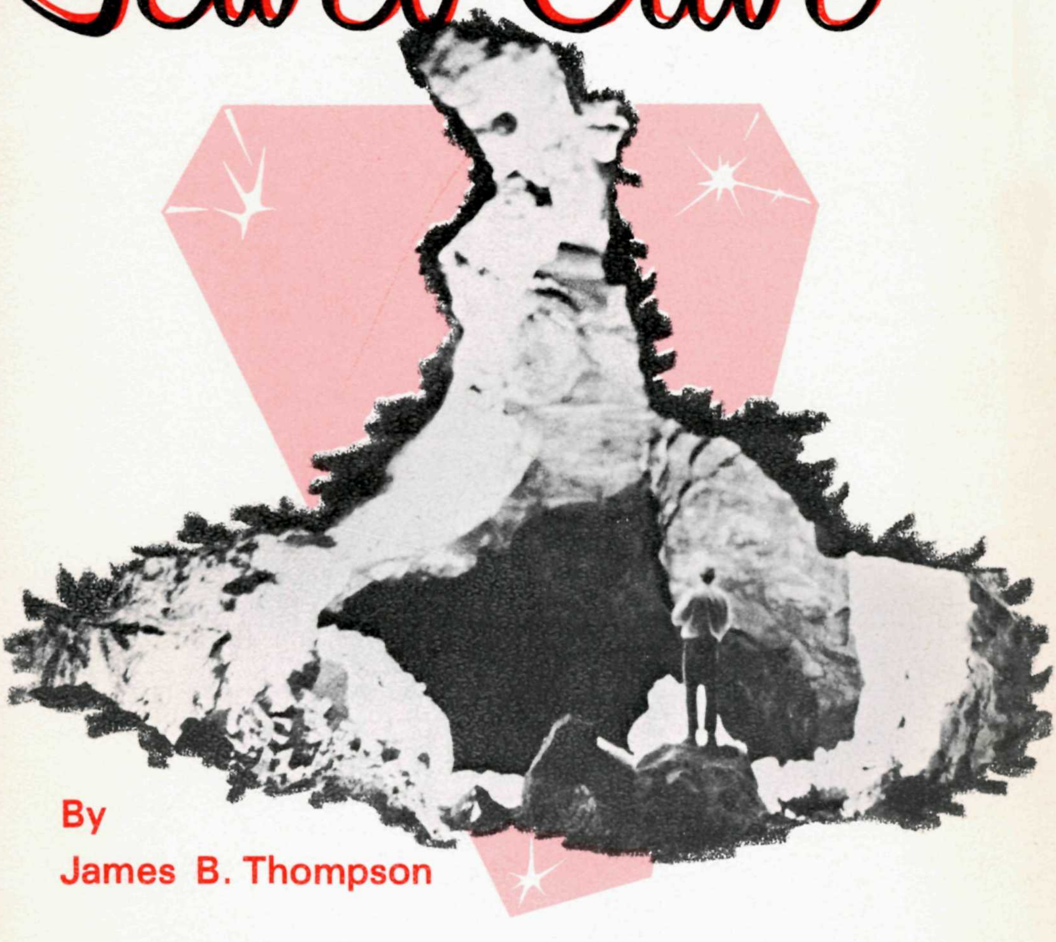
THE GEOLOGY OF

Jewel Cave



By

James B. Thompson

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This booklet is being published by the Wind Cave National Park and Jewel Cave National Monument Natural History Association.

PREFACE

PURPOSE

The publication of this booklet was accomplished to satisfy the need for a study into the geology of Jewel Cave in more detail than is found in the Monument's brochure. It is not a detailed technical bulletin but mearly an outline of some of the geological phenomina associated with the development and formation along with the mineral decoration of this particular cavern; however, many of the other cave systems in this and other areas were formed under conditions similar to those described here.

ACKNOWLEDGMENTS

I wish to thank everyone who assisted me in this project with a special thanks to John Jyers, Chief Naturalist, and Dr. J. P. Gries, Professor of Geological Engineering at the South Dakota School of Mines and Technology for their technical assistance. Thanks also to Herb and Jan Conn for the photographs seen in the following pages and to Don Gillespie for his work in making the final preparations of this booklet.

The Author

JEWEL CAVE

ITS GEOLOGY

AND

MINERALS

Jewel Cave was discovered in 1900 when two prospectors, Albert and Frank Michaud, discovered air whistling through a small hole in the side of a canyon. They enlarged the opening and mined the calcite crystals lining the cave walls. The brothers named their mining claim the "Jewel Lode" for the sparkling of the broken crystals. Of course, they could not resist exploring the cave in their spare time, but the Michauds' and others' efforts toward developing it as a tourist attraction, met with little success.

