The AMERICAN CAVER

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IN THIS ISSUE . . .

Accurate and informative articles on caves including

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To stimulate interest in caves and to record the findings of explorers and scientists within and outside the Society

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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.

Preface

During every year of its life the National Speleological Society has increased in stature, influence, and activities. The period since the last Bulletin was released has been no exception in the general progress and growth of the Society.

The Society has conducted its first large-scale, scientific study of a cave. The report of this activity is presented in a book entitled "The Caves Beyond". This is the culmination of the cooperative efforts of a large group of members who spent many long hours of heavy, arduous labor, a considerable amount of vacation time, and a very substantial personal financial sacrifice to make the Floyd Collins Crystal Cave Expedition a success. Our thanks and appreciation are extended to all who contributed time, equipment, talent, or finances to this project.

We have been honored by having the officials of our National Park Service consult us on matters of policy governing speleological activities within areas under their jurisdiction. Numerous conferences have been held and a free exchange of ideas and thoughts encouraged, which resulted in a vastly improved and more understanding appreciation of mutual problems. As a result a modified and liberalized set of regulations that affect the Society and its members has been formulated.

We have been invited to attend the World Congress of Mineralogists to be held in Mexico in 1956. This is the first time an invitation has been extended to speleologists to attend these meetings. Consequently, we feel greatly honored by this recognition. This Congress meets every four years and only rarely on the North American continent.

Our recent meeting, held concurrently with the American Association for the Advancement of Science, at Berkeley, California, was the best attended of any such session since the Society has been a member of that scientific group. Such meetings are for the primary purpose of providing sessions at which papers directed to the more serious aspects of speleology may be presented. They provide, also, an additional focal point at which widely scattered members may meet and exchange ideas.

The Annual Convention continues to be the most important and influential activity of the Society. It is at these meetings that a definite attempt is made to provide a program of papers, discussions, and activities, among which every person, regardless of the length of his membership will find something of interest.

There has been a substantial increase in our Affiliated members, all of which are foreign groups of speleologists. These memberships give our publications a world-wide circulation. In turn, we receive publications from such member groups. This arrangement brings

(Continued on Page 95)

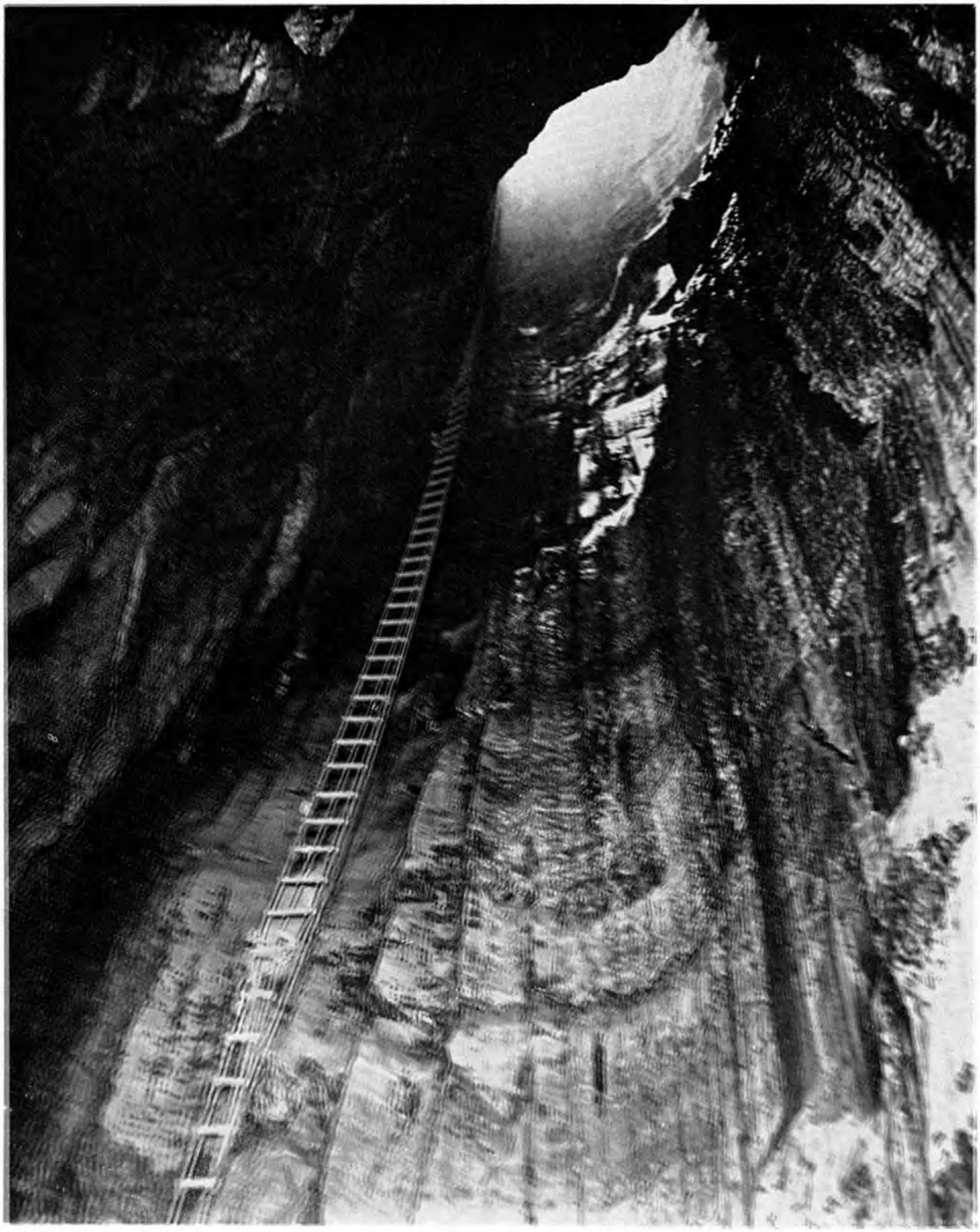

Photo by E. Simpson

This spectacular photograph taken inside the entrance to a British cave is entitled "Jingling Pot Ladder Pitch" and was awarded the silver medal in the 1954 Annual Photographic Salon of the National Speleological Society.

Ice Caves of the United States

By WILLIAM R. HALLIDAY, M.D.

Ice caves have long fascinated the speleologist but few persons realize the extent to which they exist in the United States. The accompanying article presents a detailed inventory of ice caves to be found in this country together with many other facts as to their origin and development.

That ice should be found in certain caves has long stirred the interest and curiosity of the caver, and of the imaginative observer in general. To many, familiar with the year-round comfort of the majority of our American caves, its occurrence seems anomalous if not incredible. A little reflection, however, will show that to expect this to be the universal case would be unrealistic. In the case of the Nakimu Caves, high in the Selkirk Mountains of British Columbia, the surprising feature is not that one of the caves contains ice the year round (23), but that the brief summer thaw is sufficient to keep all the others clear.

About 50 years ago, considerable interest in this subject was evident in the United States, and a number of excellent studies were conducted (9, 10, 11, 74, 75, 78, 123, etc.). These have been improved upon very little in the intervening years despite a considerable literature, much of which, unfortunately, is unsound and based upon incomplete information. In addition, the total number of caves has increased a hundred fold, so that a moderate increase in the number of known ice caves is entirely reasonable. With the increase in number has come an increase in data, which, even though far from complete, has stimulated the evolution of many new concepts, meteorological as well as speleological.

This paper is not presented as any "final" authority on the ice caves of the United States. It merely represents a long-overdue attempt to evaluate and reorientate the literature in terms of recent concepts, to discuss and summarize the ice caves known today in the United States, and to report a large number of ice caves not previously recorded.

To achieve this goal, a four-year part-time survey was undertaken with the field assistance of a large number of persons within and without the National Speleological Society. Without their inestimable contributions, far greater gaps would exist in our present knowledge, and to them, the author's appreciation is sincerely rendered. With few exceptions, the data so contributed, whether or not included in the reference list as "personal communication", is on file with the National Speleological Society.

Nevertheless, despite all the data which could be gathered through field, bibliographic and interpersonal research, this paper inevitably indicates that important data is unavailable in far too many cases, and a few seriously incorrect conclusions may have thus been introduced into this paper. Their correction would be welcomed. Let us hope that the number of new ice caves discovered and reported in the future will only be surpassed by the amount of new data on those already known, so that another survey of this type will be necessary in a much shorter time interval.

Definition

Due to the prevalent confusion as to the definition of a cave, the term *ice cave* has been applied to more mines, fissures, chasms, canyons, sinks, talus accumulations, shelters, tunnels, areas of permafrost and other unlikely spots than to true caves. Since it is usually the ice rather than the cave which is the curiosity, it must be admitted that something can be said for this point of view. Nevertheless, it is evident that if we are to reach proper conclusions, we must limit our definition to apparently related speleological phenomena.

Balch, in his preliminary report (9), listed 35 cases of subterranean ice east of the Rockies, and remarked that, of these, ". . . four . . . may properly be called caves." As one of these is a gorge, one a series of small fissures, and one contains only névé in the portion he visited, if we define *ice caves* as *true caves*, i.e., limestone cavern, lava tube, etc.) *in which ice forms and persists for a* *considerable time*. Decorah Ice Cave is left without much company in this list. Others, of course, were soon reported in the east (11), but most American ice caves belong to the west, and most eastern reports deal with non-speleological phenomena. In decreasing order of speleological interest, the latter may be subdivided as follows:

1. Natural glacieres other than "true caves"
   A. Glacieres in fissures and sinks.
   B. Talus and/or gorge glacieres.
2. Artificial glacieres
   A. Ice-forming mines and tunnels.
   B. Ice-forming wells.

It is actually the last part of our definition which is the most important. In many so-called "ice caves", the ice actually consists only of accumulated snow, known to mountaineers as névé, drifted and piled, and preserved by the insulating mechanisms to be considered later. Such neigieres do not contain true cave ice. Neither can the icicles which form temporarily in the entrance of many caves each winter be considered true cave ice. Less transient phenomena are borderline cases. Each must be considered on its own merits, for no rigid line of demarcation exists.

Misnomers

To add unnecessarily to the complexity of this field is a further matter of misnomers, and fifty years' attempts to ameliorate the situation by standardizing the nomenclature have been uniformly unsuccessful. To many glacier experts, "ice cave" means a cave in ice. To many inhabitants of Idaho and other lava areas, it means any lava tube (15), for these almost always contain a little ice in spring. To a few Coloradans, it apparently means a cave containing gypsum, for "Porcupine" Ice Cave contains sparkling crystals of this substance, but no ice. In other parts of the country, especially where caves are uncommon, the name has been applied to quite ordinary caves, due to their relative coolness on summer days. In yet other areas the name is due to drifted snow, or ice remnants which persist for a few days or weeks in hidden recesses. The following so-called ice caves appear to have no claim to the name:

1. White Chief Ice Cave, Calif.	limestone neigiere (80, 81)
2. Captain Jack's Ice Cave, Calif.	lava tube (77)
3. Clear Creek Ice Caves, Colo.	fissures (120)
4. Porcupine (Ice) Cave, Colo.	limestone (18, 60)
5. Grace (Volcano Hill) Ice Cave, Ida.	lava (15, 56)
6. Twin Butes Ice Cave, Ida.	lava (15, 34)
7. Ice Cave, Monroe Co., Ill.	limestone (70)
8. Ice Cave, Great Barrington, Mass.	fissure neigiere (102)
9. Ice Cave, Mt. Greylock, Mass.	hoax (102)
10. Devil's Ice Box, Mo.	limestone (64)
11. Snow Cavern, Nev.	limestone neigiere (95)
12. Ellenville Ice Caves Nos. 1 and 2, N. Y.	fissures (4, 44)
13. Lake Minnewaska Ice Cave, N. Y.	fissure (79)
14. Sam's Point Ice Caves, N. Y.	talus neigiere (11, 73)
15. Straddle Canyon Ice Cave, N. Y.	limestone neigiere (45)
16. Refrigerator, N. C.	talus (115)
17. Ice Cave, Spearfish, S. D.	shelter (99, 119)
18. Ice Cave, Tenn.	limestone neigiere (8)
19. Mt. St. Helens Ice Cave, Wash.	lava tube (3)

The White Chief Caves are located almost at timberline in the High Sierra country. They consist of about twenty small superficial solution caverns in white marble, and the area is so covered with snow that entry into the caves is blocked until August. It is therefore not surprising that snow and perhaps ice have been reported within their confines (80), but the reporter does not believe that true cave ice is present or that they qualify as glacieres (81).

The reason for the widespread addition of the word "ice" into Captain Jack's Ice Cave has long been a mystery to the Lava Beds National Monument staff. It is one of the earliest of their 300 caves to warm in summer (77). Clear Creek Ice Caves are a series of deep fissures which do not contain ice (120). The apparent explanation of the nomenclature of Porcupine Cave and the Idaho lava tubes has already been given. Clay Perry believes the Mt. Greylock report to be a hoax (102).

The cave in Monroe Co., Ill. (70), the Devil's Icebox (64), and the talus Refrigerator (115) contain no persistent ice, but are cool spots in regions of hot summers. Snow Cavern is a fine neigiere, but not a glaciere (95). The Ice Cave at Great Barrington, also known as Robbers Roost, is a small fissure cave which does not contain ice in summer (102).

In contrast to the Ellenville Crevice Caves, the Ellenville Ice Caves were not found to contain ice in Aug., 1952, Oct., 1952 or May, 1953 (44). The local name is probably due to transposition. Straddle Canyon Cave contains drifted snow in its entrance in early summer, but probably no cave ice (45). Sam's Point Caves, while locally called ice caves, contain little if any persistent ice (73). This is an example of talus in a gorge, about which numerous fantastic tales are told.

Mr. Frank Thomson, the well-known historian of Spearfish, S. D., has kindly investigated the "Ice Cave at Spearfish" pictured in an early issue of the Black Hills Engineer (99). After considerable research, it is his conclusion that it is only a shelter with transient icicles overhanging the entrance. A number of such "caves" are known in that area (119). Mt. St. Helens Cave has apparently become confused with those at the foot of neighboring Mt. Adams, for no persistent ice is found in this two-entrance lava tube (3). The Tennessee site is described as a single steep solution passage 150 feet long, with a little snow at the bottom in July (8). A similarly named Tennessee cave is so called because "the single formation therein supposedly looks like an ice flow" (50).

Ice Caves, Glaciere and Glaciere Caves

Balch (11) was one of the many who have felt that the French term *glaciere* should be employed for a cave containing ice, and "ice cave" reserved for caves in glaciers. This would follow the analogy of limestone, sandstone and lava caves (but excluding sea caves), but fifty years has shown

Photo by John H. Lincoln

Fig. 1. Typical ice speleothems, Mt. Adams Ice Cave, Washington.

his campaign to be fruitless. Indeed, in the last few years, quite a reverse tendency has been apparent, with increasing use of the term "glacier cave". In any event, "ice cave" now seems ineradicably fixed in popular and scientific usage, and there seems little actual harm in its use when properly defined and limited. In this paper, the terms "ice cave" and "glaciere" will be used somewhat interchangeably in discussing true caves, but "glaciere" will be applied to ice-containing subterranean cavities of all types, both natural and artificial.

Though nearly every glacier contains a small cave or two, the following examples are well enough known glacier caves to cause confusion:

1. Ice Caverns, St. Mary's Glacier, Colo. (38)
2. Ice Cave, Nisqually Glacier, Wash. (84)
3. Paradise Ice Cave, Stevens-Paradise Glacier, Wash. (84)
4. Ice Cave, Carbon Glacier, Wash. (84)
5. Kautz Ice Cave, Wash. (106)
6. Big Four Ice Cave, Wash. (13)
7. Ice Cave, Lower Challenger Glacier, Wash. (91)

Most of these glacier caves are relatively intermittent in character, formed over the emergence point of streams flowing from beneath the glacier, and constantly change with recession of the glacier. The Paradise Ice Caves, however, are relatively static (83). There is considerable reason to believe that the Kautz Ice Cave is a result of entirely different processes (106), but these are glacial, not speleological phenomena.

Theories on Formation of Cave Ice

Rather remarkable theories of the formation of cave ice have long been in existence. It has been suggested that it may originate as the remnant of a glacier, preserved beneath lava flows (11, 89). Observations in Lava Beds National Monument show that successive flows are hot enough to melt considerable portions of earlier, underlying flows in forming caves of several levels. How this would preserve glaciers is hard to imagine. Volcanic ash, on the other hand, has been known to cover and preserve snow, but this is of no speleological significance.

Many other theories have been advanced, including capillarity (11), adiabatic cooling (11, 89), and "remnants of the ice age" (11). Each has been investigated and found wanting. Kimball, for example, found that the maximum adiabatic cooling theoretically possible in an ice cave is 1°F. (89). On the other hand, glimmers of a half-truth may be seen in the belief that the ice is a remnant of the glacial ages. In most ice caves, removal of the ice deposit results in replenishment within a few days, weeks, months or years. In a few, however, the ice has never reformed. In many, the deposits are gradually diminishing. In no known case in the United States is the volume of ice increasing. These facts seem to indicate that ancient conditions were more conducive to the formation of cave ice than the present, but to attribute all cave ice to glacial epoch remnants is quite a different matter.

Modern Concepts of the Formation of Cave Ice

Two factors are obviously necessary for the formation of cave ice: cold and water. While running water may occasionally be a primary source for ice formation, ordinary seepage is the usual source. Frost crystals are undoubtedly the result of condensation of atmospheric moisture.

It is important to note that the water and the cold are often not synchronously present in the cave. Furthermore, perhaps in conformance with laws of bedrock heat transfer, there is a definite lag in ice cave temperatures behind the seasonal surface variances. This may be shown as a linearly damped phase shift in the curve of the annual temperature (12), which is a variable multiple sine curve. This is well demonstrated by a graph of the temperature of Decorah Ice Cave shown elsewhere. Since such a cave may receive little or no seepage from the frozen surface in winter, ice will be formed in large quantities only after the spring thaws, even though the temperature is below freezing several months earlier. This is the origin of the widespread popular fallacy that cave ice mysteriously forms in summer and melts in winter.

It has been repeatedly stated (63, 89) that water is frozen into cave ice by cold circulating air. This appears to be true rarely, if at all, in important glacieres. Circulating air in ice caves is generally a major katabolistic agent. *Passive settling* of the heavier cold air, instead, is the usual cause of the development and persistence of the cave ice. This is basically the theory so beautifully documented by Balch (9, 10, 11). On the other hand, Andrews (2) acknowledges Balch's work, but presents evidence of an apparently active summer circulation of cold air in the Sweden Valley Ice Mine. This, however, is not a true cave (101), and the phenomena described are due to a vastly different type of circulation which will be discussed below.

Photos by Merlin K. Potts, courtesy of National Park Service

Fig. 2. Exterior and interior of a glacier cave (Paradise Ice Cave).

Basic Speleometeorological Factors

A working knowledge of the basic principles of speleometeorology is necessary for an understanding of the formation and persistence of subterranean ice, especially in limestone glacieres. In some instances, the processes involved appear to fall among some of the most complex temperature-humidity-evaporation relationships known in caves, but the majority are more easily recognized and understood. Unfortunately, such a working knowledge is difficult for most American cavers to acquire, since nearly all the speleometeorological studies published in recent years have been European. A summary of the pertinent points of this field as they apply to ice caves is therefore in order.

Limestone Caves as Variations of Homeothermic Cavities

Below a definite but locally varying depth, a completely sealed cavity, like the surrounding bedrock, will theoretically maintain a constant temperature, modified only by long-term climatic cycles. Caves may be considered as variations of this theoretical sealed cavity, with modifications imposed upon their temperature, humidity and barometric pressure by a host of factors depending upon the inherent structure of the individual cave. These include proximity to the surface, nature and location of entrance passages, and entry of foreign substances such as air, water, snow and explorers.

Greater Weight of Cold Air

Perhaps the one principle of greatest significance in ice caves is the simple fact that cold air is denser, and thus heavier than warm air, and will therefore tend to settle, displacing upward lighter, warm air. Stratification of layers of air appears to be common in both vertical and horizontal caves, with a step-like increase in temperature from floor to ceiling (93).

Meteorological Zones

In the somewhat theoretical case of a simple sizeable horizontal cave with a single entrance and passage, particularly if not connected to the surface by the usual multitude of tiny fissures, there may be defined three rather distinct meteorological zones, somewhat reminiscent of the entrance, twilight and darkness zones. The outer zone, immediately within the entrance, is protected from many climatic factors, but approximate external conditions fairly closely. The change to the transitional zone is usually more sharply defined than might be expected. This zone is conducive to a fairly constant temperature, but one which varies considerably from season to season, and the humidity, while high, is well below saturation. The line of demarcation from the inner, homeothermic zone is usually arbitrarily chosen at the point where seasonal fluctuations become minimal. Each cave superimposes its own inherent variations upon this pattern, and conditions in different portions of a cave's homeothermic zone may vary considerably.

Alterations of Cave Meteorics

The three great agents producing disturbances in an ice cave are air, moisture and cavers. The last is usually the least important, yet in Crystal Cave, Lava Beds, Calif., it is unwise to remain in the crystal grottos for more than a few seconds, for the frost crystals begin to melt from the mere proximity of the human body, even without carbide lights. They are, then, a purely katabolistic agent in terms of the ice deposits.

Effects of Moisture

Only in the form of drifting snow can moisture entering an ice cave assist in the lowering of temperature. This is a distinction from a cave above the freezing point, in which running or dripping water in temperature equilibrium with the bedrock can act as a pronounced stabilizing agent. Even the water which directly forms the cave ice releases heat to the atmosphere and bedrock, and thus indirectly hinders the formation of additional ice. Extremely dry, warm air is necessary to produce sufficient evaporation to form cave ice (122).

Effects of Air Entering the Cave

Entrance of air into an ice cave is ordinarily the most significant factor in its temperature changes. It may occur in three major ways: by the action of wind, through greater weight than underlying cave air, or through pressure changes. In most caves, the wind causes mere convection currents, or eddys, in the single entrance. While it may blow right in one entrance and out another if multiple entrances are present, irregularity and tortuosity of passages and entrances ordinarily tremendously reduce its force. Nevertheless, it may become a significant factor in ice caves with two entrances, especially if they are approximately at the same level.

In single-entrance ice caves, changes in temperature and in barometric pressure are commonly the most important factors in alterations of cave conditions. Perhaps the greatest single katabolistic agent of this group is the atmosphere's ever-changing barometric pressure, but other processes may be even more vital in an ice cave, particularly if more than one entrance is present.

Changes Depending on Weight of Cold Air

Hot air is, of course, lighter than warm air, and consequently is displaced by the latter at the bottom of any closed container. It is thus apparent that cold air will be trapped in single-entrance caves whose extent lies beneath the entrance. Under favorable conditions, the heavy cold air thus sinks through the entrance, displacing the lighter warm air remaining at the beginning of winter. In summer, the warm air, being lighter, enters such caves with difficulty and by other methods.

Changes Depending on Levels and Temperature Differences

In the case of a horizontal cave, the stratification of air previously mentioned tends to cause, in summer and winter respectively, an inflow of warm or cold air at the ceiling or floor level, with consequent displacement of the other. In a simple cave with two or more entrances at different levels, the cave air, which is heavier than the outside air in summer and lighter in winter, will escape at the appropriate entrance, with entry of the outside air at the other.

Effect of Changes in Barometric Pressure

In contrast to these passive, anabolistic phenomena which depend on settling of heavy, cold air and which are ordinarily of significance in ice caves only in winter, changes in atmospheric pressure are occurring to a significant degree at all times, with opposing effects in summer and winter. While they cause perhaps the most dramatic alterations of the conditions in "normal" caves, they are the cause of the only important changes during summer in pit glacieres. A rise of only 10 mm in the barometric pressure will result in the ingress of large quantities of summer air in many cases. Illustrative is Duck Creek Ice Cave, Utah, a small cave with a volume of about 60,000 cubic feet, into which such a change will bring 700 cubic feet of outside air, with all the thermal changes inherent therein.

Evaporation Relationships

Quite a different, and a vastly more complicated phase of speleometeorology is made up of the interrelationships between cave humidity, temperature and evaporation. The full significance of these relationships is beginning to be emphasized by the advanced European groups, and their papers should be consulted for the technical details (122). Not only have these relationships proven a major homeothermic influence, but under certain conditions, warm dry air entering a cool saturated cave atmosphere can cause such refrigeration through evaporation that not only can the entering air be cooled below 0°C, but enough excess cold will be produced to freeze the moisture which would otherwise condense as a result of the cooling. It is quite likely that frost-crystal grottos within certain caves may owe their source to this phenomenon, but no such studies have yet been carried out in America.

Persistence of Cave Ice

From these paragraphs, it is possible to understand the persistence and formation of ice in certain caves when moisture is present to be frozen. This discussion applies primarily to limestone caverns, from which lava tubes differ in volume, the lack of overburden, and in the relative paucity of evaporation-condensation processes, but the basic structure of basalt makes it an even better insulator than limestone.

Geographic factors are obviously of great importance, for whatever protects the cave from heat and sunlight encourages the persistence of cave ice. The nature of the interior of the cave is similarly of great importance, for an irregular, tortuous course and a narrow entrance, for example, will act as baffles to air currents. A pile of névé in the entrance will not only further this process, but due to its position, will absorb much of the heat entering the cave. It is not surprising, therefore, that most ice caves are found in areas of high elevation and latitude, with small tortuous shaded entrances facing north. Nevertheless, given sufficient winter cold, many of these factors are often absent.

The nature of the ice, too, must be considered. Even in so-called perpetual ice caves, and even at very low temperatures, its surface layers are undergoing minute but distinct alterations (76), indicating that the ice is not truly immutable and perpetual, but merely persistent. In most caves, with more transitory deposits, the changes are more dramatic. Much or all the ice may melt in late summer or autumn, and the quantity varies from year to year in relation to annual climatic variation, rainfall, plant and other cycles. This dependency upon climatometeorological factors is especially marked in the case of Sunset Crater Ice Cave, Ariz., which in May, 1949, was full of ice speleothems with a large entrance pile of névé, but in April, 1953, contained only isolated clumps of speleothems. It is probable that the only truly perpetual cave ice occurs in permafrost regions.

Meteorological Groups of Glacieres

Perusal of the data about to be presented will indicate several groups of glacieres in terms of their speleometeorology. Even though there are essentially two basic types of true ice caves, limestone and lava, their mechanisms are not necessarily identical. In the United States, the limestone type is less predominant than in Europe, where they make up the majority of the great ice caves of that continent (11). Most limestone caves, as discussed, are not only homeothermic,

Photo by Basil Hritsco

Fig. 3. The Falls, Crystal Falls Cave.

but possess an active circulation. In a temperate zone cave, an active summer circulation can only be detrimental to the cave ice which it can reach, and will insure prompt melting of winter ice deposits unless certain specific factors have a strong influence.

An entirely different meteorological group is made up of most lava tubes, some limestone caves, mines and the like, in which all or part of the subterranean cavity lacks these two features. Balch compared the circulation of these two groups as dynamic and static, but the terms have not met general acceptance. It is to this second group whose circulation may be termed *passive* that most American ice caves, belong, and these are primarily lava tubes. Every lava tube, in fact, is a potential ice cave, but the deposits in most tubes soon disappear with entry of the summer's warmth.

Lava tube patterns are innumerable, but as they are intimately related to the formation of the ice, a few typical ones will be described. Simplest is the tube sealed at both ends, entered through a collapsed portion of the roof. These are often discovered by the plume of steam marking their entrance in winter. This, of course, is the condensation of vapor in the comparatively warm cave air which, being lighter, is displaced by the heavier cold air settling into the cave. In summer, the outside air enters only through eddying and through barometric alterations. As a result, warming occurs very slowly. Since warm air is lighter than cold, stalagmites and frozen lakes are much commoner than stalactites.

These same general principles are true in tubes with a single open end, and in portions of more complex patterns. It is obvious that a small entrance and a steep slope such as Skull, Crystal Falls or Arnold Ice Cave, will favor the persistence of ice much more than a level cave like South Ice Cave, in which convection currents and barometric changes can more easily cause escape of cold air at the entrance. Similarly, in a complex pattern like Mt. Adams Ice Cave, persistent ice is limited to the lower end, whose circulation is inactive. Surprisingly, direct sunlight does not preclude persistence of ice, for sunlight strikes the ice deposit in Perpetual Ice Cave, N. M., for part of each year (25).

Yet another entirely differently meteorological group is made up of glacieres in which cold air settles along an impervious slanting surface. These are primarily the hillside type of talus glaciere. They cannot be considered to have a truly active circulation even though they possess a downward drift of cold air in summer. This group is typified by Chelan Ice Cave, Wash. It is characterized by porousness but great irregularity, a steep slope, and some sort of opening at the lower end, where the ice is best found. In winter, the cold penetrates and settles into the open spaces and chills the rock. In summer, as the outside air becomes lighter, the heavier cold air tends to descend, and following some relatively impervious layer, escapes at the lower end where a sheet of ice may extend for several feet outward from the cave. The coldness of the rocks and the large ex-

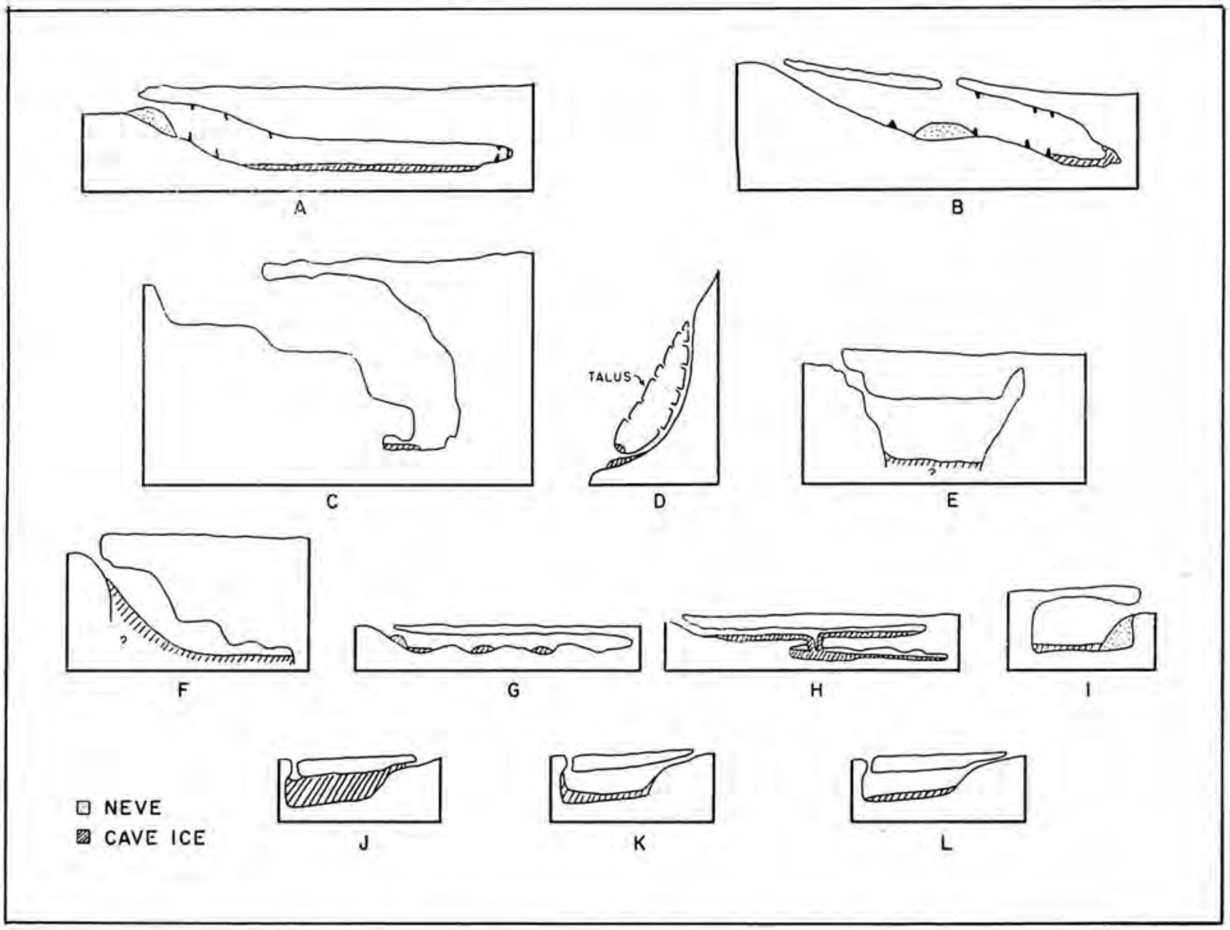

Fig. 4. Diagrammatic Sections of Glacieres

A—Sunset Crater Ice Cave
B—Mt. Adams Ice Cave
C—Skull Cave
D—Chelan Ice Cave
E—Cox Ice Cave
F—Arnold Ice Cave
G—South Ice Cave
H—Crystal Falls Cave
I—Duck Creek Ice Cave
J—Shoshone Ice Cave at time of discovery
K—Shoshone Ice Cave at time of Harrington's visit
L—Shoshone Ice Cave today

posed surface area chill the entering warm air, and it may easily be late summer before the temperature rises to the freezing point. The area involved is not necessarily large, for Chelan Ice Cave is an exaggerated horseshoe-shaped, boulder-filled depression on the hillside, measuring not over sixty feet in maximum diameter, and apparently about 6 feet in depth. Nevertheless, it is a rare summer that ice is not present in the open at its lower end, despite its western exposure and lack of protection. The Sweden Valley Ice Mine is an even more famous example of this phenomenon (50), which also appears to be of importance in certain fissures, but rarely in limestone or lava glacieres. That settling is not the only mechanism active in talus glacieres, however, is indicated by the fact that ice persists best in talus even within true ice caves. Whether this is due to insulation from air currents, evaporation relationships or other effects cannot be stated.

Talus glacieres lacking a lower egress form a subgroup somewhat similar to the lava tube group. Transitional types, however, are common in talus. As such glacieres are usually associated with gorges of some type and have common meteorological characteristics, they are included with that group in this study, as direct passive settling is their common factor.

Limestone Solution Glacieres

About 5000 limestone caves are known in the United States. Of these, a considerable but indeterminate number are so located that they inhale enough cold air each winter that ice speleothems form in their entrance and transition zones and persist a short time before melting under the onslaught of warm spring air or seasonal egress of cave air. Logan Cave, Utah, Peacock Cave, W. Va (31), and Mt. Aeolus Cave, Vt. (102) are examples of caves which fall into this group without being considered ice caves. No rigid demarcation can be made between these and the group which are on the glaciere borderline. In the latter, ice persists for a few weeks after its disappearance outdoors. Nor is it often easy to distinguish between these and the true limestone glacieres characterized by a persistence of many weeks or months. Each must be considered upon its own merits.

Major ice deposits are authentically known in about a score of American limestone solution caverns. Several of these are poorly known, not all are large, and few are true permanent glacieres, but all listed below show strong contention for consideration as significant ice caves:

1. Paris Ice Cave, Idaho.
2. Freezing Cave, Ind.
3. Decorah Ice Cave, Iowa.
4. Postville Ice Cave, Iowa.
6. Judith Gap Ice Caves, Mont.
7. Pryor Mountains Ice Caves, Mont.
8. Carlisle Center Ice Cave, N. Y.
9. Ice Cave, Galena, S. D.
10. Ice Cave, Stagebarn Caverns, S. D.
11. Gillette Canyon Ice Cave, S. D.
12. Big Brush Creek Cave, Utah, et al.
13. Duck Creek Ice Cave, Utah.
14. Skinner's Marble Cave, Vt.
15. Fossil Mountain Ice Cave, Wyo.

Paris Ice Cave (56), also known as Canyon Basin Cave (17), is an interesting example of a glaciere occurring under unusual circumstances. Located in a small, isolated outcrop of near-horizontal Cambrian limestone, it is basically a joint-controlled solution cavern consisting primarily of two parallel rooms almost a hundred feet long and half as wide, connected by a low intermediate chamber near one end of the rooms and opposite the entrance passage. At some indeterminate time in the past, the entire roof of the first room has collapsed, leaving a huge pit, and a small opening also exists in the rear of the inner room. The collapsed room now serves as a "deep freeze" in which névé persists through much of the summer to a depth of several feet, almost blocking the entrance to the inner room. Enough of an active circulation exists between these two openings, however, than by early August, 1952, the great stalactite row of the inner room had partially melted and fallen, and considerable melting of the corresponding six-foot ice stalagmites was noticeable. The portion of the frozen lake which covers the floor of this room was also partially melted along a line between the two openings, especially near the opening from the collapsed room.

The only protection afforded this unusual ice cave is that of its elevation of 7815 feet, and the consequent severe winters of that part of Idaho. Its entrances face south, and it lies in the middle of a barren "canyon basin". The accumulations of névé in the collapsed room and beneath the vertical opening in the inner room must serve as the first line of defense of the cave's ice.

Two features of the speleothems are worthy of special note. The great stalactite-stalagmite row, which comprises most of such forms in the cave, is aligned beneath the major joint of this chamber. Delicate ice crystals are to be found on the roof of a low grotto at one side of the inner room when melting is evident elsewhere. No circulation was evident here, however, suggesting that the grotto is protected from the main pattern of the cave's circulation by local factors. Origin of such crystals is discussed elsewhere.

Freezing Cave, near Elkinsville, Brown Co., Indiana, is known only from an unidentified 1896 newspaper clipping quoted by Balch (11). Recent local research by Robert D. Frederick (46), while resulting in other discoveries of interest has shed no real light on the problem. Like many other cave stories of the Gay Nineties, this may be a hoax. If so, it is skillfully done, and to err on the side of safety, it seems best to include all the data available. To quote Balch:

"The entrance is said to be overlapped with trees and to resemble a mine shaft. The winding way leads to a hollow some 15 meters below the surface, resembling a broad vaulted corridor, which is known to the natives as the devil's chamber and where the temperature is low. From this point several galleries lead further in, and from one of them comes a blast of icy cold air. This passage is similar to the one at the entrance of the cave, but after a few meters frost is visible, and further on it is thick on all sides, like the crust that is formed on the pipes of an ice plant. The narrow way leads to a big chamber, known as the ice vault. In this dome, which is fully 30 meters in width, the ice forms a large stalagmite and is of unknown depth."

This certainly has all the earmarks of a limestone glaciere, which, however, is remarkably elusive. Despite local disfavor of outsiders' cave exploration due to legends of a golden statue and other Indian treasures (46), Frederick has obtained a report from a long-time inhabitant of a nearby area:

"My parents spent the summer of 1902 on a farm in the southwest section of Indian Creek Township, Monroe Co., Indiana. This farm was the old homestead of Jacob Teague, an uncle of my father. One day while roaming through the woods on this farm, with some neighbor boys, we discovered a hole in the ground with a ladder down in the hole. Being ready to explore anything, we descended the ladder and found a good-sized room and large chunks of ice mixed in the leaves. Although this was a very hot day in July, it seemed more like a cold day in January with frost all around the walls of the room."

In another area, the search was partially successful, with the discovery of ice in a solution cavern in limy sandstone. Parts of the report of George's Pit Cave are of interest:

"The entrance of the cave is in a fallen-in room about 30 feet across. A very recent breakdown left the principal part very dangerous. It only extended about 20 feet back to the breakdown. There was evidence of snow just outside the entrance under some blocks of stone. The ice for the most part started right at the entrance. There was very little ice flow except in certain sections. It contained mostly ice formations. There were several very delicate ice flowers that at first we thought were gypsum flowers. The flow was up to four inches thick. We took the temperature and found it to be 35°F." On the other side of the fallen room was a small pit chamber with ice at the bottom, onto which a stream of rainwater was running. This is probably not a significant glaciere, but these fragmentary reports indicate that an ice cave can conceivably exist in the reputed area of Freezing Cave.

