotte requires about two hours time and a travel distance of one and three-fourths miles. Once inside the cavern, however, time and distance become vague and uncertain to the visitor. Progress through the cavern is an adventure into the unknown, and a continual change of novel features come into view without perspective and in turn pass behind with a fading conception of the spacial relations of distance and direction. The immediate aspects of the cavern are all that the visitor has in sight at any moment, and these change from one to another and so completely absorb his attention that he becomes more or less oblivious of time and distance.

The entrance to Wyandotte cavern is a yawning void about 7 feet in height and 20 feet in width in the well-bedded limestone. Both the floor and the roof descend rather steeply into the great vestibule of the cavern to a padlocked gate in the twilight 215 feet from the entrance. Beyond, the smooth-trodden pathway leads along rugged walls under a high-arched ceiling of dark limestone. It leads past a gigantic block of rock fallen from the right wall some 650 feet from the entrance. This rugged stone, called "Fallen Rock", is estimated to weigh 535 tons. It has reposed in the dark cavern for century after century and has the dust of ages accumulated upon it. At a distance of 865 feet from the entrance a large passage leads upward on the left into the old upper level of the cavern and thence over a rugged and difficult route to the great "Senate Chamber" which contains an enormous fluted column extending from floor to ceiling, known as the "Pillar of the Constitution". This route is a specialty in itself. To the right of the junction of the old cavern a descent of 30 feet or more is made rather abruptly down well constructed stairs to the main gallery system of the cavern. Here, the silt-covered floor of the main gallery system first becomes evident. It is quite dry, though it represents a deposit made by waters which formerly coursed through the great cavern passages. In places it is littered with rock fallen from the ceiling, or is interrupted by great arched rooms in which hills of rugged rock have accumulated from above. The floor of the main cavern is 110 feet below the cavern entrance and 65 or 70 feet above the water level of Blue River.

Photo by Perry D. Griffith

Entrance to Wyandotte Cavern, situated on a steep, rocky slope in the most rugged portion of scenic southern Indiana.

A succession of features in turn engross the attention of the visitor. Repetition occurs, though in different degrees. Fundamental geological aspects are impressively apparent and inescapable. The cavern is rough-hewn from layers of limestone by former water action which dissolved and eroded the passages through the limestone. Fossils are occasionally seen on the walls and ceilings. Features of irregular solution are locally strikingly apparent and some curious forms attract special attention. The rugged walls and the ceiling are dominantly covered with a coating of gypsum which has developed through ages of capillary exudation from the country rock, crystallizing on the dry walls in the dry cavern air. Locally the white, sparkling, alabastrine gypsum is of unusual beauty, and in the long galleries glorifies such places as the "Bishop's Rostrum", the "Ball Room", "Frost King's Palace", "Morton's Marble Hali", and the "Fairy Palace". Perhaps the most admired forms are the dripstone formations composing the pendant *stalactites* of the ceiling, the squat *stalagmites* of the floor, and the astonishing and preplexing *helictites* so impressively arrayed in the "New Discovery" passage.

the cavern some of the carbon dioxide is given up, causing an over-saturation of the solution, and interesting deposits are formed. The stalactites, or icicle-like pendant forms, are made where the drip from the ceiling is relatively slow, permitting release of carbon dioxide from the solution. The stalactite form grows in length by crystalline deposit of calcium carbonate on the end, and increases in girth by

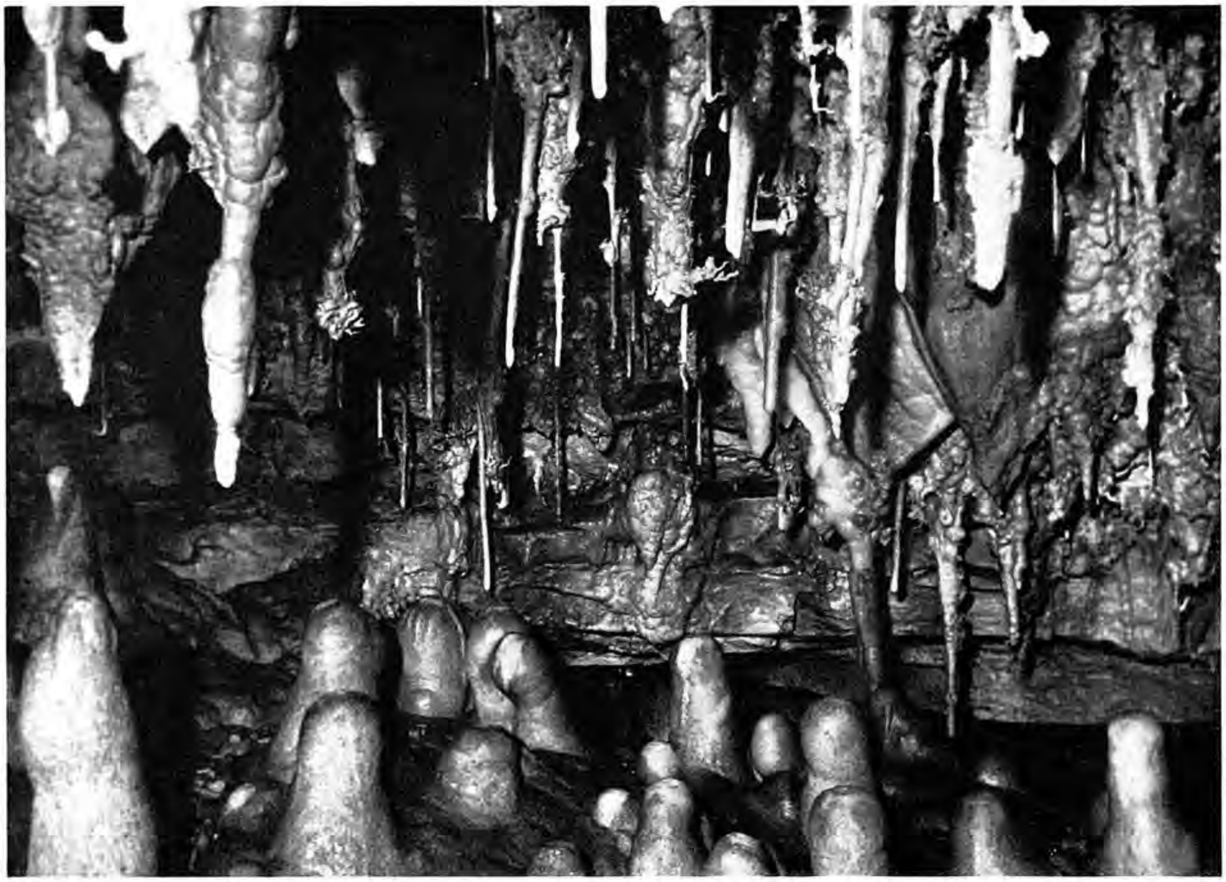

Photo by George F. Jackson

Stalactites, stalagmites and helictites in a remote passage of Wyandotte Cavern. The photograph illustrates how the stalagmites (on the floor) are always more rounded than the stalactites above them. Droplets of water, after leaving minute quantities of mineral matter on the ends of the stalactites from which they fall, splash atop the stalagmites below. Rolling downward they thus build up the outer periphery of the latter, filling with mineral matter any rough projections or corners.

The dripstone deposits of the cavern are found where seepage waters from above enter the cavern after having passed slowly through thick masses of soluble limestone. The waters, charged with carbon dioxide, dissolve the calcium carbonate composing the limestone by direct contact, moving slowly through the small cracks, crevices and through the porous beds themselves. On seeping into the free air of

successive deposits on the sides of the suspended tube which in its primitive form is hollow. Some of them may become over-thickened and develop into various heavy forms, while others may receive the deposit so as to resemble rows of long, hanging leaves of tobacco. The drip of the over-saturated solution on the floor in time builds up deposits of calcium carbonate, producing the stalagmite form. Since these are built up against gravity and usually with some spreading of the water-drip, they are usually much thicker than the normally slender stalactites. Locally a stalactite and stalagmite may join to produce a column reaching from floor to ceiling. Dripstone formations of varied character and associations are abundant in the "Throne Room", along "Purgatory Walk" to "Pillared Palace", the "New Discovery" passage, "Spades Grotto", "Penelope's Grotto", on and above

Photo by George F. Jackson

"Monument Mountain" in Wyandotte Cavern. Towering 175 feet high this is said to be the largest underground "mountain" in the world. Because of the tilted camera angle necessary the flat slab of limestone above the top of the "mountain" appears to be a flat wall. Actually it is directly above the stalagmites.

"Monument Mountain" and locally at other places in the cavern. Since much of the cavern lies 300 feet or more below the surface and beneath the ridge where the limestone beds are protected from seepage waters by thick layers of impervious shale, it is only locally that dripstone deposits are made in the cavern.

The "New Discovery" passage, opened in 1941, is especially attractive for its riotous display of dripstone formations. This passage was once one of the main water routes of the cavern stream, but in the later period of water discharge through the cavern it became silted nearly to the roof. Because the packed clay and silt reached close to the roof, it lay undiscovered until 1941, when it was trenched through and opened as a part of the regular cavern route. Locally the passage veritably bristles with stalactites, stalagmites, columns and helictites, some of which are exceedingly white and delicate. Helictites are irregularly twisted or contorted growths of crystalline calcium carbonate, frequently accompanied by bulbous and botryoidal masses, formed in caverns where seepage waters are very slow and where much of the evaporation takes place with little water drip, allowing growths to follow various directions independent of the downward pull of gravity. They are formed on

Photo by George F. Jackson
An unusual photograph taken while looking straight up into an 80-foot dome in Wyandotte Cavern.

Photo by George F. Jackson
Formation in Wyandotte Cavern known as "The Throne and Canopy."

Photo by George F. Jackson
An oddly shaped cave formation hanging from the roof of one of the newly discovered rooms in Wyandotte Cavern, Indiana. Picture shows it about one-half actual size.

normal stalactites, stalagmites, irregular roof masses, and even on one another, often in curious curls, loops and extensions and in such profusion as to defy description or explanation. Countless thousands of them run a gamut of display rarely equaled in any other cavern.

Another feature of Wyandotte cavern is the development of great rooms through rock falls from the ceiling, where the width of the channel runways became over-widened and failed to support the flat-lying beds above. The fallen rock masses rise high above the silt-covered channels into great arched rooms. Among the largest of these rooms are "Odd Fellows Hall" and the "Senate Chamber" in the old upper level, and the "House of Representatives" and "Rothrock's Grand Cathedral" in the main cavern gallery. The largest and most impressive is "Rothrock's Grand Cathedral", the ceiling of which rises 135 feet above the silt-covered floor, and which contains a great mass of fallen rock 105 feet in height. The great room is oval in shape, having a length of 360 feet and a width of 140 feet inside the room 40 feet above the base of the fallen rock. Its base at the floor level of the cavern probably covers an area in excess of one and four-tenths acres, and the mass of fallen rock is equivalent in volume to a block measuring 400 feet long, 150 feet wide, and 60 feet high, with a content in excess of 110,000 cubic yards and a weight of at least 225,000 tons. Atop this great pile of fallen rock, known as "Monument Mountain", are masses of flowstone and several prominent stalagmites, one of which is very white and is known as "Lot's Wife". Thirty feet above "Monument Mountain" is the flat ceiling forming a great oval with a thickly-set fringe of stalactites hanging from a ledge below it. The great rugged rock mass with its up-standing stalagmites and the fringed oval above it is an impressive sight when viewed as a subdued silhouette formed by a light beyond the mountain away from the observer.

In conclusion only a word may be offered concerning the "Long Route" with a suggestion bearing on the origin of the great cavern runways transecting the limestone terrain. The "Long Route" of the cavern includes the great runways beyond the "Auger Hole", a small opening at the northern end of "Rothrock's Grand Cathedral" room. A full trip requires a minimum of four and one-fourth miles of cavern travel in the mapped and readily available parts of the system. The great runway voids of the "Long Route" are obviously the underground channels of cavern streams which formerly flooded through them. Evidences of the solution, erosion, and deposition produced by flooding waters are impressively present, and the question of the origin or source of sufficient waters to carve out the great channels is a natural one for the visitor to pose. Recent study in the region indicates that the waters very probably came from Blue River which sought an underground route across the neck of a wide easterly detour. Such a route is at least seven miles shorter and possessed a hydrostatic head of 50 feet or more. The question of the abandonment of such a route when once so well developed is a complex one. It may be in part associated with massive rock falls in the mature cavern routes, which so blocked the passages that they became silted up. Such blocking and silting of the underground routes, however, cannot fully account for their abandonment. Blue River valley in its later history has undergone a relatively rapid down-cutting period and has been deepened some 65 or 70 feet below the well developed underground passages, leaving them high and dry. Such a down-cutting period was brought about by the nearby Ohio River which was greatly enlarged and deepened by the glacial waters directed down its course and which supplanted a much smaller and shallower preglacial predecessor. Thus, Wyandotte cavern is a special feature whose history of development is an intimate part of the terrain in which it lies.

Mechanics of Cavern Breakdown

By WILLIAM E. DAVIES

The fearsome possibility of the collapse of caves is one of the first thoughts of the inexperienced person when contemplating the activities of the speleologist. Cavern collapse in the catastrophic proportions mentally conceived by the uninitiated, however, is practically unknown in the history of subterranean exploration. The author shows herein that collapse, when it does occur, follows definite mechanical laws and that its probability can, at least in some instances, be predicted sufficiently in advance of actual occurrence as to preclude the possibility of any great danger to the explorer.

Roof fall or breakdown is recognized as one of the potential dangers of cavern exploration but speleologists have given little attention to conditions leading to cavern collapse. Similar failure of roofs and walls in mines, however, have been studied by mining engineers throughout the world and several theories on the cause of roof falls have been advanced that are applicable to cavern breakdown.