For a number of years after it became a national monument in 1908, the Cave was kept closed. When the National Park Service began operating the cave for the public in 1940, much of the early knowledge of the cave had been lost. The cave was thought to be quite small and significant only for the extensive coating of calcite crystals on the walls.

In 1958, spelunking seasonal park rangers rediscovered some of the "lost" passages beyond the "known" one-half mile of passages. Explorers since 1958 have extended the known portion of the cave far beyond the probings of the Michauds.

Approximately twenty-one miles of intricate passageways have been explored and mapped, making Jewel Cave one of the most extensive caves known to man. Many fascinating mineral forms are found at various locations in the cave—some not known to occur elsewhere in the world. Billions of calcite crystals line the passageways throughout.

The National Park Service is in the process of developing a remote portion of the cave for public use. In this area are passages up to a hundred feet high and more than a quarter of a mile long.

All of this is recent history — the history of man in the cave. The real aim of this booklet is to discuss the ancient history, the history of the formation of the cave and its mineral decorations.

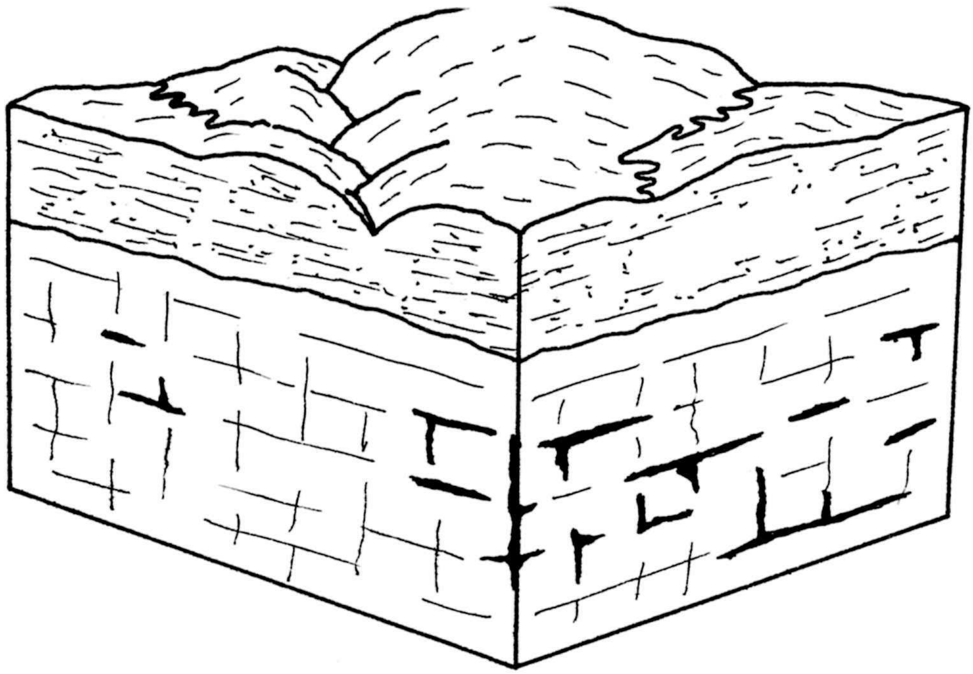
THE GEOLOGIC STORY

Approximately 300 million years ago, the entire Black Hills region was at the bottom of a sea. In the sea lived many marine animals somewhat similar to the clams and snails of today's seas. The sea bottom became littered with the calcium carbonate shells of dead marine animals, accumulating to depths of hundreds of feet. These calcium carbonate deposits were gradually formed into a thick bed of limestone. Today this bed of rock is called the Pahasapa Limestone after the Sioux Indian name for Black Hills. As time passed, the sea retreated and advanced; sometimes exposing the area to erosion, then piling more sediments on, until thousands of feet of sedimentary rocks eventually lay on top of the Pahasapa limestone. Within the bed itself, solutions of silicon dioxide replaced the limestone in some places, forming a type of rock called chert. The chert formed in a few thin layers and lenses. About 70 million years ago began a series of uplifts associated with the forming of the Rocky Mountains and, at the same time, the Black Hills. The Black Hills were warped upward like a giant bubble in the earth's crust — an eliptical, flattopped dome approximately 120 miles long by 60 miles wide. As this dome was being uplifted, its top was gradually being stripped away by stream erosion. Today, of course, the seas are gone from the interior of the continent; and the Black Hills dome stands in the midst of a sea of plains formed by the redistributed sediments which once covered the central portion of the hills. The Pahasapa Limestone is exposed today as a ring of limestone plateau surrounding the central hills. It is in this bed of rock that Jewel Cave and the other Black Hills caves occur.

