COMMONWEALTH OF VIRGINIA

DEPARTMENT OF CONSERVATION
AND ECONOMIC DEVELOPMENT

DIVISION OF MINERAL RESOURCES

GEOLOGY OF LURAY CAVERNS VIRGINIA

JOHN T. HACK and LESLIE H. DURLOO, JR.

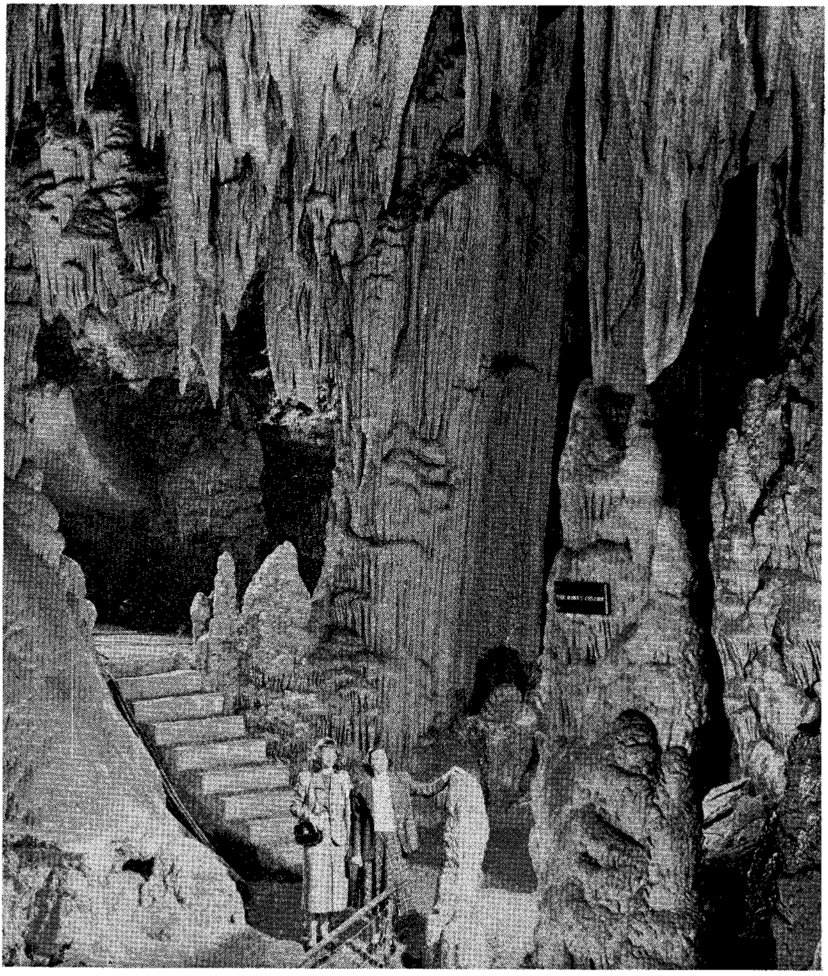
REPORT OF INVESTIGATIONS 3

VIRGINIA DIVISION OF MINERAL RESOURCES

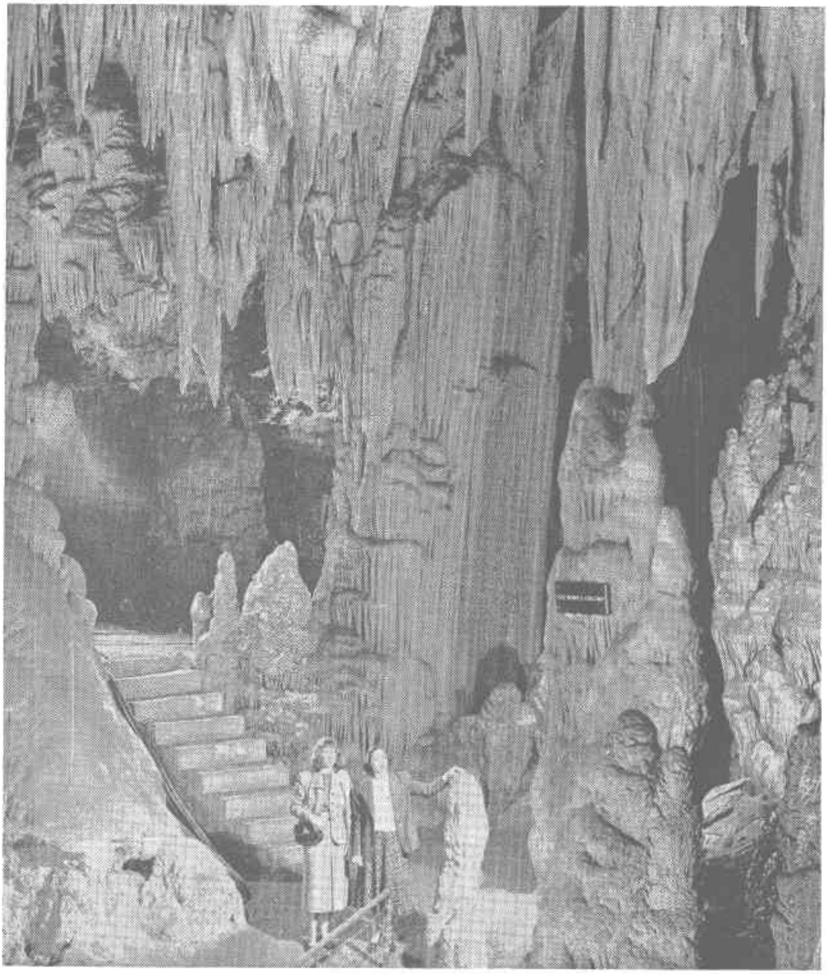
James L. Calver
Commissioner of Mineral Resources and State Geologist

CHARLOTTESVILLE, VIRGINIA

1962



The profusion of flowstone deposits that completely cover the walls, floor and ceiling of the Cathedral Room. (Courtesy of Luray Caverns).



The profusion of flowstone deposits that completely cover the walls, floor and ceiling of the Cathedral Room. (Courtesy of Luray Caverns).

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GEOLOGY OF LURAY CAVERNS, VIRGINIA

by

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ABSTRACT

Luray Caverns, Page County, Virginia, lie at shallow depth in Cave Hill a short distance west of the town of Luray. The enclosing rocks consist of granular crystalline dolomite belonging to the lower part of the Beekmantown dolomite of Early Ordovician age. The hill is on the western limb of a broad syncline whose axial plane strikes northeast. Within the limits of the cavern system the structure is rather simple. The eastern part is an open syncline with dips less than 6°. In the western part the dips are steeper — as much as 15° to the east. The entire cavern is confined to a zone only about 100 feet thick and, although all the cave is not confined to one bed, the bedding strongly controls the shape of individual rooms and groups of rooms. Much of the solution appears to have occurred in coarse-grained crystalline dolomite.

The caverns contain no deposits that indicate the former presence of large flowing streams, and most of the cave deposits including flowstone, mud, and some sand and gravel composed of chert fragments could have been transported and deposited by very small discharges of water. Nearly all the material in the deposits could have and probably did originate in the enclosing rocks. Flowstone in the form of stalactites, of stalagmites, of fanlike aprons along the walls, and of layered deposits on the floor is the most extensive deposit. The mud deposits, taken together, do not occupy a very large volume of the cave. They form several cone- or fan-shaped mud flows that issue from openings in the ceiling, and also are interlayered on the floor with the flowstone.