Breakdown for the purpose of this paper is defined as the failure en masse of the roof or walls of caverns. Occasional spalling or slabbing of small rock fragments is excluded from breakdown although, over long periods of time, rock fragments accumulated from such action may resemble breakdown.

Breakdown has been classified according to its physical appearance [1] and at least four forms are recognized—Block, Slab, Plate, and Chip—but of these only the first two are of direct interest in this discussion. Block breakdown is the failure en masse of a portion of the ceiling and walls extending short distances horizontally but of great vertical magnitude; slab breakdown is failure extending great distances horizontally but limited vertically to a single bed or a few beds at the ceiling face. The other forms of breakdown are not considered with block and slab failure since they are of small magnitude in comparison to block and slab failures and involve less intense, local stresses.

Breakdown is found in practically all types of cavern passages with low-arch ceilings or in passages which lie close to the surface. In the low-arch passages breakdown is often developed where two passages lie parallel and close to one another. It is also common in areas adjacent to the intersection or crossing of large passages but is seldom developed at the point of intersection or crossing.

Breakdown is confined generally to passages in which the dip of rocks is low. Where dips are steep it is usually absent except in passages that are developed along the strike. Rock failure is not confined to any specific limestone but is equally well developed in passages in limestone of all types and ages.

Similarity of cavern breakdown and roof failure in mines has been noted, and many of the conclusions concerning conditions in mines can be applied to caverns. Systematic studies of roof failure date back to 1885 when H. Fayol published his observations on conditions in French mines. He advanced the idea that the ceiling of a mine tends to move into the opening and that, in doing so, a zone of stress is established in the form of a dome above the opening. It is this theory of doming that forms the basis for many later theories concerning rock failure. From 1885 to 1929 numerous papers were published describing rock falls but few delved into the cause. In 1929 Henry Briggs of Edinburgh, Scotland published a book [2] which summarized the knowledge concerning rock failure. This book, along with one by Lane and Roberts,[3] stimulated considerable interest in the subject and, during the 1930's, a number of papers were published on the cause of rock

[1] Davies, William E. Features of cavern breakdown: National Speleological Society, Bull. 11, Nov., 1949. pp 34-35, 72.

[2] Briggs, Henry. Mining Subsidence: Edward Arnold & Co., London, 1929.

[3] Lane, W. T. and Roberts, J. H. The principles of subsidence and the law of support: Alfred A. Knopf, Ltd., London, 1929.

falls. P. J. Crowle and Jack Spalding working in the Kolar Goldfields of India; C. J. Irving, O. Weiss, and E. H. Joseph in the Rand, South Africa; and D. W. Phillips and J. R. Dinsdale in England made important contributions towards the understanding of roof failures in mines.[4]

Although general conditions of rock fall in shallow mines and in caverns are similar, there are several important specific differences. The most important difference is that the beds forming the ceilings and walls in caverns have not been subjected to severe shocks of blasting as have those in mines. As a result the conditions in caves allow the study of rock in which only simple uniform stresses are operating. This is a great advantage, for observations can be made that approach conditions assumed in mechanical analysis of the forces acting on the ceiling and walls. A second difference is the element of time. Drifts and stopes in most mines have been opened a relatively short time, while cavern passages and rooms have existed in their present form for thousands and possibly millions of years. As such, the stress-time factor is fully developed. A third difference is the absence of artificial supports in caves which, like the first difference, makes conditions much simpler and permits the application of simple mechanical analysis to cavern breakdown.

In analyzing the mechanics of breakdown, the strength of rocks is of utmost importance. The strength of rock varies considerably according to the form and direction of stress applied. In compression, rocks exhibit considerable strength and, in limestone, the crushing strength is in the order of 6,000 to 12,000 pounds per square inch. In tension, however, the strength is much less and the modulus of rupture for limestone is in the range of 1400 to 2800 pounds per square inch. Under conditions of shear, rock is much weaker than in tension and shear strengths for limestone vary from less than 150 pounds per square inch parallel to the bedding to about 1500 pounds per square inch at right angles to the bedding.

To understand the mechanics involved in breakdown it is necessary to review the forces acting on cavern roofs and walls from the time of origin of the cave until collapse takes place. Before a cavern is developed, there exists at depth within the earth a limestone formation which is overlaid by successive series of other rocks. Within the limestone formation two distinct types of forces may exist. The first is due to the weight of the rock above the limestone which will vary with the depth to the limestone. The second are stresses resulting from deformation of the limestone by earth movements. The first type of stresses can be determined with reasonable accuracy, but the second type varies so greatly that no reasonable analysis can be made. However, over the long period of time necessary for cavern development, stresses from earth movements reach equilibrium and play only a minor part, if any, in the ultimate cause of breakdown.

Stresses resulting from the weight of rock above the limestone are always present and play an important part in the development of breakdown. If a point is chosen at depth in the solid limestone before solution effects develop, the stresses acting will be a vertical stress (P) due to the weight of the rock and a horizontal stress (Q) which is the horizontal component of the vertical stress (about 40% of the vertical stress). Since the limestone is in equilibrium at depth there are equal and opposite forces upwards and laterally (Figure 1).

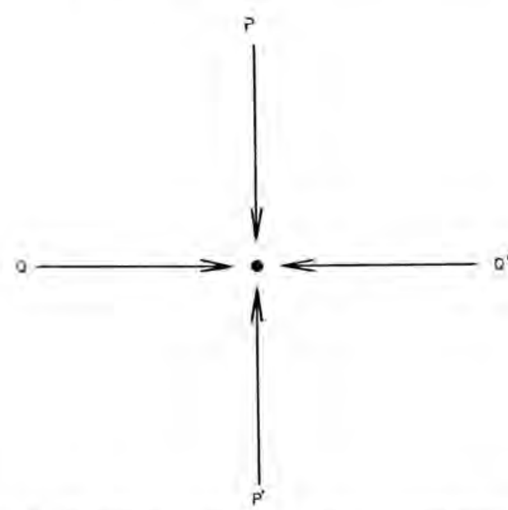

Fig. 1. Equilibrium of forces acting on solid limestone at depth. (P) vertical force due to weight of rocks; (Q) horizontal component of vertical forces. (P') and (Q') equal and opposite forces maintaining equilibrium.

[4] A summary of the ideas advanced by these authors is in: Jeppe, C. W. Review of the rock pressure problem: Jour. Chemical, Metallurgical and Mining Society of South Africa, vol. 44, no. 1, July-August, 1943, pp 3-20.

As the limestone is uplifted and the cover reduced by erosion it enters a zone in which solution and cavern development take place. With the development of large solution openings, the equilibrium of stresses is upset and new conditions of unstable equilibrium are established. The horizontal and vertical forces are rearranged so that they tend to move the walls and ceiling into the cavern opening but are restrained primarily by the strength of the rock. During this stage the vertical stresses can be resolved into two types. At the ceiling of the cavern the beds sag into the opening under their own weight. The area of sag is not confined to a single bed but is ellipsoidal in shape, extending into the rock mass above where it becomes progressively less in each bed until a point is reached at which sag no longer takes place (Figure 2). In horizontal strata the maximum sag is near the center of the passage, but

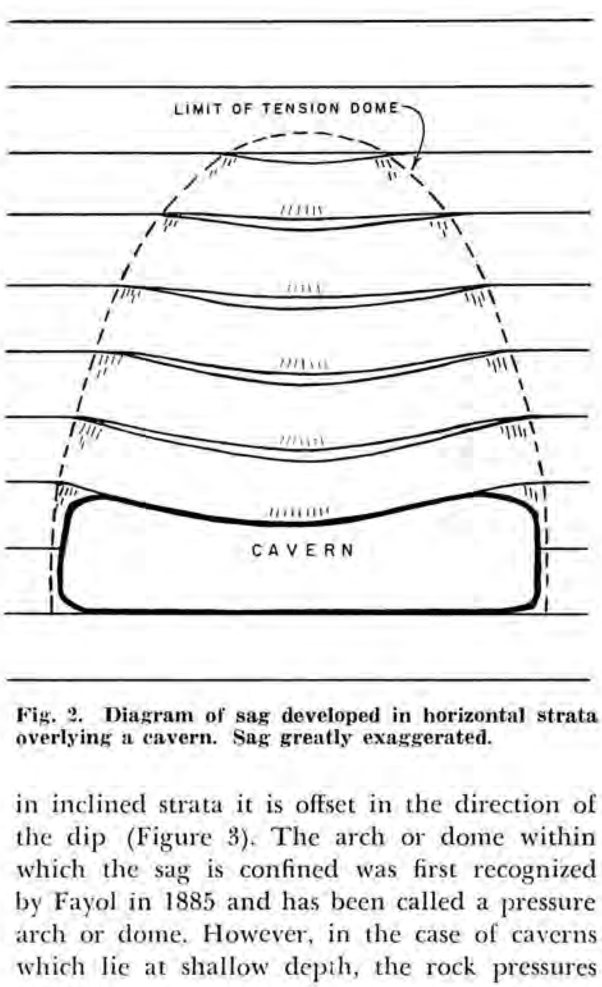

Fig. 2. Diagram of sag developed in horizontal strata overlying a cavern. Sag greatly exaggerated.

in inclined strata it is offset in the direction of the dip (Figure 3). The arch or dome within which the sag is confined was first recognized by Fayol in 1885 and has been called a pressure arch or dome. However, in the case of caverns which lie at shallow depth, the rock pressures above the opening are not critical and the sag of beds forms a zone in which vertical stresses are not transmitted. Therefore the term sag or tension dome is more suitable. Since the beds in the tension dome are not in contact they do not transmit the weight of the beds above them.

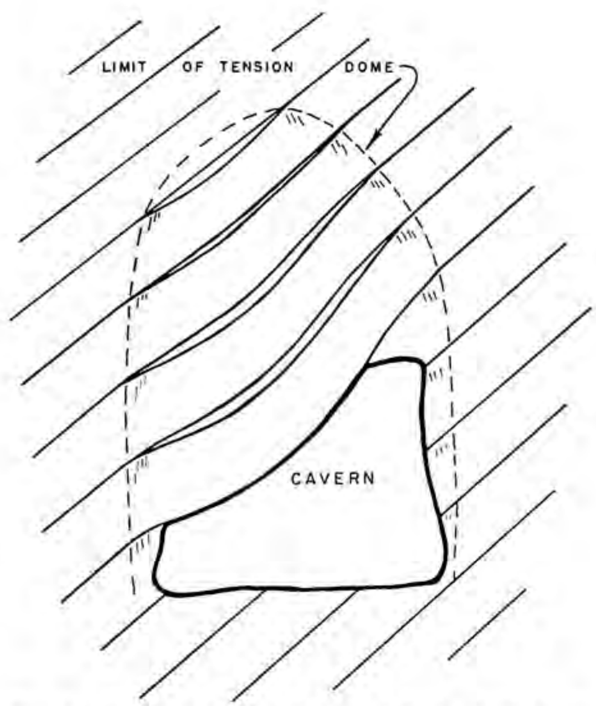

Fig. 3. Diagram of sag developed in inclined strata overlying a cavern. Sag greatly exaggerated.

The weight above the dome is transferred to the rock adjacent to the dome and to the walls of the cave (Figure 4). This greatly increases the stress adjacent to the face of cavern walls and is important in the development of some forms of breakdown.

Since the weight of the overlying rock is not effective within the dome, it may be eliminated as the direct cause of breakdown. The weight of the rock beds within the dome, however, is of primary importance in causing roof falls. Examination of cavern ceilings adjacent to areas of collapse indicate that individual limestone beds or groups of beds act as rock beams spanning the passage. On this basis a mechanical analysis of failure is possible by applying principles developed for ordinary structural beams.

Rock beams in caverns are in two forms. Where the ceiling and the rocks above it are solid and span the opening as a single unit they act as fixed beams.[5] Where the rocks contain open joints or cracks extending laterally through the beam, separating it into two distinct segments, the beam acts as a cantilever.[6]

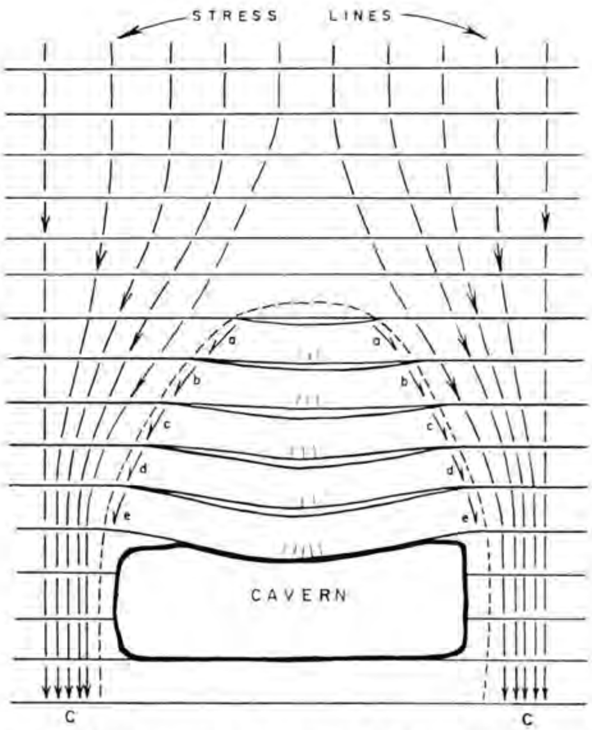

Fig. 4. Diagrammatic distribution of stress lines around a cavern opening and tension dome. (C) vertical compressive forces; (a-e) weight of sagging beams transmitted to cavern walls.