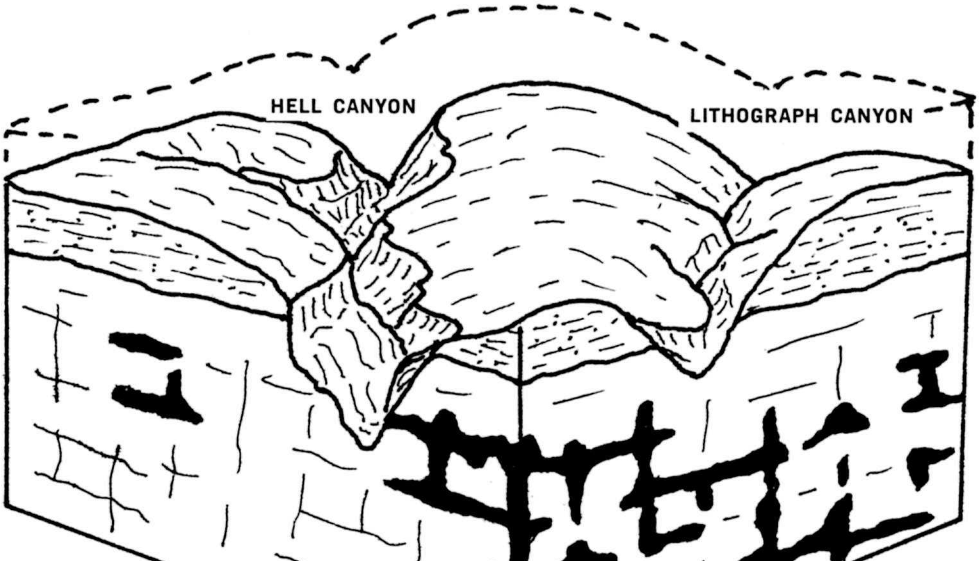
As a result of the flexing movements in the earth's crust, these sedimentary rocks were forced to bend. Limestone, however, does not bend very well; and the stretching caused the rock to fracture in essentially three planes, each at nearly right angles with the others. These fractures or "joints" vary from a few inches to several feet apart. At Jewel Cave there is one set of vertical joint planes running more or less north-south and another almost east-west. These combined with horizontal bedding planes form a pattern like a giant layer cake which has been cut into squares. It was this pattern which controlled the development of the cave.

TOP — Solution stage:
Enlargement by solution along bedding planes and joints.

BOTTOM — Present stage:
Full development of passages. Cave entrance exposed by the erosion of Hell Canyon.



SOLUTION STAGE



PRESENT STAGE

Initially, the Black Hills may not have been very far above the surrounding terrain. Ground water moved slowly in the fissures in the limestone. Rainwater falling to earth in this warm climate absorbed carbon dioxide and other gasses from the air and soils. In this way, the ground water became a weak solution of carbonic acid. This solution with its capability of dissolving calcium carbonate percolated downward until it reached the water table somewhere above the Pahasapa Limestone. (In this booklet, the terms "water" and "solutions" are used more or less interchangeably, since nearly all cave waters would include these and other impurities in solution.) Since water cannot percolate through limestone between tiny spaces as it does in sandstone, it followed the joint planes, slowly dissolving limestone as it moved along. Gradually as the limestone was dissolved and carried away in solution, the fractures were enlarged into passages. Water movement was preferentially westward, the direction of tilt of the strata, so that the east-west passages became higher, wider, and longer than the north-south passages. The passages also developed at several different levels, but not all fractures at any one level developed equally. This was probably due mainly to the varying solubility of the limestone. The zone of chert, being much harder and less soluble than limestone, helped to separate levels. The result is an irregular, three-dimensional, grid-like network of interconnecting passages. It took several million years for the initial Black Hills uplift to take place, and it took another several million years for the passages to be developed by solution. During this latter period the uplifted area apparently remained quite stable, judging from the evidence that water moved through the limestone quite slowly.