In several places the flowstone deposits appear to have collapsed as a result of solution and the formation of rooms beneath them, indicating that some of the cave originated in the vadose zone. Niches on the walls and ceilings, and rinds of

mud and silica on some walls indicate that solution and weathering are still going on, but probably to a very minor degree. It is believed that Luray Caverns formed by selective solution of certain favorable dolomite beds. Solution which has been going on for a long period of geologic time probably began below the water table but continued as the topographic surface above the cave was lowered and the cave came to be in the vadose zone.

Ruffners Cave, a smaller cavern in Cave Hill, lies in rocks that are stratigraphically below those at Luray Caverns. Ruffners is essentially a vertical shaft, nearly filled with breakdown that resulted from stoping above an opening formed originally by solution.

INTRODUCTION

The Luray Caverns on the west side of the town of Luray, Virginia, are in a hill known as Cave Hill, composed mostly of dolomite (Figure 1). The cave is entered on the east side of the hill by a stairway leading down from the entrance lodge. The cave lies beneath the central part of the hill, extending

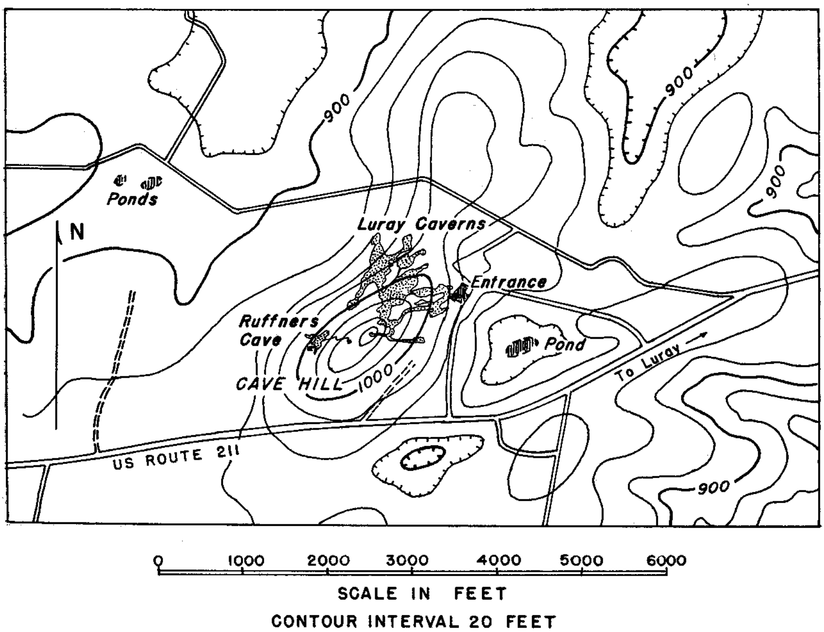

Figure 1. Map of the western environs of Luray showing Cave Hill and the location in the hill of Luray and Ruffners Caves (by stippled pattern).

almost all the way underneath to the northwest side where one of the rooms misses a connection with a sink hole on the surface probably by less than a dozen feet. On the west side of Cave Hill is another cavern system known as Ruffners Cave. This smaller system also lies in the hill so close to the Luray Caverns that some people have sought a connection between the two. Actually, however, as we will show, the two caves are probably unconnected and the main part of Ruffners Cave lies in rocks below the rocks of Luray Caverns.

Ruffners Cave was known at least 50 years prior to the discovery of Luray Caverns. It is said to have been discovered in the early 1800's by a young hunter by the name of Ruffner who followed his dog into the cave. Luray Caverns on the other side of the hill were discovered on August 13, 1878, by William B. Campbell, Andrew J. Campbell, and B. P. Stebbins, who suspected the presence of a large cave. A. J. Campbell later became the cave manager. Luray Caverns have been a popular tourist attraction ever since. They are well developed, with graded and well maintained lighted walkways through about three-fourths of the rooms.

Luray Caverns have been described in many publications, but to the writers' knowledge the geology of the cave and the rocks of the hill have never been studied before in detail. A good map of the main cave is contained in a publication by S. Z. Ammen published soon after the discovery (Ammen, 1882). Maps of the cave were also published by Hovey (1882) and McGill (1933). Butts (1940, Part I, p. 445) presents a generalized cross section through Cave Hill that includes the caverns.

PRESENT STUDY

The present study of Cave Hill was begun in 1955 by L. H. Durloo, Jr., as part of a cave mapping project of the National Speleological Society. After completing a large-scale map of Ruffners Cave and making a start on a map of Luray Caverns, Durloo was joined by Hack in a study of the geology of the two caves. The work, which continued over a period of several years, was done on occasional weekends during the winter months. The map, Plate 1, was made largely by Durloo using a tape and open sight alidade. Elevations were obtained by hand level and checked by traverses with a surveying aneroid. The traverses followed the pathways and the cave walls were sketched. On completion of the map a series of ten vertical profiles of the cavern were made (Figure 2) along lines 70 feet apart northwest-southeast through the cave. These profiles were made with the aid of a crude range finder, a device constructed of two battery-powered lecture room pointers. One of the light beams rotated through an arc of about 10° and was connected to a dial by wires. Distances could be measured simply by turning the dial to move one of the light beams in order to superimpose the two light spots on the wall or ceiling. Accuracy of the device was estimated to be about 5 percent up to a distance of 200 feet. The profiles, though sketchy, give a good picture of the shape of the cavern openings.

The relation of the caverns to surface features was determined by surveys on the hill top that connected points on the surface whose location was known with respect to points in the cave. Ruffners Cave has two openings, one near each end, that established its position and orientation. Luray Caverns are connected to the surface by two vertical cable shafts, an air shaft, and a drill hole, in addition to the entrance stairway.

After surveys of horizontal and vertical planes of the cave had been made, dips and strikes of the rocks in the cave were measured at many places, wherever the bedding planes were sufficiently well exposed. An attempt was made to determine the stratigraphic sequence of beds within the cave and to trace

