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A VISIT TO THE

MAMMOTH CAVE REGION OF KENTUCKY

BY

WILLIS T. LEE, 1864-1926.

[1925]

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ILLUSTRATIONS.

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Courtesy Geo. D. Morrison.

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Photograph by Willis T. Lee.

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Photograph by Willis T. Lee.

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Photograph by Willis T. Lee.

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Photograph by Willis T. Lee.

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Photograph by Willis T. Lee.

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19(c)25 by L.P. Edwards.

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Photograph by Willis T. Lee.

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Photograph by Willis T. Lee.

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for the entrance of sightseers.

A visit to the Mammoth Cave region of Kentucky

by

Willis T. Lee

INTRODUCTION

In the spring of 1925 I found opportunity to spend a month in the vicinity of Mammoth Cave, for the purpose of examining the several caverns of that region chiefly from the scenic standpoint, and of obtaining photographs which might be used in discussing them as attractions for sightseers.

This examination was made at the request of Hon. Maurice H. Thatcher, Member of Congress from Kentucky, under the joint auspices of the United States Geological Survey and a commission consisting of five men appointed by Dr. Hubert Work, Secretary of the Interior. This commission was instructed to examine and report on the merits of certain tracts of land in the southern Appalachian region as possible national parks. Among the places urged as possible parks is an area in western central Kentucky which includes Mammoth Cave.

Mammoth Cave is the best known cavern in America. It has been an object of public interest for more than a century and still holds high rank, although some of the more recently discovered caverns surpass it in beauty and in variety of decorations. Although it has been known by white men only since the latter part of the eighteenth century, it was known in prehistoric time, for the discovery in the Mammoth Cave region of archeological material had much to do, half a century ago, in directing attention to the presence of prehistoric man in America.

Public interest in the cavern may be gauged by its increase in value. According to George D. Morrison, manager of the New Entrance to Mammoth Cave, this cavern and the land about it was once traded for an old flintlock and later was exchanged for a mule. The dates of these early transactions are not known. But in 1797 the cavern was designated as a marker for a section of land and described as a "saltpeter cave." In 1809 a hunter named Houchins (or Hutchins, according to some writers) is said to have entered the cavern in pursuit of a wounded bear. The tale, although doubted by some, seems to have gripped public thought and directed attention to the cavern to such an extent that its discovery by white men has been somewhat generally dated from that event.

In 1811 Mammoth Cave and 200 acres of land about the entrance was purchased for $40. Then came the War of 1812, with America's need for gunpowder and the increase in value of property where the required material could be found. Mammoth Cave seems to have been the most advantageous place for obtaining the nitrogenous material needed. The cavern was rapidly developed as an important source of nitrate, and large quantities of this material were shipped to Philadelphia and other eastern manufacturing centers. The claim has been made that this material saved the Nation when the supply of foreign material for the manufacture of explosives was cut off early in that war. This use of the nitrous material resulted from a somewhat extended endeavor on the part of those interested in developing the resources of Kentucky. The caverns had attracted notice as

a source of nitrate as early as 1797, as shown by its designation as a "saltpeter cave". In 1806 Dr. Samuel Brown is said to have journeyed on horseback 1,000 miles in order to lay before the American Philosophical Society of Philadelphia the facts concerning the occurrence of the nitrate. But it was the need of gunpowder in 1812 which brought Mammoth Cave into such prominent notice that for more than a century it has been the best known cavern in America.

To complete the story of the increase in value of this property, it may be of interest to note that in 1839 it sold for $10,000, and is now valued at many times that amount.

Mammoth Cave has been mentioned so often in school geographies and in magazine articles that practically everyone knows of its subterranean avenues, its blind fishes and blind crickets, its underground streams and its pits and domes. But it is not so generally known that there are other caverns near Mammoth which present scenes that are equally strange and interesting.

The original Mammoth Cave, that is, the part of the cavern which has been exhibited for more than a century, has given name and fame to the region. On entering this region there is commonly little thought of other caverns, and unless the stranger is forewarned he is likely to be bewildered by the number of caverns offered for exhibit and by conflicting claims of superiority. There is Mammoth Cave and Mammoth Onyx Cave and New Entrance to Mammoth Cave, and several which make no mention of the name, Mammoth.

All of the neighboring caves have points of special interest, but so little is known of them that it seems desirable to list them separately and to present photographs of some of their more attractive features. If further excuse of this presentation is necessary it may be found in the just complaint that many a stranger desiring to see Mammoth Cave finds his way unwittingly into one of the neighboring caverns, and may depart without having seen Mammoth Cave at all.

Location of the cavern region

The Mammoth Cave region is situated south of Green River in Edmonson County near the part of Kentucky (see fig. 1) widely known as the bluegrass country. The region may be entered by rail over the Louisville & Nashville Railroad, or by automobile over the Dixie Highway. A branch railroad connects the cavern with the trunk line

Fig. 1. Map of Kentucky showing the location of Mammoth Cave.

at Glasgow Junction. This branch was much used before the introduction of automobiles, but most visitors approach the cavern now by way of Cave City, situated on the Dixie Highway about eight miles from Mammoth Cave.

The caverns

Mammoth Cave. - There is perhaps little excuse for repeating descriptions of the part of Mammoth Cave which has been so long and widely known, except that a visitor to the cavern region of Kentucky who omitted reference to the familiar scenes might seem negligent.

If further excuse for brief mention is needed, it may be found in the fact that Mammoth Cave consists of two parts which are virtually two caverns, as they are under different management and few visitors go through the subterranean passages from one part to the other. The old well known part of the cavern has long enjoyed distinction. The part called New Entrance to Mammoth Cave is less widely known and has been open to visitors only a few years. These two parts are sometimes called "Old Mammoth" and "New Mammoth." In the following pages the term Mammoth Cave refers to the old well known part.

The entrance to Mammoth Cave is in the side of the gorge of Green River, said to be 194 feet above ordinary water level and 118 feet below the tableland. The opening is 50 to 100 feet wide and is improved by a flight of 70 stone steps (see Pl. 1) which leads down over a mass of broken limestone to the gently sloping floor of the cavern. The arched roof of the entrance has a span of about 70 feet and from it a small stream of water leaps 59 feet to the rock-strewn floor, forming in times of flood a picturesque cascade.

At the foot of the steps we pause to get our "cave eyes" and to light the open-flame torches which are still supplied for the use of visitors. Even after one's eyes become accustomed to the murky gloom, much is left to the imagination.

Soon after passing the iron gate which protects the cavern from vandals, we enter a great dome known as the Rotunda whose ceiling arches about 60 feet above the nearly level floor. The Rotunda is a

spacious chamber with unadorned limestone walls; its impressiveness lies in the enormity of the space rather than in any decorations of its walls. One is filled with wonder that so great a solution cavity could be formed.

Leading off from the Rotunda is a large corridor called Audubon Avenue which has been fitted up as a banquet hall with a capacity to serve 500 people at one sitting. Attendance at a banquet served in a cavern far beneath the ground appeals to some as a unique experience.

Prominent among the objects of interest encountered soon after entering the cavern are the old vats where the nitrate was once obtained. Many of the split-log vats have stood undisturbed for more than 100 years, some still being filled with "peter dirt" from which the nitrate was leached by water conducted into the cavern through log pipes.

At the inner end of the line of vats is a spacious chamber known as Booth's Theater (see Pl. 2) where Edwin Booth is said to have charmed an audience by a Shakespearian recital. The resonant qualities of this and many other chambers in the cavern seem somewhat remarkable. the great variety in size and shape of the chambers makes possible the selection of points from which certain tones are echoed and re-echoed with telling effect.

The great vaulted corridors and spacious solution chambers, for which the cavern is famous, reach their climax in such dome-shaped chambers as Chief City whose floor is reported as two acres in extent, above which the arching walls meet in a vault 125 feet high. Mammoth Cave is truly mammoth in its cavernous spaces.

In a few places the chambers are adorned sparingly with ornaments of cave marble. But on the whole the cavern is surprisingly wanting in garnishment. The barren limestone walls seem repellant except where they are sparsely covered with crystalline material. These characteristics are well illustrated in Star Chamber (see Pl.3) whose walls seem cold and repulsive, although the ceiling is adorned with clusters of white crystalline gypsum which cling to a surface coated in some places with black oxide of manganese. By a clever trick of illumination this ceiling is made to resemble the star- spangled sky. The deception, which seems so realistic, is said to have inspired Ralph Waldo Emerson's observations on illusions.

But impressive as are many of the voluminous chambers, the characteristic which inspires most frequent comment is the seemingly endless avenues through which one may wander for hours or even for days. It is said that 150 miles of these subterranean passageways have been explored. This figure has led to an unfortunate misconception of the extent of the cavern. The passageways are winding and there are numerous chambers and tortuous avenues, one above the other. It is said the chambers are on five distinct levels. Although the cavern has never been adequately mapped, it is obvious to any visitor that

the cavernous spaces occur at several different levels, and these enter into consideration in making up the measurement of 150 miles.