Even today we hear about change in the world climate — a gradual warming trend, advance and retreat of glaciers, etc. Evidences of many climatic changes and events exist in Jewel Cave. For instance, it appears that the cave was drained after solution of the passages. Then, waters again flooded the cave; but instead of dissolving more limestone, this time, they deposited the calcium carbonate in the form of calcite crystals. Calcite is the mineral form of calcium carbonate and can take many different crystal forms. In Jewel Cave, most of the large crystals of calcite are sharply pointed crystals called "dogtooth spar," or a blunter variety called nailhead "spar." These crystals were undoubtedly formed underwater from very slowly moving solutions. Why the solutions began to deposit calcium carbonate instead of dissolving it is something of a mystery, but many geologists feel that it was due to a change in the temperature of the water. This probably resulted from warming of the climate. At any rate, the solution-filled passages were lined with a layer of calcite crystals up to seven inches thick.

Following the formation of these crystals, there appears to have been a series of alternate drainings and floodings caused by fluctuation in the water table. Many of the calcite crystal deposits show layering with clay sediments which were carried into the cave. The glass-like transparency of the calcite crystals is in most cases obscured by a clay "cap." This must have been deposited during one of the last of these floodings when silt-and clay-laden solutions inundated the cave. By contrast, small crystallined cavities called "vugs," which formed in joints off the main galleries, contain dogtooth spar that is "crystal clear." These vugs were more or less sealed off from the main passage and were less influenced by the sediment-filled waters.

During one of these later floodings, the waters again were able to dissolve calcium carbonate, and the outer ends of some crystals were dissolved away, leaving a flat surface of hexagonal crystal cross sections.

Today the later table is at least 160 feet below the lowest point in the cave. As it lowered to this level long ago, it drained the cave a final time. Ceilings, which were partly supported by the water, collapsed leaving piles of limestone blocks or "breakdown" as it is called, on the floor. Where major passages intersect, larger chambers were formed — the ceilings collapsing to form a single tension arch ceiling. At these points occur the largest rooms in the cave with characteristic high-domed ceilings and a high pile of breakdown in the center of the room. Evidence for the dating of this event lies in the fact that the exposed ceilings and upper walls have no crystal coating, but crystal layers do show on the bottoms of the breakdown blocks.

Resuming uplift of the Black Hills may have caused this final lowering of the water table. Certainly uplift did occur, for streams were accelerated, eroding more of the sedimentary rock cover of the Hills and excavating deep canyons. One such canyon is known today as Hell Canyon. As Hell Canyon was deepened by stream erosion, it cut across one of the passages forming a natural entrance to the cave. The stream occasionally dumped mud and clay into portions of the cave, completely filling one passage on the north wall just inside the natural entrance. When the canyon deepened to its present level, the natural entrance was left high and dry in the canyon wall, 100 feet above.

MINERAL DECORATIONS

To most cave visitors there are two principal items of interest: the cave passages and the various mineral decorations. We have already discussed how the passages were formed, and briefly described the formation of the principal mineral decoration — the calcite crystals. Some further descriptions of the calcite crystals may be of interest, however, and certainly the other mineral decorations of the cave should not be left out. Some of the minerals described are not accessible to the cave visitor as they are in very remote sections of the cave. In fact, only a handful of people have seen all of them. The many varieties are part of the significance of this cave. They are interrelated; and are, therefore, a part of this story.

BOXWORK

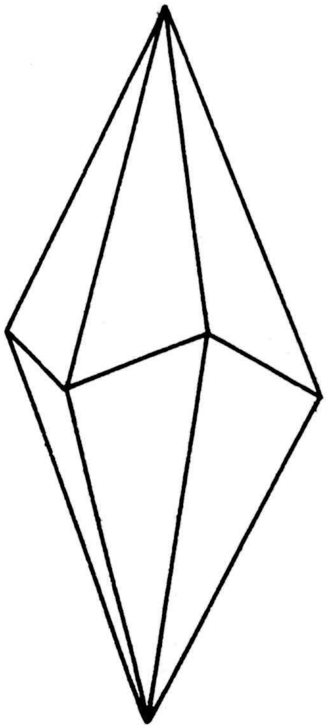
The very closely spaced joints, at some period of time after their formation, were "healed" with deposits of a brownish calcium carbonate which was more resistant to solution than the surrounding limestone. The result was that solution of the cave passages left a boxlike pattern of calcite fins protruding from the walls. The most spectacular examples of this "boxwork" are in nearby Wind Cave. Box work in Jewel Cave is mostly concealed beneath the crystal layer. Where the crystals have broken away, boxwork is occasionally exposed; showing that it was formed before the crystals. Since the boxwork also appears to have been intercepted by the solution of the cave passages, it is logical to assume that it was formed prior to the formation of the caverns.