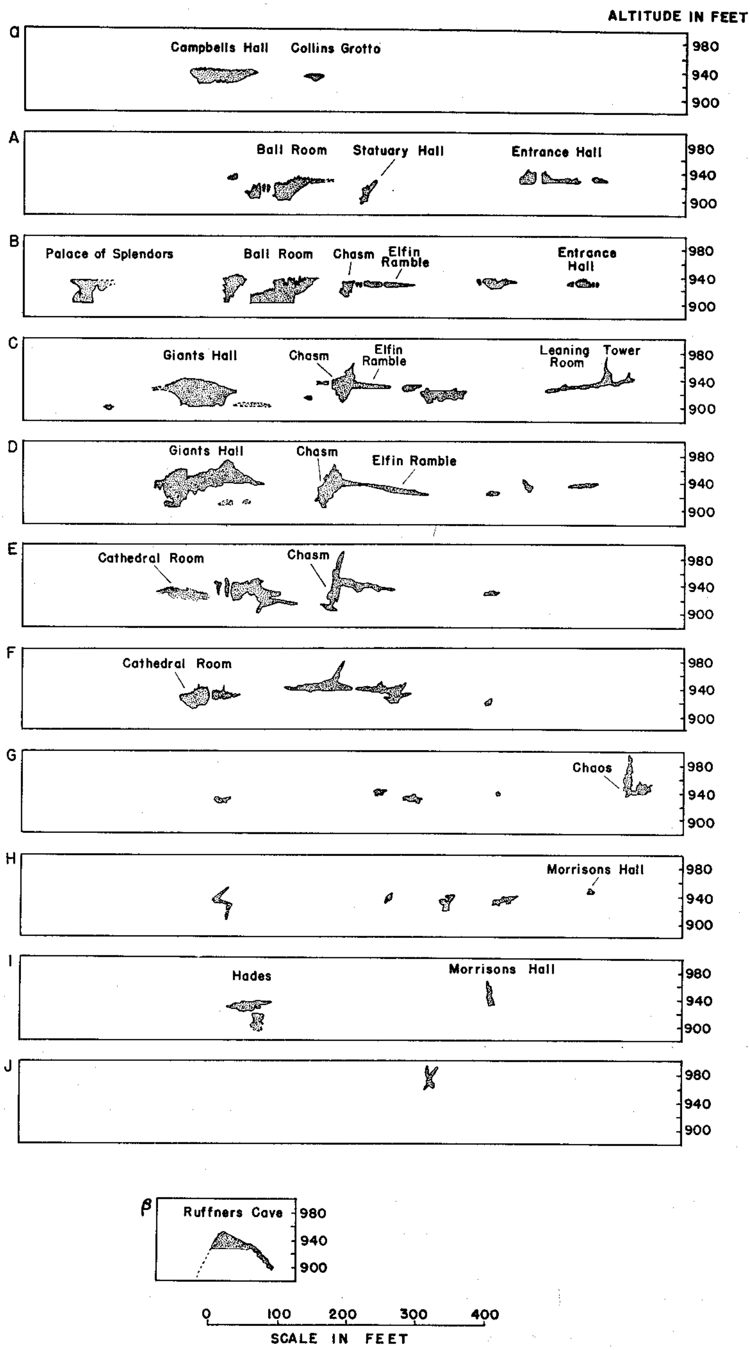

Figure 2. Cross sections showing rooms and other openings in Luray Caverns made with a range finder. The locations of the profile lines are shown on the map, Plate 1.

individual beds. This was partially successful in the eastern part of the cave.

The writers were assisted at various times by B. W. Mauck, Jr. and D. H. Powers and valuable suggestions on the manuscript were made by Z. S. Altschuler and L. D. Harris. We wish to express our particular appreciation to Mr. Theodore Graves, President of The Luray Caverns Corp., who permitted us to use the caverns for our study and made available the facilities of the Corporation.

GEOLOGIC STRUCTURE OF CAVE HILL

The relation of Cave Hill to the regional geologic structure is known in a general way from the work of Edmundson (1945, Plate 17, section B-B') and Butts (1940). The hill lies approximately in the center of a belt of Beekmantown dolomite of Early Ordovician age that is about 2 miles wide and has a thickness of about 3,000 feet. The rocks are overturned to the northwest at both margins. According to Butts (1940-1941, Pt. I, p. 445) the belt includes both an overturned anticline west of Cave Hill and an overturned syncline east of Cave Hill. The rocks under the hill itself are rather gently dipping in open folds and are probably not overturned.

In general the rocks in the hill consist of massive layers of sugary dolomite containing intergrowths and boxwork of silica, as well as very fine-grained dolomite. Some of the layers contain clay, feldspar, and stringers of calcite as impurities. The rocks are not very distinctive and except by using slight differences in color and grain size of the crystals as criteria, they cannot be readily subdivided into zones. X-ray study of polished slabs of rock samples collected within the cave as well as on the surface indicate that the entire sequence consists of dolomite, with impurities of quartz, chert, feldspar, and clay, that may exceed 10 percent in some beds (Dorothy Carroll, written communication). As the quartz and feldspar are probably authigenic and have moved about in the rock after it was consolidated, it is questionable whether they can be used to distinguish individual beds. No limestone was found in Cave Hill, but veins of calcite, breccia fillings of calcite, and beds of calcite and aragonite flowstone interbedded in the dolomite occur both in the cave and on the surface. Some of the dolomite beds may contain small amounts of calcite, undetected by X-ray analysis.

As revealed under the microscope the crystals in the coarse-grained dolomites have a range in size from about 0.10 to as much as 0.50 millimeter. The finer grained rocks have an average crystal size of 0.04 millimeter or less. Though many of the crystals are irregular in shape, areas of sharp euhedral grains are scattered through the rock, indicating that much of the dolomite is probably a replacement of something else. The chert, in the form of small quartz crystals, as seen in thin sections forms a rectilinear network in the dolomite. Exposures of the chert are spectacular where they crop out in the cave. They form large cauliflower like "heads" or masses of spongy silica that projects prominently downward from the ceiling (Figure 9). Thin beds of chert and nodules do occur in places but are much less common.

A slab with several specimens of the coiled gastropod, *Lecanospira* sp., was found on top of Cave Hill directly above the Caverns (Butts, 1940-1941, Pt. II, p. 30). According to Butts the genus *Lecanospira* is confined to the lower 1,000 feet or less of the Beekmantown. In a more detailed study of the Beekmantown Group in Maryland, Sando (1957, p. 130) reports that *Lecanospira* is confined to a zone between 207 and 564 feet above the base of the Rockdale Run formation, beds that are equivalent to Butts' lower Beekmantown (Sando, 1957, pl. 3). It is evident, therefore, that the rocks of Cave Hill are in the lower part of the Beekmantown dolomite. A good idea of the nature of the rocks in the hill can be obtained on the west side in the vicinity of Ruffners Cave where there are many outcrops exposing a section of rock about 115 feet thick.

Section 1. Rocks exposed on west side of Cave Hill between eastern and western entrances of Ruffners Cave. Altitude top of section, 1,043 feet.

(From top to bottom)

	Thickness, feet
1. Outcrop of medium light gray (N-6) to medium dark (N-4) coarse, crystalline dolomite. Slightly mottled, many stringers of white calcite. Poorly exposed.	18
2. Continuous outcrop of dolomite, mostly very fine-grained, medium gray (N-5), medium light gray (N-6) and light olive gray (5Y6/1). Some beds conspicuously banded. Contains 3-foot bed of coarse-grained dolomite 2 feet from top and several thin layers of chert.	15
3. Medium-grained crystalline dolomite, medium light gray (N-6) mottled with light olive gray (5Y6/1). Slightly vuggy with many pods of calcite. Weathered surface gray with scars where fractures have weathered.	4

4.	Mostly covered interval. Includes shallow sink hole. Outcrop east of sink hole is coarse, crystalline, medium light gray (N-6) dolomite, mottled with light olive gray (5Y6/1), similar to bed 3.	14
5.	Poorly exposed section. Mostly medium-grained to coarse-grained crystalline dolomite, medium light gray (N-6) in color, with some mottled layers. Many vugs, pods and veins of white calcite, and quartz. At 13 feet from top is a thin layer of fine-grained, banded, light olive gray dolomite.	42
6.	Thin-bedded, medium dark gray (N-3) to dark gray dolomite. Contains medium-grained and fine-grained beds, some conspicuously banded, siliceous and almost shaly. Extends to west entrance platform of Ruffners Cave.	22
	Total thickness of section.	115

It is believed that this section probably includes the same strata that are exposed in the main Luray Caverns. Unfortunately in most places the rock walls of the main cave are weathered, covered with flowstone or otherwise obscured, as for example, by a profusion of stalactites and stalagmites as shown in the frontispiece. However, a good section of 30-40 feet of rock is exposed near the entrance, and there are a few other exposures. Beds of fine-grained banded dolomite alternate with massive beds of crystalline dolomite. Veins of calcite, layers of chert, and siliceous boxwork are found in many places. Section 2 is a description of about 40 feet of rock along the entrance stairway where fresh rock is exposed.

Section 2. Rocks exposed along entrance stairway in Luray Caverns (from top to bottom). Altitude, top of section, 965 feet.