Ceilings adjacent to large rockfalls in Patton, Laurel Creek, and other caves in West Virginia are formed by continuous beds that act as uniformly loaded fixed beams with the walls serving as anchor abutments. The stress that will cause failure under such conditions is obtained from the formula:

$$f = \frac{M\ y}{I}$$

where M is the maximum bending moment of the beam,
y is the distance from the neutral plane to the edge of the beam,
I is the moment of inertia of the cross section of a rectangular beam,
f is the stress applied to the beam.

[5] A fixed beam is a single beam with both ends firmly anchored.

[6] A cantilever is a beam with one end firmly anchored and the other free of support.

For practical purposes

$$M = \frac{W\ l}{8} \text{ in a fixed beam}^7 \text{ and } I = \frac{bt^3}{12}$$

where b is the width of the beam,
t is the thickness of the beam,
l is the length of the beam,
W is the total weight on the beam.

The maximum distance y is equal to one half the thickness of the beam and may be expressed as $\frac{t}{2}$.

The stress (f) that will cause failure as determined for limestones ranges from 1400 to 2800 pounds per square inch and for many limestones averages 2300 psi. With the equations outlined above it is possible to establish the relation between the span of a beam and the minimum thickness of solid rock within the beam to support the span. For this the equation can be rearranged to the following expression:

$$t = \frac{3wl^2}{4f}$$

where w is the unit weight of the material forming the beam.

Application of the formula to Poorfarm Cave, West Virginia, where the limestone has a unit weight of 165 pounds per cubic foot and the rupture modulus (f) is approximately 2600 pounds per square inch shows the relationship between span and minimum beam thickness as:

Span	*Minimum thickness of beam*
4 feet	0.0053 feet
8	0.021
16	0.084
32	0.33
64	1.35
100	3.31

If the rock beam over the cavern is a uniformly loaded cantilever[8] it will have the same relation of thickness and span of a fixed beam if each pair of opposing cantilevers span exactly half the opening. The table below shows the relation of span and minimum thickness of a single cantilever (M in a cantilever is expressed as $\frac{Wl}{2}$ and $t = \frac{3wl^2}{f}$).

[7] This is based on a summation of the negative and positive moments of the fixed beam.

[8] Cantilevers span passages in pairs with one component anchored in one wall and the opposite component anchored in the other wall.

Span	*Minimum thickness of beam*
2 feet	0.0053 feet
4	0.021
8	0.084
16	0.33
32	1.35
64	5.40
100	13.24

The amount of sag in a beam that will cause rupture can be calculated from the following formulae:

Fixed Beams, uniformly loaded:

$$d = \frac{1}{384} \times \frac{Wl^3}{EI} \qquad (1)$$

where W is the total weight on the beam= lbtw,

w is the unit weight of the beam,

l is the length of the beam,

t is the thickness of the beam,

b is the width of the beam,

d is the deflection (sag) of the beam,

E is Youngs (Elastic) Modulus,

I is the moment of inertia of a rectangular beam $= \frac{bt^3}{12}$

The equation can be rewritten as:

$$d = \frac{12}{384} \times \frac{wl^4}{Et^2} \qquad (2)$$

The ultimate strength (modulus of rupture) of the material forming the beam is given by:

$$r = \frac{3}{4} \times \frac{l^2w}{t}.$$

By substituting this into (2) above:

$$d = \frac{1}{18} \times \frac{r^2}{Ew}$$

Calculations for fixed beams of minimum thickness in Poorfarm Cave breakdown areas, where E is approximately 6,300,000 pounds per square inch, show that a sag of 0.052 inch is the point at which collapse occurs.

Cantilever, uniformly loaded:

$$d = \frac{1}{8} \times \frac{Wl^3}{EI} \text{ or } \frac{48}{18} \times \frac{r^2}{Ew}$$

The limiting sag of beams of minimum thickness in this case is 2.5 inches.

The figures for sag, like those for thickness, are not absolute since variation in the characteristics of rock strata will produce variations in the moduli of rupture and elasticity. In addition the moduli determined by laboratory methods are generally less than under natural conditions. However, the figures given indicate the order of magnitude and are in agreement with conditions observed in Poorfarm Cave. Since the moduli of rupture and elasticity are relatively the same value for most cavern limestones, the figures for sag and beam thickness may be taken as typical for most caverns.

The failure of rock beams within the tension dome occurs in several ways to form breakdown. In the simplest case, the rock beam forming the ceiling, either a fixed beam or cantilever, sags to the point of failure and falls. This failure is typical of cantilevers and, while generally confined to a single bed in depth, is of considerable extent horizontally. The breakdown in the central passage of Poorfarm Cave is of this type.

Massive block breakdowns arise from the failure of successive cantilevers or fixed beams. The failure may start in the lowest cantilever and spread in rapid progression to the overlying beams. Based on conditions observed in caves, this type of failure appears to be of minor importance. The progressive failure of cantilevers starting with a beam higher in the tension dome apparently is the more common cause of breakdown. In this case a beam fails within the dome and transfers its weight to the beam below which in turn fails and loads the next lower beam with its weight and the weight above. Unless this action is arrested by the jamming of broken blocks to form a voussoir arch [9] the failure of beams by overloading from above will continue to the ceiling face where the mass will fall to form block breakdown. This development is confined to a short section of passage but generally extends a great distance vertically. The walls are involved in this form of breakdown with passages widened at the point of failure as a result of the rock faces slabbing and thrusting into the passage. The failure of walls is prominently shown in the breakdown area on the upper level of Laurel Creek Cave, West Virginia as indicated in figure 5.

[9] Voussoir arch is a low arch formed by blocks held in position by friction and lateral restraint.

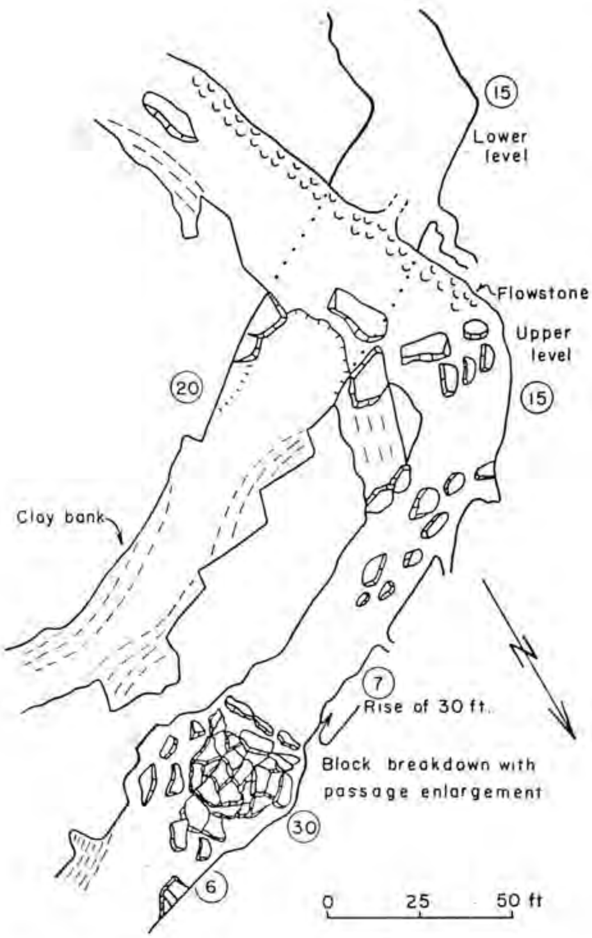

Fig. 5. Laurel Creek Cave, West Virginia: Section of breakdown near crossing of upper and lower levels. Encircled numbers are ceiling heights in feet.

The conversion of fixed beams to cantilevers is a critical stage in cavern breakdown. The conversion takes place when a fixed beam sags to the point of failure and open tension cracks develop separating the beam into distinct cantilevers. If the line of separation divides the beam into two relatively equal cantilevers it will in all probability remain suspended since the sag that will cause failure of a cantilever is far greater than that of a fixed beam. If, however, the crack separating the cantilevers is close to one wall or diagonally cuts across the passage it will form one cantilever of greater length which may exceed the length—thickness relation necessary to sustain the beam and collapse will occur. This relationship is clearly seen in the central passage of Poorfarm Cave where an open joint cuts diagonally across a wide passage and slab breakdown has developed on one side of the crack where the cantilever exceeds half the width of the passage.

Ultimate failure of both fixed and cantilever beams to form breakdown takes place close to the wall where the shear is greatest (Figure 6). The erratic fracture front of the truncated remnant of the beam at the face of the wall is inclined over the passage at a steep angle.

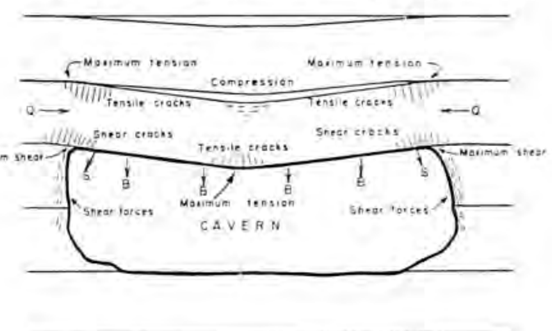

Fig. 6. Zones of stress in a sagging beam. (B) bending forces; (S) shearing forces; (Q) lateral compression forces.

Earthquakes are commonly cited as the cause of breakdown and Gardner [10] went so far as to speculate that most breakdown was brought about by an ancient quake of continental magnitude. Observations in mines and caverns do not support these ideas. The New Madrid earthquakes of 1811 and 1812, quakes of severe intensity within 150 miles of Mammoth Cave, Kentucky, caused no rock fall or other disturbance in the cave. Saltpeter workmen in the cave at that time reported no rock failure. Recent observations in Appalachian caves show no rock falls although local quakes have taken place during the period of observations.

The element of time is of considerable importance in development of cavern breakdown, for the physical condition of rocks is altered somewhat if uniform stresses exist for long periods. The time-yield in rocks is proportional to the stress applied to a certain point beyond which the resistance decreases rapidly and failure occurs under loads appreciably less than if stresses were applied for short periods. In caverns, the time that the ceiling has been subject to stresses is thousands of times longer than

[10] Gardner, James H. Origin and development of limestone caverns: Bull. Geol. Soc. Amer., vol. 46, no. 8, Aug., 1935, pp 1272-1273.

that experienced by any man-made opening. For this feature caverns offer an opportunity to study the ultimate effects in time yield.

Indications are that even after extremely long periods (10,000 to possibly 500,000 years) of exposure to uniform loads the rock beams forming the cavern roofs are far from the rupture point. Limestone, apparently, is more rigid and durable than laboratory tests indicate providing it has not been subject to severe shock by blasting.

The time at which breakdown develops in a cavern is not well established. Few caves have been observed where the process is in action today. The only active breakdown known to the author is that in Poorfarm Cave, West Virginia, where ceiling cantilevers are increasing in sag and slabs fall occasionally. Extensive breakdowns generally lie on clay fills that have been considerably eroded. The surfaces of blocks within the rock fall are fresh and show no effect of weathering or solution action and seldom, with the exception of guano deposits and stalagmitic material, are there any cavern deposits covering or lying on the breakdown. In a few caves, however, rock falls are covered with extensive deposits of flowstone and stalagmites which indicate that the fall took place a considerable length of time ago and that roof conditions have been stable since. Rock falls of this type are common in Rapps Cave, West Virginia, Shenandoah Caverns, Virginia, and several other Appalachian caves.

In some caves rock falls, generally consisting of a few slabs or isolated blocks, but no block breakdown, have been observed in the clay and gravel fills. This, however, is not common and most fills are free of breakdown. Apparently the early stages of cavern development are relatively free of extensive rock fall. Any that did occur has been removed by solution, a condition that is not too probable if large masses fell and were covered by fill soon afterwards.

The detection of ceilings that are nearing failure is all but impossible at this stage of investigation. However, the following observations may aid in preventing serious accidents. Passages with broad, low-arched ceilings free of stalactites should be traversed with caution. This condition is generally indicative of fixed beams in which some sag has occurred allowing water to travel along bedding planes rather than along open vertical joints. Since the sag causing failure of fixed beams is very small it is probable that the condition described represents an area of possible rock fall. Cantilever beams that are "peeling" from the ceiling and show distinct separation should be avoided.

In traversing passages where danger of rock fall is prevalent, it is best to stay close to the cavern walls as few breakdowns, except those resulting from failure of the entire tension dome, extend to the walls. Those resulting from cantilever failures, either singly or successively, have a fulcrom point a slight distance out from the wall face.

The interpretations presented in this paper are the beginning rather than the end of research. More knowledge will be gained concerning the mechanics of rock failure and conclusions will be more positive. With a better understanding of rock failure many lives as well as valuable property will be saved in mine operations. Caverns offer an excellent opportunity for study in this field and may, in the long run, hold the key to solving the riddle of rock fall and subsidence. However, work on this interesting subject will be hampered unless investigators can obtain data on the elastic and rupture moduli of limestones which most laboratory tests generally ignore.

SUMMARY

By application of knowledge gained in mining it is possible to explain the causes of cavern breakdown based on the following:

1. The rock strata over the cavern act as uniformly loaded beams, either fixed or cantilever.

2. The beams sag under their own weight to a point where failure takes place.

3. The critical time in development of breakdown is the point at which a fixed beam sags and separates into cantilevers. If the cantilevers are developed in nearly equal proportions across the passage it will generally stand; if it is unequally developed, collapse will take place along the longer segment of the cantilever.

4. The relation of beam thickness to length, as well as the sag causing failure, can be approximated by applying the engineering formulae developed for ordinary structural beams.

Block breakdown resulting from the failure of a tension dome, Laurel Creek Cave, W. Va.

Slab breakdown resulting from the failure of a group of cantilevers, Poorfarm Cave, W. Va.

Sag in cantilever beams directly over a breakdown, Poorfarm Cave, W. Va.