When the statement is made that one can travel underground for a distance of 150 miles, the casual listener receives the impression that the cavern is very long. As a matter of fact, the Mammoth Cave property is an irregularly shaped tract of land about 2 miles long and 1½ miles wide. The distance from the mouth of the cavern to the farthest corner of the tract of land measured in a straight line is about 1¾ miles. Some of the avenues extend underground far beyond the limits of the property. But even this extent into naighboring property can not add greatly to the length of the avenues, for the valleys which were formed by the collapse of caverns surround the highland in which Mammoth Cave is situated (see Pl.42). If an avenue extended laterally it would soon emerge from the rocks into a valley. The longest route known in the cavern, that between the old entrance and the new, is little more than 3 miles, as measured in a straight line. The winding subterranean course which one must travel between these two points is considerably longer.

The aggregate length of the subterranean avenues and the honeycombing of the limestone is impressive. It has been estimated that 12,000,000 cubic yards of material have been removed from this cavern.

Although ornaments of crystalline material deposited by water are rare compared with those of other caverns, there are places where the walls are coated with oxide of manganese, salts of several kinds, and crystals, especially of calcium carbonate (calcite) and gypsum. In a very few places cave marble has formed sparingly. The incrustations of mineral matter make curious ornamental effects. In one avenue, the ceiling is incrusted in such a manner that when properly illuminated it has the appearance of a clouded sky. In another, the ceiling is adorned with clusters of light crystalline material, chiefly gypsum, so arranged as to suggest snowballs. (See Pl.5).

The illusions of Mammoth Cave probably find their most striking example in the feature exhibited under the name of Martha Washington's Statue. (See Pl.6). The observer who would see the "statue" must stand in a certain place, carefully marked off by the guide, and extinguish his light. The guide then goes to a distant part of the tortuous avenue and illuminates it in such a way that a brilliantly lighted wall is seen through the passageway. The "statue" is the part of the lighted space not cut off by the intervening walls.

The most familiar sight in Mammoth Cave, as in most caverns of this region, are the blocks of rock fallen from the ceiling. These lie singly in some places and in great irregular heaps in other places. In fact, there are few places where the fall of roof material is not in evidence. In some of the voluminous chambers where rocks of considerable thickness have broken down, the fragments lie on the floor in great conical heaps.

The blocks of rock on the cavern floor appear as though they had only recently fallen from the roof. In few places they are cemented together with travertine, but most of them appear as fresh as if the fall had taken place only yesterday. This appearance is another of the illusions of the cavern, for on some of the rocks which appear to have fallen recently articles of wearing apparel and rude implements have been found where they were placed by the people of some prehistoric race which had vanished before the days of Daniel Boone.

The fall of ceiling rocks exposes to view solution phenomena which illustrate in a small way the formation of the large avenues. Water finding its way through crevices dissolves the limestone, forming channels which in some places are so close together that the rock resembles a honeycomb. In many places where this condition has developed above a layer of shale or other impervious material, and this layer has later broken down, the solution cavities are exposed to view in the ceiling. (See Pl.7).

This photograph also illustrates the disfigurement which is painfully in evidence at every turn. Tens of thousands of names and dates "decorate" the cavern walls; there is scarcely a smooth face of rock within the cavern that is not marred by names scratched upon it. In a few places initials of adventurous explorers and dates of their discoveries give valuable historic information; but a name and date which proves that a certain place was visited a hundred years ago is

not sufficient excuse for making unsightly all wall space within reach of the name-scratcher. To many people the interest in Mammoth Cave has been materially lessened by this practice. Many an object, which otherwise would be attractive, is made unsightly, and the visitor turns from it in disgust to some less interesting but less abused object.

The most impressive parts of Mammoth Cave are its 70 or more pits or domes, the largest of which is the well known Mammoth Dome. This pit is compound, and is formed of several pits close together with partitions broken down to such an extent that a chamber of irregular outline is formed, which is about 400 feet long, 150 feet in maximum width, and 150 feet high. The principal part of the dome contains six great pillars 25 feet in diameter and 80 feet high. H. C. Hovey, who visited them in 1878, named that part of the dome which contains the pillars, the Egyptian Temple, because it reminded him of the ruins of Luxor and Karnak.

Mammoth Dome is too large and complicated to be photographed successfully but does not differ essentially, except in size, from the smaller pits, such as Side Saddle Pit (Pl.8), Vaughan's Dome in Colossal Cavern, and Hovey's Cathedral Dome in the New Entrance to Mammoth Cave. (See Pls. 20 and 11).

Before the present entrance to the lower part of Mammoth Dome was found it could be viewed only from above. The strange unearthly appearance of such a subterranean cavity may be easily imagined, and one can scarcely be censured for doubting accounts concerning it until

its form and full magnitude was exposed to view. In his description of the "Mammoth Cave of Kentucky" (1912, p.100), Hovey states that, for a reward of two dollars, a young colored boy named Dave "volunteered to be let down, as a sort of animated plummet, to sound the depth of the pit. The story he told on being drawn up again was so wonderful that nobody believed him." His reward beside the two dollars "was the reputation of being either crazy or the champion liar of Kentucky." Dave's experience in this respect does not differ in kind from that of other explorers of caverns. I have found it difficult to convey any adequate impression of the unearthly realities of the subterranean chambers to those who are not personally familiar with them.

The pits or domes are well-like openings which extend vertically downward through the several layers of rock. Where the limestone is homogeneous the walls are scored as if carved by a machine for making molding. Where rock of irregular hardness occurs the walls are uneven and the horizontal stratification of rocks is emphasized, as illustrated in the lower part of Side Saddle Pit (Pl.8).

The so-called rivers in Mammoth Cave seem to have a special fascination for many people. Every visitor wants to see the rivers that flow 360 feet beneath the surface and the blind fishes that live in them. Two of these streams, the River Styx and Echo River, are shown to visitors. But strangely fascinating as they may be, they are not beautiful. When Green River, into which they flow, is in flood, the muddy back water fills this part of the cavern and deposits silt which remains "gooey" for a long time. The fascination seems to be

due in some measure, at least, to repulsive ugliness. A strange weirdness hovers about the scene. It is not ordinary.

These rivers are far underground, where no ray of natural light ever penetrates. The fishes in their waters have lived in darkness for so many generations that they have become sightless. Blind crickets are seen making their way about the walls with the help of long sensitive antennae, like blind men feeling their way with canes. There are blind crawfishes, mollusks, beetles, and spiders. In some places where visitors are not too numerous, bats may be seen hanging to the walls and ceiling. These little cave dwellers spend the night on the wing and the day in the dark security of the cavern, where they hang head downward until disturbed. In places where they are not often molested, they seem to have little fear and may be examined at close range.

A boat ride on Echo River, shown in Plate 5-B, is one of the prized experiences of the trip underground. During low water in Green River a boat can be floated along Echo River for a distance of a few hundred feet. The passageway is low and is confined between walls of solid limestone which give back certain tones in repeated echoes. Such echoes in a dry corridor are common enough; but here amid the unearthly surrounding they are regarded as very wonderful.

On this boat ride the timid cower and remain quiet. The venturesome enjoy themselves by rocking the boat - and sometimes tipping it over - and those who are poetically inclined are fond of recalling the familiar lines of Coleridge,

"Where Alph, the sacred river ran,
Through caverns measureless to man
Down to a sunless sea."

Echo River is said to be 20 to 200 feet wide, 10 to 40 feet deep, and three-quarters of a mile long. It flows through a symmetrically arched corridor 10 to 35 feet high during low water. But when Green River is in flood, and rises, as it sometimes does, 60 feet, back water enters through the opening shown in Plate 8-A. At such times this arched hallway is completely filled with water. It is said to be impassable for about seven months of each year.

There are other underground streams of which little is known. This is largely because of the danger of being caught by a rise of water which makes the exploration of the river avenues unpopular. According to Hovey, a large underground river described by Doctor Davidson as "stretching away in midnight blackness, a horrid pool of water" was explored in 1863 by F.J. Stevenson, who floated on it for seven hours, "a perilous voyage never repeated." The dams on Green River are said to have raised the water level in the cavern to such an extent as to make it impossible to revisit "Stevenson's Lost River."

Many other features of Mammoth Cave are worthy of notice and would naturally be mentioned in a complete account of the cavern. But Mammoth Cave is only one of many caverns in this region. Some of these are large, others small as compared with Mammoth. Some of them are well cared for, others are neglected. Some, once open to visitors, have been abandoned.

New Entrance to Mammoth Cave

No complete map of the caverns of the Mammoth Cave region has ever been made. Many parts of the caverns have been sketched and a few parts have been carefully surveyed, but the true length of the underground passageways and the correct geographic position of many of the points of interest are only approximately known.

George D. Morrison states that in 1916 he visited Mammoth Cave, traversed all its routes, ascertained that some of the avenues continue beyond the points where the guides usually turned back, and became convinced that the passageways extend beyond the limits of the Mammoth Cave property. He conceived the idea that a new entrance might reveal interesting parts beyond convenient reach from the old entrance, and at the same time render more easily accessible some of the desirable places which were reached from the old entrance with great difficulty. Mr. Morrison, who had been a well driller earlier in life, secured title to some of the land adjoining the Mammoth Cave estate and prospected it for the underground caverns with a drill.