		Thickness, feet
1.	Medium gray, medium-grained crystalline dolomite, faintly banded.	5
2.	Light gray, finely banded, fine-grained dolomite. One-half foot thick lens of dark crystalline dolomite at base.	5

3.	Light olive gray fine-grained crystalline dolomite, smooth blocky surface.	3
4.	Dark gray crystalline dolomite. Weathers to light gray color with smooth surface.	3
5.	Medium to light gray, coarse-grained crystalline dolomite, strongly mottled.	8
6.	Medium-grained gray crystalline dolomite.	3
7.	Poorly exposed bed forming wall of room. A few outcrops of medium gray (N-5) coarse crystalline dolomite. Abundant boxwork of silica and veins of calcite. Siliceous boxwork forms large brownish gray masses that project downward from ceiling sponges.	10
	Total thickness	37

(Bottom of section is floor of entrance room)

It is not practicable to measure another section at any other place in the cave because the walls are for the most part covered with flowstone or a thin rind of either weathered rock or calcium carbonate, and the bedrock is obscured. The outer rind does not necessarily prevent measurement of dips and strikes because traces of the banding or bedding planes in some of the beds may be emphasized by the weathering. (Figure 3).

The texture, color and other identifying features of the rock, however, are not visible. Samples of fresh rock were collected at several places including Morrison's Hall, the Tower Room, a room below the Elfin Ramble, and the lower part of the Chasm. Because the structure in the eastern part of the cave where all these samples were obtained could be worked out in detail it is possible to determine the relative position of the samples in the stratigraphic sequence. As is shown below the sequence of beds within the cave is included in the sequence exposed on the hillside described in section 1.

As shown on the map, Plate 1, the dip and strike of the rocks were measured at more than 25 localities in the cave. In the extreme western part of the cave, however, including the area between Hades and Giants Hall and in Giants Hall itself the walls are almost completely covered with flowstone and the structure can only be inferred. The data show plainly

Figure 3. View facing west across the Chasm showing trace of bedding on the weathered surface of inclined beds.

that the eastern part of the cave is a gentle open syncline. The axis of the syncline trends northeast parallel to the regional strike. The rocks in Hawes Cabinet and at the Entrance Hall are very nearly horizontal. In the western part of the cave, however, in the north part of Giants Hall and in the Ball Room the structure is that of an anticlinal nose plunging steeply to the northeast. In the extreme western portion, in Hades, and in Ruffner's Cave the rocks are dipping about 15° to the east.

The structural pattern obtained by study and examination of the dips and strikes can be confirmed and converted to a structural map by matching the rocks exposed and sampled in the eastern part of the cave with the rocks exposed on the

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The structural pattern obtained by study and examination of the dips and strikes can be confirmed and converted to a structural map by matching the rocks exposed and sampled in the eastern part of the cave with the rocks exposed on the hillside in the vicinity of Ruffners Cave. By this means an idea of the thickness and nature of the sequence of rocks in which the cave was dissolved was obtained.

The rocks exposed at the entrance stairway (section 2) comprise the upper part of the sequence within the cave. The lowest bed (no. 7, section 2) forms the wall of the Entrance Hall. Although the bedrock itself cannot be completely examined here because of a thick weathering rind and cover of flowstone, the bedding is fairly conspicuous and being parallel to the floor can be traced almost continuously along corridors leading both to the Leaning Tower Room and to the Elfin Ramble and Chasm. Rocks similar to bed 7, (section 2) crop out at both these areas. The rocks in the chasm, therefore, can be related stratigraphically to the rocks in section 2. Samples collected at lower levels in the Chasm and from a small room immediately below the Elfin Ramble are found to have the following relation to the beds at the floor of the Entrance Hall (Base of section 2).

	Inferred stratigraphic position below top of section 2 (in feet)
Base of section 2 (floor of Entrance Room)	37
Sample A, beneath Elfin Ramble: Light gray, medium-grained, crystalline dolomite, slightly mottled with light olive gray	52
Sample B, from wall of Chasm: Medium dark gray (N-4) fine-grained dolomite with layer of grayish pink (5R8/2) to light red (5R6/6) jasperoid chert	64
Sample C, from wall of Chasm: Medium dark gray to dark gray (N4-N3) fine-grained dolomite	66
Sample D, from wall of Chasm below Spectre Column: Medium gray (N5) fine-grained dolomite, apparently thin bedded and slightly banded. Lentils of chert of same color	75

The stratigraphic sequence within the cave as shown by the rocks examined includes a section estimated to be 75 feet thick which may be divided roughly into three parts. The upper 13 feet (units 1-3 in section 2) consists mostly of fine-grained dolomite, medium light gray in color. Below it is a poorly exposed intermediate sequence approximately 55 feet thick. The exposures and samples examined consist of distinctly coarse crystalline dolomite, mostly medium light gray more or less mottled with light olive gray. Some thing banding may be seen through the weathered rind. The lower part of the section within the cave is composed of darker rocks including a jasperoid chert and thin-bedded and banded dolomite. The threefold subdivision matches crudely the sequence in section 1 on the surface between the entrances of Ruffners Cave. The upper fine-grained banded sequence within the cave corresponds to unit 2 on the surface (section 1). The crystalline mottled rocks correspond to units 3-5 on the surface and the dark-colored rocks in the chasm correspond to unit 6 on the surface. No jasperoid chert was found in unit 6 but reddish chert fragments were found on the ground surface and a layer of jasperoid chert occurs in similar dark-colored rocks within Ruffners Cave.

The rocks within the cave can also be matched with those on the surface by consideration of the structural pattern of the rocks as revealed by dip-and-strike measurements. In the Entrance Hall the beds slope very gently to the northwest. The floor and ceiling of the room also slope in this direction. The very flat dips may be traced along the corridors and walls leading both toward the Leaning Tower Room and the Elfin Ramble and it is evident that the solution in this part of the cave is confined mostly to one thin layer or zone. In the Elfin Ramble the dip changes and the rocks rise toward the west on the west limb of a syncline. The floor and ceiling rise also, parallel to the bedding. Thus in a fairly large part of the cave the rock structure can be tied directly to the pattern of the cavern openings. It is apparent that much of the solution in this part of the cave took place in a layer only 10 to 15 feet thick. The low ceilings of the rooms (Figure 4) are evident in the cross sections (Figure 2) and the outline of the gentle synclinal structure can be made out clearly in the pattern of the openings in section C between the chasm and the Leaning Tower Room. At both places the samples include coarse sugary