1½ inch sag in cantilevers, Poorfarm Cave, W. Va. Vertical joints separate the rock beams into cantilevers of various lengths.

Arrangement of blocks within a fallen mass of block breakdown, Poorfarm Cave, W. Va.

IDYLL OF THE ENNESSBEE

Where

North thru Adirondacks sweeping,
Winds Route 9, a silver trace,
Past blue lakes, green meadows sleeping,
Emblems of this region's grace.

Saratoga scenes left lately,
With the past that name recalls;
Crossing Hudson here still stately,
At the city of Glens Falls.

Then Lake George in lovely setting,
Warr'nsburg, Chestertown, the hill,
'Round or over it we're getting
Ere we come to Pottersville.

Pottersville, for us the locus,
On this highway of renown,
Of our interests which focus
Just outside this little town.

Here, in bronze, 'mongst names of other
Boys long gone to final rest,
Note that mid-name, Neubuck, brother
Of the Lydia we love best.

To

North and left we leave this highway
On a road, by court'sy called,
When 'twas nothing but a byway
For the visitors it galled.

Visitors to what? they'd wonder
As they first essayed this trek,
With their bones half-shook asunder
And their car approaching wreck.

Here we hasten to belie you:
Gone's that byword of the past;
Now that league-long stretch won't try you,
Safe and smooth from first to last!

From the east this road comes crawling;
Northward rears the mountain ridge;
West and south the brook goes brawling;
'Neath us, quiet, and the Bridge.

How is styled this site so sightly?
What occasions these conclaves?
Both these queries answer rightly:
NATURAL STONE BRIDGE AND CAVES!

On

'Frieda, Donald, David, Janet;
Mother, sister, brothers twain;
All help do the job and plan it;
Lydia Linda's loyal train.

Dwelling house and tourist cabin,
Lydia's cabin near the bluff;
Ticket—, gift-shop for her gabbin',
And the libr'y, that's enough!

With a shop-garage for Jessie,
And a bin for storing ice,
When the weather gets quite messy,
And for use, when warm and nice.

Westward of these structures listed,
Piney grove, with mingled birch,
Air like wine, and ofttimes misted;
Finer campsite, useless search!

Nodding treetops, stars atwinkled,
  Sharp-etched dark or glistening boles;
Balsam scented, needle sprinkled,
  Springy carpet 'neath bed rolls.

Down

From atop the Bridge we wander
  Down the rustic zigzag stair;
More we see, the more we're fonder
  Of this paradise so fair.

Down, past cave mouths wide or hidden,
  Yawning chasms, devil's slide,
Jutting ledges, tendril-ridden,
  Roots of greenery topside.

To the gorge, a water channel
  Only when spring freshets rise;
For the rest, a brilliant panel
  Of wild beauty 'fore our eyes.

Canyon walls, steep Bridge rock facing,
  With Her cabin on the crest,
Hillside sheer, trees interlacing,
  Towering high, in green full-dressed.

Noisy Cave, its name well suited,
  Torrents tumbling thru pell-mell;
Potholes, Whirlpool, convoluted;
  Also here, Jen's Wishing-Well.

Under

Round a corner looms the arching
  Outline of the Bridge at last,
Varicolored brilliance marching
  In gradations shadow-cast.

In this cavern jaw's a socket
  Twisting up forked like a tooth,
Barrel Cave, so's named this pocket,
  Cave within a cave, forsooth.

'Neath the green-fringed campgrove covering
  Merging down in rock rimmed arc,
Dancing sunlit waters hovering
  Ere enveloped in the dark.

Flotsam jams this darksome tunnel;
  Half-submerged logs interlock;
Ceiling low'ring like a funnel,
  Fathoms deep ere half a block.

Then, thru siphoned mystery coursing,
  Part emerges far downstream;
Other water portions forcing
  Channelled passages abeam.

From

Gorge and Bridge-end merge together:
  Lost Pool, Echo, Garnet Caves;
Flooded depths, mouths op'n to weather;
  Over this, the tourist raves!

Cave, a lengthy half-filled boring,
  Limpid stream in gradual flow;
Heard, a gentle rhythmic snoring;
  Seen, an eerie amber glow.

Garnet Cave, its mouth smooth rounded,
  Metamorphosed shelving rock;
Thus, a wide deep pool is bounded;
  Here the bathers really flock!

Downstream, waters reunited,
  Fairyland now left behind;
To this spot our troth is plighted;
  Surely here hath God been kind!

Silhouetted 'gainst the skyline,
  Lydia's cabin seems to me
Castle of the radiant fraülein
  Of the Caves of ENNESSBEE.

JAY ESPEE

The Cave Salamanders of California

By JOHN W. FUNKHOUSER

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Among the most interesting of the relatively few creatures which inhabit caves the salamander is probably one of the most thoroughly studied. Thus the life history of this animal is contributing an important phase to our still limited knowledge of the fauna of caves.

Organisms which are fitted to life in total darkness frequently specialize into bizaare forms which are no less fascinating in their relationships to their environment than in their unusual morphology. This is especially true of cave dwelling animals, among which various salamanders adapted to a subterranean existence are of particular interest. Some salamanders are so specifically fitted to caves that presumably they could exist nowhere else, while still others occupy caves merely as one of several suitable habitats.

The true cavernicolous salamanders are highly specialized to fit an underground environment. They are colorless and sightless. There are four such salamanders in North America, three of which are permanently larval in form. These are *Haideotriton wallacei, Typhlomolge rathbuni, Typhlotriton spelaeus*, and *T. nereus*. An additional genus is known from Europe.

Haideotriton, the Georgia blind salamander known only from a single specimen recovered from a well, and *Typhlomolge*, the Texas cave salamander, have quite degenerate eyes, no pigment, and are permanently larval. *Typhlotriton spelaeus* and *T. nereus* inhabit caves and underground streams in the Ozark Plateau. The adults of both have degenerate eyes and are almost colorless, but their larvae, which frequently occur in surface waters, possess both eyes and pigment. These larvae enter caves at a critical point in their development, at which time there is a rudimentation of their eyes and a loss of pigment. (Interestingly, Noble (1931: 34, 94) has shown that *Typhlotriton spelaeus* will retain functional eyes and pigment if kept in the light.) After its entrance into caves, *T. spelaeus* loses its gills and metamorphoses into a terrestrial adult. *Typhlotriton nereus*, however, retains its gills and remains permanently aquatic. Almost nothing is known about the ecology, the breeding habits, or the life histories of any of these remarkable animals.

Aside from these highly specialized cavernicolous species, there are other salamanders which show no visible modifications for a subterranean life, but which spend most or all of their lives in caves. These are generally termed *crepuscular*, or *twilight-zone*, species, even though they are frequently found well within the zone of total darkness. Some members of the genus *Eurycea*, for example, found in certain sections of the eastern and central United States, are of this type. Another example is *Plethodon dixi*, which occurs in a limited area of the southern Shenandoah Valley, Virginia.

In addition, there are *visitant* species which, though usually found in non-cave habitats, occasionally enter caves when the opportunity presents itself.

Such a series, from visitant to cavernicolous species, probably represents the progressive steps in the colonization of caves by salamanders. The exact mechanism in the production of such bizarre forms as the cavernicolous species is not yet well understood. Though it appears to be largely governed by evolution and genetics, there is evidence to show that the physiological reaction of the individual animal to its environment plays some part. This is evident in the eye degeneration and pigment loss of *Typhlotriton spelaeus* and *T. nereus*. It should be borne in mind, however, that the ability to effect such changes must be hereditary.

That time and environmental stability are important would be indicated by the fact that all cavernicolous species so far known come from areas long geologically stable, where there are great expanses of limestone containing extensive subsurface water systems. Also there is a seeming correlation with Pleistocene glaciation inasmuch as the forms most highly specialized are the farthest removed from the scene of glaciation, while in the great cave systems of the Ohio Valley region, which were directly influenced by glaciation, colonization has gone no farther than crepuscular species (Eigenmann, 1909: 17). This may be another indication that time is an important factor and that cavernicolous species probably began evolving toward their present specialization not later than the time of the last glaciation.

In the caves of California, colonization has just begun; and those salamanders which have been observed or collected in California caves are visitant surface forms. For various reasons this would be expected. The West Coast, unlike Southeastern United States, has not been a great center of dispersal for salamanders. Its present species and genera have been derived from stocks which originated in other places. For example, the largest salamander family, Plethodontidae, which includes many California forms, had its center of distribution in the Southern Appalachians.

Perhaps the main reason why this situation exists in California is that the West Coast has not been, nor is it yet, geologically stable. The climate is another limiting factor, being wet in winter and dry in summer, with many areas showing varying degrees of aridity. Where salamanders do exist, their breeding cycles must be synchronized with a relatively short winter rainy season, or to the brief period each spring when melting snows in the higher altitudes furnish moisture. Their larval development must be completed in time for the young adult to seek out a suitable spot in which to estivate during the long dry period.

With the climate tending to become even dryer, as is indicated by distributional patterns of many plants and animals and by geologic evidence, many areas which formerly provided salamander habitats are no longer suitable. Man has also been responsible by appreciably lowering the water table over large areas, thus depriving salamanders of sufficient ground moisture for their estivation.

With the specific reference to California caves, it should further be borne in mind that (1) there are no limestone areas in the state as great as those in the eastern United States; (2) the caves are relatively young—or at least have been subjected to the above-mentioned recent geologic changes; and (3) the largest cave areas where climate permits salamanders to exist were influenced by Pleistocene glaciation.

Estivation appears to be the most important single factor leading salamanders into caves. The moist cave atmosphere provides an ideal retreat during the dry season. In non-cave areas these animals must estivate in animal burrows, mud cracks, or any other available crevice offering adequate moisture. On the other hand, some salamanders choose a cave habitat even though estivation is not necessary. *Ensatina eschscholtzii platensis* has been noted to show such a preference.

The following is a list of salamander species so far noted in California caves:

COASTAL REGION
- Santa Cruz Area:
  - *Dicamptodon ensatus* (larval)

SIERRA NEVADA REGION
- Sequoia National Park Area
  - *Ensatina eschscholtzii platensis**
  - *Batrachoseps attenuatus ssp.**
- Mother Lode Area
  - *Ensatina eschscholtzii zanthoptica**
  - *Aneides lugubris lugubris**
  - *Triturus sierrae*

NORTHERN CALIFORNIA
- Shasta Area
  - *Hydromantes sp.**

Most of these species belong to the family Plethodontidae, as indicated by asterisks in the above list. It is to this family that the various North American cavernicolous and crepuscular species belong. All Plethodontid salamanders are lungless and absorb oxygen through their moist skins. They therefore require even more moisture than most other types of salamanders. Consequently, they find caves an ideal habitat.

The single larval specimen of *Dicamptodon ensatus* was collected in Empire Cave. Since the body of water in which it was taken communicated with the outside, it is not likely that it developed from an egg laid in the cave. Probably it swam or was washed in.

It will be noted that most of the records come from the Sierra Nevada region, with but a single specimen from the Coast Range. This pattern might be expected because of the larger number of caves in the former region.

The paucity of records from the Shasta area arises from the fact that there has been little work done there during the spring, when salamanders are most readily observed. My information on *Hydromantes* in that area comes from Joseph Gorman of the University of California, who is presently engaged in studying the ecology and taxonomic status of this animal.

Recent discoveries of salamanders in caves have contributed to the general knowledge of the group. The first salamanders which the Stanford Grotto of the National Speleological Society collected in a cave were two specimens of *Ensatina eschscholtzii xanthoptica* from the Cave City Cave, located near San Andreas, Calaveras County, California. Stebbins (1949: 415, 449, 450) had recently revised the genus Ensatina, making it a complex of seven subspecies, all under the species *eschscholtzii*. His subspecies, *xanthoptica*, has as its main range the Inner Coast Range of California, between the great Central Valley and San Francisco Bay, from east-central Sonoma County on the north to northern Santa Clara County on the south.

This subspecies appears, in the recent geologic past, to have crossed the Central Valley, which now is not a suitable habitat for *Ensatina*, and to have established itself on the lower western foothills of the Sierra Nevada in the territory of *Ensatina eschscholtzii platensis*, with which it has begun to interbreed. Stebbins based this remarkable distribution pattern on only two locality records: a supposedly reliable sight record from the Berkeley Tuolumne Camp, Tuolumne County; and a collection from Jawbone Ridge, Tuolumne County. Another specimen, possibly of this subspecies, taken at Bear Valley, Mariposa County, California, was loaned to Stebbins by Sherman C. Bishop.

These facts explain the interest in the record from Cave City Cave, which extended the range some forty miles beyond the most northerly Tuolumne County record, substantiating the occurrence of *xanthoptica* in the Sierra region and suggesting that its range in this region is more extensive than hitherto suspected (Funkhouser, 1950).

Subsequently, members of the Stanford Grotto established another record for *xanthoptica* at Wendler Cave, Calaveras County, which falls roughly on a line between the Jawbone Ridge locality and Cave City.

An interesting bit of history is connected with the previously mentioned, *Ensatina eschscholtzii platensis*. In 1875, Jimenez de la Espada described a new species of salamander as *Urotropsis platensis*, naming it for the Rio de la Plata, Uruguay. This specimen was turned over to him with a collection of reptiles from the vicinity of Montevideo. To judge from Espada's description and his figure of the specimen—both of which are excellent—*Urotropsis platensis* is identical with the above California salamander.

Except in the Andean region, from Bolivia northward, salamanders are almost unknown in South America; and from this area only the genus *Oedipus* occurs. The genus *Ensatina* has been recorded only from the West Coast of the United States and the very southernmost tip of British Columbia; and it seems exceedingly strange that something identical with one of the California forms should occur in Uruguay. Furthermore, no more specimens have turned up in South America.