Decorah Ice Cave was formerly the best-known major American glaciere, but rockfalls have closed much of the cave and rendered the remainder too hazardous to warrant further study (105). Judging from the old descriptions (11, 78), the cave is Y-shaped, with entrances at two ends of the Y and the ice almost at the end of the other. That it is not absolutely at the end, as might be expected, would seem to be due to a tiny active circulation through an apparently closed crack, as is typical of limestone caverns. The diagram shows the ice begins to form at the end of March, reaches its maximum about June 1, and has disappeared by late summer (78).

An even more interesting ice cave north of Postville, Iowa, was recently reported and was under study when it was deplorably graded shut by self-appointed "safety experts" (30). Horizontal, it is a true solution cavern with two entrances, and at least three small rooms, though not completely explored due to the difficult conditions within. "The floor of the entire cave is ice most of the year, and ice and water the rest." One main passage was still too full of ice in Aug., 1952, to permit entry.

Photo by John H. Lincoln

Fig. 5. Closeup of ice speleothems, Mt. Adams Ice Cave.

From the brief description, a few inferences are possible. The second entrance would theoretically establish a direct, active circulation, and this appears probably in view of the melting which occurs. It may well be that the major factor responsible for the preservation of the ice is its massive volume, which fills so much of the cave. Further study may give an answer, for reopening the cave should be neither difficult nor dangerous to a trained team (30).

Frankford Cave, Mo., presents several interesting problems. Complete information is lacking, and a full-scale study would undoubtedly add considerably to our knowledge of these phenomena. Even the duration of the ice is not established. On March 27, 1949, it was several feet thick in places, on Oct. 2, 1949, none remained (33).

It is readily seen that the nature of the cave could produce unusual atmospheric conditions. The entrance is spacious, and the entrance room about 50 feet in length. A crawlway then leads to the next room, twenty-five feet in height and with two holes in its ceiling. The cave then continues about 3/8 of a mile to a second entrance through some tiny passages. A stream flows the full length of the cave. The ice deposits are found at the rear of the entrance room (33).

Other studies will be required before any definite statement may be made about this cave with any certainty. In many ways, however, the cave is reminiscent of Big Brush Creek Cave, Utah, discussed below.

Two ice caves in the Big Snowy Mountains of Montana, northeast of Judith Gap, are unromantically known as Old Ice Cave and New Ice Cave (41). The former is apparently identical with the Lewistown Ice Cave of Balch (10, 11). A nearby vertical cave known as The Chasm is not an ice cave. Both are said to be fairly horizontal solution caverns with relatively vertical entrances, and both are thought to contain perennial ice, though much is melted by Fall. Old Ice Cave consists mostly of a single room about 100 feet long and 30 feet high, with the entrance above and at one end. Névé accumulates on the entrance slope, and permanent ice is apparently limited to the floor in proximity to a spring, a phenomenon which is a great rarity in American ice caves. New Ice Cave is somewhat different. A vertical entrance leads to a crawlway which in turn leads to a room 200 feet along and 50 feet wide, where ice is found on the floor. High altitude, severe winters and lack of unusual features seem to indicate that these are classical examples of uncomplicated limestone ice caves, but more data would be welcomed.

McDonald's Ice Cave, Kane County, Utah, was reported in Dec., 1954. It is locally said to be about 2 miles west of U. S. Highway 89, just within Dixie National Forest at an elevation of about 7500 feet. It is west of McDonald's Ranch which is the first ranch north of Lava Narrows, about 7 miles north of Glendale, Utah. Described as a single deep shaft 10 to 20 feet in diameter and several times as deep, it may be merely a neigiere. According to Herbert E. Gregory (Geology and Geography of the Zion Park Region, Utah and Arizona, U.S.G.S. Prof. Paper 220, 1950), the area is in the Tertiary Wasatch limestone.

An unauthenticated report of an ice cave on Mt. Nebo in central Utah is recorded in *Technical Note No. 24A* of the Salt Lake Grotto, N.S.S., entitled Additional Caves Reported in Utah.

Several caves in the Pryor Mountains of Montana are reputed to be ice caves. Of these, at least two are authoritatively known to be glacieres, and another, a neigiere (1). Too little is known of Little Ice Cave, other than the mere presence of a large ice floor in the entrance room, to permit conclusions. Big Ice Cave is primarily "one immense room of ballroom proportions, whose floor is heavily underlaid with ice all year round. The ice floor is 25 feet thick." Frost crystals exist in some minor lower passages. Crater Ice Cave "consists of a natural arch approach and a large crater-like room hollowed out of the rock. Snow drifts into the mouth of the cave and lasts all summer." Red Pryor Ice Cave and Mystic Cave are other possible glacieres, but have not been confirmed (1). The limestone in which most of the caves in this area are located is the Madison limestone of Mississippian age (29). Big and Little Ice Caves are therefore classified as major limestone glacieres despite the lack of meteorological observations.

Balch (11) knew of the existence of the Ice Cave at Carlisle Center, N. Y., but no published description of the glaciere is apparent. It is basically a narrow horizontal cave, about 100 feet in length, but is strongly modified by the entrance collapse, which forms a steep slope. Several other small openings are present in the roof of the entrance area. Near the rear of the cave, the ceiling abruptly descends, then rises again in a chimney before again descending into breakdown (36, 45).

Conditions in the cave are apparently subject to considerable variation. In Sept., 1950, floor ice was reported present from the midpoint of the entrance room to the midpoint of the rear passage. In July, 1951, it was reported to be two feet thick, with many ice speleothems (36). On Aug. 21, 1953, no ice was present (45). Air circulation in the cave has been estimated to average nearly two miles per hour, with the current directed outward in summer (36). Dead leaves on the ice indicate that spring runoff supplies part of the ice deposit.

Carlisle Center Ice Cave thus appears to be an example of a cave with a typically active circulation, yet with a very large accumulation of ice. The circulation is just sufficient to melt the annual accumulation, as the cave was free of ice for only seven weeks in 1951 (36). The air current probably indicates that the known cave is merely the antechamber of an extensive cavern system, and that the ice is a transition zone phenomenon.

The Black Hills region of South Dakota contains several glacieres of various types. At least three are limestone glacieres. Oft-recorded but apparently unvisited for some 50 years is that at Galena. A first-hand account from one of the oldest inhabitants of the area (20) verifies it to be a small cave in limestone with a small entrance. Mrs. Borsch describes columns of ice 12 to 14 feet in length along the walls and in the center of the room when she visited it around 1900. Located in a young but thick pine grove, it is locally believed to have been blasted shut several years ago. A possibility that this may be an artificial glaciere must be admitted, as this is a mining district.

A second limestone glaciere of South Dakota has been described as follows:

"On a high limestone ridge about one mile northwest of Stagebarn Caverns is the entrance to

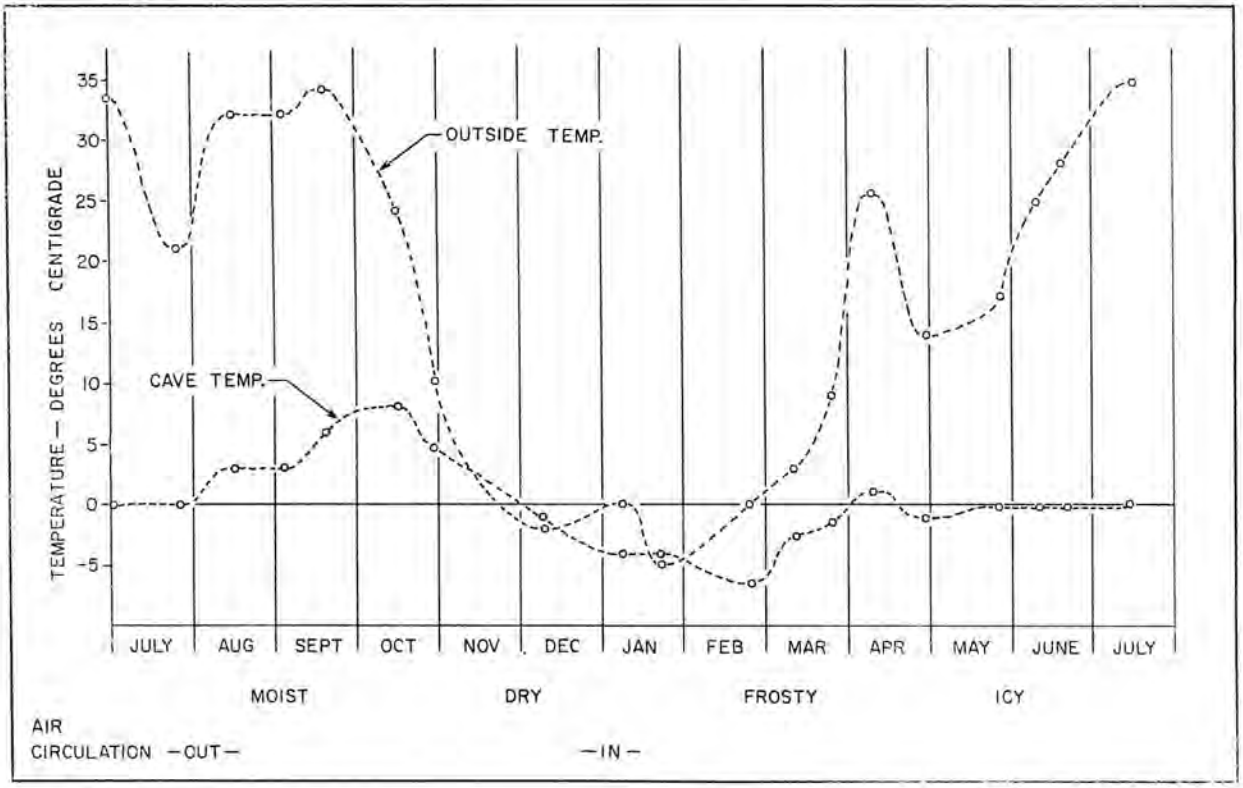

Fig. 6. Meteorological conditions in Decorah Ice Cave, Iowa (after Kovarick).

Ice Cave. The roof of the upper chamber of this cave has fallen in to form a sink about 60 feet in diameter and 20 feet deep (Plate XXI, 1). A very sinuous and boulder-strewn pasasge leads downward from the bottom of this sink for approximately 100 feet to several small chambers. The cave exhibits some crystals and a few stalactites and stalagmites, but the most noticeable feature is its low temperature. In one of the lower rooms there is a fairly large deposit of ice (Plate XXI, 2). At a point about 35 feet below the surface of the sink the temperature is low enough to cause the moisture of the air to condense and freeze on the walls of the gallery in the form of frost. The frost and ice remain in the cave during the entire year." (98).

The latter photograph shows a small flow of true cave ice. From the description, it would seem that this is a typical funnel-like pit glaciere, but its size and the coexistence of calcite and ice speleothems, a rare phenomenon, indicates that the problem is complex.

Gillette Canyon Ice Cave, in Pennington Co., S. D., is poorly understood. Consisting mostly of a single room roughly 100 by 150 feet (29), it is a limestone solution cavern at 6200 feet elevation (62). Ice is present on the floor of the center of the room each spring, sometimes forming a 20 foot column beneath a dripping point, though the ice generally disappears by late summer (29). The entrance, which faces north, is 60 feet wide and 30 feet high, and slopes down into the main cave room (62), thus suggesting a similarity to Duck Creek Ice Cave, Utah, with the larger entrance permitting entry to greater katabolistic forces.

Big Brush Creek Cave (55), in the heavily forested Uinta Mountain wilderness of northeastern Utah, at an altitude of 8140 feet, has become a truly legendary ice cave even though accessible only in late summer. This is not wholly unreasonable, for it is truly a fantastic cave. A whole canyon is swallowed in its yawning mouth, more than 200 feet in width and nearly 50 feet high. The entrance room tapers over its 300 foot length to a constriction where it is "only" 40 feet wide and 3 feet high, then opens into an equally large room. Beyond this point, the cave assumes the pattern of a three-dimensional phreatic complex of small narrow passages, heavily modified by vadose waters, and as yet far from explored. Big Brush Creek, usually dry, seasonally flows into and perhaps through the cave, which faces north, and stream deposits are everywhere. No calcareous speleothems have yet been discovered in the cave.

The writer visited this remarkable cave Aug. 24, 1952, and Sept. 7, 1953. At the time of the first visit, no ice was found. It was a great surprise, therefore, when approach to the cave 12 months later revealed a great stalagmite of ice 200 feet inside. Examination of this ice deposit, which was the only one found in the cave, revealed it to be of impressive dimensions, yet being rapidly destroyed by a continuous drip which must caused its origin several months earlier. Reaching the height of 20 feet, yet completely hollowed out by the drip, it was the central point of an oval ice sheet a hundred feet long and up to four feet thick. One edge of the great stalagmite had melted, exposing the central cavity, and a "pirated channel", representing an earlier stage of melting, led down the ice slope. A very minor channel was also melted into the ice along the margin where Big Brush Creek would be expected to flow over the deposit.

Discussion and explanation of the phenomena of this cave are hampered by the difficulty in obtaining information about their nature at an earlier season. It is evident, however, that the two entrance rooms, huge as they are, are but the antechamber to a network of smaller passages, and the cave clearly possesses an active circulation. Located as it is, it is obvious that the cave takes in an enormous quantity of cold air each winter. Considering the nature of the cave and the fact that its twilight zone is about 500 feet long, it is evident that the cave's transitional zone extends at least to the rear of the first room. Ice would be expected to form throughout the length of this zone. A few shattered remnants of ice stalactites confirm their presence early in the season. With the onset of warmer weather, normal cave circulation, eddying currents in the huge entrance, and Big Brush Creek team up to destroy the ice, first on the ceiling, and its final destruction is accomplished by the near-waterfall previously mentioned.

Two other caves a few miles to the west in an even more inaccessible area are probably very similar in the nature of their ice deposits. The few Forest Service Rangers who have reached the isolated mouths of Farm Creek Cave and of Mosby Mountain Cave report that they appear to be sizable limestone caves possessing year-round ice deposits a short distance within (55). Neither has been explored, much less studied.

Duck Creek Ice Cave, at an elevation of 8600 feet in southwestern Utah, is protected by a northern exposure and a fine stand of aspen, fir and ponderosa pine. It consists of a single large room in Wasatch limestone (51), measuring 82 by 50 by 15 feet, with a semi-vertical entrance at one side. The descent was rendered easy on July 13, 1952, by the presence of about 500 cubic feet of snow piled in and below the entrance. On that date, the walls were wet above a line about 3 feet from the floor. Below this line, they were frosty. A frozen lake several inches deep covers the entire floor of this room. A very little water was present on its surface. Later in the year, considerable melting is said to occur, and if the preceding winter is unusually mild, the lake melts entirely (124). No air currents could be demonstrated within the cave, suggesting that passive settling is the basic mechanism present in winter, and that barometric changes and convection, the main sources of ice destruction. Other minor ice deposits are known in nearby limestone and lava pits (124).

The most noted of the eastern limestone glacieres is Skinners' Marble Cave. It is small, and said to consist mostly of narrow vertical passages and a few small rooms. Located in a dense forest, facing north, and well up the slopes of Mt. Equinox, it is in an ideal location for a glaciere. Balch visited the cave, and gained the impression that it contained only snow (11). He describes only the entrance room, however, and was probably unaware of the remainder of the rest of the cave, where the walls are said to be coated with ice, which is often stratified, at all times. Clay Perry (104) believes that no active circulation is present.

Fossil Mountain Ice Cave, located at an elevation of nearly 8000 feet in the Teton Range of the Wyoming-Idaho border, is in an ideal location for an ice cave. The total absence of ice in Wind Cave, similarly located high on the west wall of glacier-carved Darby Canyon and less than a mile downstream, however, indicates that the presence of ice is due to more than factors of external location. In early Oct., 1953, following a mild winter and hot summer, truly remarkable quantities of ice were present in this little-visited cave, which is known to have been plumbed only once by speleologists (34, 35).

This solution cave, which is one of the largest in Wyoming, is probably the largest and most magnificent limestone glaciere in the United States. With ice present for nearly all of its thousand foot length, it terminates in a room some 45 feet high and 30 feet in diameter containing two great frozen waterfalls on opposite walls, a thick, smooth ice false floor, and additional deposits on the true floor level (34).

The entrance of the cave is large, measuring about 20 by 10 feet, and its height increases to a 35 foot maximum some 100 feet inside. At this point, the floor begins to assume a fairly steep slope for about 300 feet, then slopes more gently to the Cascade Room. Clear, solid ice begins to be found on the floor about 150 feet from the entrance, and becomes progressively thicker as the cave worms its tortuous way deeper into the mountain, reaching a thickness of at least five feet as it arches into the Cascade Room. Deposits of frost crystals up to 1 inch in thickness are present on parts of the ceiling of the main passage. As mentioned, a grander 30 foot waterfall, 20 feet in width, enters the Cascade Room from a small hole on the opposite wall. A small offset room 43 feet below the foot of the falls has several minor leads, but all are choked with rock after a few feet.

Meteorological conditions in the cave are puzzling. 250 feet within the entrance, the temperature was 1°C, but within another hundred feet, it became 0°, and this was maintained throughout the rest of the cave. Nevertheless, distinct currents of air could be perceived at all points in the cave, but alternating in direction from time to time. These were strongest in the broken rock area beneath the Cascades. A few unexplored side passages are known to exist. From one of these, a small seasonal rivulet has melted a trough in the ice floor of the main passage. Some melting of the larger Cascade must also have occurred, as its base is hollow. It could not be determined, however, whether this was due to atmospheric or bedrock heat transfer.

Ordinary theories of glaciere production seem poorly applicable to Fossil Mountain Ice Cave. There is no lack of moisture or of cold air, and there is evidence of annual summer melting especially in areas of heaviest active circulation, just as in other examples discussed earlier. There is every opportunity for heavy intake of cold winter air through both weight and temperature relationships. On the other hand, much the same may be said for nearby Wind Cave, which, however, is lacking the ice. To consider this to be merely the antechamber of a larger cave, as in the case of several other limestone glacieres, approaches the ridiculous in view of the speleogeology of the area. Much study will have to be devoted to this intriguing situation before a satisfactory answer can be given. Meanwhile, it is the writer's personal suspicion that the ice in this particular cave, through its great mass and tremendous potentiality of heat absorption, has been present since the Glacial Epochs, when the entire area was solidly frozen, and that today, like most of America's ice caves, its contents are delining at an imperceptible but progressive rate.

Borderline Limestone Glacieres

Of several caves which might conceivably be considered limestone glacieres, some must be included in this study out of mere courtesy, as the persistence of their ice, while of more than a few days' duration, is unremarkable. As shown earlier, it is unfortunate that no sharp line of demarcation can be made at either end of this group, so the following are included here for the speleometeorologist to judge as he may see fit:

1. Bixby Ice Cave, Iowa.
2. Freezing Cave, Ky.
3. Elephant's Den, Mass.
4. Baker Creek Ice Cave, Nev.
5. Beer Cave, N. Y.
6. Benson's Cave, N. Y.

Bixby Ice Cave is a small, steep, pit-like 20 foot limestone passage in Edgewood State Park, Iowa, in which snow and ice remain until midsummer (40), probably as a simple pit glaciere. Apparently an insignificant site, it appears to be identical with Balch's (11) Brainerd Ice Cave.

Freezing Cave, Ky., is apparently well known, yet so little authentic information can be obtained about its features that it cannot be included in a list of glacieres with certainty. It is said to be a true solution cavern with a deep vertical entrance and a "maze of passages" below (90). Enough ice to supply the vicinity at least in early summer is reported, but a cursory examination in late summer (61) failed to reveal ice deposits. It may well prove to be similar to Wilson Cave, Ky., which was recently reported (12) to possess rather massive ice speleothems in late winter in its domepit entrance room. This is undoubtedly a brief middle zone phenomenon, and Wilson Cave is not locally considered a glaciere.

The remarkably named Elephant's Den is a small solution cavern, about 100 feet in length, in which ice may be found on the walls until early May. It appears to have an active circulation, and the small entrance and severe winters are probably responsible for this transient ice (102, 104).

Ice Cave, in White Pine Co., Nev., is part of the incompletely known Baker Creek limestone solution complex. Greatly exaggerated tales of its ice deposits are told, but while considerable ice was found in March, 1952 with wintry conditions outside, only a single three-inch floor patch in a sheltered room was to be found July 4, 1953, and none at all at the end of the summer of 1952 (54).

Three rather varied descriptions of Ice Cave or Beer Cave at Watertown, N. Y., are to be found in the three references available (11, 67, 103). Balch, visiting the cave Sept. 12, 1898, after a hot summer, was totally unimpressed and does not even include it as a cave, but as a fissure. The other descriptions, however, leave no doubt that it is a true limestone cave of considerable length even if low and narrow, and ice speleothems persist for some time, though melted by late summer. The earlier statement that "when the temperature in the shade was 92°, that at the mouth of (this) cave was 32°" seems more reasonable than the later statement that it is "approximately 40° the year round". Hough mentions a current of air passing outward in summer, and Perry calls it a blowing cave. It does not appear to qualify as an important ice cave.

Benson's Cave, in Schoharie Co., N. Y., is an extensive series of narrow passageways in Manlius limestone, which have recently been discovered to connect with Secret Caverns. A deep crevice, 40 feet long and 4 to 10 feet wide, just within the entrance, is said to contain cave ice until July (45), and before the forest cover was cut, until late summer. This, however, does not appear to qualify Benson's Cave as a glaciere, and it is not so known locally.

Anomalous Sites

1. Rifle Canyon Ice Cave, Colo.
2. Swan Lakes Ice Cave, Idaho.

These two sites must be so designated because they are only incidentally in "lime rock", and yet in some ways they resemble other limestone glacieres more closely than other groups. The Colorado site proved to be a transient glaciere in a high region of bitter winters, usually without ice by mid-summer. Originally a long shelter at the base of a limestone cliff, it has been converted into a kind of a cave, open at each end, by a massive stalagmite-like mound of travertine, deposited by a seasonal waterfall. Cold air is trapped in the resulting pocket, and the source of water appears to be the waterfall.

Photo by Howard Jackson

Fig. 7. The ice slope in Arnold Ice Cave.

Swan Lakes Ice Cave is one of the most unusual caves ever visited by the writer (56, 59). It is in travertine rather than limestone, and is so located in the base of a huge ancient hot spring terrace as to leave no doubt of its thermal origin. On Aug. 23, 1953, following a mild winter and blazing summer, two deposits of clear ice of uncertain but considerable depth were found in the deepest depressions in the cave, less than 15 feet from the surface. Remarkably abrupt climatic changes were encountered in this short descent. The narrow vertical entrance was pleasantly cool and moist, with maidenhair fern growing in small niches. The main portion of the cave resembled any limestone cave in both temperature and decoration, with incipient stalactites and much flowstone evident. This room, parallel to the terrace face, is about 10 feet wide, 6 to 10 feet high, and about 75 feet in length. In two areas along the rear wall, a narrow drop of about 4 feet leads to the tiny lower levels containing the ice. Some melting was evident, even though the temperature in these recesses was much colder than in the rest of the cave. This melting water drains into a minute space between the ice and the rear wall. A six inch column of ice connects the low ceiling at one end to the frozen pool, but also showed signs of melting.

Due to their relative paucity, practically no study has been devoted to the meteorology of travertine caves. While many of their characteristics are similar to those of limestone caverns, the differences in composition of the two substances will almost certainly preclude their being speleometeorologically identical. Swan Lakes Ice Cave, therefore, must be considered an anomalous site. The melting evident indicates that it is a glaciere at the critical point. As in many of its limestone analogues, its ice appears to be the result of settling of the winter's cold, where the ice, nearly filling the small recesses at the lowest point, regulates its own environment to a considerable degree. It seems unlikely that the ice would recur if the entire deposit were removed.

In summary of the reported limestone glacieres of the United States, we may thus say that two types are encountered. One type possesses little or no active circulation, and the other possesses an accumulation of ice so great that the active circulation is unable to melt it in proportion to the out-of-doors thaw. Some, at least, of this second group represent the middle zone of a large cavern system. In most cases, both processes are present, but one predominates.

Lava Tube Glacieres

Lava tubes make up the majority of the ice caves of the United States. Discussed in theory earlier, they are so numerous that it seems better to merely list those reported, and to discuss only a few which illustrate pertinent points or pose interesting questions. This group includes:

Sunset Crater Ice Cave, Ariz.
Government Cave, Ariz. (26)
Lake Mary Ice Cave, Ariz. (26, 107)
Ice Cave, White Mountains, Ariz. (11)
(Two) McCloud Ice Caves, Calif. (37)
Eagle Lake Ice Cave, Calif. (97)
Wilson Lake Ice Cave, Calif. (97)
(Twenty-seven) Ice Caves, Modoc National Forest, Calif. (92, 97)
(Three) Ice Caves, McCloud Ranger District, Calif. (85, 113)
Skull Cave, Calif.
Merrill Ice Cave, Calif. (77)
Cox Ice Cave, Calif.
Bearpaw Ice Cave, Calif. (77)
Crystal Cave, Lava Beds, Calif.
Frozen River Cave, Calif.
(Two) Caldwell Ice Caves, Calif. (77)
Dragon Head Cave, Calif. (77)
Heppe's Ice Cave, Calif. (77)
Indian Well Cave, Calif. (77)
Shoshone Ice Cave, Idaho
Crystal Falls Cave, Idaho.
Great Owl Cave, Idaho (114)
Last Chance Cave, Idaho (114)
Boy Scout Cave, Idaho.
(Two) Ice Caves, Craters of the Moon, Idaho (114)
Dewdrop Cave, Idaho.
Surprise Cave, Idaho.
Perpetual Ice Cave, New Mex. (25, 42)
Arnold Ice Cave, Ore.
Edison Ice Cave, Ore. (32)
South Ice Cave, Ore.
Surveyor's Ice Cave, Ore. (32)
East Ice Caves, Ore. (21)
Matz's Ice Caves, Ore. (32, 52)
Fillmore Ice Cave, Utah (14)
Mt. Adams Ice Cave, Wash.

As indicated, four of these are known in Arizona. The 200 foot ice cave at Sunset Crater faces west and has neither forest cover nor large annual rainfall, so it is not surprising that all of the large spring accumulation, except for a few floor deposits, has usually melted by autumn despite partial protection by névé in the narrow entrance. Though at 7000 feet altitude, the area is really hot in summer. Government Cave, some 20 miles to the west, formerly contained massive ice deposits, but these were removed for local consumption, and have not reformed in any quantity except amid some talus (26). The Ice Cave south of Flagstaff reported by Balch, and Renoe (107), is now submerged by the waters of Lake Mary (26). No information has been obtained on the ice cave reported by Balch to be in the White Mountains, but the original description (11) and the lack of other types of caves in this range seem to place it in this group.

Forty-six such caves are presently known in California, more than any other state, and these are limited to its northeastern corner. Five are known in the McCloud area (37, 113) and twenty-seven on the Modoc National Forest (92). Little data is available on any of these or on those near Eagle and Wilson Lakes (97). Those of Lava Beds National Monument are better known. Twelve of the 297 caves there are apparently true ice caves, and, due to the 4000 foot altitude with its severe winters, many of the others like Indian Well Cave contain transient ice. The Monument staff classes them in three groups (77):

1. Major: large deposits or speleothems.
2. Minor: small domes or lakes.
3. Natural bridges: small deposits in low or sheltered points.

The major ice caves of the National Monument include Crystal, Skull, Merrill, Bearpaw and Cox's Ice Cave. Frozen River, Upper and Lower Caldwell and Dragon Head Caves are minor, and Heppe's and Upper Ice Cave are members of the third group, which, due to the expected active circulation, contain the least ice (77). Magnificent, multilevel Crystal Cave is about 800 feet long and 100 feet deep, and is specially noteworthy for its enormous deposits of ice crystals, often two inches in diameter, which eclipse its ice domes, columns, waterfalls, stalactites and stalagmites. Oddly, the domes are found near the bottom of the cave, the crystals on the roof of certain intermediate passages, and most of the other speleothems in the passage near the cave's vertical entrance. It is certainly worthy of exhaustive study.

Idaho ranks second among the states in the number of its ice caves. Craters of the Moon National Monument alone has been said (89) to contain fifteen, but closer examination of the original reference (114) shortens the list. As would be expected, most of the lava tubes in this high area contain transient ice, but Great Owl Cave is probably the only one in which it is near-permanent (27). Last Chance Cave and two undesignated ice caves are said to contain quite persistent deposits (27, 114). On Sept. 2, 1952, Boy Scout Cave contained a thick floor deposit of ice, overlain by meltwater. At the same time, Dewdrop Cave contained some two cubic feet of solid ice in protected corners amid talus at the deepest part of its single room, as did Surprise Cave. Beauty Cave was found to contain only a little ice at the bottom of contraction fissures about 5 mm wide and 20 cm deep. The 30 foot deep Crater Funnel "Ice Cave" near Big Crater was found to be bare even of the névé which it is said to store in early summer (114).

Shoshone Ice Cave, Idaho, presents an excellent illustration of the delicate balance of features permitting persistence and formation of cave ice. The cave has been known and visited for many years, and a comparison between the early description (82), that of Harrington in 1934 (63) and the cave as it is today is very revealing.

Shoshone Ice Cave is located in the midst of a sparsely vegetated lava plain in a region of climatic extremes. The ice cave is one of a series of caves remaining after intermittent collapse of a large lava tube, which was about 30 feet in diameter and about a mile in length. The glaciere is about 500 feet in length.

When the cave was first discovered, only a small entrance existed among lava talus, and the entire cave was filled with solid ice to a point a few feet inside. Settlers enlarged the entrance to facilitate removal of the ice, "an entrance was made in the ice and ladders put in. Sometimes the ladders would get coated with ice again, but as air began to circulate, the ice retreated" (82). Despite these warning signs, promoters further enlarged the entrance as a tourist lure. ". . . in 1929 . . . the front portion had no ice except on the floor . . . with portions of the floor covered by unfrozen water. At that time the rear of the cave was entirely blocked by ice, from floor to ceiling. But the wall of ice gradually receded through the years" (82). When visited by Harrington, it had receded beyond the small ceiling opening at the rear of the cave, but the ice floor and wall were intact. On Sept. 3, 1952, an extensive ice floor was present beneath several inches of water, but this was locally said to be completely melted by the end of most summers.

This evidence of the katabolistic effect of circulating air is so plain that the local inhabitants are entirely aware of the chain of events, and have neither evolved the odd legends usually associated with such a cave nor adopted Harrington's erroneous theory which implied that the ice present in the cave was the result of circulating air. Even the shape of the ice body shown in his sketch of the cave is evidence of melting as a result of circulation between the entrances. It is entirely possible that occlusion of the small rear entrance might result in re-establishment of much of the cave's former magnificence. If a trapdoor were used, and left open in winter, the result should be promptly evident. The project would at least be a harmless, worthwhile experiment.

Crystal Falls Cave indubitably ranks as one of America's two finest lava glacieres. Entered through a steep, doubly constricted entrance, it consists of a double level lava tube measuring about 900 feet in length, with a connecting pit near its midpoint. On July 5, 1953, the first ice was encountered within 100 feet of the entrance, and almost the entire remainder of the upper level was floored with ice. Water was present atop the ice for about 300 feet, ranging from one to six inches in depth. That this melting was due to atmospheric changes and not to warming of the bedrock was demonstrated by the location of the melting, which was practically absent along the walls. The great ice cascade which gives the cave its name is only one of several formed at the lip of the two-level pit, but is the only one in actual continuity with the frozen rivers, in this case, the upper distal river. The base of this great cascade almost completely seals off the main passage of the lower level, which may be entered through a small hole between the cascade and the wall. This leads down a short slide to the first of several chambers characterized by a totally smooth ice floor and ceiling masses of huge frost crystals. The individual plates in many cases reach a width of 8 inches, and a few are even larger. The ice here is of unknown depth, and the lower level ends by sinking into the ice. The other end of the lower level is quite short, and may be reached by a dangerous 30 foot slide beneath another ice cascade. The temperature of the lower level was 30°F, and the only evidence of any melting was that induced by carbide lamps. Other nearby caves are known to contain lesser deposits of ice, notably the "Ice Cave" one mile away which is indicated by road signs.

A single group of lava tube ice caves in New Mexico is the only occurrence of this type known east of the Continental Divide. Perpetual Ice Cave is well known, having been developed and publicized by the state. Here in a short tube with a large but high mouth is a large block of ice against the rear wall, whose size is said not to vary perceptibly despite direct sunshine in some winter months (25). Other similar caves are reported nearby.

Oregon is well supplied with ice caves. Arnold Ice Cave in former years supplied all the ice used by the city of Bend (21). Its small entrance leads immediately to a beautiful but dangerously steep ice slope, thence to an ice floor about 70 feet long, fifteen feet wide and of unknown depth, completely filling the cave at the rear. It is located at the lower and of a large lava sink, and is thus assured of a considerable supply of moisture. Edison Ice Cave is not known to have been visited in recent years. It is reported to have a small vertical entrance and a great quantity of névé and ice (32). South Ice Cave is about 300 feet long, and in April, 1951, contained many ice stalactites and a large pool, plus less common forms like baconrind draperies and helictites. These, however, were obviously transient. Two large stratified domes are present in small depressions further back in the cave. Our guide noted that that had shrunk perceptibly in the thirty years since he had first seen them, and this, plus the inward draft perceptible well back in the cave, indicate that this cave is at the critical point. Surveyor's Ice Cave is apparently quite similar (32). East Ice Caves (21) and Matz's Ice Caves (32) are probably identical. Unfortunately, nothing seems known of them except their existence (32). Many of the other lava tubes of this area contain notably transient ice. Malheur Cave (28), Lava River Cave (32), and Wind Cave are especially noteworthy in this respect.

The Ice Cave west of Fillmore, Utah, seems to be a short segment of lava tube in pahoehoe quaternary basalt (14), but it may actually be a sink in basalt talus like the nearby Ice Spring (49, 109).

Numerous ice caves are reported in Washington, but only in one area are any known to be true caves. These are Ice Cave, twenty-five miles north of White Salmon, just west of Guler and Trout Lake, and south of Mt. Adams, and some other less well known nearby tubes. The main cave is immortalized on maps of the area by the overlying Ice Cave Forest Campground. It is a classical lava tube, divided by collapse into four sections. The ice is limited to the lower section, which is about 200 feet in length. The main entrance consists of a hole in the roof, but the upper end of the segment is also open, permitting a perceptible draught. The draught, however, apparently does not reach the lower end of the cave, the floor beneath the pit-like main entrance, or two side passages, and these are the sites of the persistent ice. When visited in the mild October of 1950, the ice showed evidence of much melting, but was still massive, and the pile of névé below the main entrance was several feet thick.

Some special features of this cave are worthy of note. As mentioned, there are two side passages which branch off the main passage between the two entrances. They are below the level of either. One of these terminates in a small hole leading upward at a sharp angle, completely filled with cave ice, and the adjoining floor is completely coated with ice for about 5 feet. Beyond this point, the floor and walls are moist. Frost crystals were found on the ceiling here, as well as on the ceiling at the lower end of the cave. The other side passage, nearby but not connected, is an unusual room, completely dry and with a flat floor, the refuge of hundreds of hibernating harvestmen. The entranceway is a narrow passage amid lava talus, and though the adjacent walls are wet, the talus is intermingled with clear ice. Earlier in the summer, fine transient ice speleothems are present throughout the cave. This unusually accessible cave should prove an excellent laboratory for the study of many of these unexplained phenomena.

Other Subterranean Ice Deposits

As previously mentioned, other natural glacieres exist besides those in true caves. For the sake of convenience, this group may be arbitrarily divided as follows:

1. Glacieres in fissures and sinks.
2. Talus and/or gorge glacieres.
3. Fissure or talus glaciere, too poorly known to classify.

It should be recognized at the onset that this classification is, of necessity, arbitrary and subject to the inaccuracies imposed by incomplete data. Others may well place a specific cave in another group on the basis of their own experience. Nevertheless, it will at least serve as a satisfactory guide if it is remembered that the subgroups tend to considerable overlap and combination, and that great accuracy in differentiation has not been desired in this study.

Fissure and Sink Glacieres

Permanent or semi-permanent ice deposits in fissures and sinks include a heterogenous group. In some cases, they are barely distinguishable from those in gorges, talus, and even lava tubes. Without exception, they occur at a high elevation, with the usual protective factors compensating for their somewhat exposed circulation. The following are currently included in this group:

1. Cow Mountain Ice Cave, Colo. (111, 112)
2. Williams' Freezing Cave, Williamstown, Mass. (11)
3. Mt. Toby Ice Cave, Sunderland, Mass. (104)
4. Northfield Ice Cave, Mass. (73)
5. Little Bitterroot Canyon Ice Cave, Mont. (68, 69)
6. Johnson Mesa Ice Cave, N. M. (118, 121)
7. Sierra Negras Ice Cave, N. M. (42, 53)
8. Syracuse Ice Caves, N. Y. (66)
9. Chimney Mountain Ice Caves, N. Y. (79)
10. Snow Hole, N. Y. (11)
11. Ellenville Crevice, N. Y. (44)
12. Cherry Valley Ice Cave, N. Y. (45)
13. Snow Cave, N. D. (29)

Photo by U. S. Forest Service

Fig. 8. Six-foot ice stalagmites in Badger Tunnel near Ophir, Colorado.

14. O'Brien Ice Cave, N. D. (29)
15. Sink at Summit, Penna. (11)
16. Sink at Coaldale, Penna. (11)
17. Sink in Sullivan Co., Penna. (11)
18. Sink in Lycoming Co., Penna. (11)
19. Hell's Half Acre, S. D. (29, 119)
20. Sinks in Bear River Range, Utah. (124)
21. Ice Spring, Utah. (49, 109)
22. Cave of the Winds, Mt. Mansfield, Vt. (73)
23. Sink at Crowder Cave, W. Va. (31)

Talus and Gorge Glacieres

On theoretical grounds, it would seem better to separate the talus from the gorge glacieres, and subdivide the talus glacieres into those in which the cold air settles to an impermeable layer and stops, in contrast to those in which settling occurs along an inclined barrier, with the "ice cave" at or near the lower egress. This, however, is beyond the scope of this paper, and probably of speleology in general. Perhaps it will be attempted by some future investigator more interested in the ice than the cave. It is probable that this type of glaciere is actually widely distributed, but is taken for granted in most sections of the United States. The talus and gorge glacieres which have been reported to date are the following:

1. Ice Cave, Palmer Lake, Colo.
2. Salisbury Ice Gorge, Conn. (74)
3. Meriden Ice Gorge, Conn. (74)
4. Northford Ice Gorge, Conn. (74)
5. Talus at Mt. Abraham, Maine. (11)
6. Icy Glen, Stockbridge, Mass. (11, 102)
7. Icy Gulch, Great Barrington, Mass. (11, 102)
8. Polar Caves, Mt. Woodstock, N. H. (11)
9. Talus at Carter Notch, N. H. (89)
10. Talus at Mt. Garfield, N. H. (11)
11. Randolph Ice Gulch, N. H. (11, 102)
12. Rumney Ice Gulch, N. H. (11)
13. Talus in King's Ravine, Mt. Adams, N. H. (11)
14. Ice Hole, Dixville Notch, N. H. (11, 102)
15. Van Horn Ice Cave, N. J. (71)
16. Bonticou Point Ice Caves, N. Y. (4, 103)
17. Ellensville Freezing Gorge, N. Y. (11)
18. Ice Cave Mountain Cave, Old Forge, N. Y. (103)
19. Stony Clove, N. Y. (103)
20. Deep Hollow, Lexington, N. Y. (103)
21. Hell Hollow, Putnam Co., N. Y. (103)
22. Haines Falls Ice Gorge, N. Y. (11)
23. Ice Caves, Lower Ausable Pond, N. Y. (11)
24. Talus at Giant of the Valley, N. Y. (11)
25. Talus at Indian Pass, N. Y. (11, 103)
26. Talus at Avalanche Pass, N. Y. (11)
27. Talus at Panama Rocks, Chautauqua, N. Y. (11)
28. Talus at Glen Park, Watertown, N. Y. (11)
29. Ice Cave, Luzerne Co., Penna. (11)
30. Sweden Valley Ice Mine, Penna. (2, 11, 101)
31. Paradise Furnace Ice Cave, Penna. (101, 117)
32. Pittsford Ice Cave, Vt. (65, 74)
33. Pownal Snow Hole, Vt. (74)
34. Wallingford Ice Bed, Vt. (11, 48)
35. Talus at Mt. Horrid, Vt. (102)
36. Chelan Ice Cave, Wash.
37. Smyrna Ice Cave, Wash. (47, 94)
38. Lake Lena Ice Cave, Wash. (94)
39. Ice Cave, Droop Mtn., W. Va. (31)
40. Talus at Ice Mountain, W. Va. (11, 74)

Unclassified Natural Glacieres Which Are Not True Caves

A few obviously natural glacieres are so little known that attempted classification would only be futile. Those which seem to be safely excluded from the limestone or lava groups are as follows:

1. Ice Cave north of Hayden, Colo. (110)
2. John Burroughs' Ice Cave, Slide Mtn., N. Y. (22, 103)
3. Mt. Pisgah Ice Cave, Wyo. (43)
4. Coralls Caves, Wyo. (43)

Description of Fissure Glacieres

Although the present status of the cave is uncertain, the history of Cow Mountain Ice Cave is an interesting footnote to the history of Colorado as well as an interesting contribution to speleometeorology. Reference to the original accounts (111, 112), recently reprinted (57), is well worthwhile. It appears to be a fissure cave, probably on a rhyolite-granite contact. Discovered in 1897, the mine shaft which opened the cave apparently established a circulation which melted much or all of the ice in about 3 years. If it is ever possible to reopen the cave, it will be of real interest to observe the degree of re-establishment of the deposit.