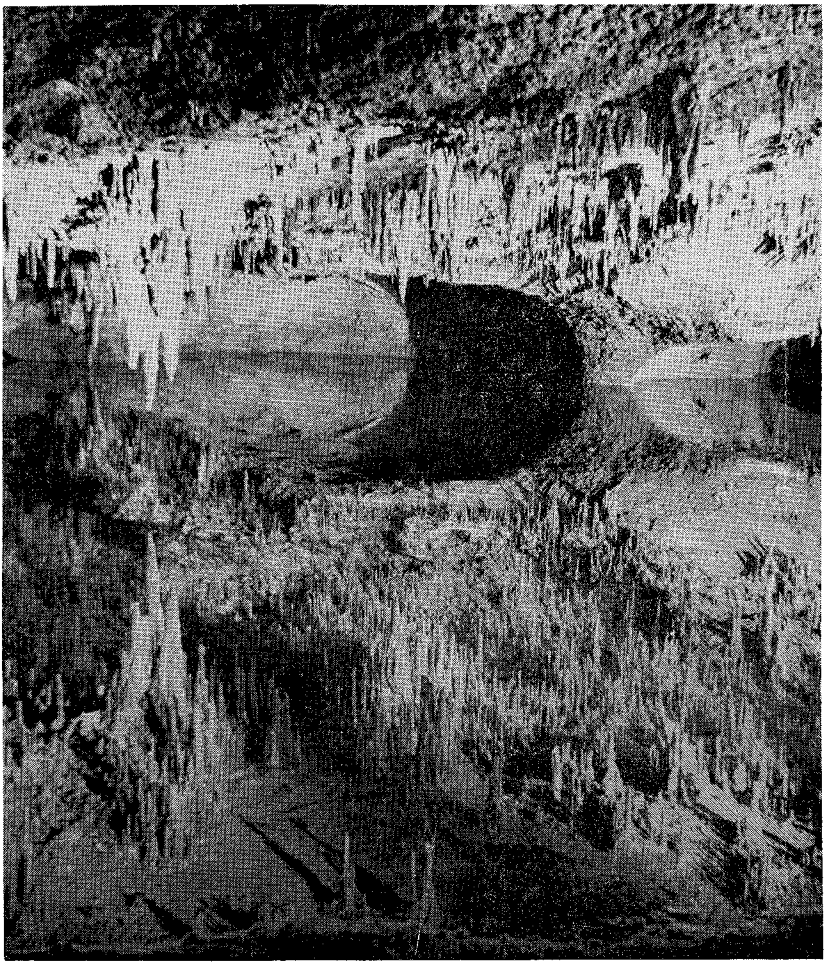
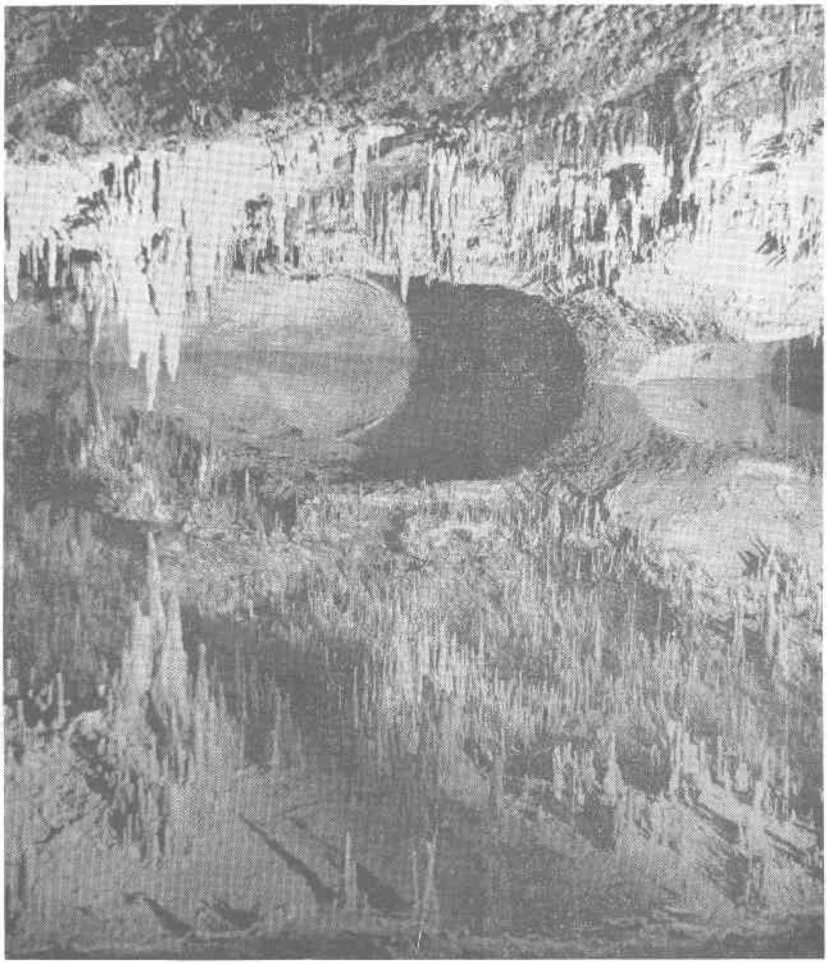


Figure 4. Reflections of stalactites in Dream Lake at the level of the marker horizon. (Courtesy of Luray Caverns).

dolomite with faint mottlings, similar to the rock at the Entrance Hall. Leaning Tower Room, shown in the detailed section (Figure 5) illustrates particularly well the localization of solution along one thin bed.

Since one zone within the coarse-grained rocks evidently was a preferred locus of solution it serves as a stratigraphic marker in the eastern part of the cave. The horizon that forms the widest part of the Entrance Hall approximately



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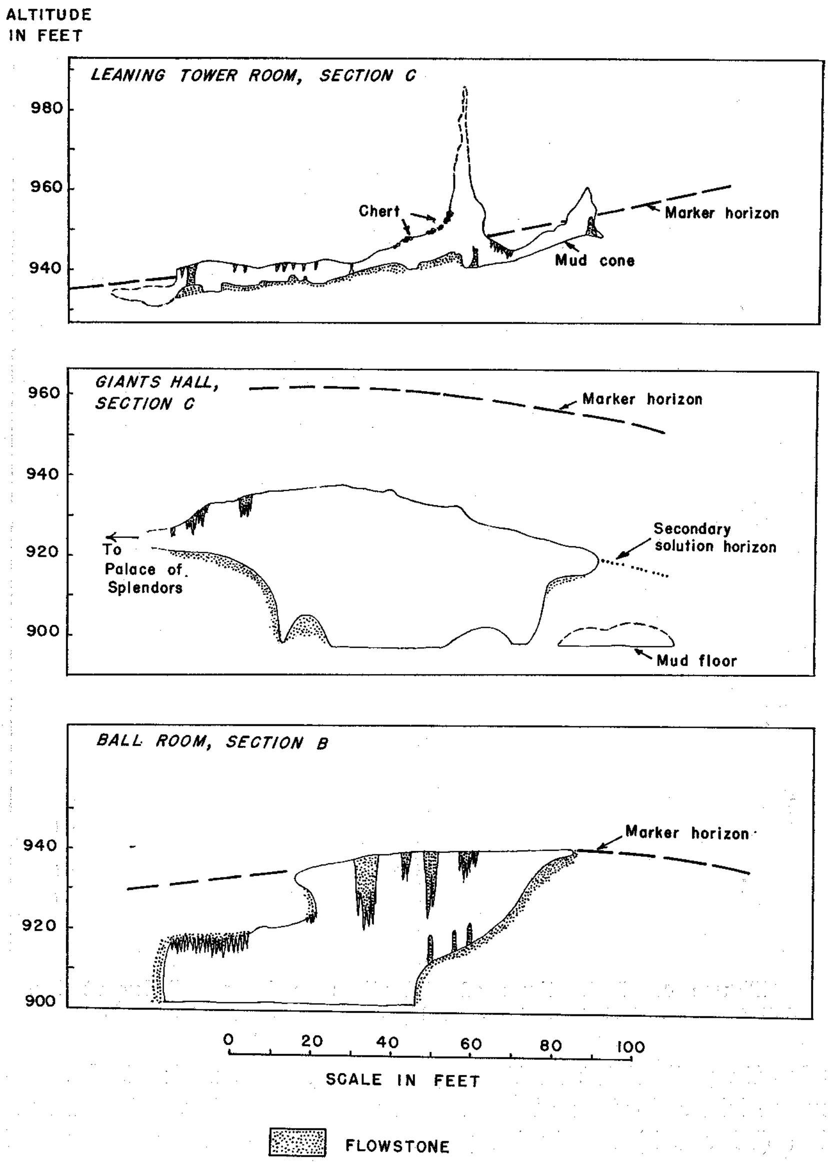