Having found a cavity, it was necessary to find a way into it and to ascertain its nature and connection. On inquiry he learned that years before his appearance in the region children had selected a point for play in a certain ravine, because on hot days a cool breeze issued from a hole in the rocks. The children's observations were verified and excavations made following the crevices from which the air currents issued. After much search an opening was found into which a man was lowered on a rope. He reported that footprints were seen in

this opening and later found on the rock wall the name of one of the Mammoth Cave guides. Then followed a survey of the passageways to ascertain the best place for a new entrance. The most favorable place proved to be beyond the boundaries of the newly acquired property. In 1921 the adjoining property was purchased and search continued, which resulted in opening the passageway now used by visitors to New Entrance. It leads into a pit called Roosevelt Dome which has been improved by building stairs and by enlarging narrow places.

The New Entrance to Mammoth Cave is about 3¼ miles in a straight line from the Old Entrance, and about 1¾ miles from the boundary of the Mammoth Cave property. The two parts of the cavern, or the two caverns as one chooses to consider them, are of nearly the same extent.

The New Entrance has many notable passageways, many tortuous corridors, and many curious freaks of nature. Soon after entering the main avenue, one finds a voluminous chamber 250 feet long, 150 feet wide, and 85 feet high, which compares favorably in size and scenic qualities with the famous chambers in old Mammoth. The corridors and chambers of New Entrance are wanting in the historic interest that attaches to those in the older part of the cavern. But they are also wanting in the disfiguration that mars many of the scenes along the older routes. The scenes in New Entrance are carefully guarded, and name-scratching has thus far been prevented.

Proceeding along the main corridor, we pass a succession of the usual scenes, all of them interesting to one seeing them for the first time. About half a mile from the opening we reach "Grand Canyon", a part of the main cavern where the floor gives way to precipitous slopes of loose broken rocks which extend down to water level,- presumably the level of Green River. Before a board walk was constructed along one wall this pit offered difficult and dangerous climbing and is said to have limited exploration from the Old Entrance.

Half a mile farther on we come to Alice's Grotto (see Pl. 10), a point of historic interest, as it is reported to be the farthest point shown to visitors entering the cavern at the Old Entrance. However, few visitors to Old Mammoth reached this point, for Alice's Grotto was on the long difficult journey, called the River Route, which necessitated crossing Echo River, a feat possible only at time of low water. Morrison's partial survey of the cavern fixed the location of this grotto about a mile beyond the limits of the Mammoth Cave property, and this part of the cavern is no longer visited from the Old Entrance.

The bower at Alice's Grotto has a decrepit look, as if it was in need of repair. This appearance may be due in some measure to vandalism, but aside from loss of the more delicate parts, the whole mass is composed of relatively old travertine on which deposition ceased here long ago and the material appears "dead".

Beyond Alice's Grotto the avenue forks. The passage which we traversed leaves the route that would take us into Mammoth Cave proper, and turns toward the group of pits which Hovey explored and named Hovey's Cathedral Domes. Some writers have shortened this name to Cathedral Domes, others call the group Hovey's Cathedral.

As this group of pits forms one of the attractive show places in the cavern region, we may stop a moment to examine them. Also, as there are some who deny that there is connection between Old Mammoth Cave and the part called New Entrance, it may be of interest to quote Hovey's description of his visit to the Cathedral Domes. This authority on Mammoth Cave, visiting the domes in 1907, or 14 years before the New Entrance was opened, naturally approached them from the Old Entrance. In his account published in 1912 (p.71) he says:

> "The River Route, * * * often styled 'the Long Route', extends to Hovey's Cathedral. * * * It is certainly 'long' as compared with the other routes; * * * Prof. H.A. Newton, of Yale University, Dr. A.E. Foot, of Philadelphia, together with the senior author of this Manual [H.C. Hovey] made an approximate measurement of the distance from the mouth of the cave to the end of the route."

Then follows a description of the points of interest on the long "river route", and finally, on page 97, appear the following paragraphs.

> "Let me anew express my personal obligation to the Mammoth Cave management for having marked their appreciation of my long-continued and enthusiastic interest in their wonderful cavern by naming, with the approval of the discoverer, and the guides, this remarkable group of domes, 'Hovey's Cathedral'.

"There is no way out other than that by which we have come in. Hence we retrace our steps through Martel and Boon Avenues, pause to refresh ourselves at Hebe's Spring, traverse El Ghor, Silliman's Avenue, cross Echo River again by boat, and the River Styx by the natural bridge."

This description leaves no room for doubt that Hovey's Cathedral was once regarded as a part of Mammoth Cave, and Hovey found that the underground path leading to it is more than 5 miles long. (He estimated the distance from the old entrance at 9,200 yards.) As measured in a straight line, the distance is about 2¼ miles. When the partial survey of the cavern proved that this group of domes lies beyond the limits of the Mammoth Cave property, this part of the long route was abandoned and Hovey's Cathedral was no longer shown regularly to visitors entering at the old opening but was regularly exhibited from the New Entrance.

Hovey's Cathedral consists of five great pits, "the five monarchs of the Cathedral Domes," so closely connected that they may be regarded as parts of a single structure. The largest is said to be 60 feet across and 175 feet high. One account gives the height as 200 feet. The inner one (see Pl. 11) is a clean, freshly formed solution pit down the side of which water continually flows. During storms the stream increases in volume, and certain mud banks on the floor indicate that water in the pit is sometimes many feet deep.

The clean walls exhibit beautifully the bedded character of the rock. The layers of slightly different composition stand out distinctly because of differences in solubility. The layers of homogeneous limestone are fluted vertically (see Pl. 12) whereas those of a shaly composition appear in the walls as horizontal bands.

One of the attractions on the long loop trip on which we visit Hovey's Cathedral is The Narrows, or Becky's Alley, named for a lady of venturesome tendency, who several years ago succeeded in making her way through this very narrow slitlike passage. The most difficult places have since been widened and the sharp points of rock broken away so that anyone not too portly for the five-mile walk can now make his way through the passage without an unreasonable amount of contortion. This narrow slit in the rocks, that in some places is only 18 inches wide, although it is 60 to 80 feet high, makes possible an underground route by which the visitor to New Entrance may travel more than 3 miles, as measured on the map, but probably nearer 6 miles if measured along the sinuous trail, without retracing his steps.

The route from Becky's Alley to the exit leads through chambers noted for their incrustations and flower-like masses of crystalline gypsum. White crystals and incrustations of gypsum are conspicuous in many parts of this cavern, as they are also in nearly all of the caverns of the region that I visited. The most conspicuous exhibits that I found are those of the New Entrance. Here the gypsum seems to form with unusual rapidity and in crusts which scale off and fall when they become thick and heavy. The individual crystals are

varied in form and arranged in flower-like clusters. Such masses as those illustrated in Plate 33, from Great Onyx Cave, are common. But in a few places very ornate clusters are found, such as The Tiger Lily (see Pl. 13) in which some of the delicate petals reach a length of six inches.

Near the end of the circuit, when we have returned nearly to the starting point, a group of decorated chambers is entered which contain many of the most astonishing scenes of the New Entrance. Many regard these chambers as the most spectacular of the Mammoth Cave region of Kentucky. The decorations consist of large masses of onyx marble of varied design, ranging from the most delicate stalactites to massive fluted pillars and great sheets of onyx, called flowstone because they resemble flowing water. Pyramids and mounds, pillars and sheets, daggers and spears are there in profusion. Balconies, grottoes, niches, and recesses are numerous, all built of cave marble and decorated in lavish profusion.

The entrance to these chambers is a passageway completely lined above and below and on all sides with cave marble (see Pl. 14), arranged in a great variety of decorative designs. Fancy nooks and playhouses (see Pl. 15) appear on all sides and the walls are covered with flowstone where carbonate-bearing waters enter from ceiling and walls and deposit their burden of mineral matter in forms resembling ice. Many of these suggest fringed tapestry (see Pl. 16) and others frozen cascades.

In the middle of the Onyx Chambers a stream of water pours from a small hole in the ceiling. Ordinarily this stream is small. But in time of storm a torrent descends in such force as to render the trail uncomfortable, and we clamber over the rocks at one side to avoid the spray. The water is used for drinking purposes and analysis of a sample (see No.1, p.____) shows that it is the ordinary calcium carbonate-bearing water, commonly known as hard water, which deposits its load of dissolved mineral matter as travertine or cave marble where conditions of deposition are favorable.

The culminating glory of the Onyx Chambers and of the whole cavern region is the mass of flowstone called Frozen Niagara. (See Pl.17). This great mass of onyx marble is built out solidly in an overhanging canopy, may feet thick, gracefully draped, and ending downward in a huge fringe. This lower part or fringe consists of long slender columns, which some prefer to compare with the pipes of an organ.

The Frozen Niagara is built out in such a way as to form a large grotto beneath it. The inner walls of this alcove are so gorgeously decorated that it has been called "King Tut's Tomb." The walls and floor are composed of masses of flowstone (see Pl. 18) and the ceiling holds stalactites in groups of down-pointing daggers and curtains of thin translucent onyx, which resemble portieres draped in graceful loops and folds.

Some of the fountain basins in these chambers are delicate and attractive (see Pl.19) and at one point a small pit has been formed which opens downward through the floor to a stream which has been named

Crystal River. This stream had been discovered only a short time before my visit. It has since that time been explored and a boat provided for visitors who desire a river trip.