According to Espada's own account, it does not appear that his specimen was separately labeled when he received it, and the donor died before inquiries about it could be made. Considering these facts, it has been postulated that the type specimen of *Urotropis platensis* actually was collected in California.

This is not as improbable as it might seem. Espada's description was published only twenty-five years after the discovery of gold in California, which precipitated the great Gold Rush and brought people from all parts of the world into the territory inhabited by the salamander we know as *Ensatina eschscholtzii platensis*. Since these animals are striking in their appearance, being jet black with bright vermillion spots, it is quite conceivable that someone preserved one—possibly in a bottle of whiskey—and that it found its way to Uruguay, as suggested by Myers and Carvalho (1945: 1-5). This explanation has been generally accepted by herpetologists.

In accordance with the International Rules of Zoological Nomenclature, the oldest name given to an animal has priority. The generic name, *Ensatina*, had been established before Espada's description, but the specific name, *platensis*, (now placed in subspecific status) was older and therefore had priority over the more appropriate name, *sierrae*, which had been applied to these animals.

A short time ago members of the Stanford Grotto came across what is probably the first record of a California cave salamander. It is recorded in the unpublished journal of Isaac W. Baker, who visited California during the Gold Rush. In the summer of 1853 he explored a cave, now known as the Cave of Skulls, near Vallecito. His description of the cave includes the following passage: "There was a living inhabitant of this dark abode, red as vermillion and rather spiteful at first—tame enough at present." A sketch of a bottle of spirits containing the salamander is included at the margin of his journal.

Mr. Baker's journal proves, if nothing else, that at least one person who took part in the Gold Rush did preserve a salamander. Though I have not been able to ascertain how Mr. Baker returned to his home in Massachusetts after that summer in California, nor what he did with his salamander, I am satisfied that his specimen was an *Ensatina*. No other salamander which occurs in that area fits his description. This first cave record could be Espada's specimen!

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Report on the Mineralogy of New River Cave

By JOHN W. MURRAY

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All photos by the author

This report from the Committee on Formation and Mineralogy of the V.P.I. Grotto, submitted by its Chairman, excellently portrays the importance of speleological research. All members of regular grottoes of the N.S.S., and members of student grottoes in particular, should realize after reading this article, that any number of scientific projects could be undertaken to add to our much-needed knowledge of literally hundreds of caves which have been "seen" but which have not yet been "studied."

GENERAL DESCRIPTION OF CAVE

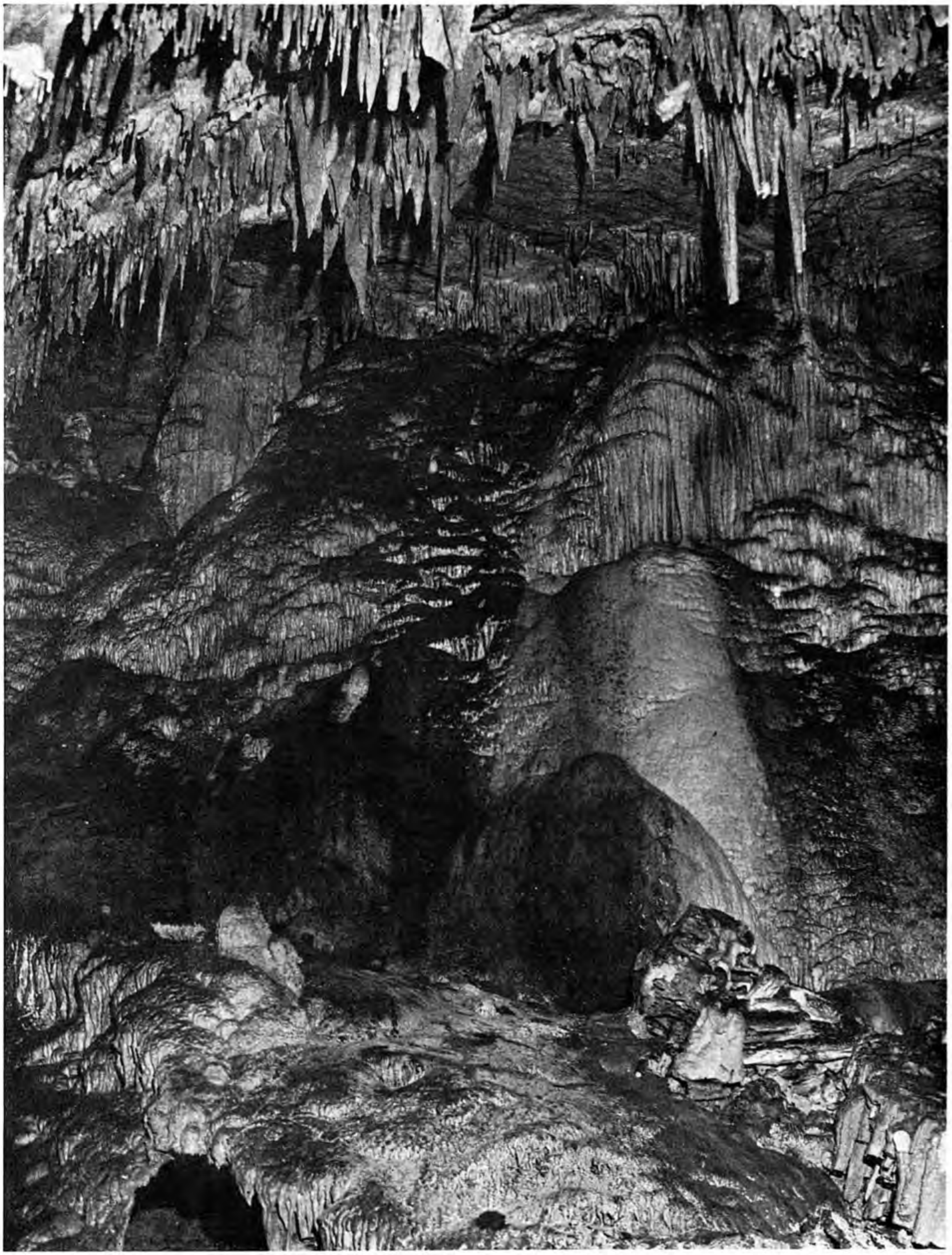
New River Cave—also called Goodwins Ferry Cave and, rarely, Spruce Run Cave, is located near Goodwins Ferry, Giles County, Virginia at Lat. 37°16′ 02″ N and Long. 80°36′00″ W. It is at the south end of Spruce Run Mountain where the New River, flowing northwest, separates that mountain from Buckeye Mountain. The entrance slopes downward slightly and enters the mountain at an elevation of 2015 feet above sea level or about 235 feet above the road through the gorge. These elevations are based on barometric measurements made by Holden, Price and Stephenson on Sept. 6, 1942. The cave is the subject of a paper in the Journal of Geology, Vol. 55, page 107-119, 1947, by E. L. Krinitzsky who did graduate work in geology at Virginia Polytechnic Institute. The geologic data in the following paragraph is based on this paper.

The Cave is developed along the Saltville Fault which has been traced for 200 miles from Craig County, Virginia, into Tennessee. The fault is an over-thrust which brought the Lower Cambrian Honaker Dolomite northwestward over the younger Ordovician and Silurian beds. A lesser fault has brought a sliver of the Ordovician Benbolt Limestone between the younger beds and the Honaker. The faulting has overturned the Benbolt and Honaker and the fault plane dips to the southeast at an angle of about 53 degrees. The cave is developed in the Benbolt limestone with the Honaker dolomite forming the roof which is inclined 53 degrees from the horizontal. The cave has been enlarged upward into the dolomite by downfall of blocks from the roof. Krinitzsky believes that the Juniata shale holds a perched water table in the more porous Clinch which feeds the stream in the cave.

The cave runs into the mountain, which is a long ridge, parallel to the axis of the ridge. It has been explored for nearly 3000 feet. Passages are developed on about four levels, the lowest of which is now occupied by a stream which reaches the surface in two springs on the end of the mountain, as demonstrated by fluorescein tests. The stream passage has been followed nearly to the point where it emerges as the upper spring. Most of the cave is now dead but water enters the cave in several places and deposits seem to be growing in the main passage within a few hundred feet of the entrance, in the vicinity of the Attic Room and Forest Room and along part of the lowest level. Dissolving of limestone seems to be taking place locally in the last two areas. Water enters the cave in quantity in at least three places. One of these is in the Attic room which is the highest part of the cave. Here extensive breakdown of the roof has occurred leaving piles of very large blocks. Back in the newer part of the cave, a waterfall some forty feet or more in height is found. The water from this source is less in volume than the stream which it joins. This waterfall is about 2400 feet from the cave entrance. A smaller waterfall of about 8 or 10 feet is found in the same stream as the big one a little above it. The main stream has been followed for about 600 feet beyond the point where the waterfall drops into it.

FORMATIONS

A great variety of formations is found in New River Cave. Almost all of it is in the first



Flowstone cascades in main passage of New River Cave. The surface is covered in places with a black coating. A small grotto is seen in the lower left corner probably caused by shrinkage or washing out of the mud bank on which the flowstone was deposited.

third of the part which is now known. Gypsum is found as an incrustation of crystals up to about a centimeter in length on the walls of a room upstream from the waterfall. This is called the Gypsum Room. This is the only part of the cave in which gypsum has been found. The deposit is dry and rather dirty looking.

Anthodites growing on calcite stalactites in the Attic Room of New River Cave.

The area above the waterfall contains a maze of passages containing a great deal of broken rock and mud. The rocks and mud are coated in places with a black surface layer which has been tested chemically and found to contain manganese. It is probably colored by an oxide of manganese.

The part of the cave near the entrance contains formations of calcite and aragonite in nearly equal abundance. The main passage near the entrance contains several spacious rooms well decorated with formations. One of these rooms is about a hundred feet in height and contains some large columns. The lower wall of this room is a tremendous mass of flowstone resembling a frozen waterfall but having a black surface coating. The Attic Room and the Forest Room which are located in the upper passages of the cave are also well decorated as is a limited part of the lowest level near the stream. The Forest Room is the prize formation exhibit of the cave. Stalactites and stalagmites of both calcite and aragonite are found in all of these areas. Often both minerals are found in the same deposit in alternating layers. Curtains, bacon and elephant ear stalactites are developed in several places. Flowstone sheets have been laid down on mud banks in the main passage. In some instances the mud has shrunk or been washed out leaving small passages under the sheet.

Anthodites of aragonite are found in the Forest Room, the Attic Room and in the main passage. Most of this material is dead and brownish but some live deposits which are pure white are found in and near the Attic Room. In a lateral branch of the main passage, the anthodites seem to grade over or to be replaced by an incrustation of small aragonite crystals. On some of the anthodites, small stalactites of aragonite are pendant from the ends of the anthodite spurs which suggests that an increase in the rate

Stalactites encrusted with anthodites, New River Cave.

Helictites and anthodites on ceiling of Attic Room in New River Cave.

of feed of water to the formation has occurred. These pendant stalactites have a rather coarse structure of needle like crystals radiating downward and outward from the axis. In some cases, anthodites are found growing from the sides or ends of calcite stalactites.

In close proximity to anthodites in the main passage and in the Attic Room, vermiform helictites of calcite are found. These have their greatest development on the ceiling of the passage northeast of the Attic Room where medusa-like groups, perhaps eight inches in length, are found. Vermiform helictites of aragonite are found in the stream passage. These are thinner than the calcite helictites, some of them being only about a millimeter in diameter. The calcite helictites have rather soft texture and are friable.

Flowstone pools are found in the main passage as well as in the Attic Room and the Forest Room. Most of these are formed of calcite and contain calcite cave coral. A part of the main passage was formerly dammed to form an extensive pool. Old water levels are evident on the walls. Below the old water level the walls are lined with masses of a rounded grape-like deposit. A somewhat similar but more jagged deposit is found in some of the active pools in the upper part of the cave. Some of the pools contain a lining of small but well crystallized dog-tooth spur. A dried up pool at the bottom of the Forest Room is covered on the bottom with a friable scaly mass containing calcite and aragonite. The walls have remnants of horizontal sheets of calcite adhering in places which appear to have been crusts formed on the surface of the pool. The upper surface of the crusts is finely granular while the lower surface is studded with rhombic calcite crystals. The lower part of the walls of this pool is encrusted with rounded coral knobs with a radiating structure. These contain both calcite and aragonite.

Cave pearls of aragonite coated on siliceous pebbles are found on ledges in the stream passage. The outer coating is very fine grained and the pearls vary in size up to about an inch in diameter.

Temperature measurements have been taken at numerous points in the cave both in air and in water. The results are given below. All readings are degrees Centigrade.

AIR AND WATER TEMPERATURES, IN DEGREES CENTIGRADE, AT SELECTED STATIONS IN NEW RIVER CAVE, GILES COUNTY, VIRGINIA

STATION	DATE									
	8-5-45		9-14-45		1-27-46		3-31-46		2-25-51	
	Air	Water	Air	Water	Air	Water	Air	Water	Air	Water
Outside of cave	–	–	–	–	−5.0	–	–	–	–	–
Attic Room, south end	+12.6	+11.4	+11.8	+11.4	+11.5	+11.0	+11.8	+11.4	+11.9	+11.6
Attic Room, north end	–	–	+11.6	+11.5	–	–	+11.5	–	–	–
Forest Room	–	–	–	–	+11.5	–	–	–	–	–
Crack below Attic Room	–	–	–	–	–	–	+12.6	–	–	–
Winter Forest Room, off main passage about 450′ from entrance	–	–	–	–	–	–	–	–	+6.9	–
Main passage, about 50′ from entrance	–	–	–	–	−2.5	–	–	–	–	–
Main passage, about 600′ from entrance	–	–	–	–	+5.5	–	–	–	–	–
Lunch Room, about 1000′ from entrance	–	–	–	–	+8.8	–	–	–	–	–
Stream at bottom of china slide	–	+12.2	–	–	–	–	–	+12.7	–	–
Stream below Lunch Room	–	–	–	–	+9.0	+11.5	–	–	+10.6	+12.0

Measurements of relative humidity were made by the V. P. I. Grotto using a Hygrothermograph. If and when these data are organized, a supplement to this report will be submitted on this topic.