Figure 5. Detailed cross section of three rooms in Luray Caverns showing the form of the rooms in relation to the marker horizon, and the location of flowstone deposits. Location indicated on Figure 2.

three feet above the floor is referred to as the "marker horizon." This horizon is about 21 feet beneath the fine-grained banded sequence (units 1-3) of section 2 and corresponds approximately to the horizon at which solution is best developed throughout the area east of the Chasm. It serves as the basis for drawing structure contours in a little more than half the cave. It can be traced across the north end of the Chasm and corresponds to the ceiling in the northern part of the Ball Room as shown in Figure 5. In the remainder of the cave, including Giants Hall, Cathedral Room, and Hades, the dips and strikes indicate that the marker horizon must be above the ceiling. As many dip-and-strike measurements were obtained in this area, however, including the outcrops at the surface, the trace of the marker horizon may be projected on vertical cross sections from its known position within the cave to its outcrop on the surface. The structure-contour map (Figure 6) was made in this way and as indicated, the marker horizon is inferred to intersect the surface at an altitude of 1,020 feet about midway between the two entrances of Ruffners Cave. This is close to the outcrop of the marker horizon as inferred by matching the rock sequences inside the cave with those on the surface.

The interpretation of the structure by the means outlined is shown in Figures 6 and 7. The eastern part of Luray Caverns evidently was dissolved mostly in the coarse-grained mottled dolomites. Ruffners Cave and probably the lowermost parts of the Chasm and Giants Hall were dissolved from rocks lower in the stratigraphic section that are darker in color and more thin bedded.

Joints may be seen in many places. The Chasm (Figure 6) apparently follows a single joint plane that trends northeast. Large longitudinal cracks are visible in the ceiling of the Ballroom and in Giants Hall. These cracks parallel the anticlinal axes that correspond to the rooms. Many tunnels and elongate rooms show a definite alignment, suggesting that the general pattern of cave development was controlled by the regional joint system, trending northeast, northwest, and east-west. Morrison's Hall and Ruffners Cave are both related to the same zone of east-west joints.

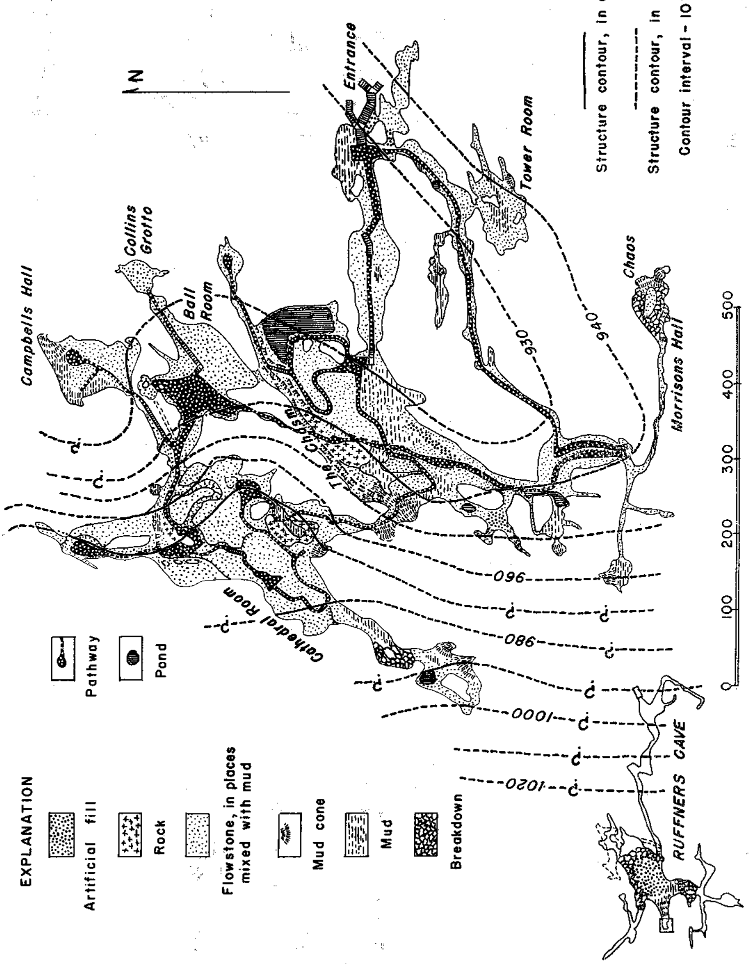

Figure 6. Map of Luray Caverns and Ruffners Cave showing cave deposits and structure. Contours in eastern part of cave are drawn approximately 3 feet above the base of section 2. In western part contours are inferred to be at this horizon on the basis of dip-and-strike measurements. Elevations are in feet above sea level.

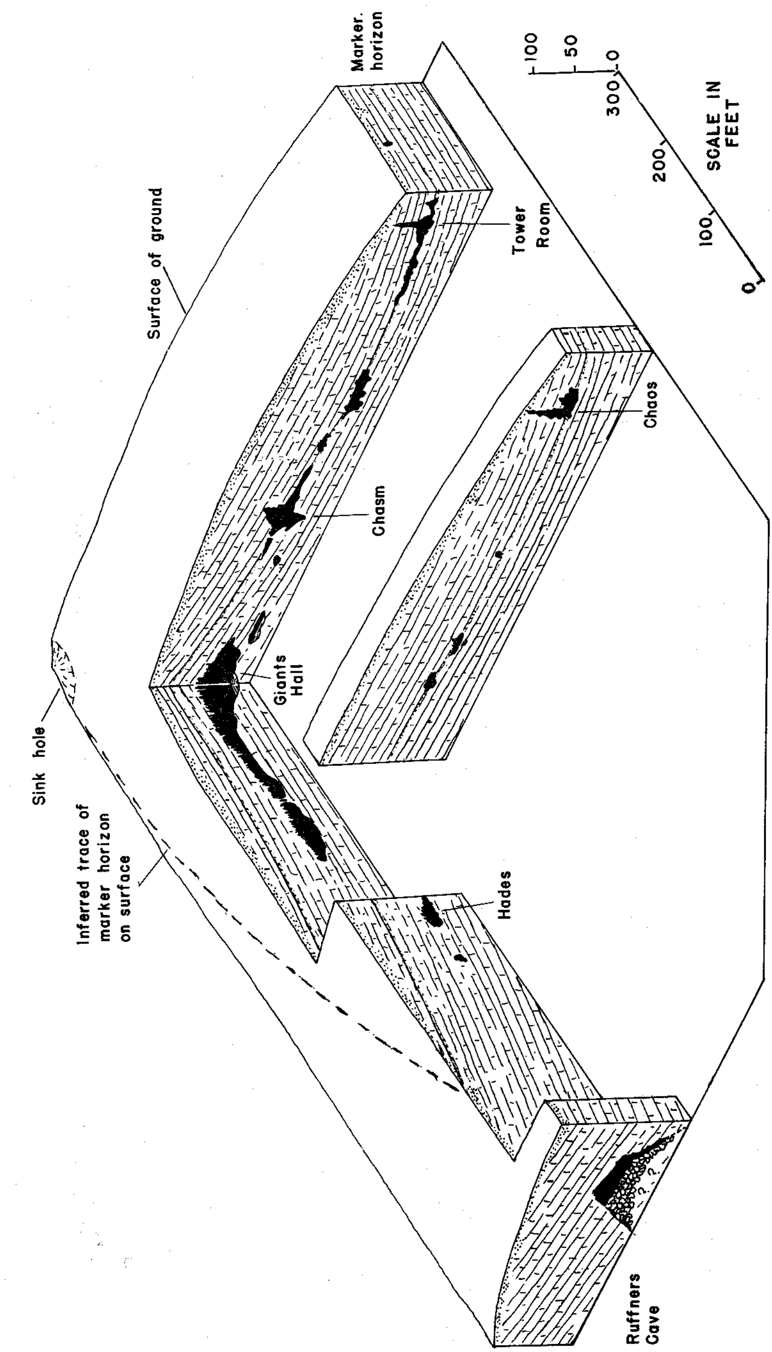

Figure 7. Isometric diagram of Cave Hill showing internal structure of the hill and the location of the cavern openings in relation to the bedding planes. Top of diagram is north.