Colossal Cavern

Colossal Cavern is a large ramifying cavity about a mile and a half east of Mammoth Cave. It contains a variety of attractive features and seems worthy of more attention than it has yet received. It is open to visitors and has been so extensively improved that a visit to it is easily made, but it has not been extensively advertised and exploited, and consequently has been seen by only a few who have visited this region.

Unlike most of the other caverns in this region, Colossal Cavern has been carefully surveyed. The map published by Hovey is reproduced as figure___. The surveys for this map were made from

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Fig.___ Map of Colossal Cavern (after Hovey).

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an old entrance no longer used and they indicated that a more desirable entrance could be found. This was located and a new entrance made which has since been in use.

As this cavern has been described by Hovey in the Scientific American Supplement (Nov. 21, 1903), in the Encyclopedia Britannica, and elsewhere, it is perhaps sufficient here to illustrate only those features which I shall refer to later in this paper.

Soon after entering the cavern we paused at a drinking fountain where a little stream entering by a crevice in the rock has dissolved out some of the limestone, forming a niche in the canyon wall. (See Pl.20). Here a sample of water was collected for the analysis given as No.2 on page . The soluble action of cavern water is beautifully illustrated here, both by the niche and by the curious solution phenomenon compared in this paper (p.) to shagreen leather. These surfaces appear on the under side of the layers of limestone.

In a similar niche in the opposite wall of the cavern known as Lizard Spring several of the silicious concretions which are found in many places in the limestone have been exposed by the solution of the rock from around them, the limestone or calcium carbonate being more soluble than the silica of the concretion. In many places fossil shells which have been replaced by silica stand out in bas-relief on the walls where the limestone has been dissolved away. Several groups of the coral Zaphrentes were noted, and also of the branching coral Tubipora.

At another locality called Horseshoe Dome, a stream of water entering from a domelike cavity in the ceiling falls sheer through the main avenue of the cavern into a cavity in the floor. During times of storm, when this stream carries a large volume of water, the sight is somewhat awesome. The water comes from somewhere and goes somewhere, but who knows where! The poets are fond of likening the stream at Horseshoe Dome to life. It is here. It is vigorous; it is hurrying

swiftly from some unknown to some other unknown. Some who are less poetically inclined, and who are impressed with the diabolical appearance of the hole into which the water disappears, recall Vergil's line: "Facilis descensus Averni", or easy is the descent to Avernus.

At one side of the main avenue we entered one of the most beautifully perfect solution pits seen in the Mammoth Cave region. This pit, or dome, was discovered in 1898 by Edgar Vaughan and named in his honor. Vaughan's Dome (see Pl. 21) is 26 to 40 feet wide, 300 feet long, and 78 feet high. The height, according to Hovey, was obtained by sending up balloons inflated with hot air.

The well constructed trail in the main avenue of Colossal Cavern passes many interesting nooks which deserve much more attention than can here be given to them. Plate 22 may be taken as illustrative of the general character of this avenue. Like most of the caverns in this region, the avenue is one formed chiefly by solution and by the fall of rocks, and is but slightly adorned by cave marble. The tendency of the rocks of the ceiling to break down is illustrated in the middle of the photograph where a huge block of limestone has fallen from the ceiling. These falls, however, are of rare occurrence, humanly speaking. In the lower right hand corner is a block of rock which looks as if it may have fallen only yesterday. Comparison of the photograph published in 1912, in Hovey's "Mammoth Cave of Kentucky," opposite page 130, shows that this rock which Hovey calls Everett Rock has not moved for fifteen years. How much longer it has reclined in its unstable situation is not known.

But not all parts of Colossal Cavern are wanting in onyx decorations. Like other caverns of this region, it has its onyx chambers. A number of such chambers are situated near the inner extremity of the cavern along the "Pearly Pool Route," shown on the map (fig. 1, p.___). These chambers contain the usual collection of stalactites, stalagmites, and wall drapery. In one of them a ceiling decoration of somewhat unusual character was noted (see Pl.23) where water carrying calcium carbonate in solution has entered the cavern through a crevice and deposited some of its mineral matter in an irregular sheet hanging like drapery from the ceiling. Other parts of its load were left below, where a corresponding ridge of onyx was built on the floor. Hovey notes finding cave pearls in Pearly Pool. I found none. Possibly these delicate and somewhat rare cave "jewels" have all been appropriated by the vandals since Hovey's time.

To many observers, Colossal Dome (see Pl.24) is the point of greatest interest in Colossal Cavern. It is an immense solution pit whose bottom, according to the statement of the guide, is close to river level, 240 feet below the entrance. It is a pit with nearly level floor 50 feet or more across, which was only half covered with shallow water at the time of my visit. A wire has been attached above in such a way that a lantern may be hoisted, revealing the marvels in the upper part of this great dome. The cavernous space must extend upward nearly to the land surface above.

The pit is formed at right angles to the bedding of the rocks and the walls appear fresh and clean. Relatively few people have visited this dome, and these few have not been encouraged to mar the clean rock faces by scratching names and dates.

Several solution features are well exhibited in the walls of Colossal Dome. The edges of the limestone layers are fluted vertically and their under surface, where exposed, exhibits the shagreen character described beyond on page____. Some of the softer shaly material is worn away, leaving narrow shelves on the underlying harder layers. Banks of silt at the bottom of the dome indicate free connection with the surface and suggest the proximity of a surface sink which gathers the rain water and guides it into some underground channel which opens into the dome.

An evidence of few visitors to Colossal Cavern is found in the presence of great numbers of bats. In caverns that are visited daily the bats are disturbed so frequently that many of them leave their old haunts. Thus far they have not been driven from Colossal Cavern. These little night-fliers spend the day hanging head downward with tiny claws hooked into some crevice or over a projecting bit of rock. They seem little concerned about callers and most of them when disturbed merely show their teeth in a threatening manner and scold the unwelcome intruder who disturbs their slumber. But some loosen their hold when approached and flit away in the darkness to some more secluded part of the cavern. Many of the bats were examined at close range near the main trail in a passage called Bat Hall. (See Pl.25).

Salt Cave

Salt Cave takes its name from the accumulations of chemical substances of several kinds found in it which are known by the common name "salts." The cave is relatively dry and the little water seeping into it evaporates, leaving its load of dissolved mineral matter in some places as incrustations and in others as fine powder. The cavern opens on the property of the Blue Grass Country Club, about two miles northeast of Mammoth Cave, and underlies the golf links of this club.

Salt Cave is one of the larger caverns of this region, and was among the first to be explored. It was here that Prof. F.W.Putnam, fifty years or more ago (1870-1875) secured much of the material which is said to have turned the current of his work into archeological channels and gave a great impetus to the search for evidence of ancient man in America. According to N.C. Nelson of the American Museum of Natural History (1917, p. 233), it is not far from the truth to say that the material secured by Professor Putnam in the Mammoth Cave region made him the "father of American archeology." To anyone visiting Salt Cave it is evident that neither Professor Putnam nor later collectors exhausted the possibilities of this cavern as a collecting ground. Fragments of ancient reed matting and cloth, some of which is woven from the inner bark of trees, and some from wild hemp, and reed torches partly burned, may still be found.

The main avenue in Salt Cave impressed me as unusually spacious, even for the Mammoth Cave region (see Pl. 26), and as indicating an unusually old cavern. It is a "ruined" cavern, long ago

abandoned by the subterranean stream which formed it, and is partly filled with great heaps of fragmental rock fallen from the ceiling. The journey through it is a constant struggle over heaps of loose rocks which are likely to be so delicately balanced as to be displaced by the pressure of one's foot.

The main cavern may be regarded as one in which the roof would have collapsed had it not been for a cap of sandstone. This insoluble rock has prevented it from having long ago been transformed into a series of sink holes similar to those of the collapsed caverns on all sides of it.

At one place in Salt Cave channels in the limestone were noted in the under part of a rock projecting from a wall, where they could be examined at close range. The limestone layer in which the channel was shown in Plate 27 was formed by solution is underlain, where the rocks are not disturbed, by a thin bed of impervious shale. The water working downward through the crevices of the rock seems to have met with difficulty at the shale layer and made its way laterally in a circuitous route for some unknown distance before finding a way through the shale. Later when the rocks in the main cavern broke down they parted along the layer of shale, leaving the channeled limestone jutting out from the wall. This may be regarded as an inverted stream channel. The observer may imagine himself looking at it directly upward as if the channel were in the ceiling of a chamber.

Great Onyx Cave

Great Onyx Cave opens in the south bluff of Green River about three miles northeast of Mammoth Cave. It is one of the newly developed caverns of this region, dating from 1915. (See Pl.28). It is well cared for and contains many of the usual characteristics of limestone caverns. It is relatively small and there are no unusually difficult or dangerous passageways. The decorations are delicate and pleasing and some of them are remarkably well developed.

The part of Great Onyx Cave which seems to be most highly prized by visitors lies close to the entrance. The visitor enters at once into a small chamber filled with decorations of onyx marble of varied design. (See Pl.29). Many of these are fragile and are carefully protected from careless hands. Others are massive and need no protection.