Samples of water have been taken from a variety of locations in the cave representing the main stream, dripping water and pools in flowstone. About 27 samples in all have been examined. The analyses ranged from single determinations of pH to determinations of all eight of the quantities listed in the table below. Due to the difficulty of obtaining some of the samples such as dripping water, and the difficulty of transporting large samples, most of the determinations were made on a micro scale sometimes by methods specially developed or adapted for the problem. Some of the results are not very consistent and the results tabulated below represent only a few of the more complete analyses. They will suffice to show the general character of the water in the cave and its variation from one situation to another.

It is hoped that when sufficient data of adequate precision is accumulated, the reasons for some of the changes in the form of deposits in caves will become apparent.

COMPOSITION OF WATER IN NEW RIVER CAVE, GILES COUNTY, VIRGINIA

All concentrations are expressed as parts per million.

No.	Source	Temp. °C.	pH	Alkalinity ($CaCO_3$)	Free CO_2	Cl−	SO_4=	Ca++	Mg++	Total Solids
34	Main Stream 3/31/46	12.7	7.5	90	—	0.4	—	24	11	110
53	Main Stream 2/25/51	12.0	8.1	63	1.1	1.2	—	17	6	60
51	Drip from Calcite flowstone sheet	6.5	8.0	230	3.3	2	15	46	30	—
29	Drip from ceiling Attic Rm. 3/31/46	11.8	7.5	122	—	1.3	27	28	23	165
52	Drip from ceiling Winter Forest Rm.	6.6	7.7	358	8	1.5	15	65	50	295
33	Drip from aragonite stalactite	12.6	7.7	134	—	—	38	27	40	—
54	Pool in Attic Rm. below drip of sample 29 8/19/51	11.3	7.8	134	1.5	—	17	18	25	156

Report on the Titus Canyon Expedition

By RICHARD F. LOGAN

Department of Geography, University of California, Los Angeles

This thrilling account of one experience of a large expedition organized by the Southern California Grotto of the National Speleological Society highlights the adventure and important scientific work which awaits speleologists with similar quests in view. It was originally submitted as a report to the National Park Service. The fifty-seven persons who took part in the exploration here described have each contributed to our growing knowledge of the treasures which exist underground.

During the Thanksgiving weekend of 1950, the Southern California Grotto of the National Speleological Society cooperated with the National Park Service in the opening and exploration of an extraordinary cave in Titus Canyon, Death Valley National Monument.

The cave is located on the west wall of the valley, at the north end of the abandoned town of Leadfield, and near the east entrance to Titus Canyon.

Lead and silver ore had been discovered in the area as early as 1905, when Barney McCann and Seaman filed a dozen claims (1). Some ore was sorted, but it proved to be too low-grade to warrant packing out of the valley. There was no road at the time.

During March of 1924, Ben Chambers and F. J. Metz located sixteen claims which were taken over in July of the following year by the Western Lead Mines Company. At a cost of $60,000 a road was literally carved out of the mountains, permitting access from the older mining centers of Rhyolite and Beatty, just over the line in Nevada; and the town of Leadfield sprang into existence.

It was essentially a waterless town. A spring of sorts a quarter-mile east provided some water, but most of the camp supply had to be hauled up a nine-hundred foot rise from a spring (Klare Spring) two miles down canyon. And so it was not surprising that, when the mining boom collapsed the following year (thanks to watering of stock and the lack of ore), the place became a ghost town.

During the 1925-26 operations, one of the "March Storm" group of mines on the west wall of the valley intercepted a cave two hundred feet from its entrance. After the demise of the town professional mineral collectors had raided the cave, removing large quantities of specimens from its walls and ceiling. The area came under the jurisdiction of the National Park Service at the time of the creation of Death Valley National Monument, in 1933. In 1940, in order to halt the vandalism and to protect unwary wanderers, the mine and cave were sealed off with masonry by Park Service employees.

Early on the morning of the day after Thanksgiving, 1950, two parties [1] of members of the National Speleological Society attempted an exploration of the cave. It was found that the mine had two horizontal tunnels, one a hundred feet above the other. Stan Kahan of Los Angeles City College led a party into the upper mine-tunnel (formerly known as the "Clark" or "Number One" tunnel), and found that it contacted the cave about one hundred feet inside the entrance. Climbing down two short lengths of old ladder they reached the top of a steep slope. Roping down it they emerged in the lower tunnel in the midst of the second party of cave explorers.

From here on, the second party, headed by Al Hildinger, also of Los Angeles City College, took the lead. Equipped with ropes, wire-rope ladders, carbide lamps and other equipment, they made the descent of the cave shaft that dropped steeply from the floor of the lower

[1] ORGANIZATION OF EXPEDITION: *Leader* — Dr. Richard F. Logan, University of California, Los Angeles. *Exploration*—Stan Kahan, Los Angeles City College; Al Hildinger, Los Angeles City College. *Radio*—Walter Chamberlin, Pasadena, Calif.; Ed Simmons, Pasadena, Calif. *Transportation*—Lillian Casler, Pasadena, Calif. *Finances*—Dorothy Chamberlin, Pasadena, Calif. *Door Construction*—William Brown, Pasadena, Calif.; Donald Emerson, Monrovia, Calif.

tunnel. The main part of the cave lay entirely below the level of this tunnel (formerly known as the "Staunton" or "Number Two" tunnel). Nearly fifty persons made the trip through the cavern in the next twenty-four hours over the route they scouted.

By means of a wire-rope ladder secured to a ring bolt in the ceiling of the mine tunnel they made the descent of a 60° shaft to a crude platform apparently erected by the miners some fifty feet below the tunnel. Ducking under the platform spelunkers emerged into a slot elongated at the same 60° angle about fifteen feet in height, and about three feet wide. Sidling along this visitors belly-crawled through a narrow throat scarcely larger than a person's body and emerged into a larger room. Down a steep, mud-covered slope beyond footholds had been chopped enabling an easy descent.

Up to this point the cave had been uninteresting—a mud-floored aperture in solid rock. But suddenly, in descending the footholds in the muddy slope, one entered a "Winter Wonderland!" On all sides the rays from the headlamps disclosed great areas of walls coated with crystals sparkling in pristine whiteness. Everywhere that one looked pin-points of light shone back from great banks of "snow" seemingly drifted into every nook and cranny of the cave. Inspection showed them to be radiating crystals of aragonite often attached to the wall by merely a single thin-shafted needle. Many were so fine and sharp that they penetrated the skin of unwary spelunkers who unwittingly leaned against them causing irritation similar to that resulting from the careless handling of rock-wool insulation.

At the foot of the steep slope the cave opened up into a series of interconnecting chambers up to thirty feet in length and fifteen feet in width with ceilings ten feet above the floor. Everywhere their walls and ceilings were radiant with clear white crystals.

Despite the frosty appearance the heat and humidity were oppressive. The temperature was 70° with a relative humidity of 96%. The exertion of climbing, crawling, and squeezing through narrow passages made one perspire freely. In the humid air perspiration would not evaporate but remained annoyingly on the skin. Even the walls seemed to perspire for on the ends of many of the crystals tiny droplets of moisture glistened.

Most of the usual cave formations were absent. Only in one place were good developments of stalactites, stalagmites, flowstone and drapery found. The stumps of a few others marked specimens removed by collectors before the sealing of the cave. Apparently this lack of normal formations is the result of the absence of running water or even of dripping water since the excavation of the cavern ceased.

The cave itself seems to have been formed in the usual manner by the solution of limestone by ground water. The solution took place along beds of the dark-gray, medium-grained Pogonip limestone (2) which occurs in a long north-south belt through the Grapevine mountains, as well as at other scattered locations in the general area east of Death Valley. Here the steeply-folded beds dip northward at an angle of 60°. In some places a bed was entirely removed by solution leaving a slot the thickness of the bed. Of such origin was the slot just beyond the miner's platform. Elsewhere, stream erosion had, by abrasion, cut through intervening beds of less-soluble material, making a narrow, twisting throat like that of the belly-crawl passage.

In conjunction with the folding of the beds there appears to have been some slipping along the bedding planes resulting in faulting parallel to the bedding. This was indicated by the presence of fault gouge at several places in the tunnel walls.

Since there is insufficient groundwater in the area today to accomplish (even over a very long period) the removal in solution of enough limestone to form the cave, it seems likely that it was formed during the Pleistocene. That period, synonomous with the Ice Age of more poleward and more humid areas, was one of heavier rainfall in the western deserts. Many of the present arid basins were partially occupied by lakes in whose waters lived clams and fish. Death Valley itself was partly inundated by the waters of "Lake Manly".

Following the termination of the rainy Pleistocene the amount of ground water diminished to the present state of aridity. Consequently the bulk of the existing formations (stalactites and the like) were probably formed during the period of excavation; although at especially-favored locations, where strong jointing admits a weak flow of seepage, growth of such formations still continues in a limited manner.

In place of the usual formations the bundles of needle-like aragonite crystals have developed. To their appearance, two similar-sounding terms may be applied: "fascicular", (from Latin, *fasces*, a bundle of rods) to their collective radiating growth habit; and "acicular" (from Latin, *acus*, needle) in reference to their individual shapes. In most cases both terms are applicable.

The development of the crystals may possibly be related to the closed (pre-1925, post-1940) nature of the cavern and the high humidities that prevail therein. Being located in a middle-latitude desert environment the outside atmosphere experiences great seasonal variations in temperature. Average daily temperatures in mid-summer approach 110°; in mid-winter, 50°. Some of this great seasonal variation must be felt within as shallow-depth a cavity as this one. With relative humidity in the middle-nineties only a slight drop thermally would produce a saturated condition within the cave resulting in condensation on the walls. Such condensed droplets might accomplish a minute amount of solution of the limestone. With a return of higher temperatures and a consequent reduction in the relative humidity the droplet would be re-evaporated leaving the dissolved matter behind in the crystalline form. At the time of the visit droplets were visible everywhere, at all positions on the existing crystals, including some points that it would have been impossible for seepage water to reach. Most of the few stalactites had their surfaces bristling with fascicles of aragonite crystals.

As was to be expected from a cave that had been long sealed no evidence of animal life was found. On the other hand a most remarkable type of plant life was seen. The first 60° shaft in the cave did not end at the miners' platform but continued downward to dead-end a short distance below. Into the small chamber at the end a mining timber had fallen from above and rested against the wall. The timber was half-encased in a grey-white mold and long "stalactites" of the mold hung pendulously from it, one swelling bulbously at the lower extremity, others merging to form a "drapery" of mold.

Since nothing of any significance or beauty lay above the lower tunnel it was decided to re-cement the entrance to the upper shaft in a fixed and permanent manner. In order to control access to the entrance to the lower tunnel members of the Grotto erected a metal door on the entrance and locked it with a padlock supplied by the Park Service.

The Southern California Grotto was greatly pleased by the friendly cooperation of the members of the National Park Service staff with whom they came in contact. Superintendent T. R. Goodwin made possible the entire undertaking by his interest and understanding in the early stages of negotiations between the Grotto and the Park Service. Park Naturalist L. Floyd Keller, Chief Ranger E. E. Ogston, and Ranger Lewis Kirk demonstrated the keen active interest of the Service in the work at the cave by making the long journey to the area and carefully exploring the cave with members of the Grotto.

There is no question concerning the unique features of the cave. Its display of aragonite crystals is unsurpassed in the United States, if not in the world. The "normal" formations—stalactites, stalagmites, flowstone, drapery—are not spectacular but are present in sufficient amounts to be of use for demonstration purposes. To anyone interested in speleology, mineralogy, geology or just plain beauty the cave has great attraction.

However, serious thought should be given to both sides of the question before any decision is made to open the cave to the general public. The crystals (the most attractive part of the cave) are fragile and easily destroyed; and also are subject to easy removal from the cave. For this reason no group should be allowed in the cave without proper supervision. This is especially the case with mineral-collecting societies.

For several reasons there is considerable doubt as to whether opening the cave to the public would be worthwhile. They are:

(A) the cave would have to have a large amount of work done in it to make it accessible:

1. A stairway from the miners' platform to the tunnel is a necessity.

2. The passage from the miners' platform

to the 60" slot should be enlarged.

3. The belly-crawl passage would have to be greatly enlarged. This would have to be an all-hand operation since blasting so close to the main center of interest might have a damaging effect on the crystals.

4. A long stairway and ramp down the mud-covered passage to the lower chambers would have to be constructed. Such stairways and ramps would have to be of metal to prevent the growth of organisms on them as has occurred on the mining timber mentioned above.

(B) it would be best to have the cave floodlighted in order to bring out the best effects of the mineral display. However, this is not a vital necessity, and the public might enjoy the novelty of wearing electric miners' headlamps.

(C) it would be imperative that a National Park Service representative be on duty all of the time that the cave is open and that he accompany all parties through the cave to prevent vandalism. Whether such expense would be justified is doubted in view of the small number of persons who would visit the cave due to the condition of the road.

In lieu of general public admittance to the cave it is suggested that the following policy be adhered to:

(A) That the cave be kept locked at all times;

(B) That a sign be placed there indicating that the National Park Service has jurisdiction over it. Since there is no sign indicating the point at which the Monument boundary is crossed on the road in, some members of the public might not be aware that it lies within the monument; and even if such a boundary sign is placed the cave-jurisdiction sign should still be set in place.