Williams' Freezing Cave and the Snow Hole, just across the state line in New York, are unusual fissures in a dark grey slate. The former consists of a narrow slope, half covered by an imperfect roof. After a steep 50 foot descent, holes at the bottom of the passage are said to lead to a lower chamber where the ice is found (11). Snow Hole is a simple unroofed fissure (11). These sites appear to be classical pit glacieres, the former complex, the latter, simple.

The "Ice Cave" of Sunderland, Mass., is a partially closed fissure in conglomerate. Each spring, fine ice speleothems are reported formed in a small protected grotto within the fissure (104). That at Northfield seems similar, but perhaps should be classified as a talus cave. Described as "a vertical crevice in tumbled conglomerate rock, about 2 feet wide, 8 feet deep and 12 feet long", it contained a foot of clear ice on July 1, 1930 (73). It is well shaded by evergreens and the slope of the hillside.

The Ellenville Crevice is a fissure in siliceous conglomerate about one-half mile long and up to 120 feet deep (44). Divided into a series of pit caves by talus accumulations, an 8 inch thickness of ice was found on the wall of several such cavities in May 1953, and a thick floor of ice was reported in one in Sept., 1952.

Cave of the Winds, Vt., is a partially talus-filled, narrow fissure about a hundred feet deep, containing much snow in its upper portion until July (73, 102). At the bottom, a sloping ice floor about 200 feet long, 2 feet wide and 12 feet thick was observed in the summer of 1933. The descent is one of the most difficult in New England, and has been made only a few times.

A Specific Type of Fissure Glaciere

The Montana, New Mexico and North Dakota sites appear to have been formed as long fissures parallel to a canyon or mesa wall, by slumping of the rimrock. They therefore resemble talus caves in many ways. The Montana cave is in sandstone (68). In some ways, its morphology is unusual, and reference to the source material is advised for the speleometeorologist. The ice is present on the surface of walls, and intermediate ledges, but apparently not in the lowest portions, which, however, are so difficult and dangerous of access that full exploration has not been accomplished (69). It is suspected that the main cave circulation bypasses the entrance area.

The Sierra Negras Cave is somewhat similarly open to wind currents in its upper portions, so that no ice was found at a depth of 50 feet (53) while it is reliably reported at a depth of 110 feet in the mid portion of the fissure (42,124). Johnson Mesa Ice Cave is somewhat different, possessing major openings at each end, with a protected central region. The upper entrance is some 50 feet above the lower, and is so arranged that considerable snow accummulates in its sink-like mouth each winter (121). A deep sheet of ice, banded with seasonal surface debris, has developed along the slope, reaching a thickness of 8 feet. This is locally known as the "Talmadge Glacier", after Dr. S. B. Talmadge, formerly of the New Mexico School of Mines, who first noted evidence of its plasticity and flow (118). While unusual, this is by no means a unique phenomena, being common to sloping deposits with an active source, such as Arnold Ice Cave, Little Bitterroot Canyon Ice Cave and others. The fact that considerable melting occurs each year (118) enhances the process.

Snow Cave, N. D., appears to be a neigiere rather than a glaciere, but is typical of this group

Photo by Basil Hritsco

Fig. 9. Crystal grotto behind Falls, Crystal Falls Cave.

although one of the smallest. "The cave is a fissure caused by a mass breaking away from the rimrock cliff of Black Butte, the highest point in North Dakota. The entrance is near the top of the cliff in the middle of the southeast side of the butte, and is partly roofed by blocks of talus. It is about 40 feet deep, 60 feet long at the top, and 20 feet long at the bottom. The width varies from 4 to 10 feet. The rimrock is hard, fine-grained sandstone of the White River formation (Oligocene). It is continental in origin, and is mostly crossbedded with occasional stream channels.

"The cave only reaches twilight. It is known for the accumulation of winter snow which persists roughly until July according to local information. This roughly depends upon the amount of snow trapped in the fissure. Last winter was very mild, and this year (1953) it contained little ice. Its position on the cliff and many openings allow air to circulate through it freely" (29).

O'Brien Ice Cave is similarly "formed by block fracturing and breaking away of rock from a 60 foot cliff of hard, calcareous buff sandstone (Sentinel Butte member of the paleocene Fort Union formation). The depression leading into the cave acts to accumulate and funnel snow and meltwater inside. The sheltered position of the entrance, which faces west, serves to preserve the ice" (29). On September 6, 1953, Danehy found a 3 foot thick floor deposit of ice within the cave, which is only 4 feet wide, 8 feet high and 25 feet long. The entrance measures about 3 by 5 feet, and is about 15 feet above the level of the ice (29).

Hell's Half Acre seems to be a similar type of glaciere, but its rugged nature and the isolated terrain have prevented satisfactory study. Danehy reports it to be somewhat like O'Brien Ice Cave, but on a much greater scale. He noted no ice in its upper portions in September, 1953, but felt that it might well exist in the depths below (29). It is locally reputed to be a glaciere (119).

The exact status of the Ice Caves near Syracuse, N. Y., is not completely clear. Some, at least, seem to be open fissures in Onondaga limestone, acting as pit glacieres. The only known reference is the following (66):

"Some of these fissures are open enough at the top to permit large quantities of snow to enter them during the winter months, and remain in the form of snow and ice during the greater part of the summer, forming what is locally known as the "Ice Caves". These occur in the cliffs around Blue Lake and at the Split Rock quarries".

There has long been discussion of the exact nature of the ice caves on Chimney Rock Mountain, N. Y. They have been variously considered as limestone, talus, fissure and gorge caves. Located as they are in the highly mixed beds of the Grenville formation (79), detailed studies reveal them to be deep fissures irregularly filled with talus (79). The studies describe "large joints, some of which are 60 feet in depth and 30 feet wide across the top, extend(ing) for 200 to 600 feet along the strike. They are frequently filled with ice and snow the year round and are also partially filled with . . . blocks which have fallen into them".

Sink Glacieres

Névé persists, and ice forms and persists in the deepest, most sheltered part of many sinks, regardless of their origin. Volcanic funnels and other blind pits have a very similar form. The first two Pennsylvania sites listed were formed by the collapse of coal mine tunnels. The second has ceased to be an important glaciere by 1900 (11). The next two reported in that state are typical limestone sinks in which ice persists for an indeterminate period (11), and that in West Virginia (31) is apparently quite similar. Cherry Valley Ice Cave contains about two feet of clear ice at the bottom of fissures averaging 2½ feet wide and 13 feet deep at the bottom of its 9½ foot solution sink hole in Onondaga limestone. "Due to the extremely hot and wet spring this year (1952), this and two other ice caves in New York state lost their ice in early July. The other caves usualy hold ice until late August and sometimes the year round. That leads me to believe that this would hold ice until late summer in a normal year" (45). A small crawlway 42 feet long leading from the base of the sink is said to contain a few stalactites but no ice. The two Utah reports, near Tony Grove Lake and Beaver Summit, are unauthenticated. All of this group occur high in the mountains and act simply as pits into which cold settles. The Ice Spring west of Fillmore, Utah, occurs in a lava flow containing tubes, but descriptions suggest that it is a sink-like depression instead (49, 109).

Description of Talus and Gorge Glacieres

While many of the caves in the talus-gorge group contain major ice deposits, in many others, the ice and snow linger only briefly after their disappearance outside. Perhaps most of this group are worthy of speleologists' or spelunkers' visits. Nevertheless, the prime reason for their inclusion in this paper is to spare the caver disillusionment if he is expecting typical limestone caves.

Chelan Ice Cave, Wash., has already been described. A typical example of the other type of talus cave is that of the "ice caves" in Indian Pass, N. Y. (96):

"Indian Pass is located in the central part of the Adirondacks at latitude 44° 8′N, longitude 74° 2′W. It is a narrow defile between Wallface Mountain and the MacIntyre Range. According to Kemp, Geology of the Mt. March Quadrangle, New York State Museum Bulletin 229-230, 1921, it is one of a group of parallel depressions formed by block faulting. The trend of the pass is northeast to southwest. The northwest side of the pass is the sheer southeast face of Wallface Mountain. The pass is notable for the profusion of large blocks of anorthosite which appear to have fallen from the cliffs of Wallface. Some of these blocks are 20 or 30 feet in diameter. The blocks are heavily coated with moss and trees grow from the tops of many of them. The elevation is about 2900 feet above sea level. The sun reaches the floor of the pass for such a short time of the day that the flora is similar to that 2000 feet higher on the nearby mountains. Labrador tea and yellow clintonia were in bloom there on July 21st.

"Between and under many of these large boulders are caves. Ice is found in several of these caves in July and August. I visited the caves on July 21, 1953. Ice was found in six places in about half an hour. Time was too short to make a thorough search. In one case, the sloping opening of the cave was about 5 by 6 feet and faced northeast. About 7 feet down was a floor 6 by 18 feet covered by ice which appeared to be about a foot thick. The air temperature in a corner about 6 inches below the top of the ice was 60°C. Another cave had a small entrance leading about 8 feet down into a small room about 4 by 6 feet. A crack about a foot wide and 5 feet high extended about 20 feet from this room. The floor of this crack was covered with ice on top of which lay about 5 inches of water."

It is neither worthwhile nor desirable to fully describe all the glacieres in this group. Worthy of brief mention are Palmer Lake and Pittsford Ice Caves, which consist of talus filling gorges. Of the gorges in the list, only the three in Connecticut and the Snow Hole appear to be unassociated with some talus. Sweden Valley Ice Mine and the Ice Cave west of Smyrna, Wash., are locally notable artificial excavations into cold-bearing talus, or perhaps fissures in the case of the latter (47, 94, 101).

Van Horn Ice Cave, a depression in talus beneath a cliff, may be identical with either or both the "Ice Hole on Blue Mountain" or the "Ice Cave in Sussex Co. on Peter Feather's farm", rumors of which were recorded by Balch (11).

Of the natural glacieres which have not been classified due to the lack of data, the Ice Cave north of Hayden, Colo., is included as a non-limestone glaciere due to regional geology. John Burroughs' Ice Cave is probably talus. The first Wyoming site is described (43) as "subterranean passages . . . contain(ing) ice throughout the year", the second as "crevices in the cliffs . . . retain(ing) snow and ice until midsummer". The chance of either being a true cave seems remote.

Glaciere Mines

Ice-forming mines and tunnels are probably quite common in cold climates, but are little known and rarely described. Probably the best-known American study is that of McNair (86). Dozens, perhaps hundreds, exist in Colorado alone. In general, they are deep, but not so deep as to be affected by the geothermal gradient, and they essentially lack an active circulation. Meterorologically, two types exist. In the first type, the bedrock never thaws, and ice deposits consist of frost crystals on the ceilings and upper walls, formed directly from atmospheric moisture. The other type is actually a pit glaciere, trapping cold air so that moisture trickling from the bedrock is frozen into typical speleothems. In such mines, thermostratification is often evident, so that only stalagmites and frozen lakes are present. The best-known sites appear to be the following:

1. Hilltop Mines, Colo. (86, 87)
2. Other Fairplay and Leadville area mines, Colo. (86, 87)
3. Mines in Montezuma area, Colo. (87, 124)
4. Sunnyside Mine, Colo. (87)
5. Mines on Mt. Lincoln, Mt. Bross and Mt. Cameron, Colo. (87)
6. Hagerman Pass Tunnel, Colo. (11)
7. Mt. McClellan Ice Cave, Colo. (11)
8. Tunnel near Ophir, Colo. (108)
9. Mines at Victor, Colo. (124)
10. Icy Mine, Little Wolf Mtns. Mont. (11)
11. Grafton Mine, N. H. (5)
12. Port Henry Mines, N. Y. (7, 74)
13. Mine at Graphite, N. Y. (72)
14. Bull Mine, Monroe, N. Y. (44)
15. Ellenville Mines, N. Y. (103, 104)
16. Rosendale Cement Quarry, N. Y. (103, 104)
17. Englewood Ice Cave Mine, S. D. (29)
18. Mines at Alta, Utah (124)
19. Silver Mine, Brandon, Vt. (11)
20. Mine near Big Four Inn, Wash. (124)
21. Freezing Mine, Wyo. (11)

The Vermont site is an unconfirmed rumor and may not exist. All the others are located at high elevations. The Montana site, which seems quite typical, is protected by the elevation, a heavy forest cover, "volcanic ash" and much loose rock. The Mt. McClellan site apparently differs in that water works its way into minute fissures and is frozen *in situ* rather than in the passages (11). Several mines southwest of Shoe Basin, in the Montezuma area of Colorado, resemble the Hagerman Pass tunnel, in that they were completely filled by clear concentric hexagonal ice deposits for distances in the hundreds of feet after they were abandoned for about 25 years (11, 124). "Englewood Ice Cave" is an interesting mine which is also locally known as "Icebox Cave". A brief but interesting study by Danehy is on file.

Perhaps the most spectacular of this group is the Ice Palace Stope in the Hilltop Mine, Colo., adorned to a depth of at least 500 feet with both flow ice and enormous wall and ceiling deposits of huge frost crystals (87).

Ice-Forming Wells

Ice-forming wells have been reported in seven localities:

1. Decorah Township, Iowa (11)
2. Ware, Mass. (11, 48)
3. Horse Plains, Mont. (11)
4. Lyman, N. H. (48)
5. Owego, Tioga Co., N. Y. (11, 48)
6. Prattsburg, N. Y. (11)
7. Brandon, Vt. (11, 48)

The Owego well has long been filled (11). Nothing is known of that reported at Prattsburg. All the others occur in gravel through which cold can percolate much as in the manner of talus caves. In some cases, cold air may enter the shaft directly, but the well at Ware is beneath a house. Many others probably exist but have not been regarded as curiosities.

Ice Caves No Longer in Existence

In view of the many changes made by man in the surface of the globe, it is inevitable that a few caves will be destroyed. Ice caves are not immune, and mention of a few examples has already been made. The following ice caves, previously recorded, no longer exist:

1. Lake Mary Ice Cave, Ariz. (11, 107)	Flooded (26)
2. Ice Cave, Perryville, Penna. (100)	Filled (116)
3. Ice Cave, Lansford, Penna. (11)	Destroyed (24, 117)
4. Freezing Cave, Farrandsville, Penna. (11)	Quarried away (117)
5. Mapleton Ice Cave, Penna. (11)	Filled (11)
6. Spruce Creek Ice Cave, Penna. (11)	Nearby excavations altered circulation (11)
7. Icy Wind Cave, Wash.	Filled (124)

Unidentified Reports

A few ice caves, while reported by reasonably authentic sources, have defied all attempts at classification or study. The existence of a few is doubtful. The ice in others may be a myth. Any information on the following, or on caves not mentioned, or those imperfectly described in this study would indeed be welcome.

1. Caldwell Ice Cave, Warren Co., N. Y. (75)
2. Ice Cave, Brandon, Vt. (11)
3. Spokane Ice Cave, Wash. (16)
4. Ice Cave Mountain, Wyo. (88)

The New York cave has escaped recognition in a nest of cavers. Unfortunately, it was reported by too excellent an authority to dismiss it. It may well be no longer in existence. The Vermont site is a third hand report, without confirmation by any authority. It may have been a confused rumor of the icy well or mine of that area. Spokane Ice Cave is a small cave in a non-speleoliferous basaltic region, in which historic relics were found (16). This seems unlike a glaciere. The Wyoming site is an obscure name known only from a map of a remote area.

Looking Forward

Hitherto unreported ice caves undoubtedly exist, and more will be discovered in the future. Yet others may be discovered by additional study of caves already known. This article has barely mentioned the types of ice speleothems, which resemble those of calcium carbonate both in morphology and multiplicity (58). It is obvious that here is a great, nearly virgin field for the meteorologist and the speleologist, working together, to open new realms of science. Innumerable problems of ice caves must await a better understanding of cave meteorology in general. The members of the National Speleological Society should be prepared to take a major part in such investigations. Let them be not long delayed!

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Pleistocene Ecology of Cumberland Bone Cave

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All Photos by the Author

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Additional digging at the site of a famous bone cave has yielded rich results in adding to our knowledge of ancient life. The author, widely known in scientific circles, is Vice President for Research of the National Speleological Society.

Most of the knowledge of Pleistocene forms comes from fossil deposits found in caves and crevices where the bones would be trapped and protected from the influences of weathering and erosion. One of the outstanding deposits of Pleistocene remains is the Cumberland Bone Cave, located three miles northwest of Cumberland, Maryland and directly south of the small town of Corrigansville. The cave is situated on the northern spur of a limestone ridge on the south side of Wills Creek Valley. Structurally, the limestone is a part of the deeply dipping west flank of the Wills Mountain anticline. It is in the Keyser member of the Helderberg formation of rock which is Devonian in age.

Although several taxonomic studies have been made of the Cumberland remains, no attempt has yet been made to correlate them with the surrounding country in order to determine what their habitat must have been. Such a study was undertaken since the area of western Maryland has been neglected, paleontologically speaking, and a knowledge of Pleistocene ecology can be used to supplement similar studies made of the Great Lakes region and the Mississippi valley.

Description of Bone Cave

A correct perspective of the Cumberland Cave is rather difficult to obtain today because of three man-made changes in the area during the past fifty years. Before 1900 there were apparently two entrances to the cave. One entrance, running about 200 feet south, led into the cave at a level 100 feet below the top of the ridge. This entrance and passageway was destroyed at the turn of the century when a quarry started operations at the base of the ridge and continued working intermittently until 1908. The cave must have been known to the local residents since remains of old rifles were found in it and it is said to have been a hideout for early settlers during Indian raids.

Another entrance to the cave was a sinkhole situated on top of the ridge. A vertical shaft led down to several small chambers and thence down to the main room of the cave, approximately 100 feet below the surface. The limestone strata are vertical so that the lines of cleavage are in a nearly perpendicular position. This gave access to surface waters which then caused the development of a typical fissure cave.

Early Excavations of Bone Cave

In 1912 the Western Maryland Railway, in excavating for a cut while pushing their tracks through Cash Valley to Connelsville, exposed the cave at its lower level. Unfortunately, dynamite was used to loosen the layers of rock down to the level of the roadbed, which was at the same level as the main room of the cave. An amateur naturalist, Raymond Armbruster of Cumberland, noticed quantities of bones being removed in the rubble and notified J. W. Gidley of the United States National Museum. All the bones exhumed before this time were lost except for some skulls retained by curious workmen. From 1912 to 1916 Gidley accumulated one of the largest collections of Pleistocene mammalian fossils found in this section of the country. Early results of Gidley's studies of the fauna were published in two papers in 1913, one describing an eland[1] and the other a new species of wolf and black bear.[2] In later papers[3,4] Gidley listed the remains found and described the peccary remains. Dr. Alexander Wetmore described the remains of a ruffed grouse. After Gidley's death in 1931, C. Lewis Gazin, curator of vertebrate paleontology at the United States Museum, continued the classification of remains and published[6] a revised list of the forms

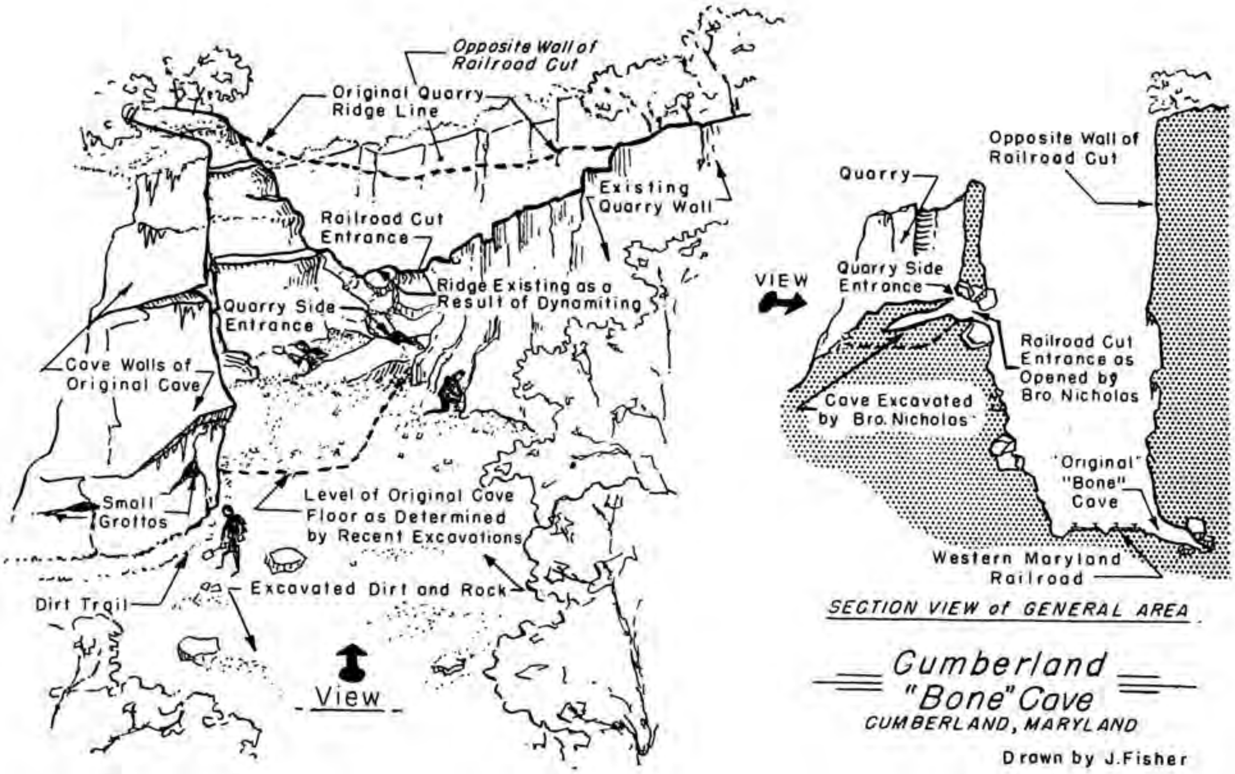

Fig. 1. Drawing of Cumberland Bone Cave showing relationship with the surrounding terrain and the excavations now in progress.

encountered together with descriptions of seven new species of mammals. Later, Gazin published a review of all the vertebrate fauna found in the Cumberland Cave, merely describing remains collected by Gidley.

In 1916 Gidley was forced to stop work at the Bone Cave when it was blocked by the Western Maryland Railway. As was proven later, many bones still remained but loose rocks had made further investigation too precarious. It should be noted that the railroad did a wise thing in closing the cave since it had become rather popular and there was the imminent danger of tourists being seriously hurt either by falling rocks or passing trains.

Later Excavations at Bone Cave

In 1950 the cave was visited by the author and it became apparent that no further access to the cave was available after several days were spent in futile attempts to re-open it. It was noted however that numerous weathered stalactities, stalagmites and flowstone could be discerned on the exposed side of the cut. This indicated the former position of the cave and it seemed that the passageway known before 1900 should open out on the north side of the cut. A search of the cliff soon revealed a small opening which did indeed lead back to a room almost filled to the ceiling with debris but fossils were immediately found in this fill.

Further exploration of this room revealed that it was about twenty feet deep, ten feet wide and two feet high. Careful digging operations were initiated in the dirt floor and other bones soon were exposed. An immediate problem arose as to the disposal of the dirt. Conditions were crowded and the narrow entrance made shoveling of the dirt impossible. A second opening was then dug, connecting to the remnants of a chimney-like formation. This afforded an entrance into the actual site of most of the findings. As a result of this, mud and rocks were gradually shoved toward the front entrance while access was obtained through the top of the chamber. By 1951 parts of the room had been excavated to a depth of two feet but work progressed slowly as each shovelful of dirt had to be sifted. After getting below the first foot of fill, bones occurred with an encouraging frequency. Some of these were obviously recent but many others were heavy with mineral impregnation.

In 1952 operations had to be halted as there was danger of undermining the whole cliff. In addition, ventilation was so poor that respirators had to be worn and goggles were needed as a result of the dust. However, through the interest shown by George Haworth, vice-president of the Western Maryland Railway, an agreement was reached whereby the railroad would remove the upper strata of rock down to the cave level, thus eliminating the danger of collapse and also opening the cave to light so that the problem of ventilation was thereby solved.

In December, 1952, work resumed with the removal of approximately 2,000 cubic feet of rock to reach the floor of the cave. Then the walls were carefully removed, the debris being constantly searched for bones. Because so many remains were lodged in the crevices, dynamite had to be used sparingly to preserve the fossils. The excavated rock and dirt were removed by placing a work train in the cut below and scooping up the material with a railroad crane.

Actually, there is slight resemblance to a cave now. Rather, there is a cut forty feet deep, twenty feet wide and about sixty feet long at the bottom of which lies more clay yet to be investigated.

In the summer of 1953 Dr. LeRoy Kay invited the writer to use the facilities of the Carnegie Museum for the cleaning and identifying of the remains found since 1950 and by the end of that summer some 200 different bones had been catalogued. The majority of these are now in the Carnegie Museum while the bones collected by Gidley are in the National Museum. In further discussion of the remains no distinction will be made between these two collections.

Paleontological Significance

The cave itself is uniquely situated for the preservation of different remains since it is on the border line of two distinct physiographic provinces. Western Maryland is in the Appalachian Province which has been divided into three subprovinces: 1) the Allegany Plateau, 2) the Greater Appalachian Valley and 3) the Blue Ridge or Catoctin district.[8] The Bone Cave is located on the ridge known as the Allegany Front which separates the Allegany Plateau region on the west from the Appalachian Valley on the east. Since the average elevation of the Plateau region is 2100 feet while the average elevation of the Appalachian Valley is 900 feet the flora and fauna have significant differences. Some of the ridges of the Valley area attain a height of 2000 feet but on the other hand some of the mountains of the Plateau area reach a height of 2900 feet.

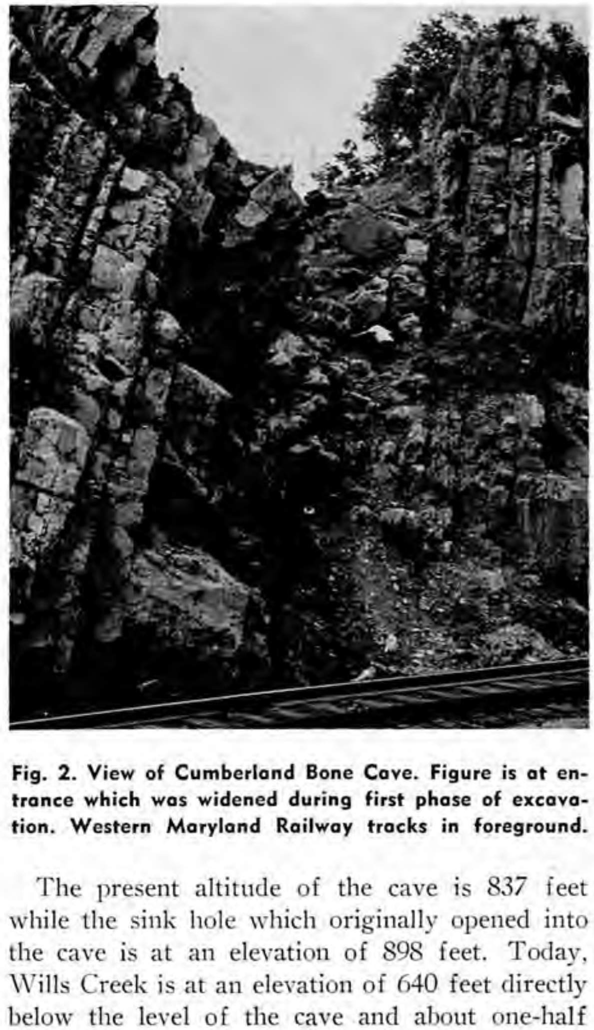

Fig. 2. View of Cumberland Bone Cave. Figure is at entrance which was widened during first phase of excavation. Western Maryland Railway tracks in foreground.

The present altitude of the cave is 837 feet while the sink hole which originally opened into the cave is at an elevation of 898 feet. Today, Wills Creek is at an elevation of 640 feet directly below the level of the cave and about one-half mile to the east. However, there is considerable evidence of a Pleistocene terrace at an altitude of 900 feet all through the Wills Creek and Potomac Valley near Cumberland.[9] Well rounded boulders and gravels of quartzite and conglomerate on the hillsides near the cave give evidence of this. Such stream terraces indicate former positions of the stream bed and show that its vertical cutting may have been interrupted for a while. Another stream terrace has been found between an elevation of 700-750 feet indicating a still later level of Wills

Creek. Since the spur on which the cave is located leads down from a ridge some 1300 feet high it makes a suitable trail from the hill down to the water level although today this is not evident as a result of the many changes in topography listed above. During the third interglacial period the stream would have been much broader, perhaps one-half mile wide from the evidence of gravels found on both sides of the present valley, and at just about the same level as the sinkhole. It is easy to visualize the animals of the region using the slope of the ridge as a trail between the principal source of water and the higher portions of the mountain. The proximity to water would also explain the number of aquatic forms found in the fossil remains. Even at the time of the lower stream bed the cave was only about fifty feet above the stream and animals coming down from the upper terraces would occasionally fall into the sink and, because of its depth, were unable to get out. Since the sink was right on the line of the trail it is not unusual to find so many animals in the cave.

Description of Remains

As originally found there were literally thousands of bones, mainly fragmented, intermingled with the clay and breccia of the cave. Although broken, the bones show no sign of being water worn and there is an absence of sand or gravel thus indicating that the bones were not washed in. The bones must have been intermixed as the result of carcasses being caught in the crevices near the surface and gradually falling apart until the disjointed bones eventually worked their way to the bottom of the cave. Some of the smaller carnivores and rodents could have survived in the cave by feeding on the remains of the larger animals. The bats could have easily escaped so that their death could have been natural. It is a rather common sight to see dead bats in the nearby caves of Maryland and West Virginia.

Forty-five different species of mammals have been recorded from the Cumberland Bone Cave.[10] Of these, 28 are now extinct and many of the others are not present day natives of the region. Beside mammalian remains, a type of ruffed grouse has been described and reptilian remains have been found including ophidian and crocodylid bones. The snake remains are to be expected but the crocodile tooth is most unusual. However, remains of *Crocodylus indet* have been reported from Saltville, Smyth County, Virginia and the same species has been noted from remains found while digging the Brunswick canal in Georgia. Numerous amphibian remains have been removed from the Cumberland Bone Cave but this was to be expected as a result of the environment.[11]

Other Pleistocene Bone Deposits

If the remains from the Cumberland Bone Cave are to be studied with the purpose of determining the ecology of the area, notice should be taken of other Pleistocene remains found within the region. Those found in some of these other sites substantiate controversial descriptions of Cumberland material and also give a clearer picture of the specimen being considered.

In 1908 twenty-five vertebrate species were described for Bushey Cavern near Cavetown, Maryland.[12] Twenty of the species are similar to remains from Cumberland which is not too surprising since Cavetown is approximately seventy miles east of Cumberland and the geological strata are similar. The most important deposit of Pleistocene vertebrates in the state of Pennsylvania is the Port Kennedy Bone Cave, Montgomery County. This cave is now obliterated as the result of mining operations in the area but fifty-one species, of which eighteen are new, were recovered from this cave before 1900.[13] Over half of the Port Kennedy remains are identical with the Cumberland remains. In Frankstown Quarry, Blair County, workmen uncovered a bone filled fissure in 1907. Thirty-seven species were recovered before the cave was quarried away.[14] Fifteen of the Frankstown species are similar to Cumberland. Durham Cave, near Riegelsville, Bucks County yielded twenty-one vertebrate species, seven of which are similar to Cumberland remains.[15] Hartman Cave, Stroudsburg, Monroe County was excavated in 1880 and produced twenty-eight vertebrate species of which exactly half are known from the Cumberland Cave.[16]

Another deposit worth noting here is the Conrad Fissure remains from Arkansas. Although these remains were discovered far from Cumberland, of the fifty species located, almost forty are either of the same species or genus as the Cumberland remains.[17] Other deposits of Pleistocene vertebrates are known from throughout the eastern United States but do not contain the quantity of fossils in the above collections.

Age of Cumberland Remains

The presence of forms such as the tapir, peccary and eland indicate that the remains of the Cumberland Bone Cave are at least pre-Wisconsin in age for since the advance of the last ice sheet there have been no temperatures consistently warm enough for these creatures to live in the region of Cumberland. The Cavetown assemblage is regarded as belonging to the Sangamon interglacial period so that the species indigenous to temperate climates may be supposed to have lived during the warm Sangamon stage with the Arctic forms at a somewhat earlier or later time when the climate was cool.

Most writers consider the Port Kennedy deposits to be early Pleistocene but since it has thirty-seven extinct species it is undoubtedly older than the Cumberland site. Hay[18] lists peccaries, tapirs, elands and mastadons as among the characteristic genera of the Sangamon period. He places the Conrad Fissure remains in the Illinoian stage although Gazin[19] believes that these remains are younger than those from Cumberland. Hay places the Stroudsburg remains as late Pleistocene although he admits that the cave was formed during the early Pleistocene. Since this cave is situated five or six miles north of the Wisconsin moraine it is understandable that many of the species would be relatively recent forms. The remains from Durham cave would also seem to be late Pleistocene. There being no extinct species from either the Durham or Stroudsburg sites they are considered to be younger than the Cumberland remains. Another piece of evidence pointing to the Sangamon stage as the age of the Cumberland remains are the stream terraces that would have been formed during that time.

Fig. 3. New Bone Cave in foreground; entrance to original cave in background across tracks. This view is on opposite side of ridge shown in Fig. 2.

Distribution of Mammals from Bone Cave

It is difficult to place an animal in a certain ecological niche and then presume it is found nowhere else. No mammal is sessile and even though their range is limited they are apt to be found in locations removed from their normal habitat. Hence, in drawing up a scheme for the distribution of the mammals from the Cumberland Bone Cave it is frequently necessary to list the same animal for several habitats. Since some mammals are known to exist in widely varying environments there is no way of deducing from the bones of the specimen the precise habitat of it. Skunks, for instance, are found in dry areas with sparse vegetation as well as in thickly wooded forests. The climatic conditions around the Bone Cave have been far from static and the animal in question could have lived near the Bone Cave during both periods. Notwithstanding these difficulties, the large number of remains permit us to list the distribution of mammals to be used as a basis for determining the ecology of the region.

Forests

Tropical rain forest.

The majority of animals in a tropical forest are arboreal and the ungulates are usually small because of the dense growth which makes movement by animals with large bodies difficult. Specimens from the Bone Cave which could have existed in this habitat are the eland, peccary, tapir and possibly the lion and mastadon in open glades or near watercourses.

Deciduous, temperate forest.

More animals from the Cumberland Bone Cave are adaptable to this environment than any other. These may be divided according to their usual niche in this habitat:

a) subterranean dens: fox, skunk, chipmunk, long-tailed shrew, short-tailed shrew and deer mouse.

b) near streams and lakes: muskrat, beaver, otter and mink.

c) arboreal: porcupine, squirrel, flying squirrel, opossum and bat.

d) forest margin: woodland jumping mouse, woodchuck and raccoon.

e) miscellaneous localities: deer, lemming mouse, white footed mouse and wildcat.

Coniferous forest.

Found at a higher altitude or closer to the poles than the deciduous forest, a forest of conifers provides food the year round and more shelter for those animals living in it. Willows and birch are common along the banks of streams and various types of berries are to be found in openings. As in the case of the deciduous forest, the specimens from the Cumberland Bone Cave may be found in the following niches:

a) subterranean dens: wolverine and skunk.

b) near streams and lakes: mink and otter.

c) arboreal: fisher and porcupine.

d) forest margin: varying hare.

e) miscellaneous localities: bear, deer and elk.

Grasslands

Tropical savannas.

The eland is the only mammal indigenous to this habitat found in the Bone Cave although the mastadon and lion could possibly be found here.

Short grass plains.

These include areas with a sparse vegetation but with an annual rainy season. The short grass plains may be considered as open terrain with a sub-humid and semi-arid climate. This type of domain, sometimes referred to as steppes, is predominately populated with reptiles but the coyote, skunk, thirteen-lined ground squirrel, pocket gopher and horse are representatives from the Bone Cave found in such areas.

High grass plains.

Herbivores predominate on these temperate prairies with the rodents abundant in the subterranean strata. The badger, lemming mouse and muskrat are found in areas such as this.

Fig. 4. Passageway opened as result of removing upper 40 feet of rock. Flowstone above entrance to passage.

Tundra.

The only specimen from the Cumberland Bone Cave that is liable to be found in the tundra is the lemming mouse which inhabits the sphagnum bogs of the far north.

Swamps and Marshes

Aquatic mammals are represented in the Cumberland Bone Cave by the beaver, muskrat and otter while the mink may be considered as semi-aquatic. Many of the rodents found in the Bone Cave use the banks of swamps and the high spots of marshes for burrows and dens. The tapir, peccary and eland with their wide, spreading hoofs for support on soft ground are found in the swamps of tropical and semi-tropical areas. There is little evidence of any swamps or marshes near

Fig. 5. Looking down on excavated bone cave. Hole on left leads into passage where most bones were found.

the Bone Cave today but when Wills Creek was nearer the elevation of the cave its course could have been a meandering one with wide stretches of shallow water. If the amount of water flowing along the stream bed was much greater, considerable areas of land could have been inundated and resulted in a marsh on either side of the main stream.

Mountains

There are no true alpine forms found among the remains from the Cumberland Bone Cave. This is to be expected since the altitude of the surrounding mountains has not changed to any considerable degree since the initiation of the Pleistocene period. However, forms which inhabit rocky hillsides have been found and include the pika, cave rat, meadow mouse and wolverine. In all probability they lived in an area too rugged for the growth of the forests but not too far removed from them. Today this condition exists in the region of the Bone Cave where steep cliffs strewn with rocky boulders afford little opportunity for plant growth yet overlook stands of timber.