A few minutes walk from the entrance brought us to the second point of special interest, called the Hanging Garden (see Pl.30) where a great variety of stalactites hang from the ceiling. These range all the way from slender, nearly transparent pipes the size of a lead pencil to masses of solid cave marble many feet in diameter. At one side of the cavern the trail mounts the wall almost to the ceiling so that the delicate pendants can be examined at close range.

In several places in Great Onyx Cave a curious solution phenomenon was noted. The bottom side of the layers of limestone, which are kept continually wet, are etched into a series of points and hollows which give the surface an appearance somewhat similar to

that of shagreen leather. (See Pl.31). The amount of relief - that is, the distance of the point from the general surface - is less than half an inch.

This etched surface may be represented by the cross section, figure 3. In some places the surface is merely damp and few suspended

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Fig. 3. Profile section of limestone showing "shagreen" surface on the underside, where water gathers slowly and drips from the points.

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drops of water are found. But in many places drops of water gather on the points of rock, as shown in the figure. The hollows between the points may contain material of slightly greater solubility than that of the points, or the difference may be due to some chemical action. It seems probable that the phenomenon is directly dependent on the quantity of carbonic acid gas contained in the water. As the ability of water to dissolve calcium carbonate depends on the contained gas, water with much carbonic acid gas in solution will dissolve the limestone readily, whereas water from which the gas has been exhausted will have no soluble effect.

It is conceivable that in places where the quantity of water is limited and where it is distributed in a thin film, as it is on the shagreen surfaces, that the carbonic acid gas is exhausted before the water gathers in drops on the points of rock. If this is true, the soluble action is confined to the hollows, and the points are protected by the drops of the water which has lost its power of solution.

The explanation finds support in the character of the water as shown by the analyses given on page____, from which it may be inferred that its power of solution is unusually low.

The gypsum crystals in Great Onyx Cave are perhaps worthy of special note, although similar crystal masses are to be found in all of the caverns of the region. In some places the curved masses of crystals stand out like tangled vegetation (see Pl.32) and in other places they occur in groups which so closely resemble flowers that the observer may readily believe that the ceiling is completely covered with delicate lily-white petals. (See Pl.33).

Another crystal form taken by the gypsum is not so common but may be seen in favorable places where groups of fine needle-like crystals made up of thousands of slender filaments appear like tufts of hair, or fine wool. These crystals are as slender and as sharp as needles, which suggest the comparison.

Crystal Cave

Crystal Cave opens in the bluff overlooking Green River at a point about a mile from the Great Onyx Cave and three miles from Mammoth Cave. It ~~is a relatively small cavern and~~ has only recently been opened to visitors. It received much publicity in 1925 when its owner, Floyd Collins, lost his life in an attempt to explore a neighboring cavern.

Crystal Cave opens at the top of the limestone about 250 feet above Green River and in some parts of it the ceiling is formed by the overlying sandstone. Within the cavern we descended to levels considerably lower than the opening. One of the points of interest is known as Grand Canyon Avenue (see Pl.34), a solution channel about 75 feet wide and 100 feet or more in height. This canyon-like slit, cut in the limestone by some stream which has long since vanished, is a splendid example of the narrow winding passageways formed by many of the underground streams of this region.

Some of the wall decorations in Crystal Cave are curious and interesting. In one chamber several groups of small delicate stalactites and helictites are exhibited, (see Pl.35) and in others the dark limestone walls are incrusted with thin layers of white, finely crystalline calcite in a manner which suggests decorative designs. (See Pl. 36). The incrusting material seems to be derived from mineral-bearing water, slowly oozing from crevices or from porous places in the rock. As the water evaporates, its mineral matter is left as a coating on the wall.

Crystal Cave is used, as are many of the others of the Mammoth Cave region, for cold storage. The even temperature of about 54° F. at all times, winter and summer, renders it useful as a place for storing provisions. Supplies of canned fruit and vegetables were observed near the opening in several of the caverns.

Small caverns

There are several small caverns near Mammoth Cave which would be worthy of special mention in an exhaustive description of the cavern region. Some of these have been widely known as show places in the past but are now neglected. Others have been opened recently, and still others are almost unknown and remain unexplored and neglected. Hovey states that 4,000 caverns have been reported in Edmonson County alone.

In the first class, or the neglected caverns, may be mentioned White's Cave, a small cavity in the hillside on the Mammoth Cave estate which was once exploited because of its ornate decorations of cave marble. Little attention is now given to it. I found its gate open and was informed that long ago it had been robbed of its more delicate ornaments. But the curio hunter and the specimen vendor have not been able to carry away the massive pillars of onyx and the still more massive accumulations of flowstone.

As Mammoth Cave is almost wanting in material for specimens that may be carried away as souvenirs, the vendors are said to visit the smaller caverns regularly, and to carry the specimens obtained from them into Mammoth Cave and out again, in order that they may be able to assure the purchasers that the specimens <u>came out</u> of Mammoth Cave.

Another neglected cavern which was popular many years ago is known as Proctor's Cave and opens not far from the entrance to Mammoth Cave. It is said that this cavern was discovered in 1863 by a "pure-blooded American citizen of African descent," Jonathan Doyle

by name. As the story runs, Doyle had deserted his master to join the Union Army, but as the line of battle approached he began to realize his error and to long for his "old Kentucky home." When the thunder of artillery was heard he was fully convinced that it was his duty to return and seek forgiveness - and support. As he approached his former home, he began to have misgivings as to the character of his reception, and turned aside into the forest to debate the situation with himself. As he sat concealed among the rocks in a secluded nook he noticed a current of cool air coming from a crevice. Having grown up in this cave region, he knew that a cavern must be near at hand. He cleared away the loose rocks and entered what is now known as Proctor's Cave.

History is silent as to the satisfaction felt by Jonathan in having a safe underground retreat during war time, but it does inform us that he guided visitors through this cavern for many years.

Several small caverns have been opened near Glasgow Junction. The Diamond Cavern, 1½ miles from the Junction and 5½ miles from Mammoth Cave, has been improved in many ways and is electrically lighted. This cavern is well decorated with onyx ornaments.

Another newly-opened cavern near Glasgow Junction is owned by Mr. Higginbottom. It had not been named at the time of my visit. Like the Diamond Cavern, it is small but beautifully decorated. A new type of decoration was noted here. (See Pl.38). The limestone of the wall rock is dissolved in such a manner that the surface is

covered with curiously shaped protuberances. Some of these are remnants left by solution of the surrounding rock, and some partly or wholly due to the deposition of hard material.

There seems to be an unusual tendency in this cavern toward lateral growth of the cave marble. Helictites are common, as are also the spongy forms ordinarily described as coralline. They do not compare in magnitude with those of western caverns where these forms excel. But they are well worth notice. With these curious forms are the ordinary fluted pillars and masses of flowstone which are to be expected in all limestone caverns.

Horse Cave and Mammoth Onyx Cave

Another cavern which seems worthy of mention as a member of the Mammoth Cave group, although situated several miles from Mammoth Cave, is located at Horse Cave, Ky. It is on the Dixie Highway and most visitors to this region hear about Horse Cave.

The opening to Horse, known to some as Hidden River Cave, is situated in the middle of the town of Horse Cave, close to the railroad station. This opening has been known since 1794 when, according to tradition, a band of horse thieves used it as a place for hiding their captured stock. Hence the name, Horse Cave.

Parts of this cavern have been exhibited from time to time and some of its long avenues have been partly explored. Tales are told of the length of some of the avenues and of the size of some of the chambers, which seem so exaggerated that I hesitate to repeat them.

One explorer is said to have traveled for 22 hours without reaching any serious obstruction and turned back only when his supply of oil for lights was likely to fail. The mouth of the cavern is about 9 miles from Green River, yet the back water is said to appear at Horse Cave, only 96 hours after a rise in this river. It is said that the hidden river is 7 to 40 feet deep and 400 feet wide, and the owner of the cavern has contemplated the introduction of gasoline launches. If on adequate investigation the reported size is confirmed, it would seem that Horse Cave deserves serious consideration as a show place.

At the time of my visit only the entrance of this cavern could be seen without the use of a boat. This entrance is an enormous cavity opening from a great sink hole having vertical or steeply inclined walls. The rocky side of the sink is lined with great shade trees and its level floor far below the general surface of the ground, on which the town is built, is utilized as a tennis court. The water seeping from the rock walls into the cool sink makes a favorable place for the growth of ferns and vines, which decorate the walls in graceful clusters and festoons. This cool sunken garden is prized as a pleasant resort on hot summer days.

The owner of Horse Cave has opened a small but highly decorative cavern called Mammoth Onyx Cave, two miles north of the town. It is electrically lighted and so improved that a visit to it is made easily and comfortably, as it is situated on the Dixie

Highway where it attracts the notice of every passerby. The entrance is an artificial one and leads directly into a number of small but highly adorned chambers. Stalactites, stalagmites, and tapestry-like wall decorations are varied in form and of entertaining design. The ordinary forms of cave marble found in most limestone caverns are on exhibition.

One form assumed by this marble is sufficiently rare to warrant illustration. It is developed here in greater perfection than I have seen elsewhere in the Mammoth Cave region. (See Pl.41). It consists of decorations resembling grapes, as if numerous clusters were partly buried in the material of the wall.