(C) That access be made readily available to reputable societies or groups. In most cases a ranger should be on duty with the group throughout the time they are in the cave. Certain organizations such as the Sierra Club would require no such supervision owing to their high standards for membership. Others such as mineral-collecting groups should be carefully supervised for obvious reasons.

(D) That on certain occasions a "tour" might be run with a cavalcade of cars organized at Furnace Creek, the drivers properly advised of road conditions beforehand, and the whole trip in charge of a ranger or ranger-naturalist. So that the interested segment of the public could be notified such tours might be announced well in advance through the press, and more especially through such publications as "Desert Magazine". Persons inquiring about entry as a result of the sign at the cave entrance then could be notified regarding the next date of a public tour.

(E) To provide lighting the National Park Service might purchase a number of miners' lamps to be rented to the public on such occasions. Such tours would, of course, necessitate belly-crawling; and the public should be fully warned of the discomforts involved and the soiling of clothing that is the inevitable result of the trip. The Service should also protect itself in some way against possible suits for personal injury or damage to clothing.

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CAVE IN ROCK

By GEORGE F. JACKSON

All photos by the author

This thrilling account of piracy on the Ohio River illustrates the adage that "truth is stranger than fiction" and highlights the fact that apparently caves have been the center of interest for not only the speleologist but, in this instance at least, for as murderous a gang of cutthroats as ever preyed upon the unwary traveler!

Cave in Rock on the Ohio River in southern Illinois has neither the great size nor the lovely beauty of many caves, but few, if any, caverns on the American continent have a more fascinating, colorful or bloody history than this huge rock-ribbed vault.

Home and hiding place of mound builders, Indians, early French *voyageurs,* and pioneers, it also housed and was the headquarters for some of the most bloodthirsty desperadoes in American frontier history. In fact, there was a time when the whole of Kentucky, Tennessee and parts of neighboring states were terrorized by the criminals from Cave in Rock. Their deeds read like the wildest fiction, and if they were not verified by authoritative sources would hardly be believed.

Speleologically the cave is something of a puzzle. Located in Illinois on the north bank of the Ohio River, it is about eighty-five miles below Evansville, Indiana, and fifty miles above Paducah, Kentucky. The entrance is in the St. Louis limestone and resembles more the "story book" idea of a cave entrance than that of any

A striking view just outside the entrance to Cave in Rock showing the horizontal nature of the St. Louis limestone.

other which the author has seen. The rocky cliffs along the river's banks here are high and sheer and, from a distance, appear to be smooth. Prominently located in a grey limestone wall is the huge arched, tunnel-like opening, seeming almost too regular to be entirely natural. But it is, and although the giant forests around it have disappeared it must look today not greatly different from when first seen by white men.

Otto A. Rothert, an authority on the cave, whose book about it is the result of many years of study and research, says that the first record of it is in *The History of New France* by Charlevoix in 1744. This account includes Bellin's Map of Louisiana, showing the general course of "La Belle Rivière" from observations made by M. de Lery when he explored it in 1729. On this map the cave is referred to as the "Caverne dans le Roc". Afterwards the place was given various names, all of them but one ("House of Nature") containing the word "cave". Apparently the name, Cave in Rock, has been the only one applied since the beginning of the 19th century.

The cave itself has a uniform width of fifty feet and extends back into the hillside approximately two hundred feet. Although there is a slight incline of the floor toward the back, the ceiling is level throughout its entire length.

Some eighty feet back is a narrow crack in the roof about fifteen feet long which connects with the surface. During the time of occupancy by river pirates this crack served as both an outlet for smoke from fires and also as an escape route if necessary. On one side at the back is a small room, at one time rather difficult of entrance but now completely dug out. This excavating may have been done when the state of Illinois took over the area and made it a state park.

The floor at the entrance is split by a wedge-shaped channel extending almost entirely across it and about five feet lower than the rest of the cave. It continues rearward into the cave, narrowing and sloping upward until it merges with the general floor level about thirty feet back, (see accompanying photographs). Some historians seem to think that this crack may have been dug by Indians or early white men, and discount the possibility of erosion. However, the author can see no other possibility than that of erosion from surface water entering through the "smoke" outlet at the rear of the cave, and possibly the waves of the river during times of extreme floods. It is almost inconceivable to think that men, red or white, could have had any incentive for all the back-breaking toil necessary to dig this big trench through solid rock. A puzzling fact against the erosion theory, however, is that the drainage area above the crack is hardly large enough to permit much of a stream to enter, even in wet weather. This is only one of many puzzling things about the formation of Cave in Rock.

That this cave is the result of erosion by an underground river, like most other caves, would seem to be the logical theory in regard to its formation—*until* it is examined closely. The front part has this appearance, but such a theory does not explain the solid limestone wall at the end. The passageway simply *stops*. It has definitely not been closed by breakdown, and there is no evidence of a continuation. Neither is there any indication of the entrance or exit of a large stream. There has been some erosion from the water which enters the ceiling crack during wet weather but, as mentioned previously, the small sink hole on the surface above it does not drain a large enough area to have furnished a water supply of sufficient quantity to form a large cave. Then, too, great virgin forests here in times past retarded the water of heavy rains. Consequently the flow through the crack years ago must have been a very small stream.

Some theorists have said that upheavals during the past have sealed off the rest of the cave. Since most of the limestones of the middle west are more or less horizontal, this explanation is not satisfactory. Upheavals great enough to completely close a huge cave would hardly leave the massive strata in their original position.

Others argue that "the pounding of the river" may have made the cave. Along sea coasts where there is constant beating of wind and waters, grottoes are constantly being formed and broken down again by such forces. It is doubtful if such an agency formed Cave in Rock, for, although the Ohio does go on terrific rampages at times of heavy storms and great floods, it is ordinarily too peaceful to have formed the whole of Cave in Rock by such a process. For one thing the cave is too deep. For another it is an entirely different type from "pounded out" coastal grottoes. There are many other theories as to how this cave was formed but a complete discussion could go on endlessly.

Almost all of the early western travelers on the Ohio River wrote descriptions of the cave and of their impressions of it. These accounts, sometimes greatly exaggerated, were either written before the time of the pirates who made the cave their headquarters, or during brief periods when it was unoccupied. Certainly during the reign of the outlaws few honest persons saw the cave close up and lived to tell or write of it.

No man knows when it first became a rendezvous for desperate criminals, but one of the first such criminals was Samuel Mason, former officer of the Continental Army, who served with distinction through the Revolution. It is interesting to speculate on how an army officer from a distinguished family and with a promising future finally came to be a river pirate. Many thousands of words have been written tracing his history and the possible reasons for his abrupt change to a life of robbery and murder, but no one seems to have determined what caused this change except that it was an easy way to get quantities of money.

He arrived in the vicinity of Cave in Rock around 1797. At the cave he posted a large sign on the river bank reading "Liquor Vault and House for Entertainment."

His carefully worked-out plan was based on the theory that river boat personnel seeing the sign would disembark for rest and entertainment and, while being "entertained" by members of his band, could be dispatched with ease. Also the boats could be looted at will. The plan worked beautifully. If any prospective victim suspected that the sign was a ruse there is no record of it today. Strange tales of vanished river craft and unusual doings at the cave drifted back to the more civilized points along the Ohio, but it was some time before river men began to avoid the place.

If it seems strange that captains and crews of early river boats, themselves a pretty tough and wary group, could be enticed to tie up at such a spot, consider the following. There were no adequate roads through the wilderness. The best artery to the west and south was via the Ohio to the Mississippi. Any traveler or shipper wishing to visit or to ship goods to any point west or south of the present middle west was *forced* to travel the stream. It was a place of dangerous currents, treacherous shifting sand bars, islands and rapids. No man knew it thoroughly. Some of the more dangerous spots were listed on the crude charts then available, but at some places it was the custom to engage local guides to pilot boats through intricate channels and rapids. Such a dangerous place was the Hurricane Island rapids, just below Cave in Rock. It may be that some boats stopped at Mason's "House of Entertainment" for a brief rest before entering the rapids; others may have sought guidance, still others the dubious "entertainment" offered. At any rate there is no doubt that crews and passengers would ordinarily look forward to a stop-over at such an interesting place as Cave in Rock seemed to be when viewed from the river. The last important stopping place had been the "Falls of the Ohio" (now Louisville, Kentucky) some distance above.

Mason operated at the cave for some time, and while there he did something that has caused considerable confusion among historians of the place. He changed his name to Wilson. The fact that later there was another Wilson operating the cave has resulted in many inaccuracies among the chroniclers of the pirates of Cave in Rock.

Mason (or Wilson) finally left the cave, began operating along the Natchez Trace, and was eventually slain and decapitated. His head was encased in clay to preserve it while the slayer took it to proper authorities for identification and reward. This seems to have been an accepted procedure along the frontier, for it happened in the cases of several Cave in Rock criminals.

Whether or not Mason instigated the plan of having outlaws station themselves at various strategic points along the river and offer to pilot boats through the Hurricane Island rapids is unknown, but this was another ruse followed successfully by pirates along this stretch of the river. If one pilot was refused by the boat's captain, there were always others farther down to entice him. Once aboard the boat, the "pilots" would either run the craft ashore for the looting and slaying of the crew or, if the cargo was insignificant, actually run it through the rapids for legitimate money.

Another character operating along this stretch of the Ohio River was a Colonel Fluger, who used an entirely different approach. He would wait until a boat had tied up along the banks and then, stealthily boarding it, would bore holes in the bottom. When the boat began to sink, he and his confederates would murder the passengers and crew and take whatever goods they could use for profit.

Fantastic as these tales seem they are quite true and are undeniably substantiated by reliable accounts and old court records.

Of all the brutal outlaws who infested the river and its environs, the most terrible and bloodthirsty were the two Harpe brothers. One historian refers to them as the "most brutal monsters of the human race." The recorded history of their deeds is astounding. When one considers that most of the travelers who actually faced them never lived to give an account of what happened, it makes their unwritten history one of mystifying horror.

The Harpes came from North Carolina. Micajah, known as "Big" Harpe was born about 1768, while Wiley, known as "Little" Harpe was born about 1770. Their early history is not too well known, but about 1795 they left North Carolina with two women, both of whom were claimed by Big Harpe as wives.

They roamed central Tennessee for several years, spending some time with Indians who were committing outrages against their own people as well as against the white man. Not only did the Harpes help the Indians, but also they added some embellishments of their own to the Indian's brutal practices.

Their progress from this part of Tennessee to Kentucky can be followed by their trail of murders. Apparently they never made any attempt to hide their trail nor to disguise themselves once they came upon an unwary traveler. When they met large parties of travelers, or when they were in communities and settlements, they simply followed what they probably thought to be common sense and refrained from killings in plain view of others.

Once, as they followed the Wilderness Road into Kentucky at Danville, the entire party—both Harpes and *three* women now—were jailed for the brutal murder of a Virginian who had asked their company through the wilderness. The Harpes escaped, leaving their "wives" in jail where, before they came to trial, a child was born to each woman. The entire account of this affair and the cost to the county may be found in the old Lincoln County Records. Eventually all three women were set free and met the Harpes at Cave in Rock.

A large group of outlaws had been living here prior to the time of the Harpes' arrival. One historian says that, since most of this group had been chased out of the so-called "law abiding" communities (which in themselves were pretty rough and hard gatherings), it can be imagined that the band at Cave in Rock was mighty tough indeed. But even these unscrupulous cutthroats found the Harpes too much for them!

One story relates how the Harpes had hardly arrived at the cave when a flatboat came down the river and landed not far above at a place known as Cedar Point. The passengers, not knowing they were near the gathering spot of outlaws, had gone ashore and were strolling along the river banks. Among them was a young man and his bride-to-be. These two strolled to the top of a bluff and sat down looking out across the river. The Harpes, who had been watching the scene, sneaked up behind the two lovers and unceremoniously pushed them over the high cliff. To them this was a great joke and they returned to the cave laughing about the trick they had played, but it did not have quite the same effect on the others of the band. Apparently they did not like it and told the brothers so.