Pleistocene Climatic Conditions

The succession of the different climatic conditions as indicated by the wide range of species from the Bone Cave must have begun with a semi-tropical phase. No temperatures in the region of the Bone Cave since the last glacial age have approached those necessary for such forms as the tapir, peccary and eland. Obviously this tropical environment could not have existed immediately preceding the last glacial age but in all probability at a period midway during the last interglacial or Sangamon period. The paucity of remains from this tropical period is also an indication of its antiquity. On the other hand, the proximity of the tropical remains to the others demonstrates that they are not so ancient as to have been deposited during the first or second interglacial period. If that had been the case a large amount of fill would have separated the remains of the two periods.

As the temperature decreased with the initiation of the last glacial period the humidity would have been reduced and a semi-arid, dry, grassy prairie would succeed the tropical rain forest and semi-tropical grassland. This short grass plain harbored such species as the coyote, badger, pocket gopher, thirteen-lined ground squirrel and woodchuck.

Following this stage appeared the deciduous forests and grasslands with moderate rainfall. This was a period similar to conditions about Cumberland at the present time. Almost 75 per cent of the remains belong to this type of environment. Wildlife was abundant with the hardier forms adapting themselves to the next stage in this gradual decline of temperature—the advent of the coniferous forest.

The coniferous or boreal forest stage presents a difficulty in that remains from the environment could have been deposited after the advance of the last ice sheet as well as before it. Evidence that supports the inclusion of remains from the coniferous period before the last ice sheets comes from the degree of fossilization of the bones themselves. All the bones removed from the cave are so thoroughly impregnated with silicon or calcium phosphate that a length of time longer than the most recent coniferous stage is necessary to allow for their mineralization. Also, many of the bones were covered with flowstone and other types of percipitated crystallized calcium compounds. Although the exact rate of deposition of cave formations varies with the amount of water present and the humidity of the cave, a length of time in excess of that since the ice sheet receded would be necessary to account for the thick layers of calcium carbonate found on some of the bones belonging to the coniferous period.

At the extreme advance of the last or Wisconsin ice sheet the site of the Cumberland Bone Cave was several hundred miles south of the glacier and climatic conditions would have been similar to the far north of today. The arctic tundra, frozen in winter and resembling a bog in summer would have existed with perhaps sparse stands of pine interspersed through the land. The grizzly bear and lemming mouse would be types that would find these conditions suitable to existence. Needless to say, other animals were present including probably the mammoth but these have not been found in the Bone Cave.

With the rise in temperature following this stage and the corresponding melting of the ice sheet and snow on the mountains the streams were flowing swiftly and the stream bed of Wills Creek was lowered quickly, reaching almost to its present level. As a result the sinkhole leading into the Bone Cave was situated in a rather inaccessible location on a cliff overlooking the stream. Thus,

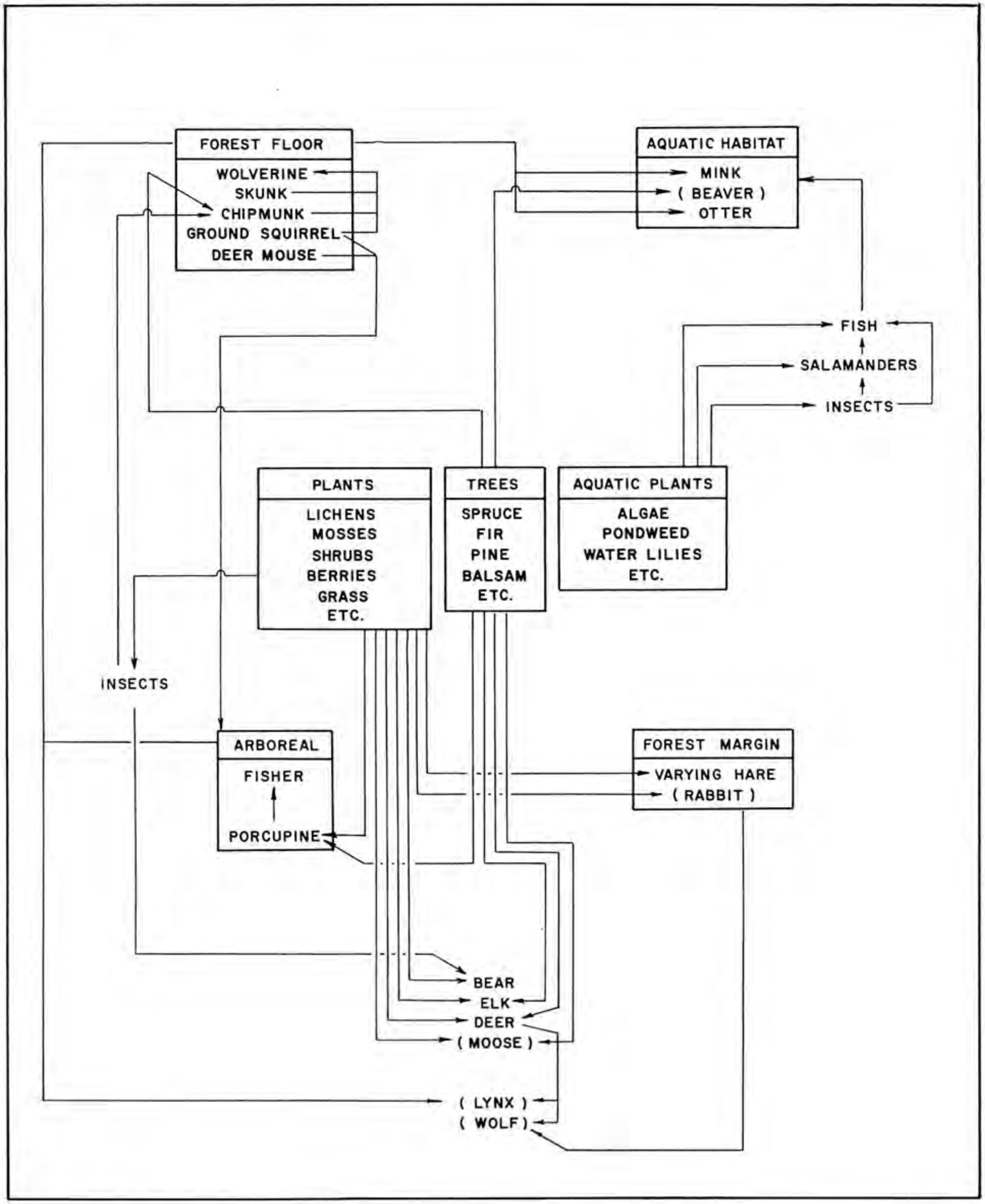

Fig. 6. Web-of-life diagram.

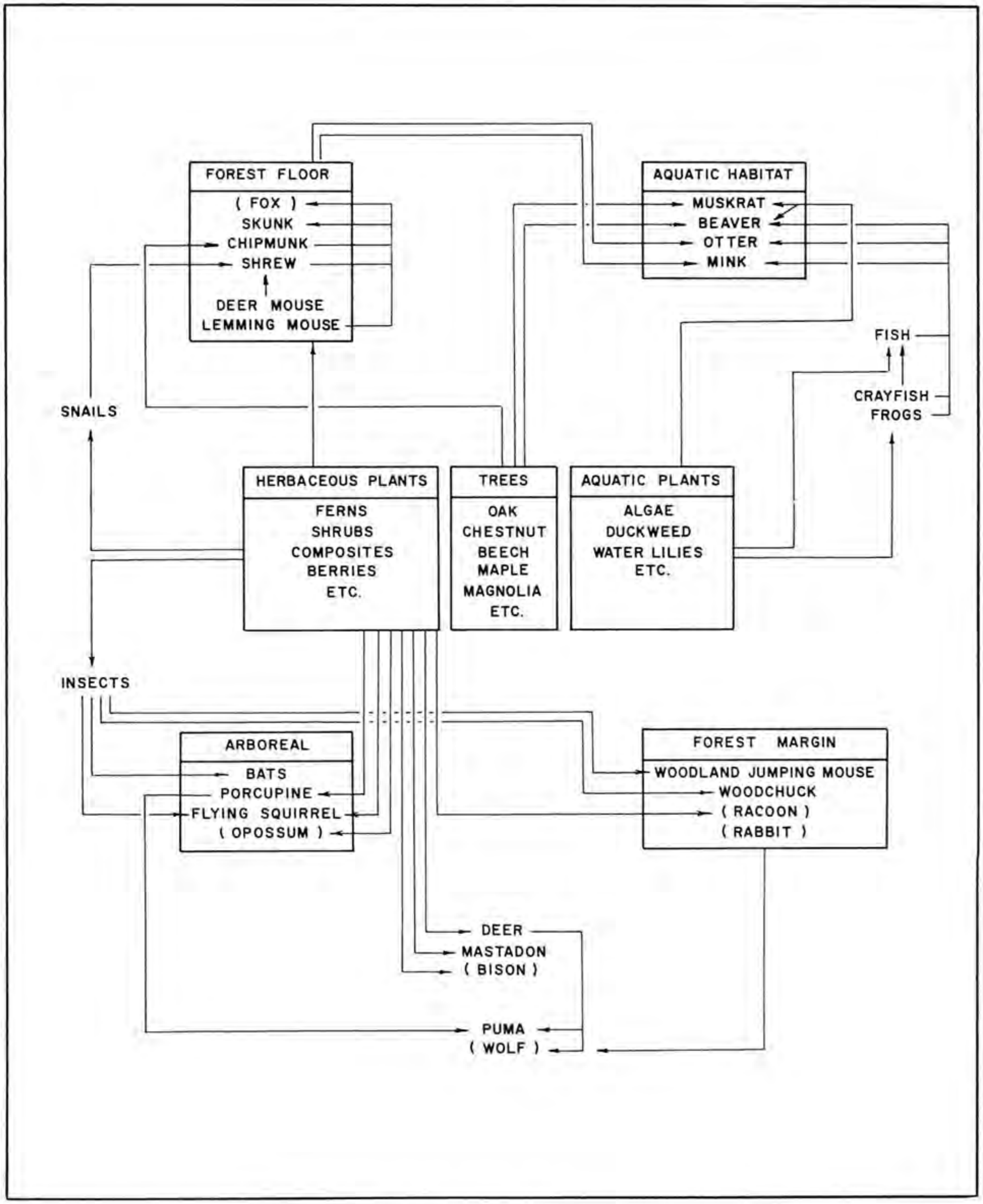

Fig. 7. Web-of-life diagram.

fewer animals would fall into the cave which accounts for the small amount of recent material found there.

The climate stages as represented by the remains from the Bone Cave may be summarized as follows:

Present mixed mesophytic forest
↑
Boreal spruce-fir forest
↑
Arctic tundra
↑
Boreal coniferous forest
↑
Deciduous forest and grasslands
↑
Semi-tropical grasslands
↑
Tropical rain forest.

Relation of Mammals from Cumberland Cave

In drawing up a diagram of the theoretical relations that existed between the various specimens found in the Cumberland Bone Cave two factors must be considered. First, because the climate varied from tropical to arctic, no diagram can show all the relations since many of the forms were not contemporaneous. Second, all the animals present in the area at any given time are not represented. Either the remains were not introduced into the Bone Cave or their remains have not as yet been detected. Few avian remains have been found yet the bird life would have been abundant during the presence of the various forest stages.

Fig. 8. View from top of ridge. Excavation in center of picture is 45 feet below camera.

For a true understanding of the Pleistocene ecology of the Cumberland area the relationship of each animal to the community should be recognized. Apart from the life cycle of each form there is a definite stratification in the environment wherein each general type of creature is found. Every animal has a specific niche in its particular strata. There is a continual intermingling among these different strata yet each maintains a certain degree of independence. In portraying the associations among the various species not only are the stratas of the community shown but the relationship of each member with other members of its own strata and with members of the same strata. Only by this method can a clear comprehension be obtained of the web-of-life of a particular zone.

There are so few forms present in the remains from the Cumberland Bone Cave from either the tropical or arctic environment that it would be too speculative to attempt to draw up a web-of-life for them. The evidence from other areas points to the existence of a typical tropical flora and fauna at one time as far north as Pennsylvania. Arctic forms are also widespread in Pleistocene fossil deposits, although because of the migration forced upon them by the advance of the ice sheets it is doubtful if the relationships were as similar as they are in a stable environment.

The remaining forms may be considered as belonging either to the temperate deciduous forest community or the boreal coniferous forest community. No plant or tree fossils have been located in the Cumberland Bone Cave but the paleobotany of the area has been studied[20] so that it is possible to obtain a general idea of the plants present.

In the web-of-life diagrams all the mammals are grouped according to their habitat with the exception of the larger carnivores and herbivores which range throughout the entire community. No attempt has been made to list all the various types of insects, arachnids and other invertebrates present since this would involve the production of a diagram whose complexity would be beyond the bounds of this article. Rather, an attempt has been made to place each mammal in its proper perspective and show that it did not exist as an isolated organism but as an integral part of a community existing perhaps 50,000 years ago.

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Caves and Karst of the U.S.S.R.

By MARYANN B. SHELLEY

The geology of the unbelievably vast land area of the Union of Socialist Soviet Republics is not well known to most Americans but it has tremendous speleological interest. The author here presents a scholarly study of the cave areas of the U.S.S.R. gleaned from a studious and exacting analysis of available literature on the subject.

Karst with its negative relief is the phenomenon of dissolution of rocks from within. It is underground architecture, adhering to its own particular law of processes. Existing generally unseen, it is only reflected upon the surface where it shows as peculiar topography and unique vegetation. In essence it is a region of solution often referred to as limestone terrain.

In addition to subterranean forms karst manifests itself upon the surface of the earth not only in gaping holes but in valleys, lakes which remain or disappear seasonally or become bogs and swamplands, undulating softened relief with rounded knolls or bleak dessicated surfaces bereft of soil and vegetation. These diverse aspects of karst reflect, and are affected by, alterations in climatic conditions, the soil processes, petrological basis, and tectonic structures.

Soviet geologists of late have greatly expanded both the concept and significance of karst. To the idea of the space factor they have emphasized the factors of time, dynamics and state in karst development. Soviet definitions of karst range from the 1932 description of A. A. Vasil'ev, "the sum of all dismembering relief", to that of V. A. Aprodov (1948): "the geomorphological process of joint development of the relief and dissolution of the rock of the lithosphere as a result of interaction and through the agency of underground waters under the influence of the earth's field of gravitational force". Within the limits of these definitions there has grown a vast body of empirical and theoretical knowledge which is progressively becoming absolute.

The Soviets have stressed the principle of vertical interaction of proceses rather than the cyclic or radial development of karst. This idea is in contradistinction to the broad cyclical theories proposed by W. M. Davis and Penck. It is based on Soviet studies of mineralized karsts, limestone soils, and on engineering problems in limestone areas.

Karst owes its recognition as a full fledged branch of the earth sciences and a serious field of research in the USSR to the collapse of the Kizel coal mine in 1931. During the development of this mine engineers had not known that deep beneath the earth but above the coal seams lay water-bearing karst beds. Unwittingly the main shaft was driven straight through fifty-one karst cavities with little understanding of engineering costs involved. No planned economy, especially one on so rigid a schedule as the NEP of the early '30's, could withstand the shock and repercussions of the three-year loss of coal production that resulted.

Early recognition of karst as a terrestrial annoyance came during the last years of the past century when the Russian railroads were being built. A catastrophic cave-in occurred on the Samara-Zlatoust line in the Southern Urals where the roadbed hugs the *kosorog* (as the steep northern bank of the Belaya River is known) in which karst, in the form of ponors, was eating into the Kungur gypsum. On a railroad in western Ukraine the Polesskiy Express was forced to slow to a four-mile per hour crawl in certain sections as karst funnels were opening beneath the roadbed. On the other hand, karst ponors and cavities were utilized in part for sections of the Moscow subway.

Exploration for foundations of dams and the water supply for hydro-electric projects has revealed karst regions, hitherto unnoticed. The Magnitogorsk (Southern Urals), the Mingechaur in Eastern Georgia of the Caucasus, the Beloretsk and the Vashkur in the Central Urals, as well as the Barkhatovsk on the Angara River near Lake

Baikal, and the Zhigulevsk on the great bend of the Volga are all large hydro-electric developments that have had serious construction problems and required constant repair because of the proximity of karst. Karst has also attracted considerable interest as a source of water supply in many areas of the USSR.

In addition to serving as a primary source of water the natural openings into recesses of the earth have also saved the labor of digging graves for dead cattle and human beings. It is likely that an even more modern exploitation may have been employed in the USSR as it was in the Carso during World War II. There the "foiba", the Serbian name for karst funnel, became expanded into the Italian word "infoibato"—to liquidate and dispose of most effectively and efficiently, with eternal oblivion of the crime and anonymity of the perpetrator.

Karst is dependent on water, either meteoric precipitation descending from the atmosphere and seeping into the rocks, or solutions percolating upward from the bowels of the earth through fissures and channels either developed in the rock by karst processes or from faults and joints. Corresponding to direction and the nature of the surrounding petrology, these waters take on different chemical properties which in turn react in differing degrees upon the rocks through which they pass. Because of this the development of karst from youth, through maturity and old age is sharply at variance with the concept of the cycle of normal surface erosion. The karst cycle is not dependent upon the position of the base level of erosion but rather upon the base level of circulation of the underground waters and the condition of solubility of the rocks along which these karst waters circulate. Many Soviet theories have been evolved concerning the vertical position in which karst develops. One geologist relates the zone of greatest activity to the interval (vadose) between the earth's surface and the level of the ground waters, the consequence of weak mineralization and relatively rapid movement of waters. In this zone the karst is primarily vertical in direction. Below this lies a zone of diminished underground flow with karst cavities horizontal and elongated in form, and beneath this a zone of little flow, which is at a point below the local level at which water moves laterally to surface drainage.

Karst in relation to vegetative cover has been elaborated into a theory by A. A. Grigoriev; to wit, that the development of karst phenomenon under the given conditions of a gypsum bed in a continental climate is in direct proportion to the development of the conifer growth on it. Conifers with a thick crown and extensive horizontal root system reflect an intensively developed karst; low-growing conifers and bushes reflect a moderately developed karst, and finally a sparse growth is related to old age karst that is nearly obliterated. From this work Grigoriev has concluded that the extent of the development of karst in gypsum is determined by the forest vegetation and the angle of slope which control the distribution of the meteoric precipitation on the earth's surface. Deforesting inhibits the subterranean development of karst but accelerates surface erosion that produces ravines and gulleys. Such conditions exist in the Ukraine, the sandy steppes of the southern Volga Valley and the vast expanse of the Pripet marshes south of Minsk.

Various conclusions have been proffered by the Soviets to relate climate to karst but as yet without positive definition. It has been established that the intensity of the karst processes apparently has no direct dependence upon temperature but is related to the amount and state of precipitation, i.e., liquid or solid.

Reflecting the Soviet trend to reduce science to a catalogue system, karst phenomenon is placed in three categories according to the extent of development: crypto-, micro-, and macro-; each grading into the other, and each mutually interrelated and integrated. A précis of this as formulated by V. A. Aprodov is presented:

Crypto-karst is the elemental form made up of microscopic pores, in which only water reacts upon the surrounding rock. This is the embryo for later physico-chemical and chemical reactions. Development of the pores is not everywhere uniform in intensity. Three steps occur in the pore growth: 1) isolated original pore and beginning of exchange reaction between rocks and water; 2) transition of concave pore walls to convex, with beginning of deposition, and 3) convergence of pores into fissurings and beginning of transport of elements and transit of waters.

Micro-karst is the stage at which volume has become sufficient for the establishment of transit movement of water but not enough for erosion. Rock corrosion and transference of the dissolved materials are characteristic of this stage. Forms are irregular small cavern passages, small dome pits, funnels, descending and ascending pulsating springs.

In *macro-karst* phenomenon mechanical erosion results from karst waters, redistribution of minerals in the rocks and the transport of karstified particles through water transit. The karst shows distinct surface forms with the disappearance of rivers, formation of karst valleys, sinks, merger of funnels into gulleys and the formation of bauxite, kaolin and other karstgene mineral deposits.

Practically speaking, the Soviet concept of karst includes not only the "negative" relief on the earth's surface—reflected as depressions solution sinks, funnels, chimneys, pit holes, lapiez, uvalas, dolines, pocket-valleys, hums— and beneath, in the earth's crust as pipes, dome pits, solution canals, cave and cavern formations, but also the conditions and factors acting upon and controlling the solution activity in the rock, the formation of concomitant mineral deposits, the resultant chemistry of the precipitates and solutions from karst waters, the paragenesis of minerals and gases and the rhythm of their occurrence and disappearance.

Statistics, an indispensable tool of evaluation, have been gathered by Soviet karst enthusiasts, perhaps to sell the idea of a karst discipline. They arrived at the figure of 18,000,000 square kilometers of potential karstification within the USSR. This sum considers only exposed and buried carbonate rocks so that the other formations subject to karst processes—gypsum, salt, loess and chalk—are not included in this formidable figure, which leaves only some 4,000,000 square kilometers of the USSR that are not subjected to this dissolving activity. Although most of the intensely karstified areas lie fully within the confines of the Union, the coincidence cannot escape the geological eye that the direction of her political strikes has often followed the line of karst across her international borders.

Limestone and Gypsum Karst

Although limestone and gypsum karst are extensively distributed throughout the USSR, in certain regions the development is such as to earn for the region the term "classic limestone" and "classic gypsum" terrain: The Crimean "IAily", the high mountain pastures in the mountain ranges extending along the southern coast are of the first type. This pastureland, a limestone region formed of three mountain ridges, affords a seeming paradox. In the USSR it is most famed as typical karst with all the bleakness and waterlessness that this implies, and yet the area furnishes some of the best pasturage. Soil rich in humus clings to the sides and bottoms of the dolines which as a rule are not of great depth, and in this grow grasses, bushes and even trees.

All forms of karst are present with dolines distributed unevenly, some in clusters and some in dense concentrations, extensive karren fields and lapiez. In the middle and southern sections of the karst mountain Chatyr-dag, the number of sinks approaches 30 to 50 in a square kilometer and the earth is so pitted that it is impossible to traverse in a straight line. Diameters of these dolines reach 800 feet and their depths 130 feet. The majority have a vertical western wall, the other sides being inclined. On the northern slope of the mountain is a well developed system of poljes and dolines. Large springs are common. The water supplying the city of Simferopol' rises through a vertical karst shaft and carries away such a volume of lime that the cavernosity of the mountain is increasing at the rate of 7,260 cubic meters a year.

Crimean caves have three distinct regionalizations according to origin: (1) Karst caves of three mountain ranges from Balaklava to Feodosiya in Upper Jurassic limestone; (2) Cave cities in Cretaceous and Tertiary of second mountain range; (3) Sea coast caves. Almost all the karst caves of the Upper Jurassic limestone open at more than 300 meters above sea level, higher than all the other cave openings. They belong to both vertical and horizontal types, with depths to 200 meters, which is the thickness of the limestone beds; some have amazing dripstone formations and several have permanent ice. In the second mountain ridge and at a considerably lower level are to be found the great cave cities of the Iron Age and the habitations of Paleolithic man. For the most part these are situated in rock benches adjacent to the rivers.

The Urals are a long range of mountains

trending north-south in eastern European USSR, formed of parallel folds of Paleozoic rocks. Later deformation in the Mesozoic altered the alignment of the Paleozoic folds and induced extensive fracturing. On the west side of the mountains the rocks range from Lower Devonian to Lower Permian and include thick Middle Devonian limestones. On the western side where an overlap of Mesozoic sediments exists, the karst lies often deep beneath the surface or on river benches in which funnels have frequently developed to the depth that tall trees are concealed. Some sinks are seasonally filled with water and others show secondary funnels forming in the bottom of the old.

Ural karst is represented by all forms of which the so-called "Paleo" karst, that buried beneath a cover of glacial deposits, affords the most dramatic display. At Kizel, the surface manifestations are only soft undulations covered with thick taiga (forest) growth. Shallow cavern development is minimal but from Molotov southward there are numerous caves with clear indications of pre-glacial habitation.

On the eastern slopes of the Urals deep karst in Mesozoic and Paleozoic limestone are combined with surficial solution effects. From Chelyabinsk eastward in the Turgai Corridor the land is decked with saucer-shaped lakes and hollows, resembling karst lakes in every detail. In the limestones of Smolina and the marbles of Miass karst is intensely developed. In the Chelyabinsk section of the Ufim Plateau the density of funnels was found to be 11.5 per square kilometer, and in the Chusovoi region, between Molotov and Kizel on the western side of the Urals, an approximate density of sinks with underground connections is 35 to a square kilometer.

The caves of the Urals are fabulous in beauty. Those in the middle section of the mountains have long been known, serving as habitation and refuge for human beings. In the Southern Urals, the caves are difficult of access, and are frequently in high cliffs in the river banks, affording more often feats for the intrepid and harbors for the hunted rather than casual abodes. Until 1937 all studies of the South Ural caves had been concerned with speleology rather than archeology. But with the discovery in that year of the large Ust'-Katev Cave the Chelyabinsk Museum organized a scientific expedition to study the caves of the area and applied the theories of karst formation to locate them. In the following year over 40 were discovered and investigated.

Near Sterlitamak, where oil is found in limestone pockets under the surface, are three small karst domes, in one of which is the famed "Crystal Cave" known abroad in the Soviet movie "The Stone Flower".

In the region of Voronezh and Kursk karst is profuse in a very fine white breccia clay of Upper Cretaceous age. In the head streams of rivers and in the sides of gulleys where the chalk has been recrystallized into limestone the karst features, mainly funnels, are best developed.

Although karst in gypsum is extensive over the USSR, the country of "Bashkiria" in the Southern Urals has been accorded the title of "classic". Here the density of dolines often reaches several hundred per square kilometers. In this gypsum lies an ice cave world known in literature since 1730, the famous Kungur Cave, celebrated for its beauty and variety of underground structures. The cave has over 100 grottoes and passages in the 4.6 kilometers so far explored and 36 lakes, the largest of which is 600 square feet in surface and 18 feet in depth. The cave temperature is 4.5 to 5 degrees Centigrade. In a study of the cave—now a State laboratory for ice studies—Soviet politics entered speleology—as in other sciences—and besmirched the scientific and scholarly integrity of the professor in charge of the investigations. The political editor of the Academy of Science inserted in the professor's article a glaring statement to the effect that the first literary note of ice caves was made in the land of the USSR in 1730. In doing so the editor merely displayed his own zealotry—or lack of knowledge—for he failed to delete from the bibliography the professor's mention of Balch's book "Glacières or Freezing Caverns", in which credit is given to the Frenchman Poissenot for the first mention of cave ice in 1586.

Other regions of gypsum karst are in the Inder region north of the Caspian Sea where two complete karst cycles, one ancient and the other current, are reflected on the surface with all forms developed in each.

The Angara Shield is a broad area of pre-Cambrian rocks in east central Siberia. The western part of the Angara Shield is a tableland monotonously level save for a range formed of Jurassic rocks in the center. The Siberian Highlands lie east of the Lena and consist of folded rocks forming a very poorly drained upland. South of the highlands are broad folds of pre-Cambrian limestones forming another poorly drained plateau. Thermokarst (karstic terrain developed in areas of permanently frozen ground) is widely developed throughout the leveler parts of these regions while solution karst is extensive in the bedrock. Along the Aldan River the solution karst has eaten into the highest of the river terraces and is extensively developed around the Maya in the forms of funnels, dolines, underground rivers, blind gulleys and uvalas. The great Balaganskaya ice cave on the Angara River lies in thick Cambrian gypsum and limestone. It is remarkable in having a temperature below zero Centigrade and a unique and magnificent form of crystals, like a sixplaned fluted rosette.

Along the high 400-foot terrace of the Amur in the delta region, ovel-shaped depressions without outlet occur with marked frequency. The bottoms of these depressions are only several meters higher than the modern river valleys and the direction of these cauldron-like formations is regularly northeast. In this region the rivers form numerous meanders but upon emerging from the area of sinks the rivers recover their characteristic of mountain torrents with numerous cataracts. The age of these depressions is quite old for Tertiary continental deposits are in the kettles and the large cauldron-shape valleys of the Amur.

In the Cambrian limestones along the River Maya in eastern Siberia is an interesting karst ice cave holding two ice lakes which, according to the natives, extend for a considerable distance into the earth. Numerous sinks and funnels near the entrance, congested with fragments of limestone on the bottom and overgrown with moss attest the karst character of this region. In some of these pits bushes have taken root with graceful birches appearing over the rims but in other stretches not only the funnel but the entire area is devoid of even a blade of grass. Near the gulf of Vladimir on the Sea of Japan is a cavern area amid a typical karst landscape.

Mountains on the Archean Shield of southern Siberia swing southward and westward culminating in the Sayan Ranges which are flanked to the north and east by the Irkutsk amphitheater in which the Lena rises and which is cut through by the mighty Angara as it flows out of Lake Baikal. In these three sections karst is active and has cut into the Cambrian rocks west of Lake Baikal along whose shores caves are frequent, at times in high cliffs and again at lake level.

The Minusinsk Basin, an ancient arm of the Upper Paleozoic Sea, is composed of massive Cambrian limestones which have been intruded by large bodies of igneous rock. Today there remain islands of limestones deeply eroded by karst. This is an old cycle of karst with dry caves, sink holes, pits, sloping fissures and some underground rivers. This region of karst lies in the mountain taiga zone.

Caves in the Altay of south-central Siberia abound in paleontological and archeological material. The Kinderlinskaya on the northern slopes near the famous spa of Chemal is noted for the size of its passages (some that are 300 square meters and height of 10 to 15 meters), and the difficulty of access. Overlooking the entire Katun' valley from the top of a crater at 1327 meters above sea level, an unequalled panorama sweeps before the entrance of this cave. Not far away is the Ardunskaya Cave which harboured the Oiroty during the invasions of the Kara-Kirghiz in the XIV and XV centuries, according to local legend. In the Salair Plateau between the Ob' and the middle branch of the Tom' is a region of karst with caves. In the limestones of Middle Cambrian in the Tayshet Basin karst is widely developed in the form of collapse sinks, funnels, corridors in valley slopes, numerous springs and frequent karst landslides. Loess karst has filled the lake depressions around the Biryusa River and the surface of the basin is a network of shallow, waterless, closed depressions, some 50 feet in diameter and 8 in depth. The rate of karstification is slow: a maximum of four centimeters subsidence per year.

From the Tian' Shan' Mountains westward run an almost unbroken series of mountain ranges either in parallel ridges separated by high mountain pamirs (meadows), or as massifs. These include the high Pamirs extending to the Kopet Dag on the Iranian border, the Caucasian Range across the Caspian Sea, and the tiny peninsula of Crimea. The limestones in the ranges are upper Paleozoic and Cretaceous in age and were folded in the Tertiary. In these mountains the predominant karst development is in the form of caves. One of the best known is the Kon-i-gut, famous since the tenth century as the "Mine of the Doomed". Into its labyrinths prisoners sentenced to death were sent with the reward of mercy promised if they extracted some precious metal.

The karst of the Caucasus has many unique features. On the summit of the Gagry Range the French speleologist, Martel found the highest location of karst gulleys in the world. The rivers of the Main Caucasian Range flow swiftly off the mountains or parallel them in deep narrow canyons with rapids and waterfalls to disappear underground into sinks along their lower courses. Enormous sinks, large funnels and disappearing rivers mark the heavily karstified mountains of west central Caucasus. Here the Upper Jurassic beds of strongly dolomitized limestones are heavily karstified. The circulating waters of this area are high in sulphates, especially where the gypsum-bearing layers are concentrated beneath the limestones, but even where there is no gypsum abundant sulphate waters abound. Such are the springs in the Assy Valley and the curious karst shaft of 258 meters depth now filled with water, Lake Tserik-kel', an unusual example of karst formed by ascending rather than descending waters. The many regions of mineral waters of the Caucasus, Kislovodsk, Pskup, Nalchik and Pyatigorsk are of karst origin.

Caves in the Caucasus, for the most part horizontal in extent, have large underground galleries through which flows abundant water. Formations are abundant in the passages. The Tertiary limestones of the adjacent area along the southern spurs of the Caucasian Range are subject to a lesser degree of karstification. Although individual sinks and funnels are almost absent, the caves are of remarkable length (from a half to 3 miles), with large, relatively straight galleries, large quantities of water and well developed longitudinal profile of the floor with pronounced evidences of mechanical erosion.

In concentration of cave cities, fortresses, monasteries and retreats Southern Georgia exceeds any other section of the Caucasus or the USSR. From these caves the Georgians defended themselves, valley against valley, tribe against tribe and against the Russians and the Soviets. The ancient city of Vardzia, including 366 caves, secures the Kura Gorge and controls access from the south.

Thermokarst

In the vast regions of the USSR underlain with permafrost, a stratum of ground which does not thaw, depressions are common and form a landscape known as thermokarst, formerly classified as "pseudo-karst". A complex of natural conditions give rise to these karst forms, alterations in surface temperature and in the periphery of the block of permafrost and the type of adjacent rock, are a few. Complicating these conditions is the combination of thermokarst in areas of the usual karst of soluble carbonate rocks. N. I. Tolstikhin, calls this combination of karst the "living link" between the surface and the sub-frozen zone of fissured karst waters.

Fissures, sinks, and basins, ranging in circumference from saucers to great uvalas and long lake-filled hollows, are the predominant forms of thermokarst. The phenomenon of "sag" or settling, similar to the dry form in desert conditions, creates thousands of lakes, bogs and swamplands. Enormous stretches of the USSR, lying in cold climatic regimes, are subject to this condition. The northern parts of European Russia and Siberia and in the lands along the southern boundary of the USSR where altitudes and elevations are high and mean annual temperatures below freezing are subject to thermo-karst.

In the mountain ranges of Eastern Siberia the thermokarst processes have developed extended basins, as in the basin in which the Yana River flows. Along the Tuostakh and Adycha Rivers it is in the process of forming isolated young depressions and connecting them into mature forms. In the mountains east of Baikal, the summits of which are bare rock, thermokarst is active in the terraces along the lower slopes where there is an abundance of mineral springs. The extensive distribution of permafrost in the mountainous region of the Pamirs is checkered in spots by thaw areas as a result of the presence of thermal springs. In some stretches the waters penetrating the permafrost form peat bogs, at other times only muddy and pebbly marshes or quagmires. Several entire river valleys and passes are karst landscaped where in winter the surface icing from springs reaches a height of six feet. The building of the new highway recently through the high mountain chain of the Pamirs was complicated more by the thermokarst than the extreme elevations, severe climatic conditions, and rock formations.

SALT KARST

In the vicinity of many mineral and salt lakes formations have been found so identical with those of usual karst that they have been taken into the geomorphological classification as karst. In many instances these forms reflect characteristics of ancient karst developed under different climatic and hydrogeological conditions. Others are contemporary and the result of more recent climatic changes and frequent alterations of the terrain brought about by man's own handiwork indifferent to the needs of the earth. This type of karst is known as salt karst, differing from the karst of rock salt only in greater intensification and acceleration of all the surface processes.

One outstanding characteristic of the salt karsts is that their waters are very high in bromine salts, other valuable chemicals and rare gases. The areas especially subject to this type of karst are those either now submerged or formerly submerged but now saltpans. The general regions of salt karst in the USRR are the vast desert regions of Turkmenistan and Kazakhstan, lands once bedding the ancient Caspian, Turanian, or Hercynian Seas, the region between the Volga and Ural Rivers, the northern line through the Central Siberian Plateau and the vicinity of the Lake Kara-Kul' in the high Pamirs.

A specific and picturesque nomenclature has been coined for the fantasies of salt karst:

1. Salt ripple: Numerous little pits and between them little mounds on the surface of the karsted salt, not covered with brine or ooze. Depth of the pits is from 5 to 25 millimeters; the mounds vary in height from 5 to 35 centimeters. These formations result as the secondary crystallization of salt.

2. Salt saucers: Shallow saucer-shaped depressions on the salt crust. During rain they are usually filled with brine; in dry periods they become decked with small snow-white crystals on the bottoms and sides. Diameters vary from 0.1 to 0.75 meters and in depths from 0.05 to a half a meter. These are formed as a result of dissolving action of the atmospheric waters which have entered the little pits and merged them into saucers. These forms are to be found around the karst lakes of Inder, Elton and Baskunchak.

3. Salt furrows: Usually in the littoral strip. In length, up to 25 meters and from 10 to 25 centimeters in width. Formed by the action of fresh surface waters or shore springs.

4. Salt windows: Usually round, one to two and a half meters in diameter; depths vary; sides are vertical or with a slight slope; walls usually are covered with large and small crystals and a mud-like coating. In dry weather they are covered with a many-layered crust of white small crystal salt. These are the so-called "blue garnet", a salt mass without definite texture but a greyish and milk-white crystal. Such is the karst product of the Lake Sultan Sandzhar near the Amu Dar'ya and also of the north shore of Lake Baskunchak, in the Volga steppe.

5. Salt burrows: similar to salt windows, differing only by the presence of small exit canals. Usually these are found on the lake surface in groups.

6. Salt gulls: on the white surface of new deposits which from a distance resemble sea gulls resting on the surface of a lake.

7. Salt mushrooms: exactly like their name; found in the Perskopskie Lakes of the Crimea, the Volga Region and throughout Central Asia.

Another type of salt karst widely distributed throughout desert stretches is that existing on the bottoms of lakes now covered with sand.

The sculpturing of karst in rock salt, closely connected with gypsum, approaches the magnificence and can exceed that of limestone. This form of karst has its particular nomenclature, closely analagous to that of limestone: salt moss, salt teeth, salt karren or massive teeth; salt tables and mushrooms which in this instance often are called "salt penitents", since they resemble a humble man in varying degrees of remorse for his sins. All the usual karst forms, funnels, ponors, caves, save the great depression shapes, are also found in this rock salt. The salt dome karst has been found to contain mineralization and frequently to have rare gases such as helium.

In Tadzhikistan salt domes dominate the landscape in majestic splendor. At the top of a great terraced stairway in one of the domes a giant shaft plunges 450 feet into its depths. The Taimyr Peninsula in the Arctic is rich in karst formations in the salt domes with funnels ponors and caves abounding.

For centuries the salt domes of Ilets in the foothills of the Southern Urals have been worked and since 1754 the mines have been a State monopoly. With the collapse of the roof of the "Great Chamber" as a result of karst action, salt tectonics and karstification became a subject of serious study in the 1930's. The wanton disregard in hewing out the salt had produced basins for collecting rainfall, with disastrous results upon the mines.

Karst in Loess

Karst formed in loess is called by Soviet geologists "clayey" or "little" karst because the surface forms are much shallower than those developed in rocks of coarser grain. Closely associated with this karst type is the dread of desert travelers, "sag" or technically, subsidence. A peculiarity of this phenomenon is that when dry the loess can sustain a weight of two kilograms per square centimeter but when wet cannot hold even the lightest of loads.

In 1907 Lev Berg first noted the peculiarity of loess karst and described the phenomenon of the barren stretches north of the Aral Sea: "A singular karst phenomenon, the more curious in that it is developed not in sandstones and limestones, as usual, but in sandstone clay. The 'valley within a valley' formed by the sinking of the floor of the sandy clay until tiers of these inverted pyramids have been formed and the karst succeeds in reaching the sea, and continuing on down. The soil in this region is so fine it is almost impossible to walk and the surface is pitted with funnels, caves and blind valleys."

A classic example of this karst is the ridge of hills to the southeast of Krasnovodsk on the eastern Caspian, the Maly Balkhan, better known by the natives and those requiring transit as "badlands".

In Ukrainia loess, first deposited in Lower Mindelian when it filtered in the deep cracks of the crystalline shield, filling the valleys and softening the relief and later partially eroded during the Riss glaciation, is an area with karst forms. Two belts of loess in European Russia follow the moraines of Pleistocene glaciers and rivers. Here the fine white dusty silt lies beneath later lacustrine deposits and is often covered with the vast bogs and marshes. Locally the surface is covered by quicksands and barchan dunes, singly, or in high chains.