Characteristics of the caverns. - The general features of the Mammoth Cave region have been known for many years. But there are several features which have not been emphasized, and some principles involved in the formation of the caverns which seem to invite consideration.

Fig. 4. Sketch section illustrating the process of cavern formations as described on p.____.

Character of water. - The water in the caverns of this group is derived almost entirely from rainfall on the surface immediately above the cavities. As the caverns are under tablelands of very limited extent, as shown by the map (see Pl.42), the water, at least that in the upper chambers, can come only from rain falling on these

tablelands, as shown by figure . The lower chambers may be supplied with water from neighboring regions which enters through channels underlying the valleys.

The water which enters the upper chambers directly from the overlying surface has little opportunity of taking up carbonic acid gas, without which it can not dissolve the limestone. Hence, the limited volume of water which finds its way into these old chambers contains little calcium carbonate. The general result of the low content of this mineral, shown by the following chemical analyses, is that the water is ready to take up an additional amount rather than part with any that it may bring into the caverns. The streams in the lower chambers seem to be loaded a little more heavily than the waters of the upper chambers, but there are few places where deposits of travertine are forming. In general, throughout the region the cavern water seems to be dissolving carbonate of lime rather than depositing it. The few deposits of the cave marble in this region denote exceptions to the general rule.

ANALYSES OF WATERS FROM MAMMOTH CAVE REGION OF KENTUCKY.

(Parts per million)

	1	2	3
Silica (SiO_2)	12	16	21
Iron (Fe)	.32	.46	.19
Calcium (Ca)	13	42	36
Magnesium (Mg)	2.8	2.6	4.4
Sodium (Na)	1.2	2.2	[a] 3.4
Potassium (K)	.6	.6	
Carbonate radicle (CO_2)	0	0	3.4
Bicarbonate radicle (HCO_3)	48	134	121
Sulphate radicle (SO4)	3.8	6.6	7.5
Chloride radicle (CL)	1.0	1.1	1.7
Nitrate radicle (NO_3)	.70	.13	.21
Total dissolved solids at 180° C	61	136	133

[a] Calculated.

1. Water entering the cavern through a dome in the ceiling and disappearing into a pit in the floor in New Entrance to Mammoth Cave near "Frozen Niagara." Collected by Willis T. Lee, May 6, 1925; analyzed by Margaret D. Foster.

2. Dome Spring near opening in Colossal Cavern. Water enters in a stream from a crevice in the wall of the cavern. Collected by Willis T. Lee, May 11, 1925; analyzed by Margaret D. Foster.

3. Richardson Spring, on Route No.1, Mammoth Cave. Collected by C. H. Kidwell and B. L. Hopkins, June 20, 1918; analyzed by C. H. Kidwell.

In several places in this paper I have repeated the fact that solution is the dominant factor in the caverns of this region and the deposition of carbonate of lime is rare. This repetition serves to emphasize the outstanding characteristic of this group of caverns. A glance at the above analyses of cavern waters indicates the reason for this condition of affairs. Ordinary ground water in a limestone region contains 50 to 100 parts of calcium in a million parts of water as compared with 13 to 42 parts contained in these cavern waters. A comparison of the water with that in Carlsbad Cavern, N. Mex., where cave marble has been deposited in great quantity and variety of form is illuminating. The ordinary spring water near Carlsbad Cavern, coming presumably from hidden caverns, contains as high as 460 parts of calcium in a million parts of water, and the water from the great cavern carries from 26 parts to 454 parts of calcium in a million parts of water.

Another characteristic which was noted in several of the caverns in Kentucky is in harmony with the idea of the nearby sources indicated by the chemical character of the water. Where water enters a cavern in a stream from the ceiling, as it does near Frozen Niagara in the New Entrance to Mammoth Cave and in the numerous pits or domes, the streams respond quickly to changes in volume at the surface. In some places muddy water is said to appear in the caves twenty minutes after a shower. In other places the response is delayed somewhat longer. Where the muddy water appears quickly, the connection

with the surface is probably direct and the crevices open. In favorable places sand and pebbles are washed into the caverns. Where the arrival of the muddy water is delayed, the route is probably circuitous and the crevices small. In some places the water entering a cavern is reported as always clear. Probably in such places the route is so circuitous that all sediment is deposited before the cavern is reached.

Origin of nitrates. - The analyses of cave water show the presence of small quantities of nitrates. These recall the occurrence in Mammoth Cave of nitrous earth which brought this cavern into prominence, and which for more than a century has justified its claim to distinction.

The former use of nitrates in the manufacture of gunpowder has led to the erroneous supposition that saltpeter or nitrate of potassium is present. This supposition is perpetuated by the use in the cavern, and in published descriptions, of such names as "saltpeter vats" and "peter-dirt." From such accounts as I have been able to find, its seems that the nitrates leached from the cave earth were treated chemically with some potash-bearing substance, such as wood ashes, before the desired saltpeter was obtained.

An authoritative answer to this question and to the still more interesting question of the origin of the nitrates has been given by F. W. Clarke, of the Geological Survey, in his Data of Geochemistry (1924, p. 254) from which I quote as follows:

"Whenever organic matter putrifies in contact with alkaline materials, such as lime or wood ashes, nitrates are produced - a process which has been carried on artificially in various countries in order to supply the industrial demand for saltpeter. In sheltered places, such as caverns, calcium nitrate is often produced in large quantities, and its formation has commonly been attributed to the nitrification of bat guano. This supposition, however, may not cover all cases, for W. H. Hess claims that nitrates are uniformly distributed in caves in Kentucky and Indiana, even in the remote interiors of caverns where no guano exists. In drippings from the roof of Mammoth Cave he found 5.71 milligrams per liter of $N_2 O_5$, whose source he ascribes to percolating waters from the outside. The cave, in his opinion, acts as a receptacle for stopping a part of the surface drainage, in which nitrates are produced in the usual way. Earth gathered far within the cavern contains nitrates, but almost no organic matter."

Channeling. - The entrance into the caverns of sand and gravel suggests a method of channel cutting which may deserve more attention than it has yet received. Much has been said in descriptions of caverns of solution cavities but little of abrasion channels. After learning of the ready entrance of muddy water into these caverns, I began to note the accumulations of sand and scattered quartz pebbles, obviously derived from the materials which cover the surface in some places near Mammoth Cave. (See fig. 3). The pebbles were found in many places where the only obvious explanation of their presence is that they were washed in from the surface through some unknown passage-way during times of storm.

A stream carrying sand and gravel will abrade its channel in a cavern in the same way that it does on the surface. There is this difference, however, that walls once formed in a cavern by cutting of a stream channel, whether by solution or abrasion, are protected in great

measure from the ordinary processes of erosion which operate at the surface, breaking down the walls and widening the valleys. As a result of this protection the walls once formed within a cavern may stand almost unchanged as long as the cavern endures.

In most of the caverns visited in the Mammoth Cave region long, high, narrow passageways were noted which resemble stream-cut rock gorges. Indeed, they have a striking likeness to box canyons (see Pl. 34), differing from them only in being roofed over by rock and protected from weathering so perfectly that the walls remain as they were left by the stream which carved them long ages ago. Other examples of these canyon-like chambers are illustrated in plates 3 and 26. The walls of these long simuous subterranean channels are vertical in most places and where the downcutting stream had worked laterally the walls now overhang the stream bed.

It is probable that this downcutting of the streams was accomplished partly by abrasion and partly by solution. Such detritus as was washed through them by the streams or picked up within the cavern would certainly abrade the bottom and side walls of the channels, just as similar material does on the surface. But the rocks in these channels are bathed with water not yet saturated with calcium carbonate and therefore ready to take this material into solution whenever it has opportunity.

These observations accord with the results of experiments by Cosyns[1/] on plates of limestone.

1/ Cosyns, G., Vitesse de dissolution du calcaire: Soc. Belge de Geol., vol. 22, pp. 64-65, 1909.

Over one plate he passed water which was saturated with calcium carbonate ($CaCO_3$) but devoid of carbonic acid gas (CO_2), and without sand or sediment of any kind. The surface of the limestone was not affected.

Over the second plate he passed water carrying fine sand but devoid of carbonic acid gas. This surface of limestone was abraded or cut and polished.

Over the third plate he passed water containing 1 to 2 grams per liter of carbonic acid gas but no sand. This surface of limestone was abraded or etched and holes, channels and ridges were formed, on the sides of which the less soluble material stood out as projections from the surface.

Over the fourth plate he passed water containing carbonic acid gas and fine sand. Figures of corrasion like those of the third plate were formed but the results were measurably greater and the limestone surface was polished like that of limestone over which floods have passed.

Over the fifth plate he passed water containing 1 gram of sulphate of iron ($FeSO_4$) per liter of water. The etching of this surface of limestone was more pronounced than that of the other surfaces.

From these experiments Cosyns concludes that the power of dissolution of water containing carbonic acid gas is greater than the cutting power of water containing sand and ~~sand~~ flowing at the same velocity, and the resulting forms on the surface of the limestone are more delicate when etching predominates.

All of the results shown by these experiments are recognized in the caverns of the Mammoth Cave region. Probably also the results of other chemical reactions will be found, particularly where sulphate of calcium ($CaSO_4$) and manganese dioxide (MnO_2) are abundant.