CAVE DEPOSITS

Luray is an unusual cave in that exposures of the enclosing rocks are not abundant. Cave deposits are conspicuous throughout the cave and in a few parts completely line the walls, floor, and ceiling. The deposits consist mostly of flowstone and dripstone formations that include stalactites, stalagmites, pillars, aprons, and linings that cover the floors and lower parts of the walls. Another category of deposit, known as cave mud, includes silt, clay, and chert fragments that occur as water-laid, laminated deposits on the floors of some rooms, as large cones or fans that have oozed down the walls from openings in the ceiling, and as deposits that are probably the residue remaining from the solution of the cave walls. A third category of deposits consists of fallen blocks of rock or "breakdown" in cave parlance, that forms the floors of some rooms, notably in the Chaos and in Ruffners Cave.

Dripstone or Flowstone Deposits

The dripstone or flowstone in Luray Caverns consists of calcium carbonate in the form of calcite. The crystals are arranged in thin bands or sheets of different grain size. Acicular crystals in places alternate with bands of anhedral crystals. So far as known to the writers, none of the flowstone contains magnesium carbonate or dolomite in significant amounts, in spite of the fact that the enclosing rocks contain almost as much magnesium as calcium. The absence of the mineral dolomite in the cave deposits is perhaps to be expected, as it has been argued that when the dolomite goes into solution at relatively low pressures of CO_2, calcium and magnesium carbonate dissolve in equal amounts. Conversely, if the pressure of CO_2 is reduced in such a solution in an open system in which there is free circulation, calcium carbonate will be deposited, whereas magnesium carbonate will remain in solution and be carried away (Faust and Callaghan, 1948, p. 58-60).

In Luray Caverns dripstone is more abundant on the cave floor and walls than it is on the ceiling. Although stalactites occur in profusion in some parts of the cave, as in the Ball Room and Cathedral Room, in other parts the ceiling is nearly bare, for example, in the Elfin Ramble, Morrison's Hall and the Chasm areas. The density of stalactites appears to be related to the geology and topography of the hill. Thus stalactites are particularly sparse directly under the hill crest, where because of the topography, little water drains through the rocks into the cave. Stalactites are denser in both the east and west portions of the cave where water can collect in the rocks from a considerable area of hill slope and where the rocks covering the cave are thin. Density of stalactites is particularly high in the northwest part of the cave where the hill slope above is long and the rocks dip rather steeply into the cave. The sinkhole above the Palace of Splendors probably provides

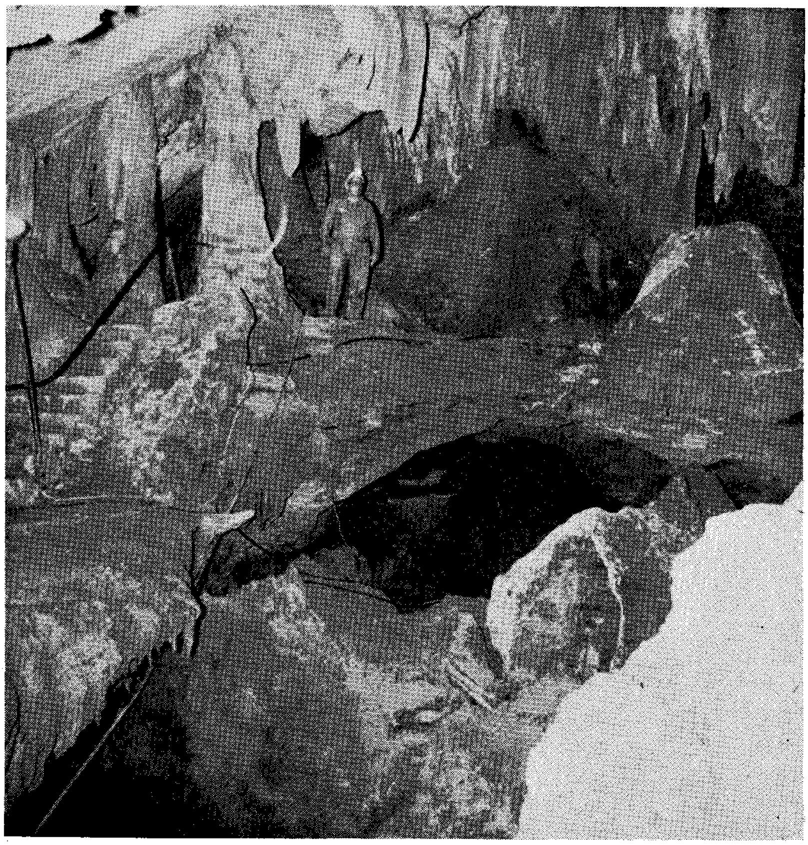

Figure 8. View of bench floored with flowstone in front of Titania's Veil. Collapse of the floor and enlargement of the room beneath must have occurred after deposition of some of the flowstone.

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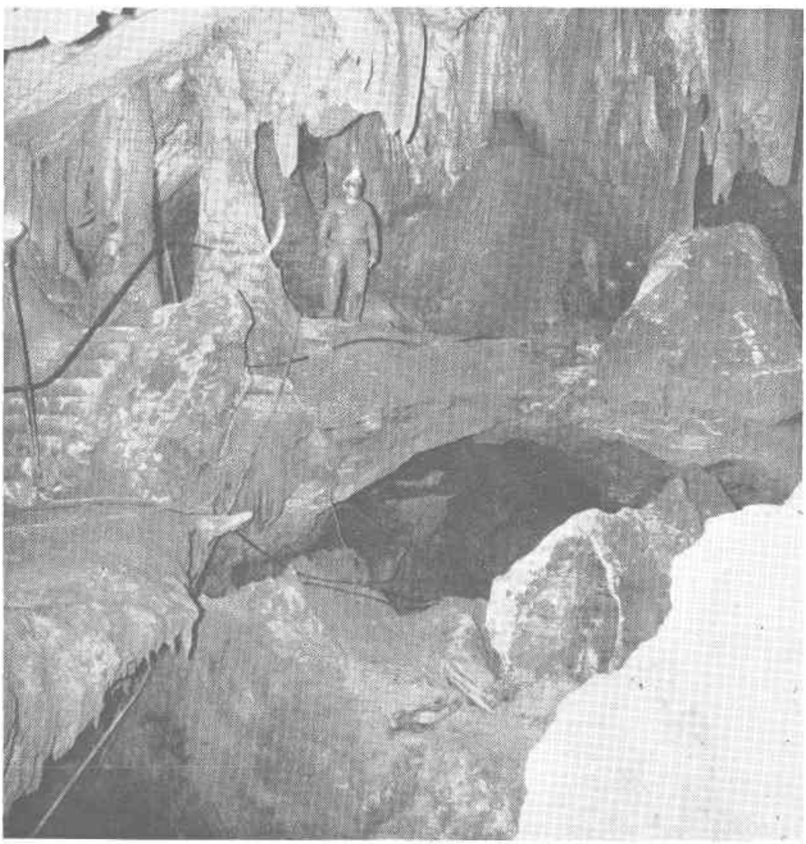

Figure 8. View of bench floored with flowstone in front of Titania's Veil. Collapse of the floor and enlargement of the room beneath must have occurred after deposition of some of the flowstone.

a large concentration of seepage water that causes this part of the cave to be particularly wet.