In Asia the loess belt, generally characteristic of regions of flash floods, forms steep cliffs, impassable gulleys, caves and deep depressions with relictual deposits. Around the Fergana Valley in the bleak foothills called "adyry" in the Kuznets-Ala-Tau, the Salair and the Altai, the loess lies on the sides and on the tops of the watersheds and terraces of wide assymetrical valleys. Covering the eastern half of the Minusinsk Basin to a depth to 50 feet in places, it extends over the entire southern half of the Irkutsk Province and as far north as the Upper Lena, an important industrial region. Around Tomsk, once the administrative center when Siberia was still an independent colony, it increases to 150 feet in thickness.

In Northern Siberia, these aeolian deposits form the strata beneath the tundra cover in company with peat and fluvio-lacustrine sediments. This loess and related sands house the remains of the ancient inhabitants of this vast tundra region, the mammoths, rhinocori, horse, elk, bison, tiger and lynx.

The following generalized table gives the approximate location of karst areas in the USSR and their characteristics. Localities cited are keyed to the National Geographic map of the USSR. Abbreviations are as follows:

TABLE
(See Figure 1 for Location)

Geological Formation	*Rocks*	*Karst Forms*
Pleist.—Pleistocene	C—Conglomerate	f—funnel, d—doline
Mio.—Miocene	L—Limestone	s—shaft, p—ponor
Tert.—Tertiary	G—Gypsum	pj—polje, u—uvala
Cret.—Cretaceous	An—Anhydrite	l—lapiez (karren), c—cave
Jur.—Jurassic	D—Dolomite	ud—underground drainage
Tri.—Triassic	Lo—Loess	bk—buried karst
Mes.—Mesozoic	M—Marl	mk—mineral karst
Perm.—Permian	P—Permafrost	th—thermokarst
Carb.—Carboniferous or Permian	RS—Rock Salt	kg—karst gulleys
Dev.—Devonian	S—Sandstone	kl—karst lakes
Sil.—Silurian		sk—suffusion karst
Camb.—Cambrian		spr—springs
Paleo.—Paleozoic		h—hums
Arch.—Archean		

Areal distribution: lim—limited, con—considerable, ext—extensive.
Degree of development: w—weak, m—moderate, i—intensive.

Map No.	*Geographical Location*	*Geological Formation*	*Rocks*	*Karst Forms*	*Areal Distribution*	*Degree*
			EUROPEAN RUSSIA			
1	Onega-Dvina	Sil.	D,G,L	f,d,u,ud.	con.	i
2	Valdai	Dev.	S	fs,s,d,u,pj,kl,ud.	ext.	m
3	Leningrad	Sil.	L,D	f,ud.d.	ext.	m
4	Tikhvin	Carb.	L	f,u,d,mk.	ext.	i
5	Ust' Ukta	Dev.	G,L,P	f,u,d,h,spr.	ext.	i
6	Vologda	Pleist.	Lo	f,s,d,bogs	con.	w
7	Moscow oblast	Carb. & Pleist.	L,M,Lo	f,c,u,ud,kl, kg,bk,mk.	con.	w
8	Ivanovo oblast	Perm.	L	f,s,p,ud,kl,mk,bk.	ext.	i
9	Tula	Carb.	L	f,s,kl,ud.	ext.	w
10	Gor'ki oblast	Perm.	G,L	f,s,d,kg,bk.	ext.	i
11	Ryazan'	Carb.(?)	L	f,s,d,pj,ud.	ext.	i
12	Samara Luka	Perm & Paleo.	L,D,G	f,d,s,c,kg,u,bk,mk.	ext.	i
13	Maria oblast	Perm.	L,S,M	f,s,kl,ud,badlands	ext.	i
14	Oka-Volga Basin	Perm. Tri.	L	f,s,p,ud,u.	ext.	m
15	Kinel-Buguruslan	Perm.	G	f,s,d.	ext.	i
16	Khazan	Perm.	G	f,sk,ud,d.	ext.	i
17	Lower Volga Region	Perm.	G,S,L	f,s,p,d,c,u,h.	con.	w,i
18	Baskunchak	Perm.	G	f,s,p,c,d,kg,mk.	ext.	i
19	Saratov	Perm.	D	f,bk.	con.	i
			UKRAINE			
20	Voronezh-Kursk	Cret.	Lo	f,s,c,bk,mk.	con.	w
21	Dnestr-Prut	Mio. & Pleist.	G,L,Lo	f,d,c,p,s,	con.	m
22	Podolsk Plateau	Arch.	L	f,s,d,u,s,c.	lim.	m
23	Oskol'	Paleo.	L,Lo	f,s,d,s,mk.	con.	m
24	Elenovsk	L. Carb.	L	f,c,mk,s,bk.	con.	m
25	Lower Dnepr	Tert.	L,Lo,M	f,c,ud,s,l,kg,d.	ext.	m

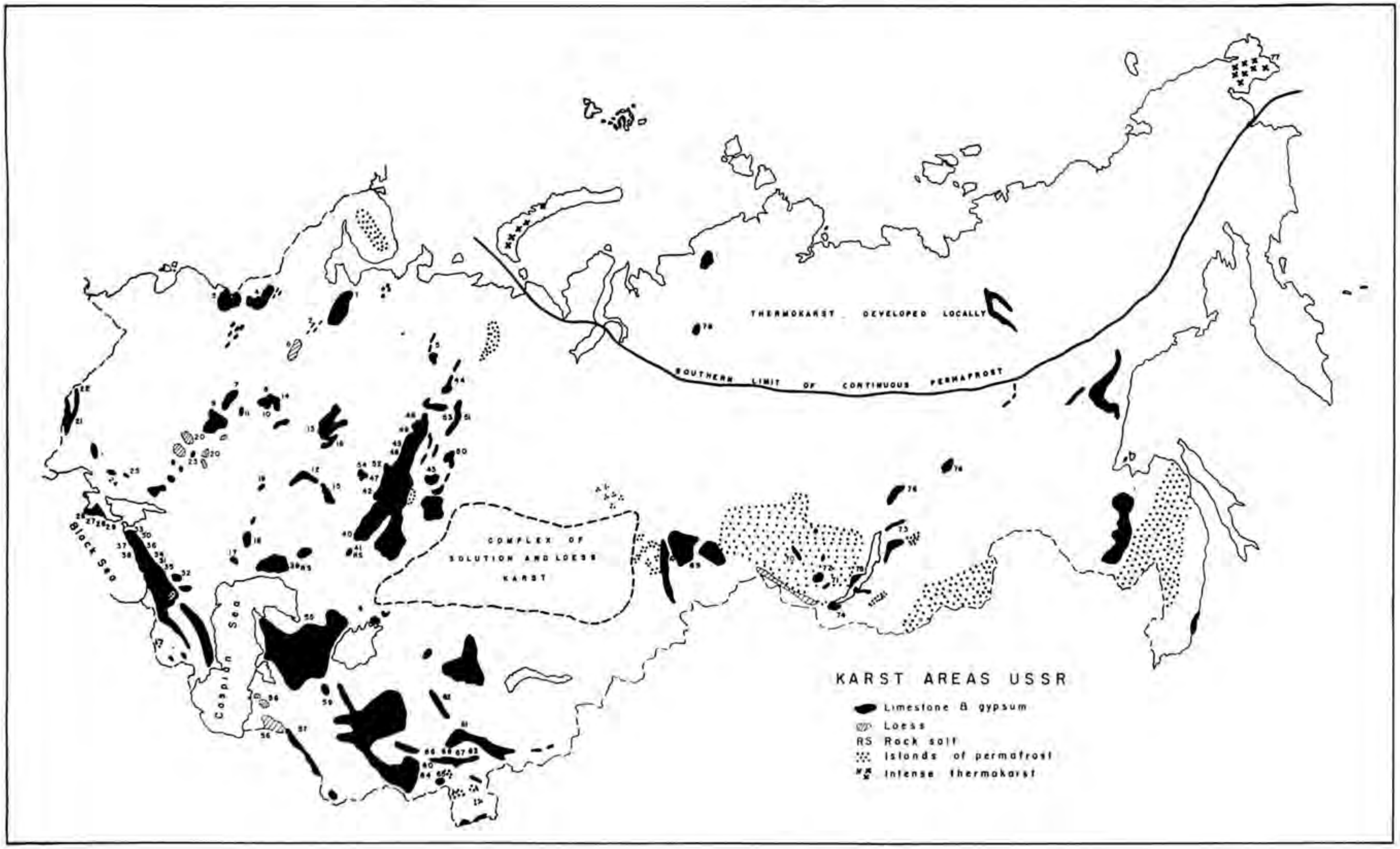

Fig. 1. Map showing karst areas of the U.S.S.R.

TABLE (continued)
(See Figure 1 for Location)

Map No.	*Geographical Location*	*Geological Formation*	*Rocks*	*Karst Forms*	*Areal Distribution*	*Degree*
			CRIMEA			
26	Chatyr-dag	Jur.	L	f,c,pj,l.	ext.	m
27	Iaily	Jur.	L	f,c,s,l,u,d,s,pj.	ext.	i
28	Baydar Valley	Jur.	L	c,pj,d,u.	con.	i
29	Babugan	Jur.	L	kg,f,pj,u.	ext.	w,i
			CAUCASUS			
30	Skalisty Range	Up. Jur.	L,G	f,u,s,d,ud,l.	ext.	m
31	Bol. Bergmamut Pl.	Jur.	L	l,f,s,u.	ext.	m
32	Mineralovodsk	Cret.	L,S	f,c,kg,d.	con.	m
33	Bzyb Range	Jur.	L	f,ud,c,s,l.	con.	i
34	Matsestinsk	Cret.	L	f,c,ud,spr.	ext.	m
35	Tserek kel' (Kabardino)	L. Cret.	L	f,s,s,ud,u.	ext.	m
36	Chvizhepse Valley	Up. Cret.	L	f,s,ud,p,u.	ext.	i
37	Abkhazia	Up. Jur.	L,M	s,d,f,c,ud.	ext.	m
38	Megrelin	Cret.	L,Lo,C	f,d,ud,u,s,s.	ext.	i
			URALS			
39	Inder	Perm.	G,RS	all forms	2 complete cycles	w,m,i
40	Orenburg Steppe	Perm.	G	f,u,p,u,d.	con.	w,m
41	Ilets		RS	f,l,c,p,s.	ext.	i,m
42	Sterlitamak	L. Perm.	L	c,f,bk,mk.	ext.	m
43	Sverdlovsk	Dev.	L	f,p,c,ud,mk,bk.	con.	w
44	Krasnaya Shapochka	Up. Sil.	L	f,d,u,mk,c,ud.	con.	m
45	Molotov	Perm.	G,L,D	f,d,s,c,bk,u.	ext.	i,m
46	Kizel	Dev.	L	c,ud,f,bk,u,mk, dry valleys	ext.	m
47	Ufa	Up. Carb.	L,G	f,ud,c,s,bk.	ext.	w
48	Kungur	Perm.	G,An	f,s,c,ud,u.	ext.	m
49	Chusovaya	Perm.	L,G	f,s,ud,c,pj,u.	ext.	i
50	Alapaevsk	Carb.	L	f,bk.	con.	w
51	Ivdel'	Dev.	L	f,d,pj,u,mk.	ext.	w
52	Belaya River	Perm.	G	f,ud,pj,u,s,c.	ext.	i
53	Severoural'sk	Sil. Dev.	L	p,ud,mk,f.	ext.	m
54	River Ik	Perm.	L	all forms	ext.	i,w
			CENTRAL ASIA			
55	Ust' Urt Plateau	Cret.		f,p,s.	ext.	i
56	Atrek-Sumbar River	Carb.	Lo	f,ud,p,pj.s	con.	i
57	Kopet Dag	Tert.	L,G	c,f,ud,spr.	con.	m
58	Maly Balkhan	Cret.	S,C,Lo	f,s,kg,l,sk.	ext.	i
59	Sarykamysh	Perm.	L,G,S	f,c,u,ud.	ext.	m
60	South of Samarkand	Mid. Paleo.	L,G	f,s,l,p,bk,u,c.	ext.	i
61	Chimkent	Mid. Camb.	L,D	f,c,s,ud.	ext.	m
62	Karamazar	Tert.	L	f,c,mk.	ext.	m
63	Tyuya-Muyun	Paleo.	L,S	f,c,mk.	lim.	m
64	Zeravshan-Gissar Ranges	Paleo.	L	f,c,ud,u.	con.	m
65	Kulyab	Low. Cret.	S,D,An,RS	f,c,l,ud.	ext.	m
66	Alai Range	Paleo.	L,S,Lo	c,ud,p,kg,mk.	ext.	m
67	Fergana Valley	Camb.	L,Lo	f,c,s,ud,u,sk.	ext.	m
68	Kokand	Camb.	L	s,f,c,spr.	ext.	m

TABLE (continued)
(See Figure 1 for Location)

Map No.	*Geographical Location*	*Geological Formation*	*Rocks*	*Karst Forms*	*Areal Distribution*	*Degree*
			SIBERIA			
69	Minusinsk	Camb.	L	f,c.	lim.	w
70	Nizhneudinsk	Dev.	S,L	c,f.	con.	w
71	Cheremkhovo	Camb.	L	s,f,c.	con.	i
72	Balagansk	Camb.	G,L	f,c,mk.	ext.	i
73	Angara	Camb.	G	s,f,u.	ext.	i
74	Dzhon-Murina R.	Camb.	L	f,ud,s.	con.	m
75	Lena-Baikal Watershed	Mid. Camb.	L,D	f,l,c,ud,th.	ext.	m
76	Aldan-Vitim R.	Camb.	L,P	f,c,spr,ud,th.	ext.	m,i
77	Chukotsh Pen.	(?)	P	f,d,u,th.	ext.	i
78	Noril'sk	Sil.	L	f,d,u,s,ud.	con.	m

MINERAL KARST

The association of karst and certain mineralization was first put forth in Russia in 1908* and later elaborated by Soviet geologists during the twenties. In 1932 a party of scientists sent to extract the secrets of the rocks from the Kazaks found the "old workings of the Kantagi mine to be pure manifestations of karst phenomenon". Expanding on this observation they concluded that the karst hypothesis could apply to all polimetal deposits of the Kara-Tau. By the late forties this thesis was elaborated: "A knowledge of the contemporary processes of karst gives the key to an understanding of the location of the ancient karst cavities which are not apparent on the surface. Thus the theory of karst is a guide for the prospecting of useful minerals".

Among the "useful minerals" cited as occurring in karst in the USSR are: tin, zinc, mercury, arsenic, lead, copper, sulphur, fire clays, Icelandic spar, oil, gold, uranium, vanadium, copper, fluorspar, salts, barites, borates, alabaster, bauxite and antimony. Karstifying limestones and gypsum create favorable conditions for gases such as nitrogen, oxygen and the inert gases. Karst waters often are attended by mineralization and radioactivity. The radioactive springs on the River Izhma, rise from heavily karstified gypsum rocks where the funnels are so closely packed that they form a knobby or *hum* relief.

Aside from the karst giving rise to the conditions for physical and chemical alterations of air, water and rocks, a retroactive process upon the karst itself has been observed. The size of the karst is enlarged by the oxidation of pyrites it contains and the formation of free sulphuric acid strengthens the aggressiveness of the waters circulating through the karst canals. The karst of Central Asia is almost invariably accompanied by this capacity of enlargement, which accounts for caves being the predominant karst form in this region. The size of the gigantic karsts in the Visim Region of the Central Urals depends on this process which here occurs in connection with pyritization of the schists and the presence of pyrite-quartz veins.

The theory of karst mineralization as presented in 1924 by A. E. Fersman and Shcherbakov would seem to be a basis for the recent theory of karst as developed by Aprodov. It is most graphically represented by an old karst in the dry hills of Fergana south of Osh, said to be the oldest town in the world because Adam came there on his way from the Garden of Eden bringing with him the silk worm. Near this town is also the site of the first radium mine in the USSR. In the semi-desert climate with low annual rainfall a greyish straw colored monolithic ridge of remarkably pure Devonian and Lower Carboniferous limestone rises besides a small stream. Beneath

*ED. NOTE: The relation of karst and mineral accumulation in the lead and zinc district of the central United States was given considerable attention in the latter part of the 19th century.

lie argillaceous and siliceous schists of Upper Silurian and Cambrian, laminated by "fetid" limestone and sandstones cut through by igneous rock, breccia and tuff. Warm springs from the rock indicate a complex phreatic action.

The karst forms a series of bell-shaped chambers which are the enlargement of connecting pipes, some straight as an organ pipe and others crooked as an elbow, that change their angle of dip in conformity with cleavage. Cavern levels reached nearly 350 feet beneath the openings of the shafts. The processes of mineralization occur after a period of normal prolonged karst activity. Descending cold water is altered by ascending mineralized solutions and accumulations of new elements takes place as the first products of deposition in alkaline solutions interacting with the calcium carbonate of the karst.

Bauxite is found in many karst hollows and funnels in the Cambrian limestones of the Eastern Sayan, in Middle Devonian limestones of the eastern slope of the Central Urals, and in the limestones of the Upper Triassic of the Gissar Range, the Cretaceous of the Middle Urals and Jurassic of Northern Kazakhstan. Whether these deposits of bauxite were sedimentary or biochemical in origin is still open to discussion but Lev Berg refutes the former and presents the latter on the basis that the marsh vegetation which once covered all these surfaces was an important factor in the production of bauxite. A surface manifestation of this is now taking place in the contemporary karst funnels along the Klyazma River of the Ivanovo Oblast' east of Moscow where bauxite is forming in leached limestone clays beneath a blanket of peat covered lacustrine deposits.

In the genesis of bauxite karst activity seems to be involved twice; first by forming the receptacle for the deposit and secondly, by subjecting the bauxite to compaction by settling. In many regions, were it not for the protection provided by the karst formation, the bauxite would long have been washed away. In fact, the bauxite strips of the Southern Urals, storied in several layers connected with the ebb and flow of the karst activity, lie deep in the Devonian limestones. Bauxite at depths close to 1900 feet have been found indicating former extensive karst activity.

As karst provides the receptacle for accumulation and protection of bauxite, so from the constant low temperature provided by the karst in the caves of Central Asia a particularly fine optical calcite,—the best in the USSR,—a form of "iceland spar" is developed. This mineralization, the last stage in a single hydrothermal process, crystallizes at low temperatures to form the Kul-i-kolon deposits of Tadzhikistan. Karst in the region of deposits of iceland spar takes the form of caves, at times large in volume and with calcite crystals adorning the walls; or, again, small with only incrustations of limestone tuffa, and occasional stalactites and stalagmites. The age of the mature caverns is estimated to be Paleozoic for most of them lie beneath a buried peneplain surface on which are bedded Upper Paleozoic rock.

Another peculiarity to be noted is the limited range of the cave formations in these areas. In the massive crenelated Upper Silurian limestones of the Kul-i-kolon region caves occur only rarely and are mainly in an area where the limestones have been subjected to deep hydrothermal activity in connection wiwth magmatic intrusions. In the latter case cavern development is extensive. Limestone tuffa, dripstone and other products of deposition belonging to the later part of karst development are generally absent in these caves and when they do occur they are developed over a deposit of crystalline calcite. Thus the conclusion can be drawn that these caves are formed by ascending calcite depositing hydrothermal waters rather than descending water.

Gold, uranium and vanadium deposits are also reported to be associated with karst. These deposits are "fossil" placers and residuum that accumulated in ancient buried karst. The gold, uranium and vanadium minerals accumulated in deposits similar to those forming bauxite but in a surface cover of sands rather than in residual clays. Over great stretches of Russia, in the Arctic regions, especially in polar Kolyma, and in the Eastern Urals, gold "bogs" can be found in the karst. This strip in the Urals is so distinctive it has been dubbed a particular name "beliki" given by the local inhabitants of the region, which is used to distinguish the peculiar depositions of quartz detritus confined in an arenaceous and mealy kaolin-like mass.

The Mesozoic was the great accumulator of gold in this form, washed away from the slopes of the Urals and lodged in the area to the east. In the Kuznets Ala-Tau the gold mines are situated in ancient karstified carbonate rocks in which the funnels and dolines served as giant panning tubs.

* * *

No attempt has been made in this presentation to evaluate varying opinions of different Soviet scientists as the purpose of the paper was not one of evaluation but rather an empirical investigation of the negative and an abstract presentation of Soviet karst areas. As for reliability, this paper has one thing in common with the descriptions of India made by Ptolemy and Herodotus: None of the three authors wrote about what he had seen.

In summation, it is perhaps sufficient to present the postulate made by Soviet engineers in 1951:

"For karst to form and develop, the rock should not be monolithic but must have cracks and openings along which waters can criculate . . . for the movement of water is the indispensible condition for the formation of karst."

NOTE: Two systems of transliteration have been employed: for place names, that of the National Geographic Magazine; for bibliography and authors, that of the Library of Congress.

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CAVES OF INDIANA

By GEORGE F. JACKSON

While Wyandotte and Marengo caves have received wide publicity as Indiana's principal commercial caves little has been written about the State's smaller but equally fascinating ones. The author, a competent speleological writer, here presents an account of some of the lesser known caves of the Hoosier state.

What might be called the cave section of Indiana covers an area of approximately 2,000 square miles in an irregular strip of land of varying width extending south-southeasterly from near Greencastle in Putnam County to the Ohio River in Crawford and Harrison Counties. This is the northern extension of the great cavernous area of Kentucky, and is known as the Mitchell Plain, because near Mitchell, Indiana the true character of the plain is most apparent.[1]

In their southward extent in Indiana the limestones reach a thickness of 575 feet and within them is found one of the largest and most complex drainage systems in the world. In this area, characterized by underground drainage, sinkholes, sinking streams, springs and resurgences are the many caves of the state.

Formations involved are the Harrodsburg (Warsaw), Salem, St. Louis, Ste. Genevieve and one or more of the Chester limestones at the top. On the northern end of the area there is considerable thinning of the limestones (where the section also becomes partly covered with glacial drift) in Putnam and Owen Counties. Dip of the formations is westerly at approximately 30 feet to the mile.

It is interesting to note that the massive deposit at the base of the Mitchell limestone is the singularly joint and fissure free Salem limestone which is quarried and has become world-famous as a building material under the name "Indiana Limestone".

The following descriptions of several of the "wild" and commercial caves of the state include some of the more than 100 known to the author and which have been personally explored by him. Omission of many is due solely to space limitations. It is not meant to imply that they are lacking in interesting features. A few caves of lesser importance, speleologically, have been described because of other interesting features such as history, folklore, personal preference or as a means of comparison or to show a similarity to others described.

Photo by George F. Jackson

Fig. 1. The author (left) and a guide examine one of the palettes in Marengo Cave, Indiana.

Some of the caves have been known since pioneer days and interesting tales and legends of their discovery are told. Nearly every one of the long-known caverns has the old story of its entrance first being noticed by a hunter, who while trailing a wounded bear, or deer, or any such animal as the case may be, followed him to a place where the animal "disappeared into the ground". Upon investigation there came to light an amazing underground labyrinth unequalled in the realms of previous knowledge. In a very few instances this may be true, but some caves have been known so long that the actual facts of their discovery have been forgotten, the owners merely guessing at the

[1]The first systematic research in respect to this region was conducted, in 1837, by David Dale Owen, chief of the United States Geological Survey when its headquarters were at New Harmony, Indiana. The cave-bearing stratum, the Mitchell limestone, was then called the "cavern" or "mountain" limestone.

truth, the most logical theory being the bear incident. Human nature being what it is, it is not surprising that these same incidents seem to have happened with amazing regularity all through the cavernous regions of the United States.

Other than the two famous commercial caves, Wyandotte and Marengo, perhaps the best known cavern in Indiana is Donaldson's Cave, three miles from Mitchell in Lawrence County. Here, in

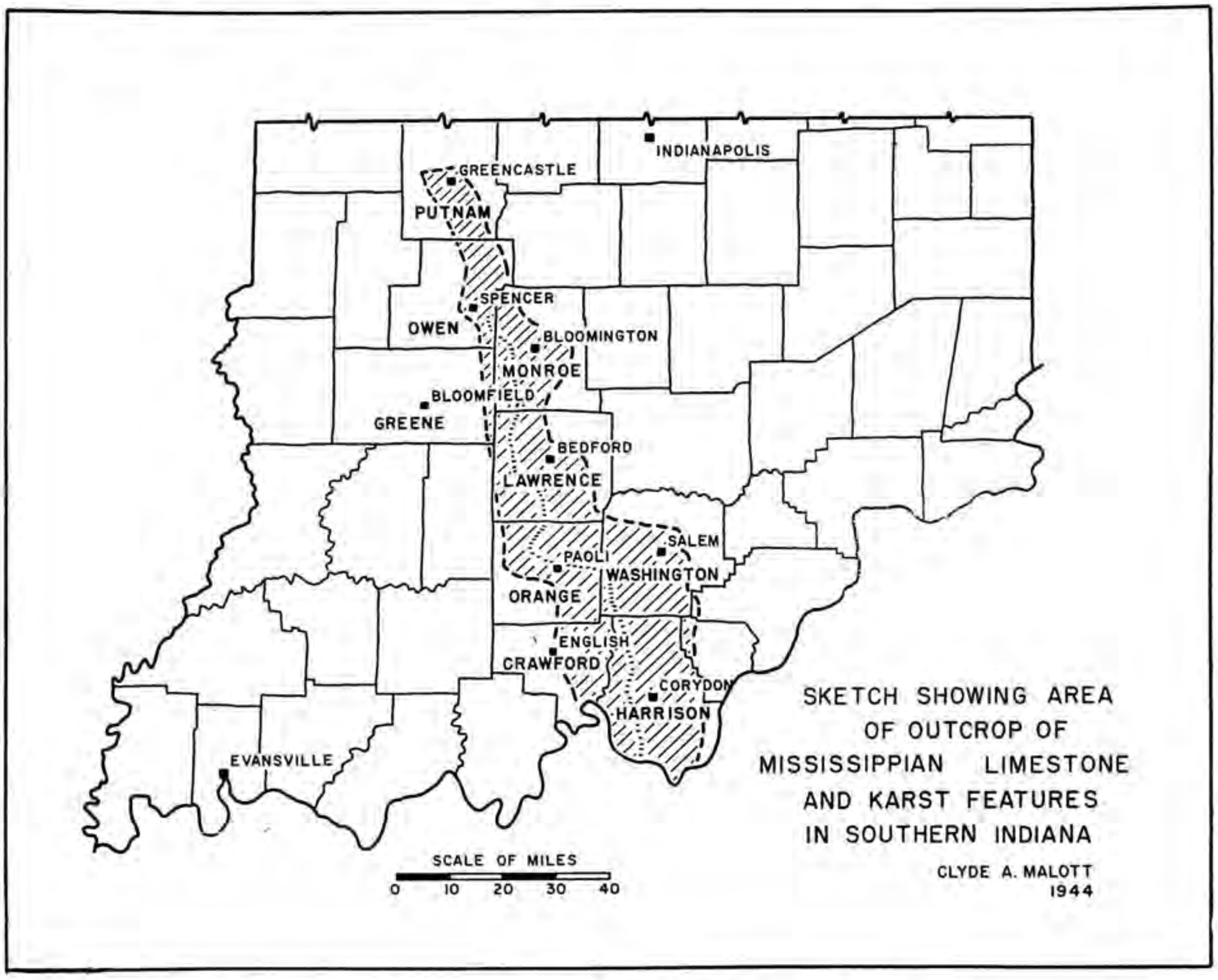

Fig. 2. Map showing area of outcrop of Mississippian limestone and karst features in southern Indiana (after Malott).

Spring Mill State Park, is found a completely reconstructed pioneer village, along with grist mills and restorations of every other activity that was pursued in settlements on the outskirts of civilization early in the 19th century.

Donaldson's, formerly known as Shawnee Cave from its proximity to the hunting grounds of that Indian tribe, has an unusually picturesque entrance. From it issues one of the largest streams of water to be found in any cave in Indiana. Located at the head of a deep ravine, the opening is about 22 feet high, 20 feet wide and offers an excellent illustration of how caves are sometimes converted into deep valleys. At one time, the cavern extended the full length of the gorge into which it now opens, but excessive erosion by the waters wore the roof to such thinness that it collapsed and the continued breaking down has extended the gorge to its present length.

Early in the 19th century saltpeter was made on a small scale from the nitrous dirt in one of the dry passages near the entrance, but long before this the region about the cave attracted primitive man. The Delaware, Shawnee and Piankeshaw Indians all lived in adjacent sections at various times and numerous traces of them have been found along nearby streams. Although early geologists have reported the cave as showing signs of prehistoric occupation "as flints, stone axes, and bones have been found in and around the mouth in great numbers" (Prof. John Collett, Indiana Geological Survey, 1873) these were probably not prehistoric at all, but were accumulations left by the tribes mentioned above, and the early saltpeter miners.

There are only three passageways of note in Donaldson's Cave, all opening into the vestibule. The center one is high and narrow with rough, jagged walls. Some hundred feet within a small waterfall drops with great force, and during the rainy season may be plainly heard at the entrance. Visitors are now taken for a short boat ride on this underground "river", but former explorations were made by the highly exciting method of wading the cold creek, or inching along the narrow ledges 20 feet above the water. Neither method of travel is recommended for comfort.

Photo by Roy Davis

Fig. 3. Speleothems in Boone's Mill Cave, Indiana.

The other two passageways are dry, and have no formations worthy of more than passing interest, the only speleothems being a few dirty-colored "tobacco-leaf" deposits.

It was at Donaldson's Cave that Dr. Carl H. Eigemann did the research for his elaborate and authoritative volume on the cave vertebrates of North America. For 12 years he conducted experiments at the mouth of the cave, using specially built culture basins and studying the *Amblyopsis,* which he called the "blind fish par excellence". Today, eyeless fish and blind crayfish are plentiful in the cave stream but they are probably not as plentiful as Dr. Eigemann claimed when he said the place contained "more blind fish than all other localities put together".

Within the boundaries of Spring Mill State Park are several other caves, notably Hamer's Cave, Twin Caves, Wind Caves, Bronson Cave and Whistling Cave. Each of these has been formed by the same river system which still flows through all of them. In Twin Caves the river—which averages about four feet in depth and twelve feet in width—fills almost every available niche. On a recent trip we found only one spot of earth large enough to stand upon. The entire trip was made by boat.

The entrance to Twin Caves is an excellent example of what the late Professor Clyde A. Malott referred to as a "karst window", a sinkhole depression produced by collapse over an underground stream allowing the cavern and stream to show, and permitting an entrance to caverns both upstream and downstream.

The brook issuing from Hamer's Cave furnishes the water supply, carried by a quarter-mile-long flume, which turns the huge mill wheel in the reconstructed pioneer village of Spring Mill. Although greatly exaggerated by many of the early explorers, the cave is extensive and contains several waterfalls and cascades. Since exploration is not permitted by the State of Indiana it will not be described here.

One of the most beautiful of Indiana's wild caves is Richard's Cave, located on the Richard Smoots farm in Harrison County, about three miles from White Cloud. It is reached via the Blue River bridge and two miles of county road. Discovered just a few years ago by Mr. Smoots, who is an avid spelunker, it contains a splendid array of formations of varying size and color.

Noteworthy among them is a large group of straw stalactites, ranging up to two or more feet in length, which literally cover the ceilings of some rooms.

It was the good fortune of the author to be able to explore and photograph Richard's Cave shortly after its discovery. The delicate and delicately-colored formations, a floor of comparative smoothness for a wild cave, and the possibility of finding still more rooms and passageways, coupled with the thrilling sensation that comes with being "one of the first" combined to make it a delightful underground experience.

The following quotations about the cave are from a letter written to a speleologist-friend immediately after the exploration trip while the beauty of the cave was still fresh in the author's mind:

"One of the things that interested me was a room, the ceiling of which was literally covered with thousands of white, brown, red and reddish-brown stalactites, none any larger in diameter than a pencil and from one to three feet long. So many and so colorful! In an area of about 100 square feet it was impossible to touch any part of the ceiling without breaking dozens of them. Fortunately the roof is just high enough that it cannot be reached easily.

Like many others, the cave was discovered quite by accident and required very little digging to admit a man. The whole thing is very clean, and from one end to the other—about 2,000 feet—is formation filled. Formations range from the type mentioned to lily-pads, draperies, pillars, peculiar rough stalagmites and just about every type of cavernous formation except helectites and gypsum."

On a later exploration trip we managed to dig and chisel our way into a small room at the very end of the main passage, but if there are any other leads in the cave they are well hidden.

Borden's Cave in the same general area is of much more interest to adventurous spelunkers for it is entered through a sheer pit. Like many another cavernous hole the depth is frequently exaggerated and various accounts have it anywhere from 65 to 125 feet deep, but it actually is not more than 45 feet. The first few feet of the drop are through an elliptical hole in the solid limestone roughly eight feet in diameter.

Below this the walls recede and the cave expands into a large room with the result that climbing ropes hang free, adding to the thrills of a descent. The entrance is a memorable one in the author's mind because it once conveyed quite forceably the serious difficulties that even experienced spelunkers can get into when all available climbing ropes get covered with slippery mud!

There are many spelothems in the cave, varying from small stalactites to massive stalagmites and flowstone wall deposits. Most are highly colored and offer a fine display for the color photographer. Perhaps because Borden's is rather difficult of entrance, it has not been visited by spelunkers as often as some of the more accessible caves and there are few broken formations and for the same reason, the chances of finding more cave are probably better here than in some of the nearby caverns.

Photo by George F. Jackson

Fig. 4. Entrance to Donaldson's Cave in Spring Mill State Park, Indiana. This is one of the largest streams of water issuing from any Indiana cave.

In a round, dome-like room at the far end of the cave is the only large *eroded* stalagmite to be found in any Indiana cave. At one time the formation was probably six to eight feet high and 15 feet in circumference, but streams of water from above have etched three and four inch channels down all sides until the greater part of its bulk is gone. These channels, or grooves, go all the way around the stalagmite and their edges are sharp enough to inflict a severe cut on a hand placed carelessly against them. Yellowish-white with thin horizontal brown streaks here and there on its sides, the formation would make an interesting color photograph but is unfortunately located in such a position that a good camera angle is almost impossible.

At the time of the author's first trip to Borden's Cave a four-foot black snake was found sunning itself in a shaft of sunlight on one of the ledges near the bottom of the entrance pit. Assuming that it had fallen in we attempted to capture it and return it to the surface where it could lead a more normal life, but were unable to do so for the ledge was higher than a man's head and far too narrow to walk upon. Although there was an abundance of bats and a trace of mice nearby which indicated that the snake might have food for a considerable length of time, whether or not it survived is a matter of conjecture. It was not seen on later visits to the cave and it would be interesting to know how long it managed to live on the ledges which were warmed by the sun for only a few hours each day during the summer months.

In an open level field 300 feet from the entrance to Borden's Cave, and possibly once connected with it, is a vertical shaft which extends downwards for at least 120 feet. There are no side passageways and nothing of particular interest in the cave, but it does offer an excellent spot to practice rope climbing techniques. The entrance is neither covered nor fenced and in a less isolated spot would be dangerous.

Nearby Langdon's Cave in Harrison County State Forest is much easier of entrance than Borden's but is of the same general type and formation. It, too, has many spelothems, and is longer with one high and narrow main passageway. This is "undercut" to a height of two or three feet along its entire length and both here and on some of the many ledges, 20 to 50 feet above the floor, there seem to be definite leads to virgin passages. The breakdown in the large room at the end also offers possibilities for finding more cave but little systematic work has ever been done here.

Perhaps one-half mile distant is Mauck's Cave, full of fantastically-shaped formations and plenty of crawlways on several levels. Since many of these tunnels are wet and muddy and twist and turn in all directions, making it difficult to explore completely, this cave has not received the attention some of its more accessible neighbors have.

A short distance south of Corydon is Bussabarger's Cave, containing an immense room with an intriguing lake at one end. Visiting this cave searching for that rarest of eyeless fish—*Typhlicathys Wyandotte*—we entered through a shallow sinkhole-like depression and found ourselves at the top of a tremendous breakdown. Clambering down over huge broken rocks, old tin cans, discarded farm implements and the refuse of years from a nearby farmhouse we marveled at the size of the room. Once, it had been a mighty cavern, now it was simply a smelly hole in the ground. About 200 feet down we passed out of the "dump area" and came to a steep slope of slippery mud. This led directly to a "lake", perhaps 30 feet wide and the same distance across. On all sides, except where we stood, the walls came down sheer, offering not the slightest toe or finger hold. The mud slope below us continued down into the muddy water for an unknown distance. The steepness of the bank made it extremely hard to move around without slipping into the water, and the author even tried this—quite unintentionally, however, since he had several hundred dollars worth of camera equipment in one hand at the time. We captured no eyeless fish (possibly due to the fact that they prefer not to associate with photographers!) but did spend many minutes gazing at the far walls wondering what might lie beyond. In that direction there is space for a mighty cavern—does such a cavity lie just beyond those smooth rocks, we wondered? If so, then how to get into it? We finally left the underground lake and climbed back up the mountain of rocks making plans to return and fully explore the vast region on the other side. To this day we have not yet returned. Perhaps in the future . . .

Another Indiana cave with an interesting river of unknown source is Wildcat Cave (sometimes known as Sheep Cave) one and one-half miles northeast of the entrance to Wyandotte Cave. In a heavily wooded section aptly named "Tanglewood" this cave has been the scene of extensive explorative work, but no man has yet seen the huge cavern which most Hoosier speleologists agree lies beneath the ridge in back of it.

It is entered through a four-foot hole halfway up a 100-foot cliff. A short passageway leads to the top of an old breakdown in a very large room. At the base of this great pile of rocks—about 200 feet from the top—is a room floored with fine sand and mud. A few feet away is the "river", four to five feet wide and three feet deep and crystal clear. The author has been in this cave many times and has always found the water clear, which would seem to indicate that it has been flowing underground some distance and has deposited its mud and impurities far from this spot.

Downstream the watercourse may be followed some 40 feet to where it disappears through a mass of broken rocks. Roof and walls come together here in such a manner as to make further progress almost impossible even after a considerable amount of work.

Upstream 50 feet, the walls curve around the water in a semi-circle. Here, just below the surface is an opening the width of the stream. This is the extent of man's penetration. It is an intriguing spot for an adventurous speleologist. Does the stream flow through a siphon, and if so, is it long or short? Does a vast unknown cavern full of fantastic wonders lie just on the other side of the smooth rock wall? Any spelunker desiring some real—and wet—exploration is welcome to try and find out.

In this cave we once had the unusual experience of having a mouse (probably a deer mouse) move a specimen bag several feet and place it *under* a great pile of winter-stored nuts, wild grapes, etc. This happened during a period of about an hour while we were trying to capture eyeless fish in the cave stream, having left the bag near the mouse's nest to pick up on our return trip (described in the January, 1951 NSS News).

Some Indiana speleologists are of the opinion that the stream flowing through the cavern is the same one that is found in Sibert's Well Cave, located 800 feet south of the entrance to Little Wyandotte Cave, and at least one and one-quarter miles from Wildcat Cave. Observations by the author, too detailed to go into here, do not bear out this statement, which probably arose because the natural flow of both streams is in the same general direction: towards Blue River a short distance away. The Wildcat Cave stream is more likely the one that issues from a rocky hillside on the Sharp farm and which is known for miles around as "Sharp's Spring".

Sibert's Well Cave contains nothing of interest other than the usual aquatic subterranean fauna. It was frequently visited in the past by scientists for specimens and several well known naturalists of the last century credited specimens of blind fish from this cave, in error, to nearby Wyandotte.