Solution chambers. - The caverns of the Mammoth Cave region are chiefly solution cavities. Some of the smaller ones contain notable deposits of onyx marble, but on the whole they show great complicated systems of ramifying and forking underground stream channels with unadorned walls of limestone. The explorer in these caverns tramps mile after mile between barren, uninviting walls and spends hour after hour in chambers partly filled with masses of broken rock fallen from the ceiling. It is strikingly apparent that the chemical action of water in nearly all of these openings has been almost exclusively that of solution. In the few places where the process has been reversed and the water has deposited its load of mineral matter in the form of alabaster or gypsum flowers (see Pl.33) it has done so grudgingly and most of the deposits are small.

The waters were little more lavish with their contributions of calcium carbonate, and ornaments of cave marble are large in a few places (see Pl. 17). But they are distributed sparingly. In a few places the decoration is lavish, as near the opening in New Entrance to Mammoth Cave (see Pls. 15, 16, and 18) and in Great Onyx Cave (see Pls. 19 and 20). But the spectacular ornamentation is rare. The impression forced upon the observer at almost every turn is that the dominant process here is one of destruction. Solution cavities large and small are everywhere in evidence. The rock is honeycombed where the tablelands still persist and is in a general broken or collapsed state under the intervening valleys.

The process of collapse is illustrated in many places in the larger caverns. Obviously a channel is worn down by the combined forces of abrasion and solution and cut laterally until the rocks of the ceiling fall (see Pl. 26), as they have in Salt Cave and many other places. The water percolating through the fallen material dissolves the soluble parts of the fallen blocks and releases silica in particles which are added to the abrasive material washed into the cavern from the outside. This process of removal of rocks from the ceiling by caving and solution is temporarily halted when the overlying sandstone is reached. (See fig.3). The slow process of widening the cavity then proceeds until a chamber is formed so wide that the spanning sandstone rock breaks down under its own weight and a sink hole or depression of the surface having the shape of an inverted cone is formed like that illustrated at (e) in figure 3.

When this process of collapse is carried to a point where the table-lands between the sink holes break down, a valley without surface stream may be formed. Eden Valley, an area of about 2,000 acres, is a complicated sink of this kind, that is, an area where large caverns have been destroyed by collapse of the surface rock. The final stage of this process is illustrated in the sink hole topography of Plate 43 which shows a large area where caverns probably once existed but where no remnant of the highlands now remains.

Minor characteristics

Cavern breathing. - Reference has been made to the air currents which led to the discovery of Proctor's Cave (see p.____) and to the New Entrance to Mammoth Cave. The blast of air at the opening of old Mammoth is sometimes so strong as to extinguish the light of the oil-burning torches carried by visitors.

This "breathing" or "blowing" of caverns is well known in the Mammoth Cave region, and depends on barometric conditions or differences in air pressure. In the great subterranean space of Mammoth Cave (12,000,000 cubic yards according to estimate) the temperature is about 54° F. at all times, and the volume of the air is not affected by changes of temperature. In caverns having large openings or many small openings, drafts might be produced by convection. But in all of the known caverns of the Mammoth Cave region the openings are so small that convection within the cavern is probably negligible.

The "breathing" of the caverns is probably due to the same cause as the "breathing" of wells, which has been explained [1] as due to change in barometric pressure. When for any reason the

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1/ Hall, C.W., et al, Geology and underground waters of southern Minnesota: U.S. Geol. Survey Water Supply Paper 256, p. 90, 1911.

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air outside the cavern becomes lighter than that within, it tends to rise and allow some of the cavern air to escape. Onthe other hand, when the air outside is heavier than the cavern air, some of it is forced into the opening and the cavern is said to catch its breath.

Attempts at utility. - Remains are found in Mammoth Cave of abandoned mushroom beds. As nothing has been done with them for many years, there seems to be nothing to add to the description given by ~~H. C.~~ Hovey in his Mammoth Cave of Kentucky (1912, p. 79). He found in 1881 a "natural mushroom bed, that suggested the idea of a mushroom farm here, similar to those in France, whence thousands of bushels are anmually marketed. My suggestion met with favor, and extensive beds were laid out in Audubon Avenue, on which many thousands of dollars were spent; but with meager results for lack of suitable irrigation. There is no reason why the plan should not work well by proper methods."

Another attempt at utilizing the caverns was suggested by the even temperature and the pure air of the subterranean spaces. The unchanging temperature said to be always 54°F., and the absence of dust, led fifteen invalids suffering from consumption to believe that the conditions within the cavern were favorable for overcoming the disease. In 1843 they built several cottages in Mammoth Cave,

some of which still remain, and spent five months there. Needless to say, the experiment failed and the survivors were glad to return to the open air.

Radio tests. - An experiment of quite different nature was tried in 1923, when a radio receiving set was installed in Mammoth Cave. Several preliminary tests failed but when proper ground connections were made, messages are said to have been received as successfully 2 miles from the opening and 378 feet under the surface, as above ground.

How were the caverns formed?

In several places on the preceding pages I have referred to natural processes of cavern formation whose results were illustrated in the scenes described. It seems desirable, even at the risk of some repetition, to describe and illustrate the manner in which a cavern may be formed. It may perhaps be well to admit that as some of the processes take place within the rocks, these processes cannot be observed and are not well understood. But the chief process, that of solution of calcium carbonate in slightly acidulated water is well known and the manner in which it acts to form hollows in the limestone seems clear. Meteoric water takes up carbonic acid gas from the air or from the soil and carries it into cavities of the limestone where it acts as a solvent.

This chemical action has been described so often that it need not be considered here. However, it is desirable to seek the causes of variation exhibited by this action in order to explain why some chambers in the caverns are mere solution cavities; others appear to be abrasion channels; and still others contain small deposits of calcium carbonate.

It is noticeable that many of the chambers and avenues which were obviously formed partly or wholly by solution are now dry, whereas others contain flowing water. Also, it is obvious to anyone visiting the larger caverns that the cavities, although connected by passageways, are situated at different depths beneath the surface. There are said to be five levels in Mammoth and its neighboring caverns. These levels probably correspond to stages in the erosion of Green River valley. That is, the higher chambers, with local exceptions, are old and were formed when the river was flowing in a shallow valley. As the river cut deeper into the rocks the underground waters abandoned their older courses and sought lower exits.

In attempting to answer the query, how were the caverns made?, I shall attempt to arrange the events as nearly as possible in chronological order. Unfortunately, the physiography of the Mammoth Cave region has not been studied in sufficient detail to prove either the existence of cycles of erosion or their absence. Nor have the caverns been examined sufficiently to determine whether the several levels at which the long corridors occur have any relation to benches in the bluffs of Green River or other surface features resulting from erosion.

In early Carboniferous time the Mammoth Cave region was covered with sea water in which the limestone was formed which now contains the caverns. The limestone of Mississippian age consists of two formations, the Gasper oolite and the St. Genevieve limestone. 1/

1/ Butts, Charles, Mississippian series in western Kentucky: Ky. Geol. Survey 1917.

The two limestones are normally separated by a sandstone. But near Mammoth Cave the sandstone is absent and the Gasper and St. Genevieve forma single mass of limestone. The upper one, the Gasper limestone, was covered with the sand of a formation formerly called Chester sandstone but now known as the Cypress sandstone, a formation in the lower part of the Chester group.

The next event which directly affects the Mammoth Cave region is the formation in the early part of the Coal Measures epoch of the Pottsville beds, some of which are conglomeratic. The erosion of the pebble beds at a much later time may have liberated the quartz pebbles of the conglomerate and spread them widely over the country. Remnants of these gravel deposits are now found on the highest ground. (See fig. 3).

This highland gravel probably denotes the level at which Green River once flowed. When this stream began eroding its gorge it first carried away some of the gravel and parts of the underlying sandstone. When in its downcutting it had reached the limestone, outlets were afforded which initiated the formation of caverns.

If the time of this downcutting could be dated the geologic age of the caverns might be fixed. They seem to be geologically very young, possibly glacial, or even post-glacial. Prof. N.S. Shaler states that they date"not earlier than the close of the Tertiary."

The process of cavern formation, described in part on the foregoing pages, may be summed up by the use of the diagrammatic illustration, figure 3. This summary is in reality the explanatory title of this figure but is too long to print under the illustration.

Referring then to this figure: When the river had cut to a depth represented by (a), water entering the rocks at such places as (b) made its way through crevices, dissolving the limestone along routes such as (ab). Later when the river had lowered its course to (c) a new outlet was formed, the avenue (ab) was abandoned, the water of the surface sink at (b) found its way downward through a pit to the point (d) and thence to the river at (c). These old abandoned channels are now among the most familiar objects of the caverns. Few of the channels in which water is now flowing can be traversed but the old dry chambers, such as that represented by Plate 26 and many of the other photographs, are entered readily.

The deepening of the river channel made it possible for underground drainage to develop from greater distances, as for example from point (e) of figure 3. We may reasonably suppose that the sink at (e) began its development in a small way and that the water entering it found a way through the limestone by some such route as (ef), and thence by way of (d) and (c) to the river.