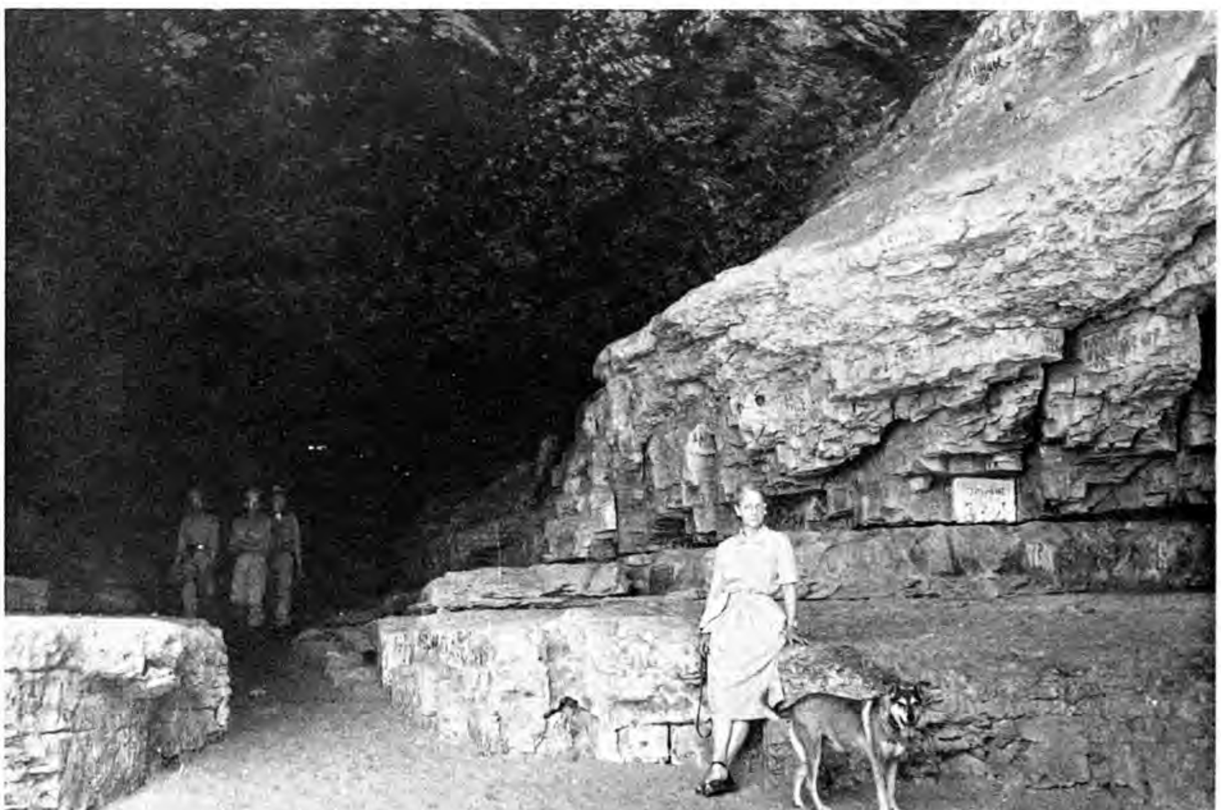
Shortly afterward the Harpes saw what they thought to be an opportunity to make amends. A boat had been captured and most of its passengers slain and their goods stolen. One or two of the men, however, had not been killed, but were tied up as captives while the outlaws debated what to do with them. The Harpes quietly took one of the captives, stripped him, tied him to the back of a horse and led the animal to the top of the cliff one hundred feet above the cave. Below, the rest of the band was gathered around a great fire, talking. Suddenly the Harpes drove horse and bound rider over the cliff's edge and both fell, screaming and thrashing, directly upon the fire and outlaws gathered around it. The other outlaws found this feat a little too much for them and actually drove the Harpes away from their hangout.

After this the Harpes committed twenty-two known murders (including those of several women and children) while wandering in central Kentucky. It must have been during this period that Big Harpe took one of his own offspring and dashed its head against a convenient rock because its crying bothered him. When he was dying he said this was the only one of his acts he regretted.

Big Harpe was killed and beheaded near Roberson's Lick, Kentucky, by a man whose wife he had earlier slain in her sleep. Little Harpe, though wounded, escaped to resume his life of outlawry in another part of the country but was eventually also killed. His brother's head was mounted on a pole and for many years served as a revolting warning to other bandits. Thus ended the careers of the two most famous Cave in Rock pirates.

Although Mason and the Harpes were the most notorious of the Cave in Rock criminals, there were many lesser ones who used the spot for a hideout or for headquarters. Their lengthy stories are of interest because they are a part of the history of our country. They were men who, indirectly but none the less surely, helped to bring law and order to the country.

Cave in Rock today is the chief attraction of Cave in Rock State Park, and although the grounds have been cleared of their underbrush and probably appear more pleasing than when first seen by the pioneers, the great cave still looks the same as when the first French explorer glimpsed it from the blue waters of "La Belle Rivière". It stands above the peaceful river where power boats cut the waves at speeds the old-time river pilots would have thought unbelievable. And it keeps its enigmatic silence about its formation and about its bloody history.



This view inside Cave in Rock shows the five-foot high channel which extends rearward into the cave for some distance.

Who's Who in Bulletin Thirteen

DENNIS J. BATTEN is connected with the Civil Engineering Department of the Iraq Petroleum Company. He is responsible for the organization of the Iraq Potholers made up of a group of employes of his company who are interested in cavern exploration. Through the courtesy of the IPC's General Manager at Tripoli he was granted three weeks' leave of absence without pay to join the expedition headed by Henry Field whose article entitled "Caves and Rockshelters in Southwestern Asia" appears in this issue of the Bulletin. In addition to his caving equipment Batten contributed a good technical knowledge of cave exploration and the ability to speak Arabic fluently and to deal effectively with Arabs, Kurds and Assyrians.

DONALD M. BLACK was born in 1921 at Vincennes, Indiana. He received his elementary education at West Terre Haute, Indiana and studied forestry at Purdue University and Utah State Agricultural College from 1940 to 1942. After serving as seasonal Ranger National Park Service at Yellowstone National Park in the latter year, he entered the U. S. Army as a private in 1943 and was released from active duty in 1946 with the grade of captain. In December 1946 he received his MS degree in Geology from the Utah State Agricultural College and enrolled in the University of Arizona in 1947 as a graduate student, minoring in education and biological sciences. A seasonal Naturalist at Yellowstone National Park in the summer of 1948, Black accepted a permanent appointment in the National Park Service in February, 1950. First acting as guide at Carlsbad Caverns National Park he was transferred as a Ranger to Grand Canyon National Park in 1951.

WILLIAM E. DAVIES was born in Cleveland, Ohio in 1917. He is a professional geologist now with the U. S. Geological Survey in Washington after having been with the Army Map Service for three years. Before that he was in the Army. Davies became interested in caves in 1940 while working with the Pennsylvania Geological Survey (influence of Dr. Stone obvious). Since then he has covered the caves of Maryland and authored a report entitled: The Caves of Maryland for the Maryland Geological Survay. He has also been with the West Virginia Geological Survey and investigated the caves of that State for a report since issued, entitled: Caverns of West Virginia. He has done work on the terraces of the Potomac river including data on the relation of caves to them. His true interest is the application of electrical surveys to the mapping of cavern systems from the surface. This work got under way in 1947 but with the other commitments coming along it has been sidetracked. His article on the mechanics of cavern breakdown is the result of studies carried on during the past 3 years primarily in the caves of Virginia and West Virginia.

HENRY FIELD, renowned archaeologist, was born in Chicago, Illinois in 1902. He received degrees of BA, MA and DSC at Oxford, England, and began the study of caves for archaeology, anthropology and primitive art in 1926 with Abbé Breuil in Spain and France. Since then he has been on 5 expeditions to the Near East and was leader of the Peabody Museum—Harvard Expedition to that part of the world in 1950. He resides in Washington, D. C.

JOHN W. FUNKHOUSER was born at Beaverdam, Virginia, in 1926. Entering Washington and Lee University in 1943 he had his first taste of caving in the Cave Springs Cave (Spring Hill) located a short distance from the university campus. His studies were interrupted by naval service but he returned to Washington and Lee in 1946 with new enthusiasm for caving and was influential in establishing the Lexington Grotto, of which he was the first president. In 1948 he graduated with a B. A., majoring in biology and minoring in geology, and entered Stanford University for graduate study in ecology and systematics, specializing in South American amphibiology. There he joined forces with other N. S. S. members to stir up interest in caving and helped to found the Stanford Grotto, of which he was also the first president. He received a predoctoral travel grant to study the ecology of Ecuadorian amphibians in the field and spent half of 1950 on this assignment. Returning to Stanford he completed his Ph. D. in 1951 and is now instructing in the School of Biology at that institution. He is also continuing his research on tropical American amphibians. His main interests in speleology are the tracing of the geologic history of individual caves, cave photography, and cave vertebrates.

MARK RAYMOND HARRINGTON was born at Ann Arbor, Michigan, July 6, 1882, the son of Professor Mark W. Harrington, at that time professor of astronomy and director of the observatory at the University of Michigan. "M. R." attended school at Ann Arbor, at Washington, D. C., Seattle, Washington, and Mt. Vernon, New York, with college work at Ann Arbor and at Columbia University, where he graduated and took his A.M. degree. Always interested in the American Indian, ancient and modern, Harrington specialized in anthropology. He has worked at different times for the American Museum of Natural History, the Peabody Museum of Harvard, the University of Pennsylvania Museum, and for the Museum of the American Indian, Heye Foundation. Except for a brief period when he was borrowed by the National Park Service, he has been Curator of the Southwest Museum of Los Angeles for the past 23 years. Ethnological work has taken him to more than 35 Indian tribes, and archeological expeditions to New York, Florida, Tennessee, Oklahoma, Arkansas, Missouri, Texas, New Mexico, Nevada, California and Cuba. He is the author of a number of books, most of them of a more or less technical nature and of many shorter articles and some fiction. "M. R." is married, lives at San Fernando, California, and is still Curator of the Southwest Museum at Los Angeles. He has one son and two grandchildren.

GEORGE F. JACKSON, of Evansville, Indiana, specializes in cave photography. His hobby is Indiana caves, his favorite one being the huge Wyandotte Cavern. Over 125 of his articles on caves and cave photography have been published. For the past three years he has been a member of the Board of Governors of the NSS. At present he is working on a detailed map of Indiana cave locations and completely re-writing his book-length "Cave Region of Indiana" which will contain all known facts about Hoosier caverns. His collection of cave pictures includes dozens of color slides and hundreds of black and white negatives. He does free lance writing as a "sideline" in addition to his voluminous writing on the subject of caves. During the course of his speleological exploration all over the country he has used all kinds and sizes of cameras and even the smallest of them has often been too large for comfort in some of the small holes he has explored. He is now trying to design one to fit his particular needs. Jackson was responsible for the formation of the Indiana Grotto which, according to him is apparently the most unusual of all of the NSS Grottoes. Only two members of it live all year in Indiana. Of the others, two live in the state of Washington, one in Colorado, and one in Ohio. This, Jackson says, causes considerable confusion at headquarters of the NSS and gives rise to the rumor that *he* is The Indiana Grotto. He is one of our most active members and carries on a voluminous correspondence pertaining to Indiana caverns and to Grotto affairs.

RICHARD F. LOGAN was born at Great Barrington, Massachusetts in 1914. After attending school in Massachusetts and Connecticut, he received his BA and MA from Clark University in 1936 and 1937 respectively. Degrees of MA and PhD were received from Harvard in 1948 and 1949 respectively. He was first chairman of the reorganized (after the war) New England Grotto of the NSS. Along with William B. Halliday he assisted in organizing the Southern California Grotto in 1948 and has served as its chairman. Before associating himself with the University of California at Los Angeles, where he is now an Assistant Professor, he taught at Clark, Yale, Harvard, and Connecticut College for Women.

JEROME M. LUDLOW, NSS Vice President for Publications and Editor of the Bulletin, was connected with the Brookings Institution at Washington, D. C. when that economic and governmental research organization was founded. He spent two years with a Chicago firm of consultants in municipal administration and seven years as chief clerk and research assistant with the New Jersey Taxpayers Association before joining the U. S. Geological Survey in January, 1940. An invitation from Charles E. Mohr to participate in an NSS field trip in April, 1947 resulted in his gradual change from a somewhat normal individual to a speleoeditor.

CLYDE A. MALOTT, who died on August 26, 1950 was a native Hoosier and long was connected with Indiana University. He had made special studies of the karst features and underground drainage phenomena of the limestone belt of southern Indiana. He was familiar with its many caverns and had given special attention to their connections with water sources which were responsible for their development. Among them is the noted Lost River region of Orange County which offers unusual opportunities for the study of cavern phenomena and the relations of caverns to the subterranean waters which develop them. Out of these studies has come his invasion theory of cavern development, in which accent is placed upon cavern development by rainborn surface waters which ream out and align initial and rudimentary sub-surface joint openings into long and integrated cavern systems at or near the watertable. The present paper, previously unpublished, was graciously given by his family to the National Speleological Society for publication.

JOHN W. MURRAY is associate professor of Chemistry at Virginia Polytechnic Institute. He is chairman of the VPI Grotto Committee on Formations and Mineralogy and represents that committee on the corresponding National Committee. He is also a faculty advisor to the VPI Grotto and as such tries to keep the members conscious of safety and conservation and to interest them in the scientific aspects of cave exploration. He is a native of Flushing, N. Y. and got his Ph.D. from Johns Hopkins in 1933, but he has long since migrated to a land where the mountains are higher and the caves more numerous.

G. ALEXANDER ROBERTSON has been associated with the Department of Public Utilities, City of Richmond, since 1925, during which time he has been responsible for the installation and maintenance of generators, water wheels, pumping and other heavy equipment used in water purification, gas and water pumping, and electric generating stations. Mr. Robertson has been engaged in work of an engineering nature since completing his schooling. He has been interested in photography since his early boyhood and for the past five years has been Chairman of the Photographic Committee of the National Speleological Society. It was through his interest in photography that he was introduced to spelunking and because of his engineering experience and extensive use of rigging, it was only natural that he became alarmed at numerous caving practices which he considers dangerous. A member of the Archeological Institute of America, the Archeological Society of Virginia, and the Central Virginia Engineers' Club he has been a member of the Board of Governors of the National Speleological Society since 1946.

IVAN T. SANDERSON was born in Edinburgh, Scotland. In 1932 he received degrees in Zoology, Geology, and Botany from Cambridge University, England. His interest in speleology developed as a sideline from his work during nine zoological expeditions to the Orient, Africa, and South America on behalf of American and British scientific societies and museums. His major work has been tropical ecology and the relationships between the distribution of animals and plants on a worldwide basis. He published a number of papers on this subject before the war. After a period with British Naval Intelligence and in wartime propaganda he became a resident of the United States. His efforts to popularize the natural sciences through books, magazine articles, lectures, radio and television have resulted in his forming the only company in America incorporated solely for this purpose. He joined the National Speleological Society in 1948, and is now president of the Metropolitan Grotto of New York, and national Vice-President in charge of Public Relations. He plans to initiate a palaeontological exploration of eastern caves, using color-film as a recording medium in such a manner that it may be applied to color-television. In the latter field he recently started the first regular broadcast for the Columbia Television Network. His hobby is firsthand investigation of reports of monsters and other weird animals. He has actually found several of the latter, some of which are named after him.

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