Two other Indiana underground rivers deserve mention here: the famous Lost River of Orange County where a whole river suddenly leaves the surface and flows underground, and the *rise-pit* of the great Harrison karst spring in Harrison County, some six miles west of Corydon, which erupts into an open field. This spring, or cavern-stream resurgence, is 85 feet wide, 115 feet long and of considerable depth. During dry periods it is filled with crystal clear water, but following heavy rains it becomes greatly swollen with muddy waters which boil vigorously upwards. No ob-

Photo by George F. Jackson

Fig. 5. Unusual and highly colored speleothems in Richard's Cave.

server can doubt but that below is a large water-filled cavern which drains the higher sinkhole plain to the northeast. This natural artesian "well" is, incidentally, below the local drainage level of Blue River valley.

Two caves in Harrison County bear the name of "Boone", both named after the brother of the famous pioneer, Daniel: Squire Boone's Cave and Boone's Mill Cave.

Squire Boone's Cave is in a wild, almost impassible region near Mauckport and is not much of a cave, speleologically, but it has an interesting and little known history. It was here, so legend has it, that Squire Boone swung across a ravine on a wild grape vine and hid in a cave while a band of bloodthirsty Indians searched for him. While the grape vine tale may not be true, it is fact that he discovered the cave entrance while on a hunting trip with his brother Daniel. Few people know today that the famous frontiersman knew and loved this section of Indiana and that in his later years he erected a mill and lived near the cavern which later became his grave.

Born in North Carolina in 1744, nine years after his now better-known brother, Squire Boone helped Daniel explore and map the wild "Dark and Bloody Ground" that was later to become Kentucky. It was on a hunting expedition into the unknown section north of the Ohio River that he found the cave which supposedly saved his life.

Years later he settled with his family at the "Station at the Falls" (Louisville) where he hoped to spend the last few years of his life. Well liked by the backwoods folk, he was elected to represent them in Virginia Territory, and for a number of years did so ably.

Suddenly, almost overnight it seemed, he found himself "broke". Unscrupulous land sharks fleeced him out of every penny of his modest fortune. Disillusioned and bitter he took his family to the Harrison County retreat he had found many years before, and erected the structure later known as Boone's Mill. There, with his four sons, he attempted to repair his fortunes, even using his spare time in mending firearms for his neighbors.

It is said that it was his hand that carved the inscription, "The Traveler's Rest. Consecrated by Squire Boone, 1809" over one of the doorways. Another inscription read: "I sit and sing my Soul's salvation, and pledge the God of my Creation".

Searching for these stones, the author was told they had been built into a farmer's porch and covered over with concrete. Like the hero whose handiwork they were, they have passed into the realm of forgotten history.

In 1815 when Squire Boone died it was his request that he be buried in the cave and his body rested there undisturbed until about 40 years ago when the stone caping was removed and vandals broke open the coffin and scattered his bones.

Boone's Mill Cave "just over the ridge", with its four levels, waterfalls, and many formations is rated by many as Indiana's most spectacular wild cave. Exploration is somewhat complicated by the fact that ladders are necessary to accomplish some of the falls but this is only a minor hinderance to a determined spelunker. Plenty of color, a fair-sized running stream that often plunges over unexpected drops, large pillars and unusual flowstone effects make this a paradise for a spelunker-photographer.

There are at least three "Saltpeter" caves in Indiana and one "Salt" Cave. The latter is located in Lawrence County; the others in Lawrence, Monroe and Crawford Counties. Crawford County's Saltpeter Cave is the best known and probably the most interesting. It is one half mile northwest of the entrance to Wyandotte Cave and is mentioned here principally because of its historical connection and its fauna which includes several species of bats, cave crickets, spiders, moths, harvestmen, crustaceans and just about every other kind of cave dwelling insect and animal.

The entrance is six feet high and 20 feet wide. Just inside a gigantic room expands about 250 feet long, 75 feet wide and 10 to 60 feet in height, with a smooth ceiling and a floor composed of alternating smooth dirt and huge chunks of fallen rock. During the War of 1812 this cave was "mined" for saltpeter as was nearby Wyandotte and enormous quantities of the then much-needed chemical were taken from this single room. Until recent years the remains of many old wooden hoppers, troughs, pipes, vats and furnaces were still to be found in and around the mouth.

With the exception of a short side passage of great height, the one room comprises the known part of the cavern. Located in a different "ridge" than the vast Wyandotte Cave system and not part of it, there is little doubt but what an enormous cave lies beyond the entrance room of Saltpeter.

Getting into this suspected immense cavern has intrigued Hoosier spelunkers for well over a hundred years. It is doubtful if any wild cave in the midwest has had as much actual digging done in it as this one cavity. For example, one team of "explorers" worked periodically here for one whole year, but all they had to show for their efforts at the end was a tremendous pile of rocks they had dug and chiseled from the back of the cave. Along with two others, the author once moved enough rock "bare handed" to "completely cover a house" as one spelunker put it. Dynamite and even bulldozers have been used in an effort to get to the unknown regions but all to no avail. Saltpeter Cave keeps its secret passageways well hidden. No one doubts that they are there—it is just getting into them that drives explorers frantic!

There are three commercial caves in Indiana: Wyandotte, Little Wyandotte and Marengo Caves. As one of the largest and best known caverns in the country, the former has been written about and pictured so frequently in many NSS publications that it will be passed over in this article in order that more space may be devoted to those caverns which are not as well known to readers of the American Caver.

The entrance to Little Wyandotte Cave is located 1,000 feet south of the Wyandotte Cave

Photo by George F. Jackson

Fig. 6. One end of the "river" in Wildcat Cave, Indiana. The men in the picture are scientists who, with the author, were searching for rare specimens of eyeless fish in the cave stream.

Hotel. Although very small when compared with the huge cavernous giant nearby, the ease with which it may be visited and the elaborate indirect lighting system which brings out all of its beauties, make it a top attraction for those who do not have the time for a more lengthy trip underground.

Just when it was discovered is not definitely known. The earliest date found scratched on its walls is 1856. For some years it was occasionally exhibited along with Wyandotte Cave, but since it was not then on property owned by the Wyandotte estate, disputes arose and the entrance was closed about 40 years ago. From then until 1947, when the small cave was purchased by Mr. Frank M. Rothrock, principal owner of the "big" cave, no one entered Little Wyandotte Cave.

In the old days a trip through the cavern was a spelunker's delight, for it was necessary to cross pits, climb steep walls, and crawl through low tunnels. Now, however, it has been completely "modernized" with steel bridges, concrete steps, iron railings and an excellent indirect lighting system.

Entering through an artificial opening the visitor steps almost at once into a room the ceiling of which is covered with dozens of stalactites which flash and sparkle in the light of the flood lamps. From here it is a short distance to what was formerly known as the "Double Pit", a thrilling spot where two pits are separated by a narrow ridge of slippery stone. The route now crosses the shallower of these by means of a steel bridge, certainly a far cry from earlier days when it was necessary to inch carefully along a muddy partition of rock only a foot or so wide. Then, progress was further complicated by a larger fallen stalactite, about four feet in diameter, which lay directly across the narrow pathway. Now this danger is just a memory to the older speleologists and visitors see only the top of the deepest pit, which is about 75 feet in depth. Despite rumors there is absolutely no accessible passage leading from the bottom of either pit, both of which have been thoroughly explored by the author many times.

Beyond the pits the path leads on to a higher level, past an enormous fluted pillar and fantastic and curious groupings of stalactites and stalagmites to a spring-fed pool with water of extreme clearness.

The route once ended in a spot known as "Peri's Prison", where one passageway is separated from the main channel by a row of slender pillars, each but a few inches from its neighbor. This lovely little grotto was the extent of exploration, and from here it was necessary to retrace one's steps, back across the perilous pits, to the entrance. However, shortly after the cave was opened to the public in 1947 it was felt that another opening to the surface at this point would be of benefit, and in exploring and excavating more cave was opened and the whole is now exhibited to visitors. The new exit makes unnecessary any retracing of steps, thus saving considerable time.

Jam-packed as it is with formations of many colors, Little Wyandotte is indeed a delightful "show" cave. The average visitor is usually surprised, upon leaving the cave, to find himself still within sight of the Wyandotte Cave hotel. It seems inconceivable that so much underground beauty can be contained within such a small area.

Despite their proximity, there is absolutely no connection between Little Wyandotte and "big" Wyandotte Cave. Many speleologists—including the author—have looked long and arduously hoping to find such a connection, but there is none. The little cave is on a much higher level and of much more recent origin, geologically, than the vast and far-flung reaches of the big cavern.

Located also in Crawford County, one-third of a mile from the town of the same name is Marengo Cave. Although probably the second largest cave in Indiana, it is much shorter than Wyandotte and has no great piles of fallen rock, or rugged passageways which seem to be characteristic of that cave. Lying wholly on one level with no pits or domes, its lack of great size is more than made up for in the number, beauty and excellence of its formations, which literally fill some passageways and rooms.

It was discovered in September, 1883 when two children playing in a sinkhole spied an opening in the bottom. Consumed by the age-old curiosity that an unknown spot arouses, they peered down into the dark hole. To their awe-struck eyes the limits of the place seemed lost in infinity and they hurried home to tell of their discovery. Their story was repeated and within a few weeks neighbors had explored the cave almost to its present known limits.

Fortunately the owners of the land were wise enough to prevent breaking of the formations by souvenir-seekers and the cave may be seen today much as it was when found. It is now entered through an artificial opening and the two routes shown to visitors, when combined, require in the neighborhood of two hours to traverse.

Marengo is the only large cave known to the author which has a naturally smooth floor, there being an almost complete absence of breakdown in the entire part shown to tourists. Its floor is also unique in that a large area of the main passageway shows definite "ripple" marks which were left by the original cave river.

Professor Clyde A. Malott of Indiana University devoted considerable study to these marks and reported that there was no doubt in his mind but what they were actually "ripples left in the solid rock by the stream which formed the cave".

Like all other commercial caves Marengo has many fancifully named rooms, passageways and formations. There are few helectites or gypsum but the stalactites and stalagmites certainly are many and varied.

Possibly the largest room is Mammoth Hall, some 300 feet in length and 70 feet wide with a smooth ceiling and containing grotesquely shaped speleothems, all pointed out and explained by the guides.

An interesting spot is Cave Hill Cemetery, where there are a number of beautiful stalagmites and pillars, with, surprisingly, only a few very short stalactites above them. Many of these formations are translucent, the most striking being dubbed "Washington's Monument". Composed of clear, sparkling calcium carbonate, standing five feet high and only two feet in circumference it is —in the author's mind—the most beautiful sight in this part of the cave.

An unusual object along the same route is a thin slab of limestone jutting out from under a ledge. When lightly tapped it gives out a hollow sound not unlike that of a so-called "jungle drum". If one happens to be in another part of the cave when the slab is tapped it is one of the eeriest sounds imaginable. Since it is in a long and open passageway the sound reverberates all up and down the channel, echoing and re-echoing, seemingly louder and louder until one is almost tempted to pull in his ears and dash for safety from the pursuit of blood-thirsty savages.

By far the most wonderful room in Marengo and one of the most beautiful rooms to be found in any cave is Crystal Palace. This is a commercial cave operator's dream: a room filled with all manner of colorful cavernous formations. Although the rest of the cave is lighted by gasoline lanterns carried by the guides, this part is shown by an elaborate system of indirect lighting and by a giant searchlight with different colored lenses.

From the ceiling, about twenty-five feet high, hang literally thousands of straight, needle-like stalactites of varying lengths and colors, all so close together that it seems impossible to find an open space between them. Ninety feet in front—across the far end of the room—is a huge mass of "tobacco leaf" pillars extending from ceiling to floor. Naturally this is called the "Pipe Organ".

The side walls are covered with formations of all sizes, from tiny, feather-like stalactites to large and rounded dome-like stalagmites. All sparkle brilliantly in the colored lights that are flashed on them and on the various niches of the room. It is a wonderful display of underground beauty.

Nearby Pillared Palace is almost completely filled with stalactites, stalagmites and varied forms of flowstone, all lovely to look upon, but whose beauty is dimmed by the much more lovely Crystal Palace. It was in this part of Marengo that we discovered the pallettes as described in the October, 1953 NSS News. Although thousands of visitors, many of them speleologists, had gone through this part of the cave, none had ever noticed the pallettes until they were spied by M. Seronie-Vivian, a leading French speleologist to whom the author was showing some of the Indiana caves. We found a number of the unusual flowstone formations all within an area of about ten feet. As far as is known these are the only pallettes in any cave in Indiana.

There are few forms of animal life in Marengo Cave, possibly due to the fact that there has been a door at its entrance since shortly after its discovery. This, and the continual passage of visitors, may have prevented many animals from entering and living therein. Although the guides report a few bats and mice none have been seen by the author on his many trips into the cavern.

There are many other caves in southern Indiana. Among them are the caves with the legends of buried Indian silver, which still persist to this day in two widely separated parts of the cave area, caves like Danner's with a profusion of formations, Trinkle Cavern, which Professor Malott explored while searching for the answer to some perplexing underground water problems, Jug Hole Caverns with a 160-foot drop, caves with lakes and streams in them, dry caves, caves with possible prehistoric remains, caves named and unnamed. Each has peculiar attractions of its own, each offers different and exciting subterranean problems to the speleological enthusiast.

Origin and Development of Caverns in the Beech Creek Limestone in Indiana

By PRESTON McGRAIN[1] and
ORVILLE L. BANDY[2]

This detailed geological study of a portion of Indiana's limestone terrain is paired with another article herein on that State's caves in an effort to show that both the technical and non-technical approach to cave study is necessary to a proper evaluation of its many-sided nature.

INTRODUCTION

The purpose of this paper is to describe four caverns developed in the Beech Creek limestone in Indiana, to discuss theories as to their origin and development, and point out some of their characteristics. The caverns described herein are located in Orange, Martin, and Greene Counties, Indiana (fig. 1). The investigations of these cavern systems included primarily the major mappable portion of each cavern system and did not encompass all of the remote and generally inaccessible passageways. Cave traverses were accomplished by means of a Brunton compass and steel tape.

Other cavernous openings in the Beech Creek limestone have been entered but not mapped in detail. They are located in Martin County east of Shoals and near Newark in northeastern Greene County. They exhibit the patterns and characteristics of those described below.

The Beech Creek limestone is the eighth member of the Chester Series, Upper Mississippian, in Indiana. The name Beech Creek was proposed by Malott (1919, p. 11) from its excellent exposures along Beech Creek in Greene County, Indiana. Its position with respect to the overlying Cypress[3] sandstone makes it a conspicuous lithologic and stratigraphic unit and an excellent horizon for mapping structure.

The physical features of the Beech Creek limestone, as described by Malott (1919, p. 11), are present from its most northerly outcrops in Owen and Clay Counties to Harrison, Crawford, and Perry Counties along the Ohio River. Along the Ohio River the Beech Creek limestone extends from western Harrison County, where it is present on the higher ridges and hills, to eastern Perry County. At the town of Derby, Perry County, the Beech Creek may be viewed continuously for

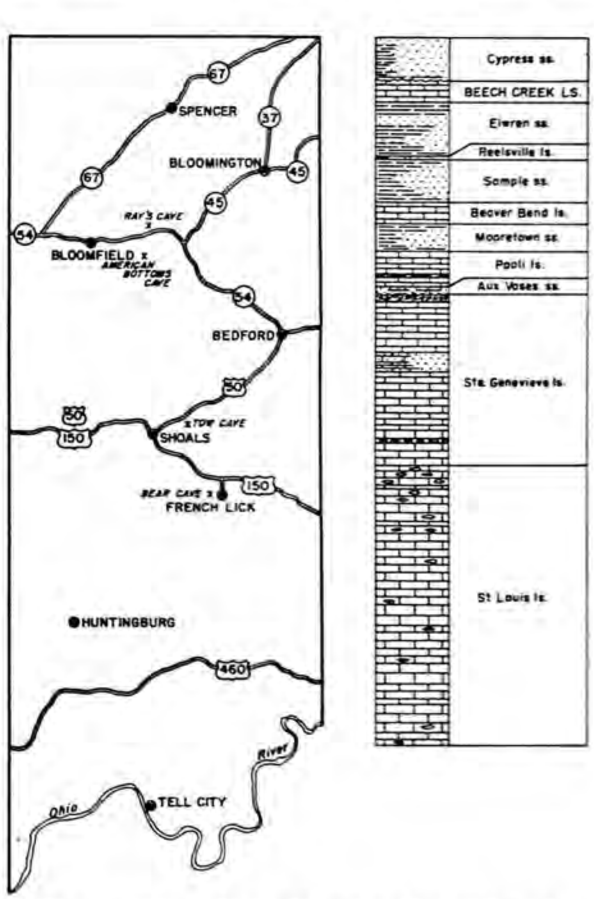

Fig. 1. Geolographic and stratigraphic location of the caves described in this report. Stratigraphic section adopted from Malott et al (1948).

[1]Kentucky Geological Survey.
[2]University of Southern California.
[3]The correlation of this formation with the Cypress sandstone of Illinois is in doubt. For the purpose of this paper the Indiana outcrop nomenclature is being used.

a distance of approximately one-fourth of a mile along the Ohio River when that stream is at low stage. The formation consists of two or more massive- to thin-bedded ledges with a total thickness of 8 to 24 feet, and an average thickness of about 15 feet. The formation is invariably massive appearing on the outcrop. It is the thickest in Greene and Owen Counties and gradually thins to the south. One of the most striking features of the Beech Creek is the presence of two conspicuous sets of joints. One set of joints runs in a general north-south direction; the second set of joints, aligned approximately normal to the first, runs east and west. Both sets of joint planes are essentially vertical. This jointing characteristically causes the formation to break up into cubical blocks where it is exposed in weathered outcrops. The stone is gray, hard, compact to sub-oolitic, and contains large numbers of fossils, principally brachiopods. The most conspicuous faunal feature of the Beech Creek is the presence of large, white crinoid stems which protrude from the weathered surface in a very striking manner. In Indiana these large crinoid stems serve to distinguish the Beech Creek from all other Chester formations. *Productus inflatus* is also present in great numbers.

One of the best datum planes for use in drawing structural contours is the contact between the Beech Creek limestone and the overlying Cypress sandstone. The extreme regularity in thickness of the Beech Creek, the presence of bold springs below, the massive character of the sandstone in connection with its position immediately overlying the limestone, render the contact easy to recognize and serve readily to distinguish it from other limestone contacts in the Chester.

Physiographically, the area of exposure of the Beech Creek limestone is located entirely within the Crawford Upland. The region is an upland area composed of diverse bedrock strata in a highly dissected state. Stream erosion has practically everywhere cut deeply into or through the many geological units, and exposures are very common, especially in the case of the massive sandstones. The Chester Series, consisting of alternating sandstones or shales and limestones, comprises the greater part of the strata of the Crawford Upland. The highest hills and ridges are capped with Mansfield sandstone of the Pennsylvania System. None of the area under discussion has been subjected to glacial action. However, blocking of drainage lines in the "American Bottoms" region in Pleistocene times has caused the valleys to be filled a great many feet with silts and clays. For details of the physiography in the "American Bottoms" region the reader is referred to Malott (1919).

The geologic structure of the area is relatively simple. The region is well down the gently dipping western flank of the Cincinnati Arch adjacent to the broad structural Illinois Basin. The normal dip of the strata is slightly south of west, about 35 feet to the mile. The structure is usually quite simple, though it does possess small irregularities of dip and changes of direction of dip. Terraces and slight flextures have been found.

The Beech Creek limestone forms the most important spring bearing horizon of any of the Chester formations. Locally openings have been enlarged until they have reached cavernous proportions. The lithologic and structural features of the Beech Creek, combined with the characteristic features of the overlying and underlying formations, produce a condition particularly favorable for the development of these karst features. The Cypress formation, which overlies the Beech Creek limestone, is characteristically a thick, massive, and porous sandstone which collects precipitation, runoff, and subsurface waters. These waters move freely in the sandstone until they reach the massive Beech Creek limestone, where the downward percolating waters are concentrated in streams along the pronounced joint planes and bedding planes. The upper strata of the subjacent Elwren formation are characteristically gray shale or siltstone. Here the downward movement of the water is obstructed, and it then moves laterally to the surface. Thus, it is at the contact of the Beech Creek limestone and Elwren shale that springs are most common. Many of these springs are fairly large and discharge volumes of water in the magnitude of 10,000 gallons per day. Where solution has been carried on to a greater degree, caverns have been formed.

Descriptions of the Caves

Caves have long excited interest in Indiana, a state possessing an abundance of karst features. However, little attention has been given to caverns developed in the Beech Creek limestone. Both

Ray's Cave and American Bottoms caves were mentioned by Malott (1919, p. 15) in connection with his discussion of the physical characteristics and physiographic importance of the Beech Creek limestone in the "American Bottoms" region. Esarey's (1939, p. 3) report of Indiana caverns includes a brief description of American Bottoms Cave. Neither of the above reports includes maps nor detailed descriptions of these caves. To the writer's knowledge, neither Bear Cave nor Tow Cave have been described in Indiana literature. Although the latter caverns are not as large nor as well-known as the former, they exhibit the same joint control pattern which characterize Beech Creek limestone caverns.

Bear Cave.—The southernmost of the caves investigated in this study is Bear Cave which is located in the southeast corner of sec. 5, T. 1 N., R. 2 W., on the east side of a county road, 1¼ miles north of the French Lick Country Club, and about 1½ miles west of the center of French Lick (fig. 2). A spring discharges from the cave at all times.

The Beech Creek limestone, exposed at the mouth of the cave, is 14.5 feet thick. Overlying the Beech Creek is the thin, shaly, and flaggy Cypress sandstone, while underneath about 2 feet of the upper part of the Elwren shale is exposed. Here the Beech Creek limestone may be subdivided into three zones. An upper zone, 7 feet thick, is composed of massive, coarsely crystalline limestone with an abundance of fossils in the upper 3 or 4 feet. The characteristic fossil elements of the upper zone are an abundance of large crinoid stems and large specimens of *Productus inflatus*. Underlying the upper zone is a layer of gray- to brown, thin-bedded limestone 2.6 feet thick, the individual layers of which range from 3 to 4 inches in thickness. Beneath the thin-bedded zone is a basal section of massive, coarsely crystalline limestone 5 feet thick. The cave entrance is 7.2 feet high and 9.2 feet wide. At the entrance, 2 sets of joints are visible, in addition to the set along which the passageway is developed. One set strikes N. 82° E. and the other N. 13° W.

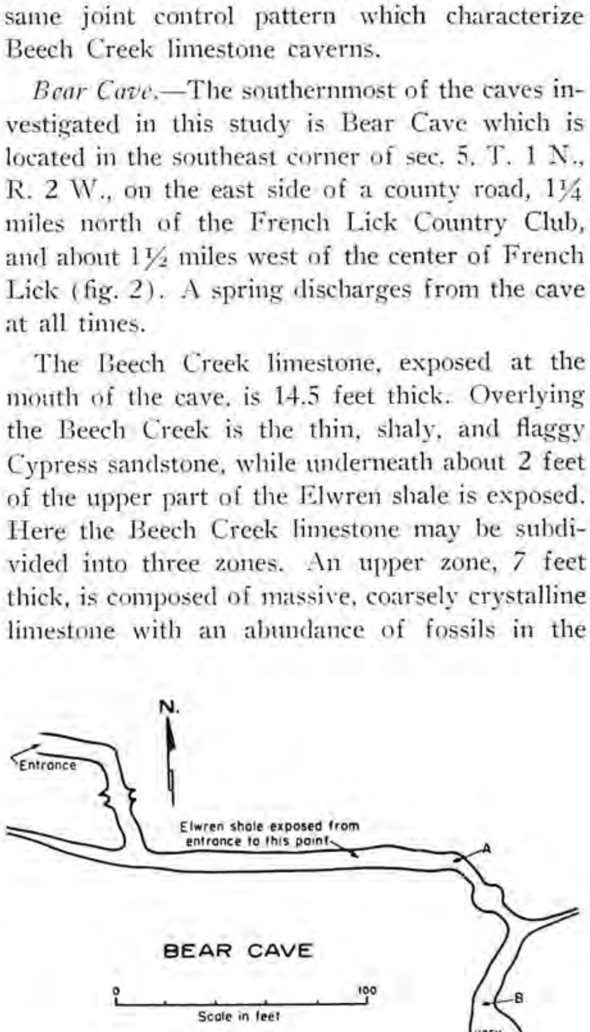

Fig. 2. Sketch map of Bear Cave near French Lick, Orange County, Indiana. A spring emerges from the cave mouth. South of this locality caverns are not well developed in the Beech Creek because of the thinning of the limestone interval.

In general, the main body of the cave is developed at or near the base of the Beech Creek. The roof is generally flat with only occasional sculpturing and fluting; there is an absence of depositional features. Three prominent sets of joints occur in the lower portion of the Beech Creek limestone, one set striking roughly S. 82-83° E., a second set S. 14-16° E., and a third set N. 82-84° E. As one proceeds past Point A (fig. 2), the cave becomes rapidly lower and wider indicating a change from predominantly joint control to bedding plane control, and this trend culminates beyond Point B where the passageway is 20 feet wide and about 2 feet high. The end of the cave appears to be in the base of the massive upper zone, and it is undoubtedly due to the massive character of such stratum that the upper reaches of the cave are expansive along the bedding plane.

Tow Cave.—Tow Cave is located in the northeast corner of sec. 21, T. 3 N., R. 3 W. The entrance is near an abandoned quarry east of a bridge across a tributary of Beaver Creek, approximately 1/4 mile north of former U. S. Highway 50, which is about 3/4 mile west of the entrance to Martin County State Forest (fig. 3).

The section exposed at the entrance to Tow Cave consists of 11 feet of Cypress sandstone overlying about 15 feet of Beech Creek limestone. The upper 10 feet of the Cypress is massive, the lower one foot is composed of a thin-bedded, flaggy sandstone. The upper 8 feet of Beech Creek limestone is massive, somewhat crystalline and fossiliferous in character, whereas the lower 7 feet of exposed Beech Creek is thin to medium-bedded and massive appearing limestone, also crystalline and somewhat fossiliferous in part.

The excellent joint-controlled system of Tow Cave is readily apparent, as seen in figure 3. There appears to be a highly complicated joint system with about 5 sets indicated in the cave diagram. The micaceous Cypress sandstone forms the ceiling along much of the route and is probably present at the upper termination of narrow joints along most of the passageways. At Point A (fig. 3) there is a room approximately 10 feet long in a northwest-southeast direction and 5 feet wide. The ceiling of the room is formed by the Cypress sandstone, about 15 or 16 feet above the floor. There is considerable etching, fluting, and sculpturing present, caused by the downward moving waters. The main accessible passage is terminated at a moderate sized room full of collapsed material; the ceiling is in the Cypress sandstone. In general, there is pronounced joint-control throughout with local expansion laterally along bedding planes.

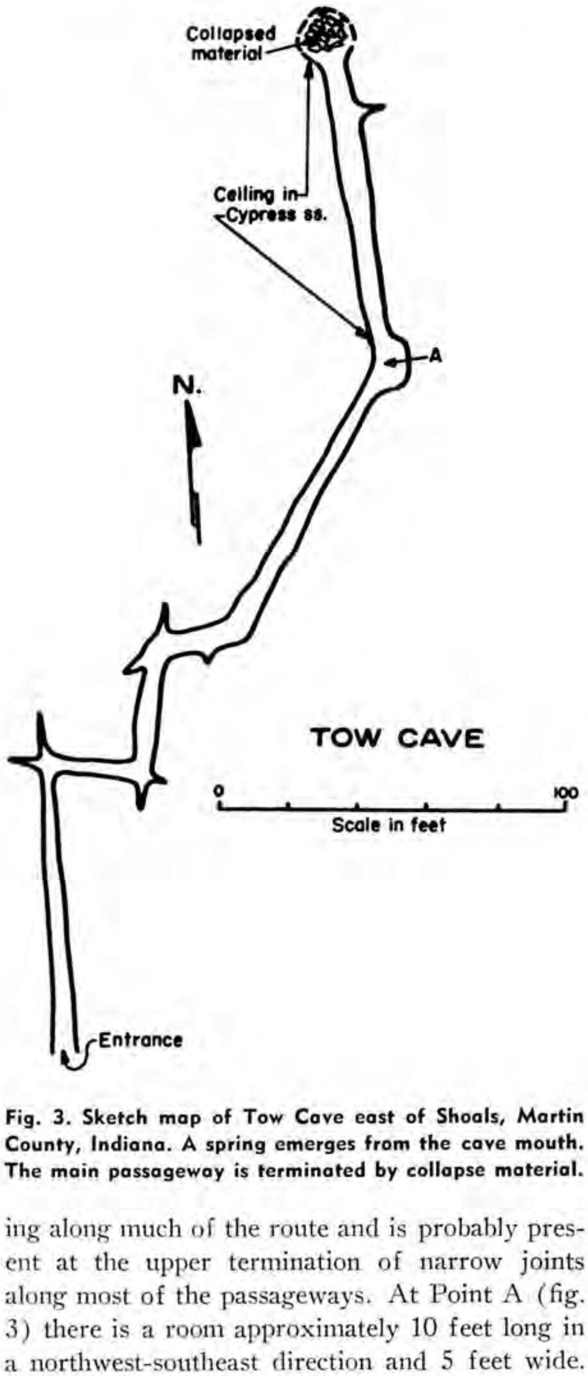

Fig. 3. Sketch map of Tow Cave east of Shoals, Martin County, Indiana. A spring emerges from the cave mouth. The main passageway is terminated by collapse material.

American Bottoms Cavern.—The upstream entrance of American Bottoms Cavern, which is located in the northeast corner of section 26, T. 7 N., R. 4 W., 1¾ miles southwest of Ridgeport on Indiana Highway 54, is a cave-inlet for the storm waters of Bridge Creek. The initial opening is in massive Cypress sandstone just a few feet above the Beech Creek limestone. Timber and other debris blocks much of the opening. The waters of Bridge Creek come to the surface nearly two miles southwest of this point (Malott, 1919, fig. 8).

This cavern is hazardous and difficult to traverse and should be entered only during dry periods. Storm waters deposit mud on all surfaces. Downstream portions of the system contains numerous deep pools of water. The present mapping was pursued only in the more accessible upper portion in order to record the magnificent joint control governing development of the passages. Access to passages beyond the mapped area (fig. 4) may be gained by descending a rope or a ladder to a level 10 feet below.

Except for the entrance to cavern, which is a low crawlway, the mapped passages are narrow, the height being several times as great as the width. Where the Cypress sandstone forms the roof it may exhibit the same joint pattern as the underlying limestone.

Evidences of great quantities of waters coursing the passages are on all sides. Decorative cave deposits are lacking. It is a great cavern in youthful stage of development.

Ray's Cave.—Ray's Cave is located in the central portion of the northern 1/2 of Sec. 13, T. 7 N., R. 4 W., about 1/4 mile north of Ridgeport on Indiana State Highway 54. The town of Bloomfield, county seat of Greene County, lies about 7 miles west of the cave and Beech Creek is about 1/2 mile to the north. A large spring discharges water from a gaping cave opening.

The Beech Creek limestone at the entrance to Ray's Cave is 24 feet thick. It is overlain by massive Cypress sandstone and underlain by argillaceous and sandy Elwren strata. As described by C. A. Malott (1919, p. 12) the Beech Creek limestone approached its maximum thickness in this

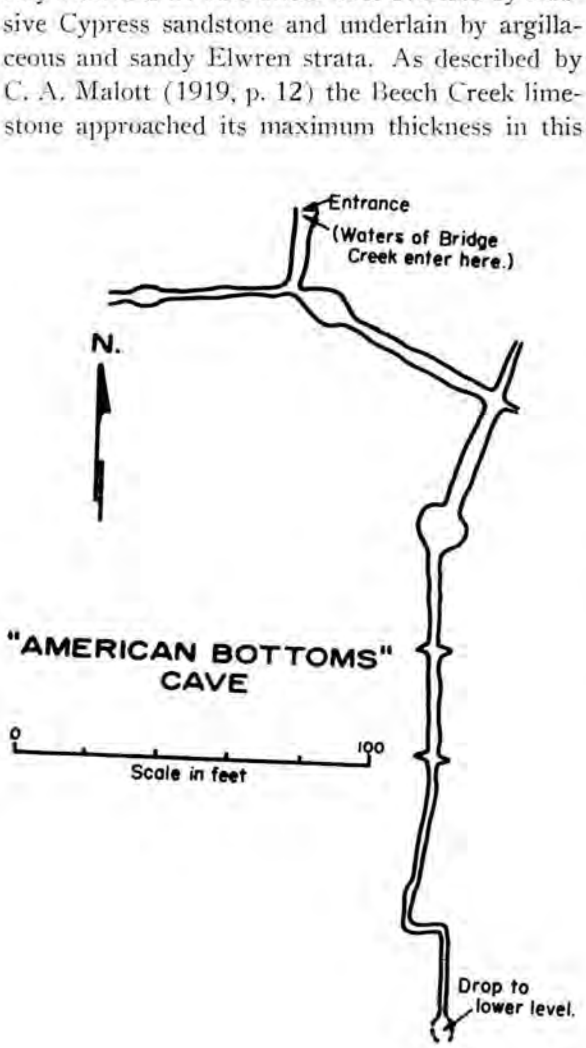

Fig. 4. Sketch map of portion of "American Bottoms" Cave on Bridge Creek in eastern Greene County, Indiana. The waters of Bridge Creek disappear into the entrance of this cavern and reappear two miles to the southwest of this point. The cave is characterized by narrow passages and high ceilings.

vicinity. The limestone exposed at the entrance is grayish, compact, crystalline and fossiliferous. The characteristic large, well-preserved crinoid stems stand out prominently on weathered surfaces both in the cavern passages and along the valley wall.

The entrance to Ray's Cave is about 15 feet wide and 11 feet high. Apparently three sets of joints entered into the development of the major portion of the cave. Facetting and sculpturing by running water is dominant just within the entrance to the cave but is present in other passages. Small amounts of dripstone are present locally in the form of rather poorly developed stalactites. The main portion of the cave maintains a rather uniform height and width, and is conspicuously joint controlled.

Summary

Caverns developed in the Beech Creek limestone of Indiana strikingly reflect the physical characteristics of this formation. The main passages are joint controlled; they are narrow, tall, and turn frequently at abrupt angles. Side passages at intersecting right angles are common.

These caverns are in youthful stage of development. Streams course the main arteries at all seasons. Decorative dripstone and flowstone formations are rare. Rockfalls and collapse features are also rare except where the surface cover is thin.

The outcrop of the Beech Creek limestone forms the most important spring-bearing horizon

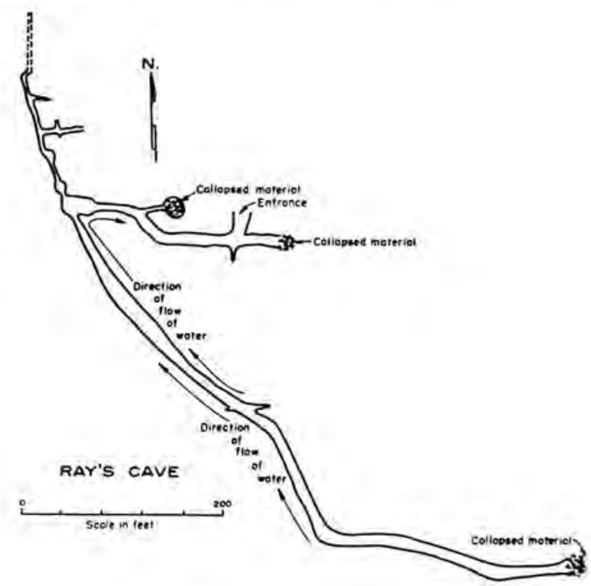

Fig. 5. Sketch map of Ray's Cave near Ridgeport, Greene County, Indiana. The main passage is terminated by a mass of fallen rock. The amount of water which emerges from beneath this collapse material suggests the presence of considerable additional cave beyond this point. Opportunity for cavern development in the Beach Creek in the northern part of Owen County, the next county to the north, decreases appreciably because only a part of the Lower Chester series is present here below the Pennsylvanian overlap.

of any of the Chester formations. Locally openings have been enlarged until they reach cavernous proportions described above. The Cypress formation, which overlies the Beech Creek limestone, is characteristically a thick, massive, jointed, and porous sandstone which collects precipitation, runoff, and subsurface waters. In the highly dissected Crawford Upland physiographic region, where major drainage lines have cut through these Chester formations, waters move freely in the Cypress sandstone until they reach the massive Beech Creek limestone, where downward percolating waters are concentrated in streams along the pronounced joint planes and bedding planes. The upper strata of the subjacent Elwren are characteristically gray shale or siltstone. Here the downward movement of water is obstructed, and it then moves laterally to the surface. The origin and development of Bear, Ray's, and Tow Caves can be explained in this manner. Enlargement is still continuing. Modification due to collapse and diversion of surface waters through sinkholes is minor.

The initial openings in the American Bottoms cavern system were formed in the same manner. Enlargement has taken place, and is taking place, as a result of the invasion of waters from Bridge Creek.

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Origin and Development of Sea Caves

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All Photos by the Author

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The cave scientist, more familiar with limestone caverns because of their relatively large areal extent, will find this article of especial interest because it deals with another type of cave, less familiar, perhaps, but equally important to speleology.

Introduction

In recent years, considerable attention has been given to the geologic processes of shore lines. The formation and destruction of beaches, the origin of marshes, and many other related littoral phenomena have been investigated and described. Strangely enough, one of the most interesting of shore processes, the formation of sea caves, has been almost completely neglected.

This paper is concerned with sea caves in general, and some of the more obvious processes which act to create, enlarge, and destroy them. A classification of sea caves based on geologic structures which bring about their origin is included, and certain features of individual caves, visited by the author, are discussed for their particular interest.

Field work for this paper consisted of an examination of the sea caves along the southern California coast — notably those of Palos Verdes Hills, Catalina Island, Corona Del Mar, and La Jolla.

A thorough coverage of the geology of sea caves is not the purpose of this article. The author attempts only to discuss features and problems of caves which became apparent during his limited investigation.

Environment of Sea Caves

Caves can develop on shorelines only under a special set of conditions. The prerequisite conditions of cave formation are: (1) the presence of a sea cliff which is in direct contact with the erosive force of the waves and currents; (2) the exposed face of the cliff must contain certain geologic structures, or textures, which will allow the establishment of differential erosion; (3) the rock of which the cliff is composed must be of a sufficiently resistant nature so as to prevent the rapid formation of a protective beach at its base.

Assuming the above conditions to be fulfilled, one might expect that all sea caves would be formed under similar environmental conditions, and that the appearance of the caves would not vary to a great degree. Actually this is not the case. Caves at the junction of sea and land are a part of the littoral environment and as such are subject to many variables. The size and direction of prevailing waves, the accessibility to storm waves, the magnitude of the tides, the strength and direction of long shore currents, and currents within the cave itself, all are important factors in the environment of sea caves. Other variables, partially dependent on those above, are the nature of the sea bottom both off-shore and within the cave. Whether the bottom is bed rock, sand, or boulders; whether it is of gentle or steep slope will affect the final environmental picture. Finally the organisms which inhabit the cave locality and live within the cave itself will be affected by all of the variables and may themselves play an important role in the formation and enlargement of caves.

Cave Formation

Differential Erosion

Erosion and weathering are the basic processes involved in the formation, enlargement, and destruction of sea caves. These processes, however, will not in themselves form caves, as is shown by the many miles of exposed sea cliffs on our coasts which are devoid of caves. In order that caves may result from erosional processes on such coasts, the exposed rocks of the cliff face must contain within them zones of weakness which will be more easily eroded than the remainder of the cliff. A weak zone may be caused by a variety of geologic phenomena. For example, it may be structural such as folding, faulting, or jointing; or stratigraphic such as unconformities, irregular

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cementation, etc. These features which bring about differential erosion are discussed in greater detail under the classification of sea caves.

Erosional Processes

Dynamic Erosion. By far the most powerful agent of erosion which would attack an incompetent zone in a sea cliff is the physical force of waves and their accompanying load of rock fragments and sand particles. Fragmental material carried in suspension by waves is of primary importance because of the powers of abrasion which this material possesses. For this reason, the erosive power of waves varies directly with the supply of suspended material.