The regularity of the drainage lines was interfered with by layers of different solubility and in some places by layers of shale which are insoluble, like that represented by (fg). The water from the catchment sink at (e) encounters the shale at (f). It can not make its way through the impervious shale, and follows along on top of this layer until it finds a joint or break in the shale or some place where the impervious material is not present. Here a fall develops as at (h). These falls develop into the pits or domes which constitute many of the most spectacular features of the caverns.

The pits have been emphasized as solution cavities. There seems to be no reason to doubt that in large measure they are formed by solution. But in some places, if not in all, abrasion may have accomplished important results. Silt, sand, and pebbles washed from the surface into the subterranean streams would have the same abrasive action here as they have at falls in surface streams. Also blocks of limestone broken from the walls and silica concretions released from the limestone by solution of the soluble material around them would grind like a pestle in a mortar, when the force of the falling water was sufficient to move them. In this way the pits are in some measure subterranean pot holes.

When the sink hole is enlarged and deepened, water enters at an opening lower than (e) and dissolves such passageways above the shale as those pictures in plates 7 and 27.

When the river had cut its channel to its present level, still lower outlets were formed as that at (i), represented now by the outlet of the River Styx. (See Pl. 8-A). It may reasonably be presumed that such upper chambers as (ab) and (ef) become entirely dry and that some of the water entering at (e) found its way past points (f) and (h) into a crevice which it enlarged by solution to a pit or dome (j), and now passes down through this dome to the lowest channels and thence to the river.

Other parts of the water entering through the sink at (e) found crevices connecting more directly with the lower channels and cut pits either directly below the sink as at (k), or indirectly below as at (l). The pit (j) receives an abundant supply of water only at time of storms, as most of the water entering the sink hole would seek the lower outlets and enter pits (l) and (k). This intermittent supply may have produced such relatively dry pits as Vaughan's Dome in Colossal Cavern (see Pl.21), while such pits as (k) may be represented by Hovey's Cathedral where a strong flow of water is found (see Pl.11) and by Colossal Dome (see Pl.24) where during times of storm the flow is torrential. It is significant in this connection that, according to such maps as are available, Hovey's Cathedral is under the surface depression shown on the map (Pl.42) as Hunt's Sink.

Another obvious result of the lowering of Green River is the extension of the underground passages to regions still farther removed from the river, as those illustrated under (g) of figure 3. It is

clear that the deeper the river cuts, the wider may be the belt of country drained by it through underground channels.

The sink holes such as that represented at the point (e) of the figure and by Hunt's Sink of the map illustrate early stages of the general collapse of such surfaces as that near Glasgow Junction. It is a well known fact that the open caverns which may be entered are in those highlands which have an unbroken surface. The main avenues and chambers between the opening known as Old Entrance and New Entrance, which are near the extremities of the explored part of Mammoth Cave, lie directly under the tableland traversed by the automobile road between Mammoth Cave and Little Hope School. Near the rim of this highland are such depressions as Hunt's Sink and Double Sink which show the first stages of collapse. Still farther away are depressions such as Houchin's Valley, which have no surface streams. They are great complicated sinks where collapse of the surface has been general, destroying caverns which once were present there but which have been ruined by caving.

A still more extensive area where the surface rocks have collapsed is found south of Glasgow Junction (see Pl.43) where the surface is pitted thickly with sink holes and where no remnant is left of the tableland which once probably extended unbroken over it. In some places bordering this area of general collapse are a few small round hills locally called knobs. They mark small areas which have escaped undermining and therefore represent parts of the old surface which has not collapsed. The partly collapsed surface is represented

on the map(Pl.43) north of Glasgow Junction between the sink hole country to the south and the tablelands to the north near Highland Springs where the familiar caverns begin.

Plate XLII — Karst Topography —

a part of the topographic map of the Mammoth Cave quadrangle, showing the collapsed country near Mammoth Cave. North of Glasgow Junction the surface shows partial collapse and is characterized by knobs and sinks. South of the Junction the surface shows complete collapse where no knobs remain. The surface drainage finds its way through sink holes to underground channels.

Scale 1/62500

1 1/2 0 1 2 3 4 Miles

5000 0 5000 10000 15000 20000 Feet

1 1/2 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.

Datum is mean sea level.

TRUE NORTH
MAGNETIC NORTH

PROXIMATE MEAN
CLINATION, 1922

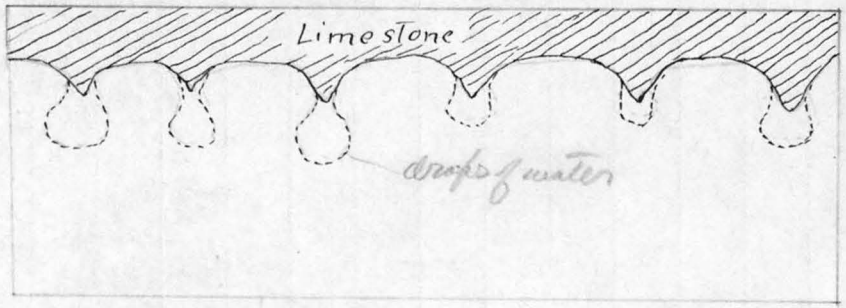

Fig 3 Profile section of limestone showing shagreen surface on the underside where water gathers and drops from the points.

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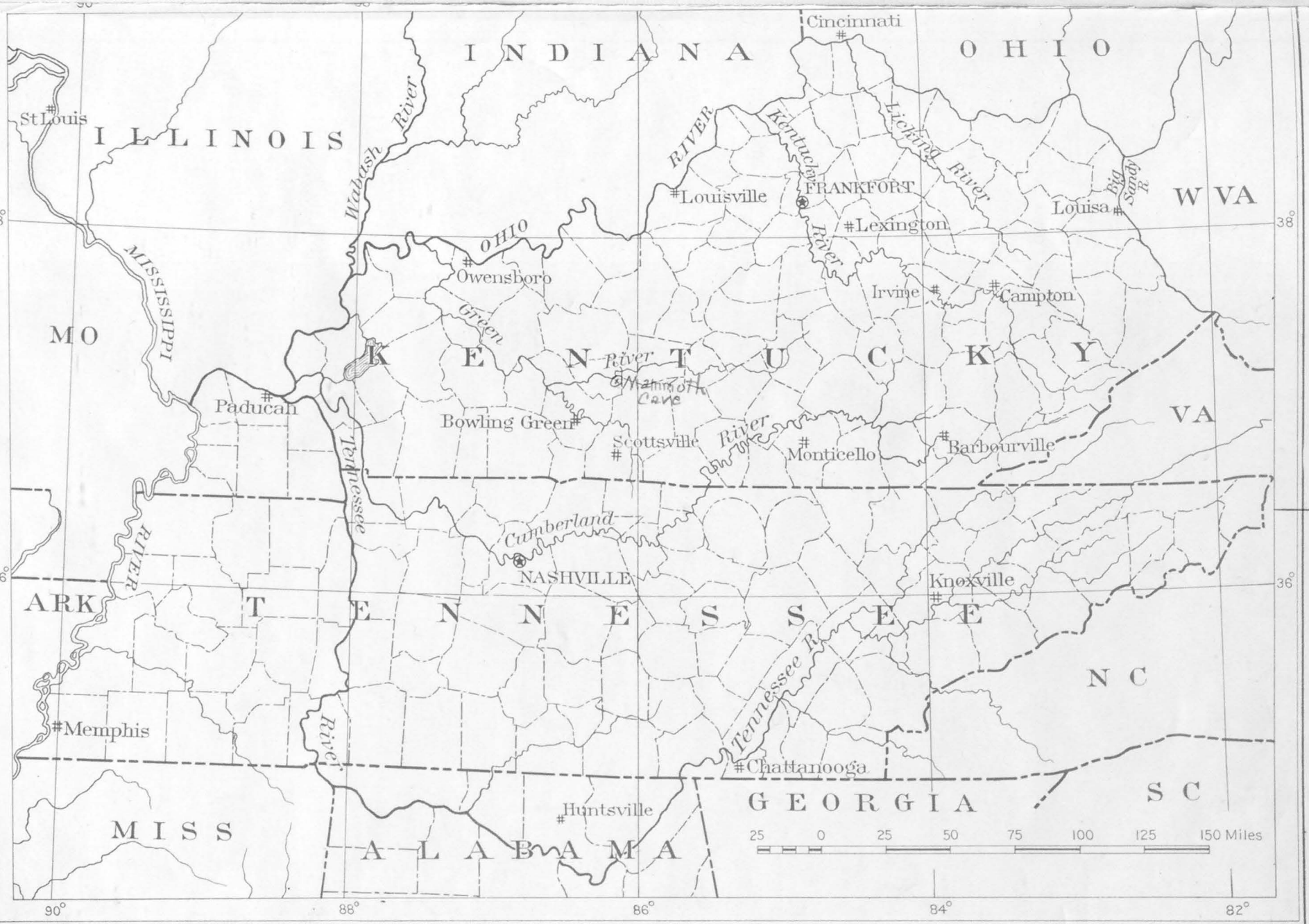

Figure 1. Map of Kentucky showing the location of Mammoth Cave.

Sicha Hill

XLII

Plate — Map of the Mammoth Cave region of Kentucky.—

a part of the topographic contour map of the Mammoth Cave quadrangle, showing the location of most of the caves described. Also a profile section.

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