CALCITE CRYSTALS

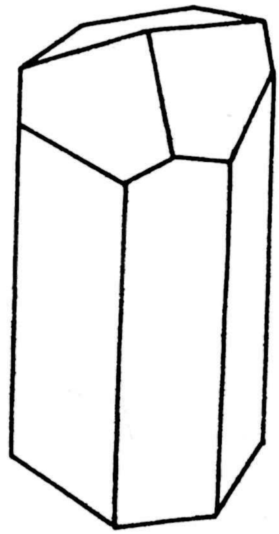
The calcite crystals, unlike most of the other mineral decorations, were presumably formed under water; that is, at a time when the cave was filled with solutions. Similar crystals have been "grown" in laboratories, where it was found that by adding certain impurities in varying amounts, the form of the crystal could be changed. In fact over 300 different crystal forms of calcite are known.

The calcite crystal layer often appears as large as knobs, accentuating the differential solution of the cave walls. Often the prominent knobs or ledges are chert lenses or layers covered with the calcite crystal layer. In many cases crystals pointing upwards on these knobs will be smaller and sharper than crystals growing outward or downward. The reason for this difference may be due to sulfate ions in the solution becoming more concentrated on the upward surfaces, resulting in a sharper crystal. The sharper crystals are generally referred to as "dogtooth spar" and the blunter ones as "nailhead spar." Actually there is almost a continuous gradation of forms between the two, but the drawing at right, shows the idealized relationship.

Typical occurrence of calcite crystals (mostly Dogtooth Spar). The best specimens are found in vugs or cavities and on the underside of protruding ledges.

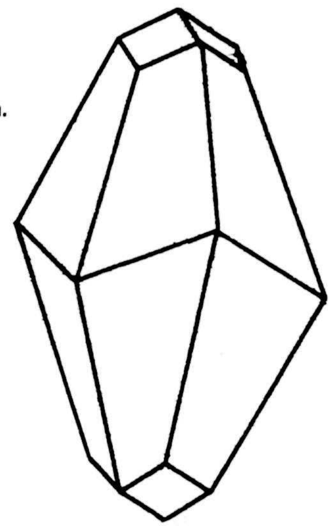


DOGTOOTH SPAR



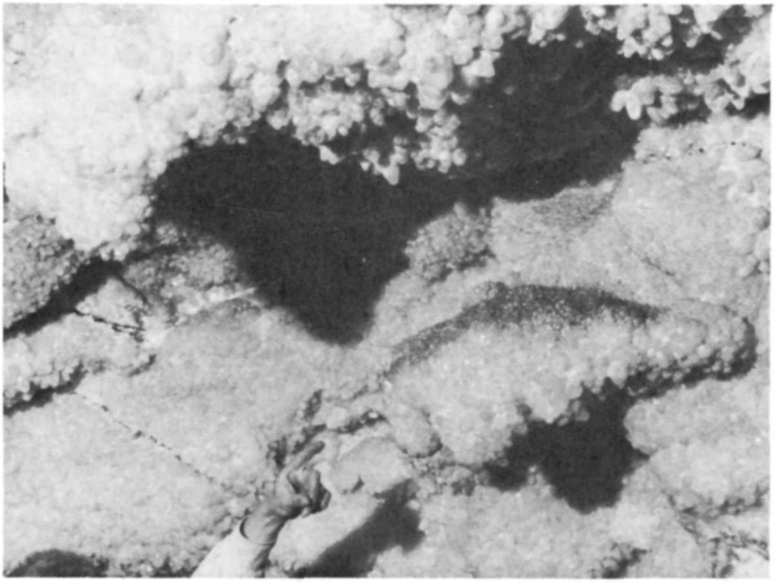
NAILHEAD SPAR

RIGHT — Typical Calcite Crystal Forms, normally only the upper half of the crystal will be seen.



COMBINED FORM

Along the tour routes the layer of calcite crystal can be seen separated from the limestone walls in some places. The separation, as much as three or four inches, shows that solution took place between the layer and the limestone wall at some time after the crystal layer was formed. The layer itself has broken away and fallen to the floor to form breakdown at many sites throughout the cave.



Typical occurrence of calcite crystals (mostly Dogtooth Spar). The best specimens are found in vugs or cavities and on the underside of protruding ledges.