In addition to material in suspension, waves also carry material of relatively larger sizes by traction (rolling and sliding). The tractional load is of great importance in the shallower waters where caves are generally formed. Evidence of the high erosive power of waves with a large tractional load is displayed by the under cut channels which lead into the caves of Inspiration and Portuguese Points in Palos Verdes Hills, California. A cross-section of these channels would reveal a greater width at the bottom where they are being more actively cut by sliding and rolling particles.

Storm waves, although they occur during relatively small time intervals, are as important as normally occurring waves in the erosion of cliffs. The importance of storm waves results from the tremendous pressures which they are able to exert. According to Kuenen (1950), pressures of 132,-300 kilograms per square meter have been measured on the Scottish coasts by means of dynamometers. Kuenen believes that the small gaps of bedding planes, joints, and other openings, which are exposed to the great pressures of storm waves are, in effect, subjected to a wedging action resulting from compressed air. He further believes that, as the wave recedes the air is allowed to escape with an explosive violence which loosens and eventually carries with it small and large blocks of rock.

It is reasonable to assume that this effect of compressed air is of fundamental importance in the formation of caves, and that the same compression occurs as a result of normal wave action. However, it is probably only effective in removing particles which have been previously loosened during periods of low tide. Loose weathered material is also removed by the hydraulic action of the water and by the impact of material in suspension.

Solution by sea water. In the absence of strong wave action, or where the waves carry no material in suspension or traction, chemical action or solution may become an important factor in the enlargement of a zone of weakness within a sea cliff. This is probably true, however, only when the cliff or its included zone of weakness is composed of a more soluble rock, such as limestone. Solution of carbonate rocks as a result of contact with sea water must be a slow process even under ideal conditions, because the warm surface waters of the sea are known to be nearly saturated with calcium carbonate. The action of solution will greatly aid in forming sea caves under certain conditions, however, as is illustrated by the Blue Grotto Caves on the Isle of Capri in the Mediterranean Sea.

The solution of limestone is known to be activated by pressure (Kuenen, 1950). Thus, the pressure exerted by waves as they strike a cliff face may cause a more rapid rate of solution than would be in effect during periods of calm.

Cave Enlargement

Once an initial depression is formed in the face of a cliff, enlargement progresses both laterally and vertically. In some cases, an initial depression in the form of a fissure or open joint may be brought into contact with the sea after formation, as a result of change in sea level. In this case, the work of the waves is shortened and enlargement may begin at once. Basically, the same forces are at work in the enlargement of fissures or initial depressions as were effective in the first stages of cave formation.

Weathering. As the depression becomes larger, portions of it become out of reach of normal wave action. In these portions of a cave, weathering assumes importance as a factor of enlargement. Several examples of this may be cited. The caves on Inspiration Point in the Palos Verdes Hills are formed in intrusive basalt, which is extensively jointed. The roofs of the caves, although seldom touched by solid waves of water, are exposed to atmospheric weathering, aided by spray from the waves. As a result of this weathering along the joint planes, large blocks have been loosened and have fallen into the rather shallow water below. Processes such as these are continually occurring on a much smaller and less obvious scale and contribute significantly to the enlargement of caves.

Another example of the effectiveness of weathering in caves is found in Painted Cave on Santa Cruz Island. This cave is a result of differential erosion of volcanic breccia (agglomerate) deposits within the basalt cliffs of the northeast side of the Island (Emery). The entrances to two of the large chambers of this cave are only a few feet above sea level, yet their ceilings are very high. Evidently the roof has been considerably heightened by the weathering of the agglomerate matrix and the subsequent falling of particles to the water below. In a cave such as this, with a small restricted opening, the air is saturated at all times with water vapor which must speed up decomposition of the rocks.

In a smaller cave, with a relatively large opening, it seems unlikely that the atmosphere would be at all times saturated with water vapor. However, it is possible that a higher humidity might be found at the back portions of even a small cave, which would aid in corrosion of ceiling and wall rocks.

Solution by Ground Water. Another factor in the enlargement of caves is the action of percolating ground water. If the water table within the rocks intersects any portion of a cave, the solution of cementing media will loosen the rock constituents and contribute to weathering and enlargement of the cave.

Organisms. Organisms also have a role in the enlargement of caves. Certain boring organisms such as chitons and echinoderms commonly inhabit sea caves and their borings are significant in the weathering of the underwater and tide wetted portions of the caves. These organisms show preference for certain rock types, such as sandstone. For this reason they may be found in great abundance in some caves, while in others they may be completely absent. An example of the work of organisms is found in the caves of La Jolla, California, where chitons have pock-marked much of the lower portions of cave walls.

Destruction of Sea Caves

Destruction of caves may result from several different phenomena. Most obvious among these is collapse of the roof. Other methods of destruction are erosion of the roof from above by rain water, or filling of the cave as a result of a change in the equilibrium of the erosive and depositional characteristics of the shore line. Undoubtedly many other methods of destruction occur, but a thorough listing of all possible methods does not seem essential. One example of cave destruction by the action of rain water may be seen on the beach at the southwestern edge of La Jolla, where the roofs of several caves have been cut through, leaving only a large deep crack in the cliff face (fig. 1).

Classification of Sea Caves

In order to classify sea waves geologically, it is necessary to choose a basis for classification. A classification could be made using the lithology of the sea cliff as a basis, but such a system would have several defects. For example, a single cave may intersect several rock types, also several kinds of caves may occur within any given rock type. The physiographic characteristics of a sea cave

Fig. 1. Showing the destruction of a cave roof by rain wash, La Jolla, California.

could be used as a basis for classification, but the classification would be purely descriptive and would imply nothing as to the origin of the cave. Probably the most logical classification would be one which is based on the method of origin, but the method of origin of all sea caves known to the author is differential erosion of the face of a sea cliff. Differential erosion will result, however, only when there are certain structures present within the cliff face. It is on these structures that the author's classification is based; therefore the classification must be in reference to various structures rather than to caves themselves. It should be remembered in reading the classification, however, that each structure listed is capable of forming a sea cave, if it intersects sea level and is exposed to wave action. Also, not only does the origin of sea caves depend upon these structures, but in addition the dimensions and the shape of the cave after formation are largely the result of the originating structure.

Structures responsible for the formation of sea caves by differential erosion are as follows:

- I. Fractures and fracture structures resulting from deformation.
  - A. Faults
  - B. Joints
  - C. Breccias
    - 1. Frictional breccias
    - 2. Volcanic breccias
    - 3. Intrusion breccias
- II. Original structures resulting from deposition or consolidation.
  - A. Depositional structures
    - 1. Stratification
    - 2. Variations within a given stratum
    - 3. Uniformities
  - B. Consolidation structures
    - 1. Irregular cementation
    - 2. Internal structures of lava flows

Fractures and Fracture Structures Resulting from Deformation

Faults. Faults may be defined as fractures within rock masses along which there has been slippage. The effectiveness of a fault in forming a sea cave depends on the size of the fault, the amount of fracturing and weakening of rocks adjacent to the fault, and to some extent on its age, since a recent fault is less likely than an ancient one to have strong cementing material within its open spaces. Faulting commonly forms breccias or gouge which fill openings in the fault plane or occupy a zone between the two relatively undisturbed rock masses on either side of the fault. As a result of this crushing and fracturing of rocks on a fault plane, and the weakening of adjacent rocks, faults are ideal structures for the formation of sea caves. Many examples of fault caves are found along the California coast (fig. 2).

Fig. 2. A cave resulting from faulting, Inspiration Point, Palos Verdes Hills, California. Note the irregular ceiling, developed because of complex jointing in the basalt.

Joints. Certain cracks within rocks are oriented in such a way as to divide the rocks into well defined blocks. Such cracks are termed joints. Joints are classified by Lahee (1941) on the basis of their formation by tension or compression. Tension joints form as the result of cooling of ingenous rocks, loss of mass, rock alteration in sedimentary rocks, and various other processes. Compression joints include those formed by regional deformation, and by expansion of rocks upon chemical alteration. The majority of the extensive joint systems in stratified rocks result from compression.

Joints are probably the most important structures which result in the formation of sea caves. The presence of a well-developed set of large joints in a sea cliff allows wave action to first enlarge the joint openings and then to concentrate the attack of abrasive agents in the fissure. In addition to large joints being the primary control of cave formation, smaller sets of joints are very effective in speeding up the processes of enlargement of caves regardless of their primary control. Sea caves formed as the result of jointing are among the most common types of southern California. The famous La Jolla caves among others are primarily of this origin (fig. 3).

Breccia. The term breccia refers to a group of angular fragments which have been broken by various methods and are contained in a matrix of the same or different compositions. Breccias, as a result of their fragmentary nature, are more easily eroded than are homogenous rocks. For this reason, a brecciated zone within an exposed sea cliff may be expected to develop into a sea cave providing its dimensions are within reason.

Friction breccias are formed as a result of mechanical stresses acting within the earth. These breccias are in the form of shatter zones or fault breccias. Shatter zones may be independent of any faulting; fault breccias are sometimes localized within a fault plane and for this reason are included as distinct structures, rather than under faults.

Fig. 3. A cave formed along joint planes, La Jolla, California. Note the rectangular cross section.

Volcanic breccias, or agglomerates, result from violent ejection by volcanic explosions and are therefore associated with lava flows. The combination of hard resistant volcanic rock and intercalated agglomerate deposits forms an ideal condition for differential erosion. The extensive development of sea caves in agglomerate is shown by the many caves of this origin on Santa Cruz Island.

Intrusion breccias may be formed by two separate and distinct processes. First, the intrusion of magma into sediments is often accompanied by much brecciation due to the forces of expansion and to the rapid temperature changes. This type of brecciation is a marginal feature of intrusive bodies and could possibly result in a structure which would cause the formation of a sea cave. The second process, which occurs only to a limited extent in certain intrusions, is the formation of limestone dikes. Limestone dikes develop when intrusive bodies are implaced under a thin cover of calcareous sediments on the sea floor. Under conditions such as these, the intrusive mass will be highly fractured and brecciated by contact with the moist sediments. Macdonald (1939) believes that the limestone dikes of Palos Verdes were formed when calcareous ooze from the sea floor, a short distance above the intrusion, moved down into the fractures and cemented together the fragments of the breccias. Along the Palos Verdes Hills coast, there are several locations at which limestone dikes are exposed to wave action and the more rapid erosion of the dikes relative to the enclosing basalt has formed sea caves. Two such caves are located on Portuguese Point in Palos Verdes Hills (fig. 4). It is probable that sea caves of this origin are relatively common in shallow intrusive bodies, but they are often mistaken for fault caves.

Original Structures Resulting from Deposition or Consolidation

Depositional Structures. Stratification in sedimentary rocks may in some instances include a sequence of competent and incompetent rocks. If strata of this nature is inclined relative to sea level and exposed to erosion in a sea cliff, it follows that differential erosion would take place and sea caves would develop. At Corona Del Mar, California, the sea cliffs are made up of Tertiary, Monterey shale, which is highly fractured and jointed. Certain beds within the formation appear to be less resistant to erosion and, where these are in contact with the erosive powers of waves, small caves are developed. It is uncertain whether the formation of the caves is totally the result of stratification, as the entire formation is complexly folded and jointed.

Variations within a given stratum may consist of such sedimentary features as: the lensing or pinching-out of a given bed, or lateral variations in texture, porosity and permeability. Although these features could result in cave formation, it is doubtful that they are of any great importance.

Unconformities represent a period of erosion of exposed rock, followed by the deposition of additional material. If fissures were formed on the eroded surface during the period of erosion the superposition of additional clastic material would form clastic dikes. These clastic dikes would be probable structures for the development of differential erosion. Unconformities in general are planes of weakness and there are conceivably many such structures which would form sea caves if in the proper environment.

Fig. 4. A cave formed along a limestone dike, Portuguese Point, Palos Verdes Hills, California. This cave extends through the point and opens onto a cove to the northeast.

Consolidation structures. Cementation of clastic deposits is sometimes of an irregular nature due to variations in porosity, permeability, and supply of cementing media. These irregularities in cementation may cause zones which are relatively soft and more easily eroded. Such structures are rare, however, and sea caves formed as a result of this phenomenon must be very uncommon.

Internal structures of lava flows result from the preservation of flow structures and gas bubbles in cooled lava. Lava tubes also are formed by the hardening of an outer crust beneath which the less viscous lava moves. These various features cause lava flows to be well suited for the formation of sea caves. Stearns and Macdonald (1936) in discussing the geology of Hawaii, state that "The clinkery beds, tubes and other internal structures in the late lava flows, where subjected to wave attack, give rise to spectacular spouting horns, caves, natural bridges, and stacks."

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Supplemental Report on Mineralogy of New River Cave

By **JOHN W. MURRAY**

All Photos by the Author

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The extent to which the study of cave minerals requires precise scientific methods of study is ably illustrated herewith by the author who ranks as one of the Society's most competent mineralogists.

Several trips to New River Cave have been made by members of the Committee on Formations and Mineralogy of the VPI Grotto of the N.S.S. since the original report on this cave was written a little over a year ago. More data on temperatures and water composition have been obtained, several new observations on mineral occurrences have been made and chemical analyses of several samples of cave deposits have been made.

Gypsum crystals ranging up to about a centimeter in length have been found on the ceiling of the Attic Room. A crust of fine crystals of gypsum has been found at the north end of the Pool Room. Formerly, gypsum had been observed only in the Gypsum Room which is near the innermost part of the cave.

In the outer part of the cave, several localities have been noted, (e.g., the flowstone sheet in the large photograph published in Bulletin Thirteen) where a variety of cave deposits have been coated with a thin layer of a black material. Such black coatings have been ascribed in the past to carbon from the smoke of torches or to oxides of manganese. As mentioned in the original report, a black coating on the rocks above the waterfall was shown to contain manganese. A sample of the black coating on the floor of the Winter Forest Room, which is a few hundred feet inside the cave, showed no manganese on testing with periodate or bismuthate. When a sample of the black layer was ground and then extracted with HCl and HNO_3 to dissolve carbonates, the residue was black. Part of this was heated to incandescence in air and it turned white, suggesting that it was composed of carbon. This hypothesis was confirmed by placing the material in a quartz combustion tube through which oxygen passed and bubbling the gas through a solution of $Ba(OH)_2$ to test for CO_2. Only a faint turbidity was obtained with the quartz tube at room temperature but a dense precipitate appeared on heating which shows that the black deposit contains carbon.

The question remains as to how the carbon was deposited, by smoke from fires in the cave, from forest fires, from the railroads in the valley below, or perhaps by the carbonization of organic matter such as the white fungus-like material sometimes found on flowstone in this part of the cave. Which, if any, of these is the origin has yet to be determined. A thin section of a stalactite coated with the black deposit shows that the black material has been covered with a very thin layer of calcite. Thus the conditions which produced the black deposit may no longer exist in the cave. Two facts which should be considered in any attempt to explain this deposit are that the black layer is found in general on upper or vertical surfaces but not on downward facing surfaces and that the deposit is not uniform in covering a given area but leaves some parts uncoated.

Additional samples of water have been obtained from the cave and analysed. Two of these—No. 62 and No. 67—were collected with a new type of sampling tube designed to obtain a sample of the drop hanging from a stalactite with as little change as possible. The inlet tube is made of capillary of less than one mm. bore and is drawn to a fine tip which is bent inward to the axis of the reservoir. The device is suspended from the stalactite to be studied and adjusted so that the tip enters the hanging drop. The tip is bent downward at the end so that the water cannot flow along it outside. The bore of the capillary is so fine that it will remain full even when removed from the drop. When water is fed to the tip, it

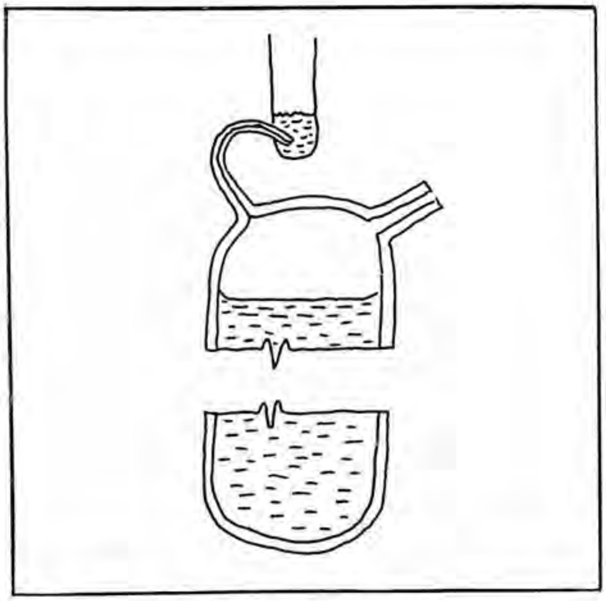

Fig. 1. Sketch of capillary collector described in text.

is siphoned to the inside of the tube as the end of the capillary attached to the reservoir is lower than the tip. The reservoir is also equipped with an air vent which is made of capillary tube t restrict loss of water vapor or CO_2 by diffusion. The results obtained from several new samples are given in Table I.

The data on magnesium given in the original report[2] are all high by 50% due to an error in the standard use. The figure should read: Sample 34—7 ppm., 53—4 ppm, 51—20 ppm, 29—15 ppm, 52—33 ppm, 33—27 ppm, and 54—17 ppm.

Samples 69 and 70 were of large size to permit a macro check on some of the micro methods previously used. SiO_2 was determined gravimetrically on 500 ml samples and found to be 8 ppm. in both of these. Strontium was estimated spectrographically and found to be about 0.1 ppm. in both of these.

The very low concentration of sample 69 is of interest in conection with the suggestion of Krinitzsky[1] that the water entering the cave comes from a perched water table held up by the Juniata Shale. It is evident from a comparison of this sample with those from the main stream in the lower part of the cave (Nos. 34 and 53 in the original report[2]) that the upper stream has not been able to dissolve much limestone on its way into the cave. This observation and the occurrence of many pebbles of quartzite in the bed of this upper stream suggest that the roof of the Attic Room is near the top of the carbonate rocks.

Some of the water analyses given in this report have been applied[3] to the study of the conditions determining whether calcite or aragonite is formed in cave deposits.

The data given on pH of water samples is of doubtful value in most cases as the sample will lose CO_2 and consequently rise in pH on standing or even during the collection of the sample. In several cases, values have been obtained around 7.6 in the cave immediately after sampling while a repetition of the measurement in the laboratory may give a value over 8. For this reason, a special cell was devised for use with a Beckman Model N-2 portable pH meter. The water to be measured is placed in a small cup-shaped hole drilled in the top of a small block of plastic. The size of this hole is such as to fit the bulb of the glass electrode supplied with the instrument. A small notch is cut at one edge of the hole to accommodate the fine tip of a special calomel reference electrode of the asbestos fibre type. This apparatus permits the measurement of a single drop of water. The following measurements have been obtained:

TABLE II

Source	*pH*
Column Room—Upper pool—(as in Sample 633	7.68
Attic Room, south end—Upper pool (as in Nos. 54 and 68)	8.1
Attic Room, south end—Lower pool (as in No. 55)	8.1
Attic Room, middle—Composite samples from drops from five stalactites each: Calcite	8.0
Aragonite	8.0
Aragonite	7.7
Aragonite	7.8

More data on temperatures in the cave has been obtained. The accompanying table summarizes all the data available to date. It is evident from this table that the temperature rises as the distance from the entrance increases. This has been shown to be true in all seasons of the year. Two explanations might be given for this fact. Firstly, it is known that the temperature of the earth increases toward the center and becomes very hot in deep mines. The entrance of the cave is on the end of Spruce Run Mountain where the New River has cut through the ridge and mountain slopes upward for a long distance beyond the point where the cave enters it. Thus the distance

TABLE I

No.	Source	Temp. °C.	pH	Free CO_2	Alkalinity $CaCO_3$	Alkalinity HCO_3^-	Cl^-	$SO_4^{=}$	Ca^{++}	Mg^{++}	Total Solids
55	Attic Rm. Lower pool 10/28/51	11.4	7.4	—	119	145	1.2	11	24	12.5	144
68	Attic Rm. Upper pool 5/18/52	11.4	7.8	1.2	130	159	—	—	27	16	135
59	Pool Rm. Pool on floor 10/28/52	11.4	7.6	—	127	155	1.0	7	26	13	132
63	Column Rm. Upper pool 12/11/51	7.7	8.1	1.5	237	288	—	15	40	26.5	238
56	Column Rm. drip from flowstone sheet 10/28/51	10.2	7.8	—	189	231	1.9	15	31	28	Mn neg. 214
58	Stream passage drip-dissolving 10/28/51	11.5	7.9	—	183	223	0.8	10	20	34	186
60	Attic Rm. Drip from Arag. Stal. 10/28/51 to 5/18/52	11.4	—	—	—	—	—	—	20	20	
61	Attic Rm. Drip from Arag. Stal. 10/28/51	11.4	—	—	—	—	—	—	24	20	
67	Attic Rm. Drip from Calc. Stal. 10/28/51 to 3/30/52	11.4	8.2	0.4	116	142	—	35	27.5	22	185
62	Stream passage drip from Arag. Stal. 10/28/51 to 12/11/51	10.9	8.3	<1	162	198	—	—	26	24	—
64	Stream passage drip from Arag. Stal. 12/11/51	10.9	—	—	—	—	—	—	22	27	—
69	Stream entering at highest point in cave (Attic Room)	11.4	6.8	—	6.6	8.1	1.0	—	1.4	0.14	—
70	Lower pool in Attic Room	11.4	8.25	—	110	134	0.6	—	23.6	13.4	—

from the surface increases with distance from the mouth of the cave even though the main passage is nearly horizontal. A second possible explanation may be connected with the direction and temperature of air currents blowing through the main passage. Although only one entrance to the cave has been discovered, air usually blows into the cave in the winter when the outside air is colder and therefore denser than that inside, the reverse is true in the summer time. This would tend to cool the outer part of the cave in winter and the outward blowing air would warm it in summer.

Samples of several types of cave deposits have been analyzed to discover what variations from pure $CaCO_3$ occur and how they are related to the form of the deposit and the conditions of deposition.

Samples 1 and 2 respectively are the outer and inner parts of an aragonite stalactite about an inch in diameter. It was found on the cave floor in a horizontal position, still attached to the rock on which it grew, due to falling or sliding of a block. The surface had a dull earthy look and was coated with black deposit on the upper side. The interior was clear white aragonite.

Samples 3 and 4 are from the interior of a stalagmite found broken off in the main passage of the cave. Most of it is silky looking aragonite but a few patches of calcite occur surrounded by

TABLE III
NEW RIVER CAVE TEMPERATURES

LOCATION		DATE										
		8-5-45	9-14-45	1-27-46	3-31-46	2-25-51	8-19-51	10-28-51	12-11-51	5-18-52	7-13-52	9-8-52
Outside of Cave Entrance	air	—	—	—5.2°C.	12.0	11.6	—	15.2	3.4	23	23.9	>20
100′ inside cave	air	—	—	—2.5	—	—	—	—	—	—	9.9	10.0
Winter Forest Room—400′ inside	air	—	—	—	—	6.6	—	10.3	—	—	9.7	—
Column Room—500′ inside	air	—	—	+5.5	—	7.3	—	—	7.6	8.8	—	10.4
Column Room	upper pool	—	—	—	—	—	—	—	7.7	—	—	—
Column Room	lower pool	—	—	—	—	6.5	—	—	7.2	8.4	—	—
Main passage above Lunch Room—1000′ in	air	—	—	—	—	—	—	10.8	10.4	11.7	10.9	11.0
Lunch Room—1000′ in	air	—	—	8.8	—	—	—	—	—	—	—	—
Stream passage within 150′ of Lunch Room	air	—	—	9.0	—	10.3	—	11.6	10.9	—	—	11.3
Stream passage within 150′ of Lunch Room	water	12.2	—	11.5	12.7	11.7	—	12.4	12.2	—	—	12.5
Pool Room—1400′ in	air	—	—	—	—	—	—	11.4	—	—	—	—
Pool Room—1400′ in	pool on floor	—	—	—	—	—	—	11.4	—	—	—	—
Stream passage at foot of waterfall—2300′ in	air	—	—	—	—	—	—	—	13.33	—	12.3	—
	water	—	—	—	—	—	—	—	13.38	—	12.3	—
	mud	—	—	—	—	—	—	—	—	—	12.2	—
Attic Room—N. end—1200′ in	air	—	11.6	—	12.0	—	—	—	—	—	—	—
	pool on north wall	—	11.5	—	—	—	—	—	—	—	—	—
Attic Room—middle—1000′ in	air	—	—	—	11.5	—	—	—	—	11.4	11.6	—
Attic Room—S. end—900′ in	air	12.6	11.8	11.5	11.8	11.6	—	12.0	12.0	11.4	—	—
	upper pool	11.4	11.4	11.0	11.4	11.3	11.3	—	11.7	11.4	11.5	—
	lower pool	—	—	—	—	—	—	11.4	11.4	—	11.6	—
Crack below Attic Room—900′ in	air	—	—	—	12.6	—	—	—	—	—	—	—
Forest Room—700′ in	air	—	—	11.5	—	—	—	—	—	—	—	—
Spring below Cave Entrance	water	—	—	—	—	—	—	—	12.0	12.5	—	—

NOTE: All temperatures are expressed in degrees centigrade. Readings taken before 1951 are uncorrected. From 1951 on, the thermometers used were compared with a standard thermometer calibrated by the National Bureau of Standards and the corrected values are given here.

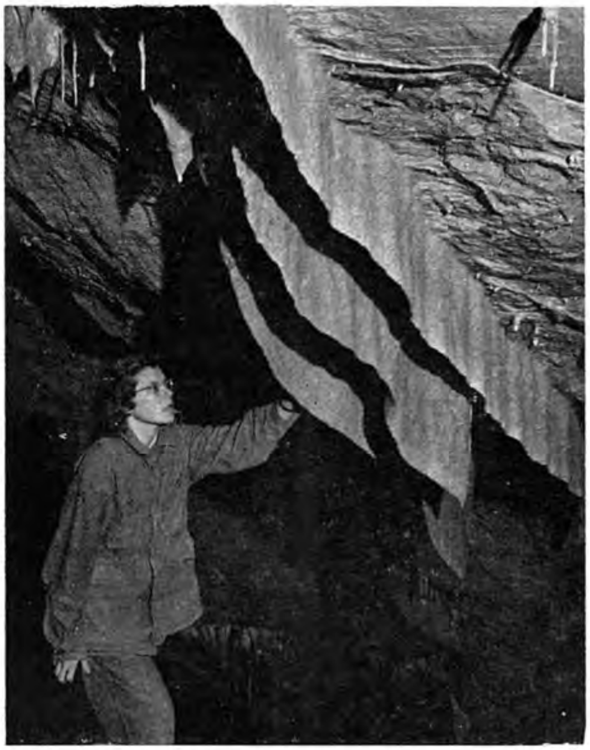

Fig. 2. Unusual speleothems in Attic Room, New River Cave.

Fig. 3. Helictites on ceiling of Attic Room, New River Cave.

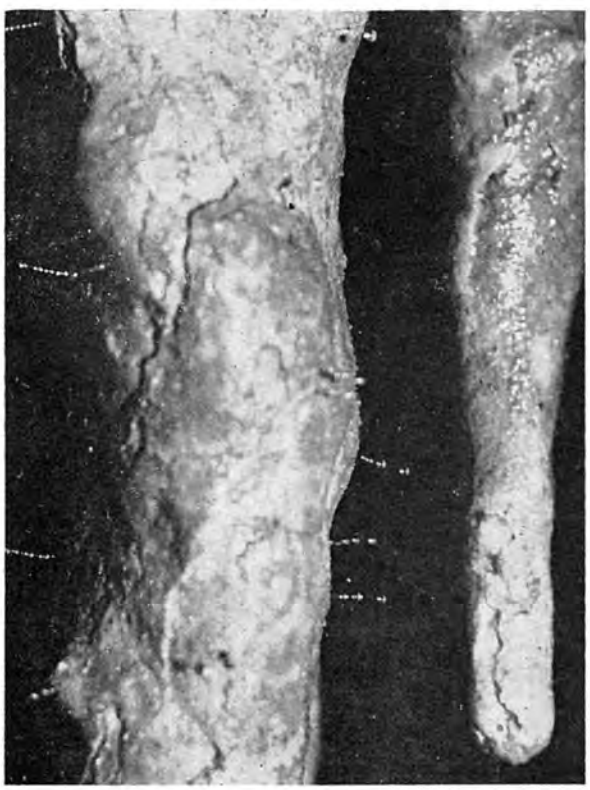

Fig. 4. Filaments of mold (?) growing on a stalactite and carrying water droplets. Forest Room, New River Cave.

Fig. 5. Helictites on ceiling of Attic Room, New River Cave.

TABLE IV
ANALYSES OF CAVE DEPOSITS

No.	Source		SiO_2	$(Fe,Al)_2O_3$	CaO	MgO	CO_2	$SO_4=$
1.	Aragonite Stalactite	exterior	5.62	3.68	47.1	2.90	41.2	nil
2.		interior	0.03	0.01	55.8	nil	43.7	nil
3.	Stalagmite	calcite part	0.05	0.05	54.3	1.20	43.9	nil
4.		aragonite part	0.05	0.01	55.6	nil	43.5	nil
5.	Anthodite—aragonite		0.03	0.01	55.5	nil	43.5	nil
6.	Helictite—calcite		0.01	0.03	55.1	0.90	44.1	nil

Differences of less than 0.1% should not be regarded as significant.

Committee on Formations and Mineralogy
V. P. I. GROTTO
National Speleological Society
John W. Murray, chairman

the aragonite. No. 3 is from the calcite part and No. 4 from the aragonite.

Sample 5 is from a fragment of an anthodite cluster. The reddish iron-stained surface coating was removed by brushing with dilute hydrochloric acid with a toothbrush and the sample taken from the white interior.

Sample 6 is from a calcite helictite of the vermiform type. The stained exterior was scraped off with a knife and the white interior analysed.

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Regional Development of Limestone Caves in Middle Tennessee

By THOMAS C. BARR, JR.

This article is a splendid example of the serious nature of the type of work undertaken by many of our members who devote their spare time to recording for posterity their speleological findings. Much of the information contained herein was gathered in 1953 and 1954 while the author was engaged in summer work for the Tennessee Division of Geology.

The State of Tennessee stretches for more than 400 miles from east to west, from the blue haze of the Great Smoky Mountains to the levees of the mighty Mississippi. This varied terrain of valley and mountain, plateau and coastal plain, falls naturally into three grand divisions—East, Middle, and West Tennessee.

The thick sediments of East Tennessee, most of which were laid down during Cambrian and Ordovician time, have felt the impact of the Appalachian orogeny, and are extensively folded and faulted throughout the eastern valley of the Tennessee River. In most of Middle Tennessee, structural disturbances are locally comparatively slight, and the sediments usually appear to be horizontal, or nearly so. West Tennessee is a region of coastal plain sediments laid down by the shallow inland sea which covered southeastern North America during the Cretaceous and later periods.

Middle Tennessee exhibits three major physiographic provinces—the Nashville Basin, the Highland Rim, and the Cumberland Plateau. Limestone caves are developed in all three of these provinces to a varying degree. It is of considerable interest to consider the distribution, pattern, and size of the caves with respect to the stratigraphy, physiography, and structure of the three provinces.

About 600 caves have been recorded in Middle Tennessee. All are of the joint-bedding-plane type; dip-and-strike caves, which occur in tilted strata, normally are absent in limestones with a low angle of dip. It is hoped that continued study of these caves may supply additional data with which to construct a satisfactory theory of cave origin. It was once believed that all limestone caves were formed by the action of free-surface streams, but the work of Davis[1], Swinnerton[2], and Bretz[3] has shown that the development of many caverns may best be explained by supposing it to have taken place below the water table. Using the criteria of Bretz[3], the various groups of Middle Tennessee caves may be classified as *vadose* or *phreatic*, according to the predominant phase of their development, i.e., above or below the water table, respectively. The conclusions reached in this paper, however, are only tentative, since Tennessee speleology is still in the exploratory and descriptive stage, and a considerable amount of detailed study will have to be done before we have an adequate understanding of sub-surface solution within the region. Moneymaker[4] has supplied direct evidence that deep solution is taking place in many parts of the Tennessee River valley, and it is not unlikely that such solutional excavation of limestone has been largely responsible for many caves in Tennessee.

Stratigraphy

The oldest widespread sedimentary rocks in Middle Tennessee are of Stones River age (Ordovician)*; they crop out in the center of the Nashville Basin and the Sequatchie Valley, and in certain stream valleys along the southern portion of the Basin. Ordovician formations of later age are widely distributed throughout the Basin and along the inner margins of the Highland Rim. Silurian and Devonian rocks appear in the stream valleys of the southern half of the Western Highland Rim, to the north and northwest along the edge of the Basin, and at a few other points. Mississippian formations underlie the surface of

*The Knox group, which lies below the Stones River rocks in stratigraphic sequence, has been exposed at a few places in the lower part of the Sequatchie Valley.

the Highland Rim and form the basal part of the Cumberland Plateau, while the thick Pennsylvania shales, sandstones, and coals of the Plateau are the youngest rocks to be found in the area, with the exception of Quaternary fluvial deposits scattered about in the river valleys.

Physiography

As Piper[5] has pointed out, the physiographic districts of Middle Tennessee are the end products of successive erosion cycles. The resistant Pennsylvanian sandstones of the Cumberland Plateau have been preserved relatively unchanged in large areas. Where overlying sandstones have been removed or extensively fractured, the soluble Mississippian limestones have been exposed to the leaching action of water and have been removed by erosion, resulting in a lower plateau surface, the Highland Rim. Most of the surface of the Rim is underlain by the resistant and insoluble Fort Payne chert. Remnants of St. Louis limestone occur in the Eastern Highland Rim near the foot of the Cumberland Plateau, and the Warsaw limestone appears in the northwestern corner of Middle Tennessee. To the west and north, stream valleys have cut down into the older Silurian formations, many of which are cavernilerous limestones. In the central part of the State, renewed upwarping and erosion have produced a third and lower terrace—the Nashville Basin—on the Ordovician limestones. This basin is surrounded on all sides by the Highland Rim, and toward the margins are low hills and ridges formed by the outliers and salients of the more resistant limestones.

Structure

The *Nashville Basin,* structurally a dome, is an elliptical uplift lying toward the southwestern extremity of the Cincinnati Arch. Extending radially from the center of the dome, at a point near Fosterville, in Rutherford County, there is a regional dip of 15 feet to the mile.[6] A steeper regional dip, 25 feet to the mile, is noted in the northwestern corner of the structure, near Nashville.

The *Highland Rim* surrounds the Nashville Basin with an erosional escarpment averaging 400 feet in height. At its margin the Chattanooga black shale occurs some 500 feet lower than at the center of the Basin.[6]

The *Cumberland Plateau* is basically a shallow

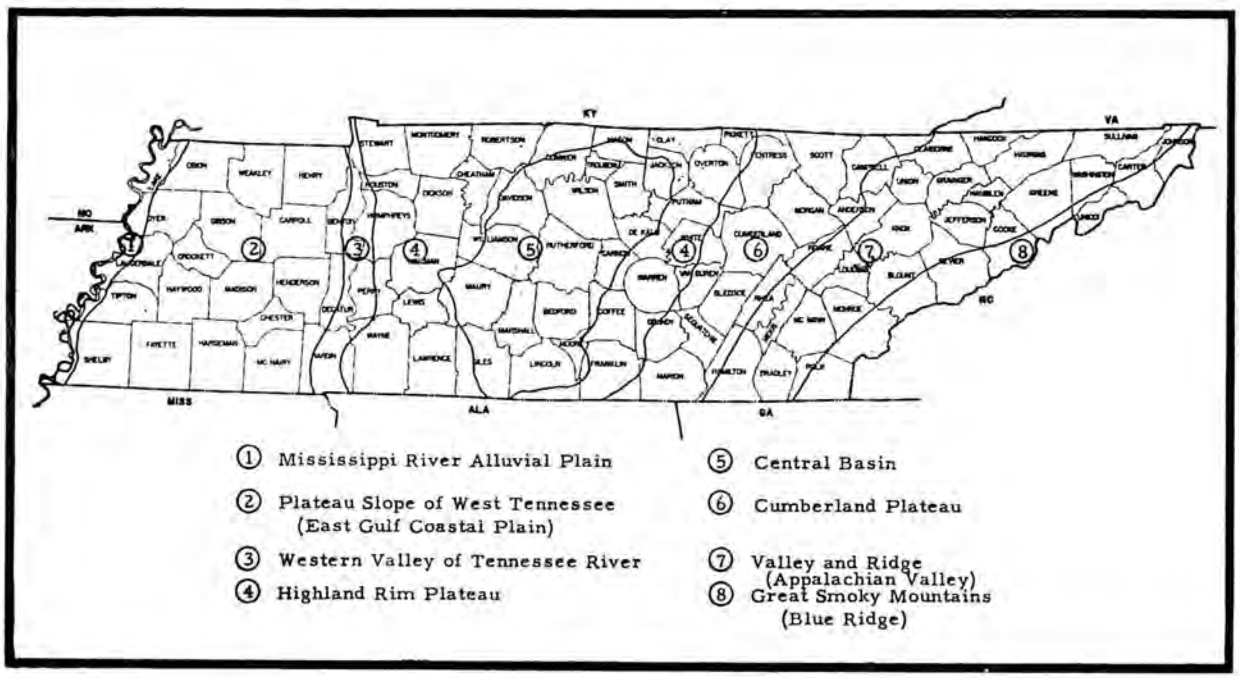

Fig. 1. Physiographic provinces of Tennessee. Regions 3, 4, 5, and 6 are discussed in this paper.

structural low. In Franklin, Marion, and Hamilton Counties (vicinity of Chattanooga and westward to Winchester), erosion to the base level of the Fort Payne chert has exposed a tremendous thickness of limestone, from the Warsaw to the Gasper oolite, along the western marginal slope of the Plateau. In Overton, Fentress, and Pickett Counties (between Cookeville, Tenn., and Albany, Ky.) only the Gasper and Ste. Genevieve are exposed. Between these two extremes various intermediate conditions prevail from one locality to another. The degree of dissection varies from the sharply delimited escarpment of Franklin County in the south to the rough, hilly terrain in Overton County to the north. In the Sequatchie Valley a thrust fault at the edge of a narrow anticline extends from Jasper at the southern end of the Valley to Devilstep Hollow at the northern end.* The anticline continues to the northeast, and may be observed in Grassy Cove, Little Cove, and Crab Orchard Cove, where islands of Mississippian limestone have been exposed in the interior of the Plateau. To the east the margin of the Plateau turns up sharply in Walden's Ridge, which forms the western wall of the Great Valley of East Tennessee.

Photo by Roy Davis & T. C. Barr

Fig. 2. Phreatic channel in a cave in the Catheys formation at the edge of the Eastern Highland Rim. Ward Cave, Bedford County.

The southernmost tip of a second structural low—the *Western Kentucky Coal Field*—extends into Stewart, Dickson, and Montgomery Counties. The strata in this area dip northward at about 12 feet per mile.

The Western Kentucky Coal Field and the Hartselle Escarpment of northern Alabama are separated by the *Clifton Saddle*[6], in Wayne and Hardin Counties. The *Cumberland Saddle* stretches along the axis of the Cincinnati Arch between the Jessamine Dome of north-central Kentucky and the Nashville Dome.

Nashville Basin

In the Nashville Basin caves appear in low uplands of the Ridley limestone, in hills and ridges of the more resistant limestones which occur at the periphery of the Basin—the Carters limestone, the Bigby-Cannon limestone, and the Catheys formation—and in deep stream valleys cutting into the Highland Rim escarpment.