TRAVERTINE

Most cave mineral decorations are lumped into a single scientific term — speleothems. Probably the most common types of speleothems are the various forms of travertine. Travertine speleothems are calcium carbonate deposited by dripping of flowing water. They include the familiar stalacitites, stalagmites, domes, columns, flowstone, draperies, etc. Jewel Cave does not have large or extensive travertine speleothems compared to those in caves in some regions, but travertine does occur in many localized areas throughout the cave, always located beneath a surface drainage feature, such as a gully or canyon. Solutions of carbonic acid and calcium bicarbonate percolate downward through the limestone and deposit travertine along the way. Most travertine (but not all) consists of thin concentric rings or parallel layers of calcite, which consist of millions of microscopic crystals grown with their long axis at right angles to the layer. In a microscope, the horizontal layer appears to be made up of short vertical fibers. The reason for the deposition of the calcium carbonate may not be precisely the same in all cases. The relative humidity in the cave has been measured many times and in a number of locations. It seems to vary from 81 percent to a maximum of 93 percent in some of the wet areas. Under these conditions, it is possible that a certain amount of evaporation would take place leaving a deposit of calcium carbonate behind.

Evaporation, however, cannot account for all deposition. For example, water dripping from a stalactite at a rapid rate would leave little time for deposit and evaporation under conditions of high humidity. Another occurence which would be hard to explain by the evaporation theory is the deposition of popcorn-shaped deposits forming in the bottom of pools where there can be no evaporation. The probable answer has to do with a reduced ability of water to keep carbon dioxide in solution in the cave atmosphere. The ground water solution probably contains a higher gas pressure than it can maintain when it enters the cave atmosphere. As the carbon dioxide gradually comes out of solution, the solution becomes less acid. This results in the deposition of calcium carbonate in the form of travertine.

The most familiar travertine form is the stalactite. Water seeping from the surface starts dripping from a wall or overhanging surface, and begins to deposit a tube. The water is conducted through the tube, and the tube grows forming a slender "soda straw." "Soda straws" up to 38 inches in length, and only one-fourth inch in diameter have been found in Jewel Cave. Unfortunately, many of these forms near the natural entrance were destroyed by early visitors to the cave.

The solutions may also flow along the outside of the tube. In this case, deposition takes place on the outer sides of the tube as well as at the end, resulting in a concial stalactite.

The opposite of the stalactite is the stalagmite. It grows upward from cave floors or ledges when water dripping from the ceiling or from a stalactite retains some of its carbon dioxide. As the droplet strikes the floor, the gas is given off, and the calcium carbonate is deposited. As water drips again and again in the same place, layers are added; and the stalagmite grows higher. Occasionally a stalactite and stalagmite will grow closer and closer together until they join to form a column.

Another form of travertine commonly found in Jewel Cave is flowstone. This speleothem is formed in much the same way as is described above, except that water flows in sheets over ledges and boulders, depositing successive layers of travertine. The solutions will usually carry impurities in varying degrees, adding color to the otherwise clear-to-white calcite.

Flowstone draperies, a common type flowstone, are found where calcite laden waters move over an overhang. Jan Conn is seen inspecting the flowstone wall.

Most common are the yellow, red, or brown of iron oxides and the blue and black tints of manganese dioxide. When these many colored layers form along a seam in the wall or ceiling of a passage, the flowstone may form as a thin sheet protruding from the surface. This type of travertine is called a "drapery" and occurs in various remote parts of the cave. Often the color bands give it the appearance of a slice of bacon. One such drapery is over twenty feet long, protrudes outward from the wall more than twelve inches, and is approximately one-half inch thick.

One particularly strange travertine form is the polished pebble or cave pearl. Dozens of these are to be found in Jewel Cave, always in areas of dripping water. The pebble nearly always lies in a wet pocket on the floor or top of a boulder. The pocket itself is usually formed by other pebbles which have been cemented in place by travertine dripstone or flowstone. The cave pearl, however, is not cemented in place and is coated on all sides with travertine layers. Some pockets have several of these pebbles, intermingled in such a way that they cannot freely be moved about by dripping water.

It has been theorized that the pebbles are slightly agitated by dripping water, and the coating is applied on the various sides while the pebble is being slightly tipped. At the same time, the tipping keeps the pebble from being cemented. One small problem in this theory is in the fact that the author has observed these pebbles for extended periods of time during times of both heavy and light rates of dripping. On none of these occasions has a drop of water been observed to fall into the pit while other spots (including empty pits) were being repeatedly hit. The water in the pit itself may have come from nearby dripping or flow.

Probably the most significant thing about travertine in Jewel Cave is its relationship to the calcite crystals. It forms directly on top of the crystal, covering the crystal layer. From this we know that the travertine formed after the crystal layer and after the last flooding of the cave.

HELICTITES, GLOBULITES AND ANTHODITES

These three speleothems have two things in common — they are composed of calcium carbonate, and they seem to grow in defiance of gravity.