Jackson Cave, in the Cedars of Lebanon State Park, Wilson County, and the Taylor Herron Cave, near Lascassas, Rutherford County, are examples of the first group. Both occur in the Ridley near the base of low hills. Jackson Cave is about 300 yards long, with no side passages, and ends in a pool of water. A permanent stream flows through Taylor Herron Cave for 2000 feet. In southwestern Rutherford County there is a series of large and unusual caves which has been called the Snail Shell Cave system. These caves are part of an underground drainage which feeds Overall Spring at the head of the main branch of Overall Creek, and contain many large reservoirs of water. The system is developed within an extensive mass of Ridley limestone which presents a peneplain surface in the region of the caves.

*The Sequatchie Valley anticline and the Sequatchie thrust fault continue southward into Alabama; the resulting valley is occupied by the Tennessee River from Jasper, Tenn., to Guntersville, Ala.

There are numerous side passages, at least three of which are almost as large as the main channel. 4.6 miles is the total known length of this cavern, but exploration is far from complete. It seems probable that the major part of the development of the Snail Shell system has been accomplished by vadose streams.

Along the flanks of the Nashville Dome there are hills and ridges of the Carters limestone, the Bigby-Cannon limestone, and the Catheys formation, which grade into the erosional escarpment of the Highland Rim. Benderman's Cave, near Southport, Maury County, is a mile-long cavern developed along and just above the contact between the Bigby-Cannon and the *Dalmanella* coquina member of the Hermitage formation; it is largely vadose, but has had a long phreatic history. Skeleton Cave and Piper Cave, near Monoville, Smith County, are rather large phreatic caves (averaging 15 feet high and 25 feet wide) in the Cannon facies of the Bigby-Cannon. Piper Cave is half a mile in length. In the vicinity of Nashville, Davidson County, caves in the Carters limestone are seen at Una (Brent's Cave, Gillespie's Cave) and Antioch (Mill Creek Cave); they are relatively small, averaging 8 to 10 feet in height, 5 to 6 feet in width, and about 1000 feet in length. These caves are predominantly vadose in origin.

In DeKalb and Wilson Counties there is a series of caves which occurs in the Catheys formation capping outlying hills near the edge of the Highland Rim. Corley Cave, near Temperance Hall, DeKalb County, and Anderson Cave, in western DeKalb County, are examples of this type of cave. Both consist of truncated segments of large (30 to 40 feet in diameter) phreatic galleries. These caves are genetically related to the extensive Catheys caves occurring in stream valleys extending into the margin of the Eastern Highland Rim. Solution in the Catheys and Bigby-Cannon has produced many large and interesting caverns in these valleys, especially in Smith and DeKalb Counties. John Fisher Cave in Smith County, and Cripps's Mill Cave and Indian Grave Point Cave in DeKalb County are notable examples of this type. In Indian Grave Point Cave huge breakdown rooms are linked with passages averaging 40 feet in width and 20 feet in height; a mile and a half of passages have been explored. Catheys caves appear also in Jackson, Cannon, Coffee, Moore, Franklin and a few other counties.

To the north and west stream valleys at the edge of the Basin cut through limestones of the Wayne Group (Silurian)—the Laurel and Lego. A few small caves are developed here. The largest—Mason Cave, Sumner County—is only 250 yards in length, and is apparently a phreatic cavern.

Photo by T. C. Barr

Fig. 3. Indian Grave Point, DeKalb County, is a salient of the Eastern Highland Rim. It is underlain by the Bigby-Cannon limestone and the Catheys formation. Indian Grave Point Cave is the largest known Highland Rim cavern.

In general, the Nashville Basin caves seem to be predominantly phreatic toward the east, whereas many vadose caves appear in the flat-lying portion of the Basin and in the stream valleys to the west.

Eastern Highland Rim

In the eastern portion of the Highland Rim caves occur in the outliers of St. Louis limestone near the foot of the Cumberland Plateau. Some are primarily phreatic (Jarrell's Cave, in Flat Top Mountain, Coffee County), but most appear to be vadose in origin. Some, like Rocky River Cave, Warren County, and Ament's Cave, Putnam County, are analogous to the Snail Shell Cave system, with collapse sinks opening into active vadose channels of considerable length. Others, such as Swift Cave, Overton County, and the Ewing Howell Cave, White County, underlie low uplands and resemble Jackson Cave and the Taylor Herron Cave (Ridley limestone of the

Photo by Roy Davis & T. C. Barr

Fig. 4. Solution channel in the Bigby-Cannon limestone. Willie Todd's Cave, Cannon County.

Nashville Basin) in size and morphology. Bunkum Cave, Pickett County, exhibits a typical dendritic pattern, with several small stream branches tributary to a large trunk channel which attains dimensions of 100 feet by 50 feet at the mouth.

Western Highland Rim and Western Valley

Three groups of caves may be delineated in this region. Those of the first group have been developed in the St. Louis limestone of the Cumberland Saddle, a structural feature separating the Highland Rim of Tennessee and the Pennyroyal Plateau of Kentucky. Such caves are best seen in Robertson County. The Bell Witch Cave, near Adams, and the Jesse James Cave, near Cross Plains, may be cited as examples. None of these caves is over half a mile in length, but some of the passages may be 30 feet wide and 20 feet high. Most of them are phreatic in origin, but at least two show considerable vadose enlargement.

Development of caves in the Warsaw limestone where it occurs on the southeastern flank of the Western Kentucky Coal Field has been rather extensive in Montgomery and Dickson Counties. Dunbar Cave and Bellamy Cave in Montgomery County are both over a mile in length, and cross-sections of many of the passages are over 50 feet in width and 30 feet in height. In Dickson County these Warsaw caves are smaller but numerous (Jewel Cave, Ruskin Cave, Columbia Caverns).

Three units of Silurian limestones are important in the development of caves in the Western Valley of the Tennessee River and the southern portion of the Western Highland Rim. These are the Wayne group (Laurel and Lego limestones), the Bob limestone, and the Decatur limestone. Blowing Cave, Hickman County, contains a solution channel measuring 30 feet wide, 40 feet high, and 540 feet long; it is in limestones of the Wayne group. Blowing Cave, Perry County, is in the Bob limestone; it contains a large breakdown chamber 50 feet wide, 30 feet high, and 200 feet long, and 300 yards of gravel-floored passages averaging 30 feet wide and 10 feet high. Walker Springs Cave, Wayne County, is a large network cave constructed along normal sets of joints in the Decatur limestone of the Clifton Saddle; the total length of all of its passages is 800 yards.

Cumberland Plateau

The caves of the Cumberland Plateau are the largest and best known in Tennessee. A dozen are over a mile in length, and Higgenbotham Cave, in Cardwell Mountain, near McMinnville, has a total length of over six miles of explored passages. Most Plateau caves occur in the Gasper oolite and the Ste. Genevieve limestone, but to the south and southeast the St. Louis and the Warsaw limestones increase in importance. A bench of fairly porous Cypress sandstone may in some cases overlie the limestones in which the caves have been developed, but the Mississippian Pennington formation and the thick complex of Pennsylvanian sandstones and shales appear to prevent the access of ground water to the underlying limestones.

In Franklin, Marion, and Grundy Counties cave explorers long ago observed that caves at the base of the Plateau do not extend under the sandstone cap. Caves in this section are most prominently developed in deep, narrow valleys called *coves;* a low-angle slope to the cove walls, resulting in the exposure of a greater amount of limestone surface, was found to be highly favorable to the occurrence of large and long caves. An additional peculiarity was noted, viz., that almost all of the caves occurring in "cove" terrain were found to open at the level of the cove floor. Only in areas where the rough, hilly type of dissection predominates do cave mouths appear high up above the valley floor; caves of this latter type may be seen in Warren, White, Van Buren, Putnam, and Overton Counties. They frequently extend under a bench of Cypress sandstone. For example, the ridge beneath which Big Bone Cave, Van Buren County, lies is capped with Cypress. Saltpeter Cave, Van Buren County, is largely roofed over with the Cypress; the presence of stalactites on the roof of the cave is an indication of the porous and calcareous nature of this sandstone. Most of these caves are decidedly phreatic.

To explain the formation of caves in deep coves in the Plateau, the following theory is suggested. Let us consider the development of a single cove. In the early stages of erosion (Fig. 5-A) the sandstone cap has not yet been breached, and caves have not developed. At a later stage (Fig. 5-B) a small amount of limestone will have been exposed to the action of water. Caves, primarily vadose, will have formed in the upper strata of limestone. The gradient of the cove-forming stream will be so steep that development of phreatic caverns seems unlikely. As the cove deepens and widens (Fig. 5-C), we see that these earlier caves have been removed by erosion. The gradient is less steep, and phreatic solution may in some cases occur. The process of the formation of new caves and the erosion of old ones is a continuous one. It results in absence of caves at higher elevations, even though readily soluble limestones may be exposed there.

Most of the large stream caves in the southern portion of the Plateau in Tennessee probably had their origin at or slightly below the water table, but are now undergoing extensive vadose enlargement. Wet Cave and Sinking Cove Cave in Franklin County, and Gizzard Cove Cave, Marion County, have upper and lower mouths, the upper ones having been abandoned by the cave streams as they degraded their channels. The remnants of the downstream portion of Wonder Cave, in Layne's Cove, Grundy County, may be traced for nearly half a mile along the right hand side of the cove below the present mouth of the cave. Blind Fish Cave, in Long Valley, a tributary of Calfkiller

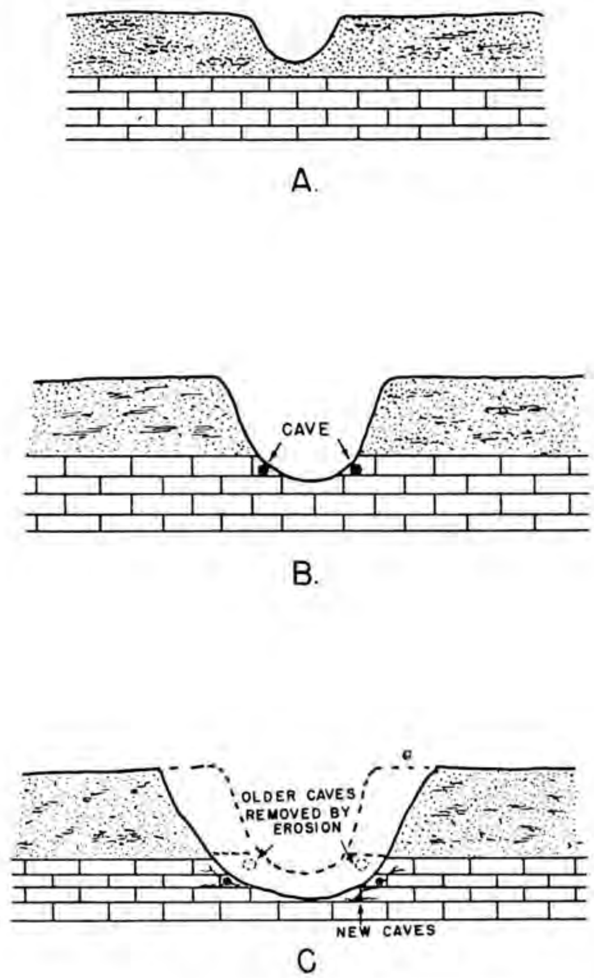

Fig. 5. Origin of caves in the southern part of the Cumberland Plateau in Tennessee. For explanation see text.

Valley in Putnam County, extends beneath the floor of the cove, and has probably only recently become vadose; both ends of this 3000-foot-long cavern are blocked by siphons. Dry Hollow Cave, Overton County, is a small network cave in the floor of Dry Hollow.

Three large, completely phreatic caves occur in the vicinity of McMinnville. These are Higgenbotham Cave and Hubbard Cave, Warren County, and Big Bone Cave, Van Buren County. Most of the caves of the Calfkiller Valley in White and Putnam Counties are phreatic, with the exception of Bridge Creek Cave and Arch Cave, in England Cove, where sections of the cove-forming stream have been diverted into underground channels. Caves of both vadose and phreatic origin may be seen in Overton, Pickett, and Fentress Counties, but solutional development has been predominantly phreatic in these areas.

The excavation of vertical solution cavities in the Gasper-Ste. Genevieve of the Plateau has produced many deep pits, commonly known as "devil's holes" or "hellholes". The most prominent of these are Mystery Falls, in Lookout Mountain, Chattanooga; the Conley Hole, in southern Warren County; the Devil's Hole, on Little Short Mountain, Cannon County; and Hellhole, on Hellhole Mountain in Overton

Photo by Roy Davis

Fig. 6. Bone Cave Mountain, Van Buren County, is composed of Gasper oolite and Ste. Genevieve limestone capped with Cypress sandstone and Pennsylvanian rocks. The Cypress bench is prominently displayed in this photograph.

County. Mystery Falls, which is 331 feet deep, widens to 100 feet in diameter near the bottom. Hellhole has never been completely explored, but preliminary reconnaissance indicates that it may be nearly 400 feet deep. All of these pits open in the Gasper oolite just below its line of contact with the Cypress sandstone, and it is the opinion of the present writer that they are the abandoned swallet holes of seepage springs emerging at the base of the Cypress.

Sequatchie Valley Anticline

To the east the Cumberland Plateau exhibits a number of structural disturbances correlated with the Appalachian orogeny. Foremost among these is the Sequatchie Valley anticline, which extends southward from Crab Orchard, in Cumberland

Photo by courtesy of Wonder Cave

Fig. 7. Cathedral Hall in Wonder Cave, Grundry County. An extensive upper level in a large, primarily vadose cavern in the Ste. Genevieve and St. Louis limestones.

County, to northern Alabama. In the Sequatchie Valley, from which the structure takes its name, rocks of Ordovician age are exposed. The Sequatchie thrust fault truncates the anticline on its northwestern flank beginning near the head of the Valley, and extends southward into Alabama. North of Devilstep Hollow at the head of the Valley, three isolated coves of Mississippian limestone are exposed, surrounded by Pennsylvanian sandstones—Grassy Cove, Little Cove, and Crab Orchard Cove. A number of caves are known in these areas, especially in the Gasper-Ste. Genevieve of Grassy Cove. The drainage from Grassy Cove enters Mill Cave, which opens at the base of Brady Mountain, and has been traced for 7000 feet, through a channel averaging 80 feet high and 50 feet wide. The Mill Cave stream is said to emerge at the head of the Sequatchie River in Devilstep Hollow Cave; the two caves are 7½ miles apart. Saltpeter Cave in Grassy Cove exhibits over a mile of complex passageways; it is a dry, dusty cave of phreatic origin. The Blowing Hole opens near the top of the Gasper oolite in Brady Mountain; a vertical shaft of 254 feet leads down into a grotto 100 feet high, 150 feet wide, and 400 feet long.

Caves within the Sequatchie Valley itself are small and rather infrequent. Low's Gap Cave, in northeastern Bledose County, is in the Catheys formation several hundred feet above the valley floor. Its main passage is 260 yards long, averaging 8 feet wide and 9 feet high. Aaron Tollett's Cave, in the Carters limestone of the Valley floor a short distance north of Low's Gap Cave, is 8 feet high, 10 feet wide, and 190 yards in length. Farther to the south caves may occur in Mississippian rocks at the base of the West Valley wall, but the steep slope of the wall and the small amount of limestone exposed has tended to keep these caves small.

Conclusions

The distribution of limestone caves in Middle Tennessee shows definite control by stratigraphy, physiography, and structure. Twelve formations, of Ordovician, Silurian, and Mississippian age, are decidedly caverniferous, a character arising from their solubility and cohesiveness. The presence of impermeable strata, such as the Fort Payne chert or the Pottsville series, above these limestones will reduce or prevent the development of caves. Many of the 300 caves studied are apparently of phreatic origin, but the origin of over half of them may be explained by the action of vadose water.

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The Speleo-Barometer

By DONALD N. COURNOYER

The development of specialized equipment for speleological investigations is a field that is much in need of additional study. One such piece of equipment is here described in the hope that its use may be adapted to similar investigations.

INTRODUCTION

At Breathing Cave near Burnsville, Virginia, a very unusual phenomenon exists. This was discovered on October 8, 1944 by Burton S. Faust, who was the first to begin investigations. In 1947 a report of his discovery and possible theories were published in the N. S. S. Bulletin, Number 9, "An Unusual Phenomenon". He discussed this with the author on August 1, 1953 and related the problem of inaccuracy of pressure change data collected by a barograph. This effected the construction of a sensitive barometer to obtain the most reliable data.

From the throat of a small crawlway approximately 125 feet from the cave entrance, the air flow has been observed to undergo persistently unusual motion. This air motion, which has been under observation for the past 10 years, is a periodic pulsation (breathing) type of air flow involving repetitious cycles of inhalation, pause, exhalation, and pause. Individual cycles have been observed to range anywhere from 4 to 25 minutes.

PROBLEM

Thermographs, barographs, thermometers, hand anemometer (wind vane type) and a stop watch were used to investigate the "Burton Phenomenon" (which was named for Burton Faust, who first observed it) to uncover what the relationship, if any, prevailing atmospheric conditions have in developing this phenomenon. Wind velocities ranging from 1 to 8 miles per hour have been observed with a pronounced increase and decrease in temperature. Yet the barograph tracing sheets fail to record any change in pressure. Therefore, since the barograph could not record these changes, a highly sensitive pressure-measuring instrument was needed for the recording of delicate atmospheric conditions, which may result in the solution of the problem; i.e., what causes this unusual respiratory phenomenon.

APPARATUS

Mr. Joe R. Fulks of the U. S. Weather Bureau designed a sensitive barometer which would fluctuate consistently to correspond with this inward and outward flow of air. Mr. Edwin D. Wiedemann, a Model Instrument Maker also of the Weather Bureau, gave the author considerable assistance in the construction of this highly sensitive instrument which shall be referred to as the "Speleo-barometer". The Speleo-barometer con-

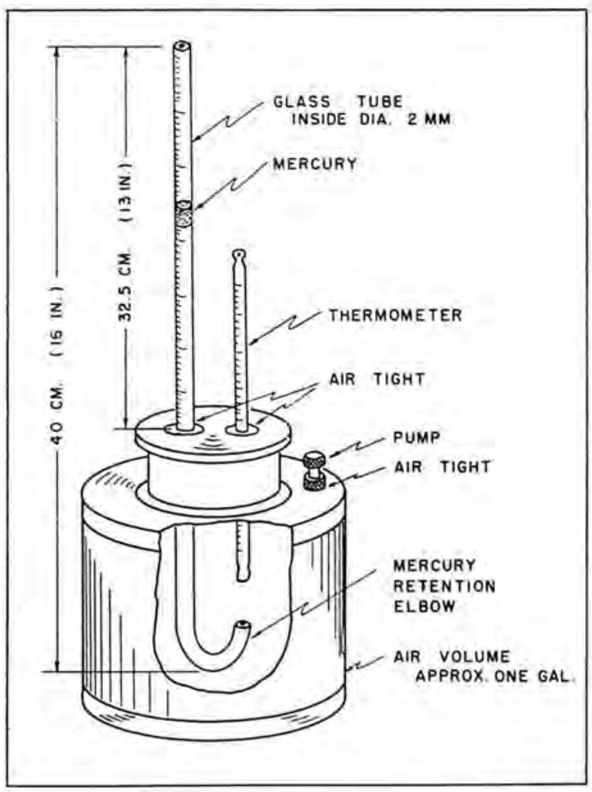

Fig. 1. Diagram of the Speleo-Barometer.

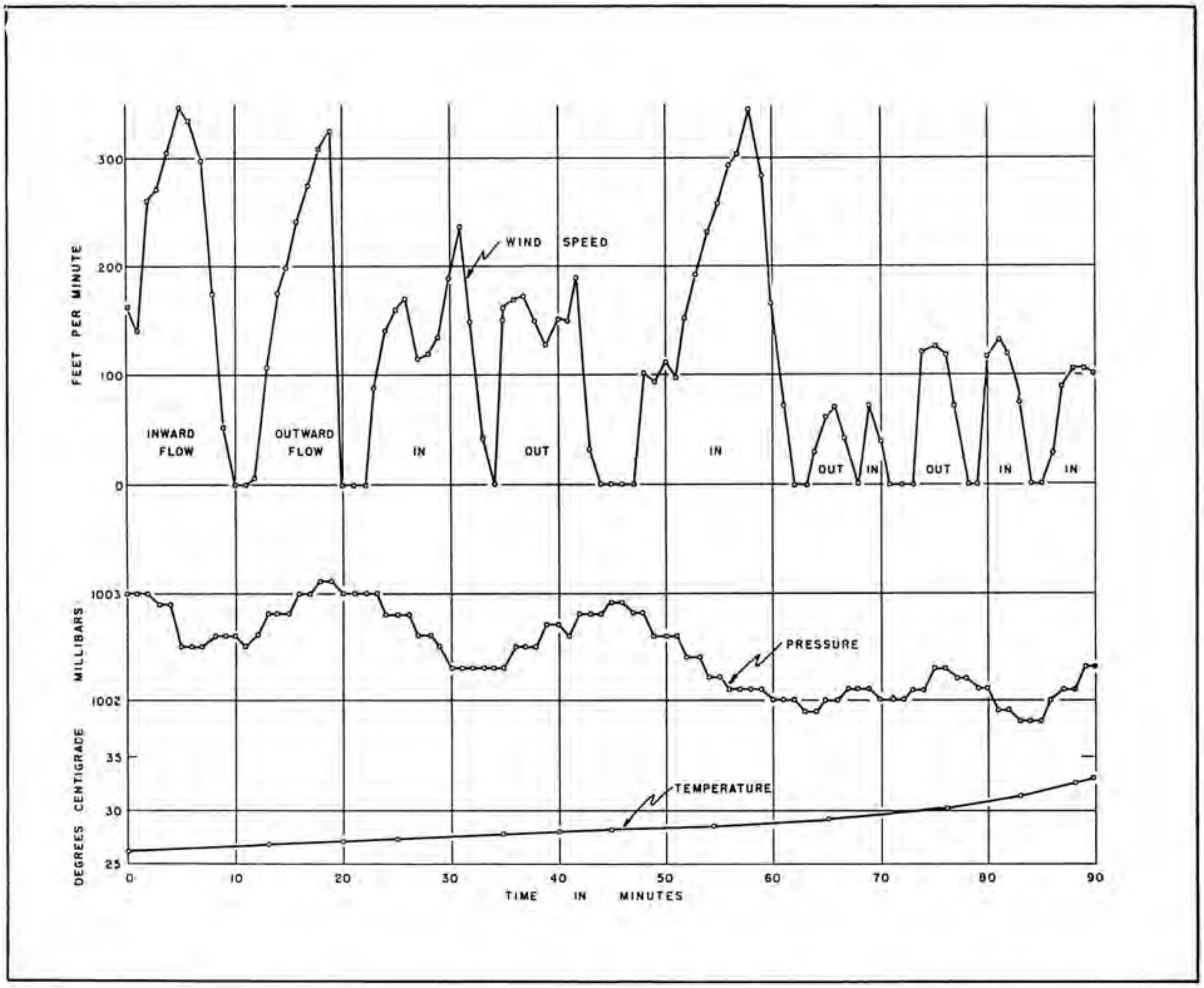

Fig. 2. Graph showing meteorological conditions in Breathing Cave, Virginia, on Jan. 9, 1954.

sists of an airtight cell, very similar to that of a Coleman gas lantern, into which a standard Fahrenheit thermometer and a "J"-shaped glass tube 40 cm. long by 2 mm. diameter (inside) have been inserted from the top. The purpose of the thermometer is to ensure that the temperature within the pressurized air cell is equal to that of the cave before the instrument is put into use.

The J-tube, open at both ends, extends 32.5 cms. above the top of the air cell. A small drop of mercury (approximately .54 gram) is inserted into the upper end of the tube by means of an eye-dropper; the curve at the bottom of the "J" prevents the mercury from spilling out of the tube. Pressure is now gently introduced into the air cell by means of the built-in-pump, until the mercury is suspended approximately midway in the exposed section of the tube. With the pump locked to prevent leakage of air, the instrument is allowed to settle for about one hour, so the temperature of the air within the cell will equalize with that of the cave. The air cell portion of the instrument is then placed in an insulated container to prevent temperature fluctuations within the instrument, which otherwise would result from temperature or heat from other lighting sources.

A very slight deviation in atmospheric pressure within the cave will cause the mercury to rise or lower on its supporting air column. Graduations on the J-tube permit direct readings to be taken. When storing the instrument, the pressure should be released slowly from the container so that the mercury comes to rest at the bottom of the J-tube.

Use

The instrument was introduced on October 31, 1953, when it was given its first trial in Breathing Cave. The author, with the assistance of other interested persons, used the following method in obtaining the valuable data. Three persons worked at the throat of the crawl, one measuring the wind velocity, another calling off the seconds per minute, and the third person recording wind speed (feet per minute), barometric pressure readings and changes in temperature, from the "Speleo-barometer". The recording of these minute by minute observations are made for any length of time that may be deemed necessary.

Photo by Donald N. Cournoyer

Fig. 3. Sid Teweles, Weather Bureau meteorologist, pressurizing container preparatory to recording observations.

Preliminary Results

At the time of our observations the pressure was dropping steadily over the Burnsville area, where Breathing Cave is located, and was corresponding to the barograph tracing sheets and also the Speleo-barometer. However, what did not appear on the barograph tracing sheets was an increase in pressure, whenever a reverse movement of cold air came outward from the crawl, and yet the Speleo-barometer showed a pronounced increase of pressure advancing from within the crawl.

This instrument proved to be more accurate than the barograph, because it registers changes in pressure which occur for brief periods, while the barograph requires a longer period of time to register any change.

Acknowledgment

The author wishes to express his sincere appreciation to Mr. Burton Faust for his untiring efforts and assistance in bringing about the idea for this paper; to Mr. Benton Hickock for his assistance in drawing the instrument plan; to Mr. Carl H. Gaum for his assistance in drawing the illustrated graph showing the magnitude of pressure variation and to Miss Marguerite Klein for a splendid job in editing this paper. He further wishes to express his gratitude to Mr. Ernest A. Wood of the Arctic Operations Project for his help in writing the specifications of the instrument.

REGIONAL ORGANIZATIONS AND LOCAL UNITS OF THE NATIONAL SPELEOLOGICAL SOCIETY

Wherever sufficient interest in speleological activity exists members of the National Speleological Society are encouraged to form regional organizations or local units called "grottoes". At present there are 3 regional organizations and 42 grottoes, the latter located in 21 states and the District of Columbia. The regions and local units select their own officers, organize and conduct field trips, carry on research projects and otherwise implement the efforts of the parent body. A list of such regions and local grottoes, with the names and addresses of persons to contact for information, follows:

REGIONS

1. *Mid-Appalachian Region*
C. N. Bruce
R. D. 4
New Castle, Pa.
2. *Northeastern Region*
Russell Gurnee
231 Irving Avenue
Closter, N. J.
3. *Virginia Region*
Earl M. Thierry
5 Mohican Drive
Portsmouth, Va.

GROTTOES

ALABAMA
1. *Auburn Grotto*
J. D. McClung
306 N. 9th Street
Opelika, Ala.

CALIFORNIA
2. *Southern California Grotto*
Carroll S. Slemaker
1735 North Orchid St.
Hollywood, Calif.

COLORADO
3. *Colorado Grotto*
Glenn E. Pollard
4265 Kendall St.
Wheat Ridge, Colo.

DIST. OF COLUMBIA
4. *District of Columbia Grotto*
Marilyn Bozeman
4528 32nd Street
Mt. Ranier, Md.

GEORGIA
5. *Atlanta Grotto*
J. Roy Chapman
Box 701
Atlanta, Ga.

INDIANA
6. *Kentucky-Indiana Grotto*
Charles B. Fort
1426 South 3rd St.
Louisville, Ky.
7. *Scotto Grotto*
Jack W. Dorsey
R. F. D. 3
Scottsburgh, Ind.
8. *Tarevac Grotto*
J. L. Ell
General Electric Co.
Tell City, Ind.
9. *Central Indiana Grotto*
Kathryn A. McCartney
53 N. Sherman Drive
Indianapolis, Ind.

KENTUCKY
10. *Kentucky-Indiana Grotto*
Charles B. Fort
1426 South 3rd St.
Louisville, Ky.
11. *Western Kentucky State College Grotto*
Martha Wade
Box 291
College Heights Station
Bowling Green, Ky.

MARYLAND
12. *Baltimore Grotto*
Maxon L. Goudy, Jr.
5002 Hampshire Ave.
Baltimore 7, Md.

MASSACHUSETTS
13. *Boston Grotto*
Donald L. Peters
Rm. 115A, Grad House
Massachusetts Institute of Technology
Cambridge, Mass.

MINNESOTA
14. *Twin Cities Grotto*
David S. Gebhard
1665 Montreal Avenue
St. Paul 5, Minn.

MISSOURI
15. *Missouri School of Mines Student Grotto*
J. C. Dotson
Faculty Advisor
Missouri School of Mines
Rolla, Mo.
16. *Western Missouri Grotto*
Deloraine C. Walker
434 E. 65th Terrace, N.
North Kansas City, Mo.

NEW JERSEY
17. *Enterprise Dilettante Speleology Grotto*
William Hulstrunk
139 Halsted Street
East Orange, N. J.
18. *Northern New Jersey Grotto*
Margaret Mueller
549 Jerusalem Road
Scotch Plains, N. J.

NEW YORK
19. *Cornell Grotto*
T. L. Paulson
216 Park Ave.
Manhasset, N. Y.
20. *June Memorial Grotto*
George M. Wilson
25 Belle Avenue
Troy, N. Y.
21. *Metropolitan New York Grotto*
Alice M. Rowehl
1365 York Avenue
New York 21, N. Y.
22. *Natty Bumpo Grotto*
Bradford Cobb
R. D. 3
Remsen, N. Y.
23. *Rensselaer Outing Club Student Grotto*
Charles R. Hine
Dept. of Mechanical Engineering
Rensselaer Polytechnic Institute
Troy, N. Y.

NORTH CAROLINA
24. *Duke Grotto*
John H. Gibbons
Physics Department
Duke University
Durham, N. C.
25. *Piedmont Grotto*
Samuel Phifer, Jr.
1111 Charlotte Avenue
Monroe, N. C.

OHIO
26. *Central Ohio Grotto*
Richard D. Seifried
510½ W. Greene St.
Piqua, Ohio
27. *Cleveland Grotto*
Julius Kovacs
12528 Griffing Avenue
Cleveland, Ohio

OKLAHOMA
28. *Tulsa Grotto*
Richard Tenney
1304 South Yale St.
Tulsa, Okla.

PENNSYLVANIA
29. *Nittany Student Grotto*
John A. Stellmack
Petroleum Refining Laboratory
Pennsylvania State University
State College, Pa.
30. *Philadelphia Grotto*
Audrey E. Welsh
161 Lakeside Boulevard
Trenton 10, N. J.
31. *Pittsburgh Grotto*
J. Robert Dunn
7198 Shannon Road
Verona, Pa.
32. *Shippensburg State Teachers College Student Grotto*
John A. Judge
State Teachers College
Shippensburg, Pa.
33. *Standing Stone Grotto*
Maurice A. Henry
Apt. 5, The Village
Huntingdon, Pa.

TENNESSEE
34. *Nashville Grotto*
Roy A. Davis
Box 770
David Lipscomb College
Nashville, Tenn.

TEXAS
35. *University of Texas Student Grotto*
Arthur Carroll
Box 7672
University Station
Austin, Texas
36. *Belcones Grotto*
Joe C. Pearce
5713 Avenue G
Austin, Texas

UTAH
37. *Salt Lake Grotto*
D. B. McDonald
178 North Main Street
Salt Lake City, Utah
38. *Utah's Dixie Grotto*
LeRoy J. Bailey
Washington, Utah

VIRGINIA
39. *University of Virginia Student Grotto*
Joe Dreese
Theta Chi House,
Charlottesville, Va.
40. *Virginia Polytechnic Institute Student Grotto*
Richard J. Wagner
Virginia Polytechnic Institute
Box 6116
Blacksburg, Va.
41. *Wytheville Grotto*
Elizabeth M. Sabatinos
102 Faculty Street
Blacksburg, Va.

WEST VIRGINIA
42. *Charleston Grotto*
Martha McVey
1812 Beechwood Drive
So. Charleston, W. Va.
43. *Morgantown Grotto*
William D. Conner
P. O. Box 72
Morgantown, W. Va.

Preface *(Continued from Page 1)*

much information, on speleological activities and studies in far distant spots, that otherwise we might not receive and which is made available thru our library facilities. The net result is the promotion of mutual appreciation and understanding which contributes to better and more friendly relations between ourselves and the peoples of other nations.

There has been a gratifying growth in Sustaining and Life memberships, as well as a healthy expansion in the number of Sustaining members who have converted to Life status. This trend is considered to be further evidence of continued growth in interest, influence, and understanding of the way the Society is attempting to promote the science of Speleology.

A recapitulation of Society accomplishments would not be complete without mentioning the persons who have been and are responsible for this growth and progress. The members of the Board of Governors, the Executive Committee, the National Committee chairmen, and Regional and Grotto officers have spent many hours considering and discussing the multitude of problems involved in making the Society function smoothly. Most members do not realize how much work takes place behind the scenes — necessary work performed by persons who are sincere and conscientious and who have the best interests of the Society at heart. Let us all give these persons our wholehearted support, and let each of us resolve that we will do our best to help them carry the load. In that way we will continue to grow into a Society second to none in the world.

BURTON S. FAUST,
Acting President.

WHO'S WHO IN BULLETIN SIXTEEN . . .

THOMAS C. BARR, JR. received his A.B. in biology from Harvard University in 1953 and went on for his M.A. in zoology at Columbia University the following year. At present he is taking graduate work at Vanderbilt University where he is making a study of the cave fauna of the Interior Lowlands province and the Cumberland Plateau. Since joining the N.S.S. in 1948 he has been cataloguing Tennessee caves and studying their fauna. He has explored over 400 caves in 13 states. His special interests are the evolution, ecology and geographic distribution of cave animals and the origin and regional development of caves.

DONALD N. COURNOYER was born in Woonsocket, Rhode Island, in 1925. He attended schools in Rhode Island and Massachusetts. After serving in the U. S. Army for a brief time, he returned to Woonsocket where he attended Hill College. Upon completion of college he obtained a position with the Patent Office in Washington, D. C. It was at the Patent Office in January, 1947 that he was first introduced to speleology by John S. Petrie. In 1948 he transferred to the U. S. Weather Bureau. The following year he took a group of W. B. Recreational Club members on a trip to Endless Caverns. Appropriately enough his future wife, Marty, was one of the Club

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members who was in the group. They were married in Arlington, Virginia, in 1951. His pet project in speleology is studying meteorological conditions in caves and the influence of atmospheric conditions from the surface. In February 1954, he served as the meteorologist for the Floyd Collins Crystal Cave expedition. At present he is employed in the Arctic Project of the Weather Bureau, and is looking forward to additional trips to the Joint Canadian-U. S. Arctic Weather Stations.

WILLIAM R. HALLIDAY received his B.A. at Swarthmore College and his M.D. at George Washington University. He has done considerable caving in the Virginias as well as all the western states, with a total of 200 caves to his credit. He was the founder and former chairman of the Southern California, Cascade, Colorado and Salt Lake Grottoes of the N.S.S. He is a member of the Society's national Board of Governors and of its Mineralogy Committee and has served as chairman of its Grottoes Committee. Completing his training in chest surgery he has entered the United States Navy for the second time. His favorite caving areas are northeastern Nevada and Sequoia National Park in California.

GEORGE F. JACKSON of Evansville, Indiana is N.S.S. member No. 151 and says he has been interested in caves for more years than he cares to tell. His especial interest is Indiana's vast Wyandotte Cave, one of the largest in the country, and his book about it is the only complete history and description of it ever written. In addition he has had well over 100 articles on caves and cave photography published. He does free lance writing as a "sideline" in addition to writing about caves. He is presently on the N.S.S. Board of Governors and previously served on the board from 1949-51. He was responsible for the formation of the now inactive Indiana Grotto and carries on a large correspondence pertaining to Indiana caves and to N.S.S. activities. Some of this "correspondence" is by means of tape recordings which are passed back and forth between eastern and western members, particularly Burton Faust of Washington, D. C. and Don Bloch of Denver, Colorado. All three agree that tape recorders are a splendid means of conveying information and ardently wish more N.S.S. members and Grottoes had recorders so information and programs could be circulated more readily. In August, 1954 George married Norma Lipman of Pennington, New Jersey, N.S.S. member No. 1227 and both say they now spend their spare time trying to devise ways and means to get into some of southern Indiana's unexplored caves.

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 N.S.S. field trip in April, 1947 resulted in his gradual change from a somewhat normal individual to a speleoeditor.

PRESTON MCGRAIN and ORVILLE L. BANDY were graduate students in the Department of Geology, Indiana University, when field investigations for this paper were made. During that period they came under the influence of the late Dr. Clyde A. Malott, recognized authority on the origin and development of limestone caverns and other features of the Indiana karst region. As the text of the report indicates, their efforts and interests in mapping cavern systems has been directed more toward unravelling the geological controls than merely for the spirit of adventure. McGrain's main fields of interest include economic geology, stratigraphy, and hydrology. He is Assistant State Geologist on the staff of the Kentucky Geological Survey, Lexington, a position he has held since 1950. Dr. Bandy is Associate Professor of Geology, University of Southern California, Los Angeles, and has been associated with that institution since 1948. His principal area of interest is ecology and paleoecology of Foraminifera.

DAVID G. MOORE was born at Long Beach, California, in 1925. After serving with the Eighth Air Force in World War II he entered the University of Southern California, receiving an M.A. in Marine Geology in 1951. He was a member of scientific fraternities Sigma Gamma Epsilon and Sigma Xi. The presently published paper was written while he was a graduate student at the University of Southern California. Moore's interests center about the ocean both in recreation and in professional work. At present he is engaged in research on recent marine sediments at the Scripps Institution of Oceanography at La Jolla, California. His hobbies as a spearfisher and an exploratory Aqua-Lung diver has resulted in his being a partner in a consulting firm engaged in underwater geological mapping.

JOHN W. MURRAY is professor of Chemistry at the Virginia Polytechnic Institute. He serves as faculty advisor to the V.P.I. Grotto of the National Speleological Society in which capacity he tries to cultivate an appreciation for safety, conservation and the scientific aspects of cave exploration. He is a member of the Committee on Formations and Mineralogy of the N.S.S. and heads the corresponding committee of the V.P.I. Grotto. His longstanding interest in geology as well as in chemistry has led him to the study of several problems on the mineralogy of caves including the conditions favoring the deposition of aragonite in speleothems, and the origin of some supposed prehistoric inscriptions. He has been a member of the National Speleological Society since 1944.

BROTHER G. NICHOLAS, F.S.C., was born in Philadelphia, Pennsylvania in 1927. In 1945 he entered the Christian Brothers, a Catholic religious order devoted to the education of men. He received his B.S. degree from Catholic University in 1950, an M.S. degree from the University of Pittsburgh in 1953 and is completing work on a Ph.D. Since 1950 Brother Nicholas has been teaching religion, physics, chemistry and biology at LaSalle High School, Cumberland, Maryland. He joined the N.S.S. in 1949, was chairman of the paleontology section in 1951, became a member of the board of governors in 1952 and Vice-President for Research in 1953. Brother Nicholas is also associate editor of the *American Biology Teacher*, state membership chairman of the National Association of Biology Teachers, member of Phi Beta Kappa and Sigma Xi as well as half a dozen other scientific societies. Since 1950, he has written twenty-five papers in the fields of botany, biochemistry, education, paleontology and speleology and has appeared on many radio and several television programs. Much in demand as a public speaker, Brother Nicholas has delivered lectures before scientific and educational groups throughout the United States and Canada. At present he is devoting his spare time to writing a book on Cave Ecology which will probably be published in 1956.