HELICTITES

Although not rare in caves, helictites are confined to wet areas and, therefore, are localized in a few places in Jewel Cave. Helictites protrude from walls and ledges and grow in every possible direction.

They can probably best be described as resembling mildly deformed pretzels. Although most helictites are small, oc-

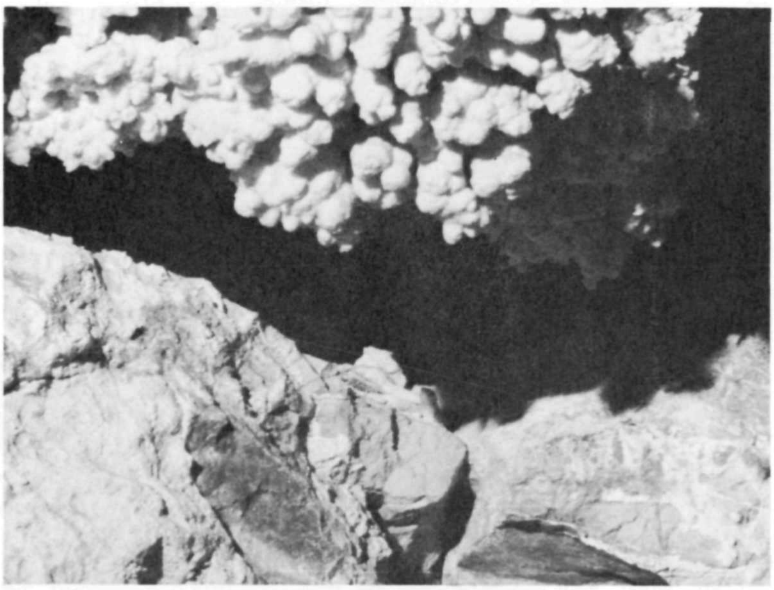
Helictites pictured here are larger than the average (Note film can for scale). This formation always invokes curiosity because it seemingly defies gravity.

casional specimens are as large as an inch in diameter and more than six inches long. A microscopic inspection shows a tiny central canal. Water apparently travels along this canal and deposits a small cap of calcite around the open end. As each succeeding cap is irregularly imposed on the last, a twisting shape develops.

GLOBULITES (Popcorn)

Globulites is the technical term assigned to a very common cave mineral form which resembles popcorn in appearance. The name globulites comes from the fact that the form is made up of small calcium carbonate beads or globes. In other parts of the country, globulites are often called "cave coral," but the local name of "popcorn" seems particularly suitable.

Popcorn in Jewel Cave varies from a thin layered coating to agglomerations several inches high. It usually has a dirty clay-colored appearance like much of the calcite crystal, but some specimens are pure white.



Globulites (commonly called popcorn) are a frequent occurrence in Jewel Cave. Many clusters exceed 7-8 inches in depth.

The formation of popcorn is a subject of controversy. Much of the popcorn in Jewel Cave seems to have "roots" in the contacts between calcite crystals. Water, moving along the common plane between the faces of adjacent crystals, would deposit calcium carbonate when entering the cave atmosphere.

In other areas, there seems to be evidence for a splashing origin, for popcorn is formed directly on top of dripstone surfaces, and water drips from the ceiling are striking the surface today. Above these formations, there are often hanging masses of popcorn which are wet and dripping. The obvious similarity to the stalactite - stalagmite relationship leads the author to believe that these types of popcorn are caused in a seeping-dripping-splashing cycle.

In these environments also are found drip holes. These are vertical holes, an inch or more in diameter, and several inches deep. Popcorn surrounds the hole suggesting that it formed around the splashing cup. There is no evidence that the water dissolved and drilled its way through the popcorn. This brings us to an unusual, perhaps unique and certainly controversial formation in Jewel Cave. In a remote section of the cave were found several tall spires, several inches in diameter and as much as eight or ten feet tall. This general description might fit a stalagmite except for three differences: (1) The spires are coarsely crystalline and not layered, (2) They are covered with a popcorn surface, and (3) They have a large vertical hole in them which varies from a few inches in depth to the full length of the spire. In one case the hole penetrates even the floor and through the ceiling of a passageway beneath. These "logomites," as they have been called, so far defy any completely satisfactory explanation. It seems possible that they were in some manner formed by dripping water, and that a hole was subsequently drilled in them by the dripping water. Another possibility is that they were built up by splashing, but different specimens present serious problems to each theory. It may be that not all logomites have the same origin.

Not all types of popcorn, however, were deposited in the cave atmosphere. In the bottoms of pools of water in the cave, a popcorn-like formation often forms. This probably forms as the calcium carbonate is deposited on the floor and sides of the pool. Undoubtedly, some of this type of popcorn formed during times when the cave was flooded, and some of it is exposed to the air today. The difference between this type, which was subaqueously deposited, and the type which was formed subaerially (that is, in the cave atmosphere) is apparent on close inspection. Subaqueously deposited calcite has a cross section similar to that of travertine. The individual layers are thin and even suggesting that, like travertine, it is made up of very minute crystals. On the other hand, those popcorn formations forming in the air, while still banded, have a very coarse crystalline structure. Individual crystals can be discerned with minor magnification, and the surface is not truly smooth at all.

ANTHODITES (Frostwork)

Anthodites are needle-like crystals usually found in radiating clusters. The clusters may extend outward for distances of three or four inches or only as much as a few centimeters. The crystals may be clear, white, or tan in color and may be coarse as broom straw or finer than human hair. The individual crystals are seldom more than a quarter inch long, but the radiating masses so often resemble the beautiful but

Clusters of calcite—aragonite frostwork. (Note pencil used for scale in upper left-center). Some frostwork reaches depth in excess of 6 inches.

irregular growth of frost on a window pane that anthodites are commonly called frostwork.

Most of the frostwork in Jewel Cave is calcium carbonate, but usually is not calcite. Instead the mineral aragonite makes up the greatest share of the most spectacular frost-work. Aragonite has a different crystal structure than calcite, and tends to form the tiny needle shaped crystals. Aragonite frostwork probably forms similarly to the sub-aerial calcite popcorn; in fact, they are often found intermixed.

GYPSUM

All of the above mentioned mineral forms have been composed of calcium carbonate. This seems logical since they are derived from the limestone which is also composed of calcium carbonate. The limestone, however, does contain other chemical ingredients. Earlier mention has been made of the role of sulphate ions in forming the various types of calcite crystals. Where conditions were right, the sulphate took the place of carbonate, and combined with calcium to form gypsum.

Gypsum has several spectacular but rare forms in the cave. Gypsum flowers look like toothpaste which has been squeezed from a ragged fracture in the tube. Gypsum needles grow upward or outward from red clays in the cave. They are arrow straight, thin as a human hair, and as muc has a foot long. In one remote spot gypsum beards are found. These are massed needles which hang downward and wave slightly in a breeze.

MANGANESE

Often, a mineral form of manganese dioxide, called pyrolusite, will be seen as delicate fern-like markings on the limestone. These are known as "dendrites" for their resemblance to ferns.

Thick layers of a black, soft material resembling clay form the floors of many passages, particularly in the lower levels of the cave. This too is manganese dioxide; a form called "wad." Wad probably had its origin as a result of a concentration of materials dissolved from the limestone. Iron and manganese are found as impurities in limestone and their release into solution would result in oxidation to limonite or wad. Apparently, these impurities were present in sufficient quantities to result in the thick layers of wad found on some of the passageway floors today.

MOONMILK

Moonmilk may be a strange enough name, but when you see the stuff, the name seems appropriate. It is an almost phosphorescent white material with the consistency of very soft cottage cheese. The fact that it so often is seen on deposits of wad is probably significant, but so far remains another mystery. Moonmilk is a magnesium carbonate compound, not uncommon in caves. Perhaps unique to Jewel Cave is a form of it which resembles a silvery bubblegum. These hydremagnesite bubbles are another unexplained feature of Jewel Cave.

Hydromagnesite bubbles (a form of moonmilk). These bubbles have wall thicknesses in the vicinity of 3 to 4 thousandths of an inch and are known only to be found in Jewel Cave.

OTHER MINERALS

Many other minerals color and decorate the cave. The iron oxides, hematite, and limonite stain the walls, crystals and clays with shades of brown, red, orange, and yellow.

Scintillites are tiny quartz crystals covering fins similar to those in boxwork. The sparkling of the crystals give this speleothem its name. The quartz has its source in the chert layers in the limestone.

Breccias are not speleothems, but their multicolored prominence makes them worthy of mention. They consist of broken bits of limestone and chert which have been cemented in a matrix of silica or calcite particles. Perhaps the larger pieces are bits of breakdown, carried into passages and then filling them early in the cave history.

There are many unexplained things in the cave. Theories are made and destroyed by each new discovery. The many minerals and their forms, the bits of evidence for theories, all are too numerous to mention here. After all, who knows what will be found around the next unexplored corner?