There is, however, almost no part of Luray Cavern where flowstone does not form thick deposits on the floor and walls. Several rooms including, for example, Collins Grotto, are floored with a horizontal layer of pure flowstone. The floor of Morrison's Hall and of the Leaning Tower Room are veneered with flowstone. In some places flowstone forms rims around the walls of rooms where a former floor of flowstone has collapsed because of solution of the rock beneath. This kind of collapse can be seen in the Chaos and north of Titania's Veil as shown in Figure 8.

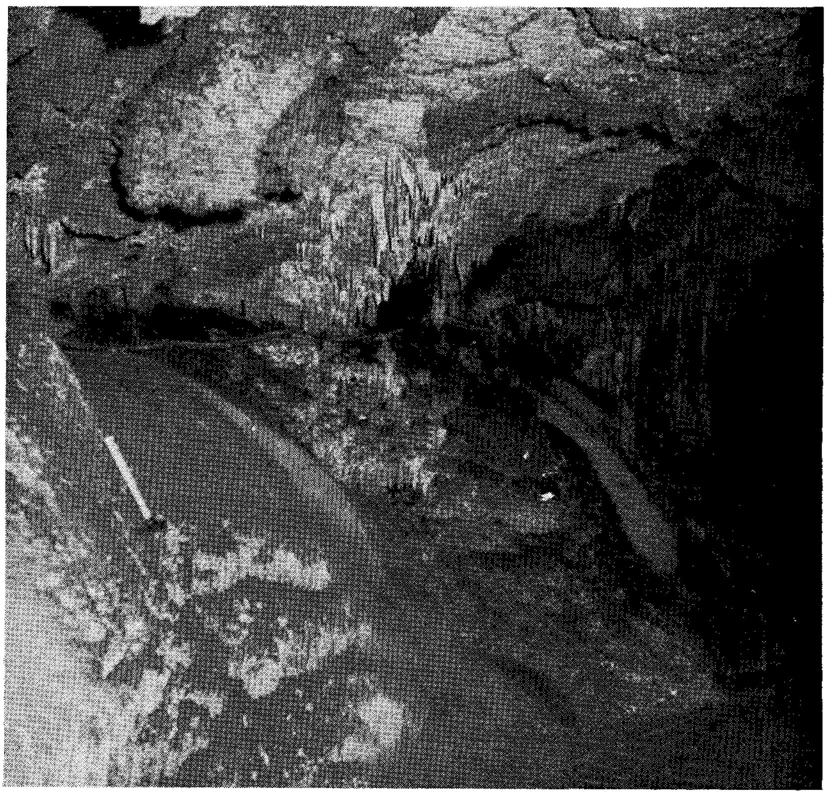

Figure 9. View showing aprons of flowstone issuing from the edge of the Entrance Hall, Luray Caverns. Note cauliflower like heads of siliceous boxwork that make up the ceiling.

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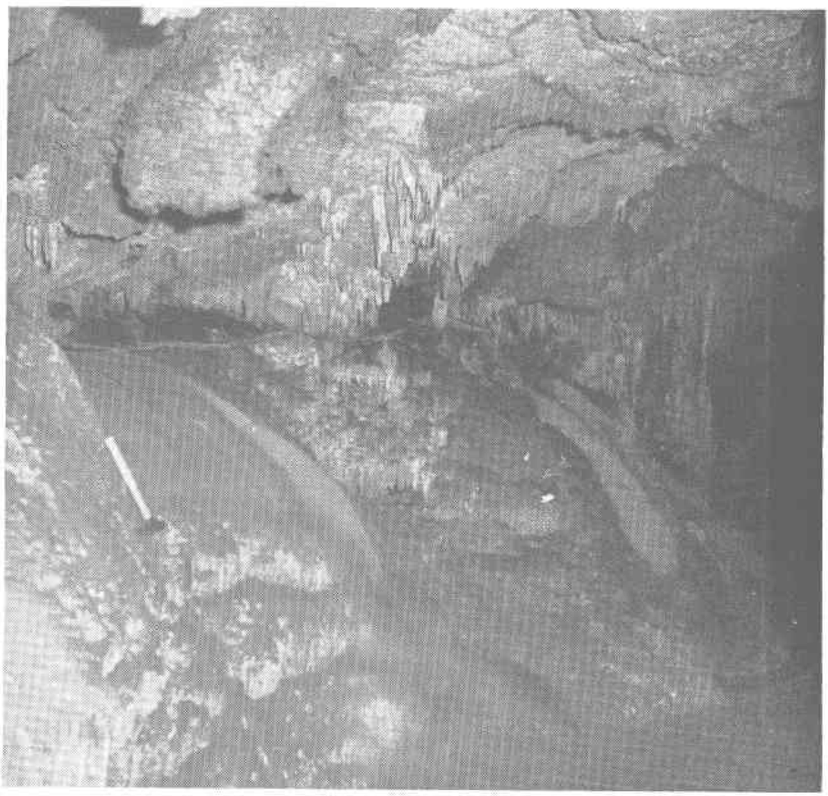


Figure 9. View showing aprons of flowstone issuing from the edge of the Entrance Hall, Luray Caverns. Note cauliflower like heads of siliceous boxwork that make up the ceiling.

The most conspicuous flowstone deposits are the aprons or veils of calcium carbonate that drape over the lower walls in places resembling frozen cascades. They are conspicuous features in many parts of the cave and appear to have formed where calcium carbonate was deposited by solutions issuing from the adjacent walls, perhaps along the bedding planes.

Stalagmites are, of course, common features in the cave and may occur in association with stalactites. In places these features have merged to form pillars and columns.

MUD DEPOSITS

The deposits collectively classed as mud include fragments of the siliceous boxwork that occurs in the dolomite, fragments of quartz, chert, and clay. The clay, which makes up the largest proportion of the mud, has been analyzed by X-ray methods by John C. Hathaway of the U. S. Geological Survey. The clay is a mixture of several minerals, including montmorillonite, kaolinite, goethite, and mixed-layered mica. The occurrence of montmorillonite is of interest because it has not been found in the surface soils of the region. (Hathaway, written communication).

The cave mud is conspicuous to the visitor, who becomes covered with it whenever he strays from the beaten path. Actually, however, mud does not form a very large part of the volume of the cave deposits except possibly in Giants Hall where it underlies the floor. It occurs as incrustations on the bedrock walls wherever it is left as a residue from the weathering of impure dolomite beds. In some places it has oozed down onto the floor and forms thick accumulations that may be interlayered with flowstone. In some places it is actually intermixed with the flowstone so that it resembles frozen mud. In at least two horizons in the cave, beds of clay are more than a foot thick (Figure 10).

Among the most conspicuous features of the cavern are mud cones that rise from the floor to the ceiling, disappearing in a solutional opening or crevice. The features are especially common in the southern part of the cave (Plate 1 and Figure 6). The Chasm itself ends at the south in a large cone of slithery mud. It may be closely examined where it is crossed

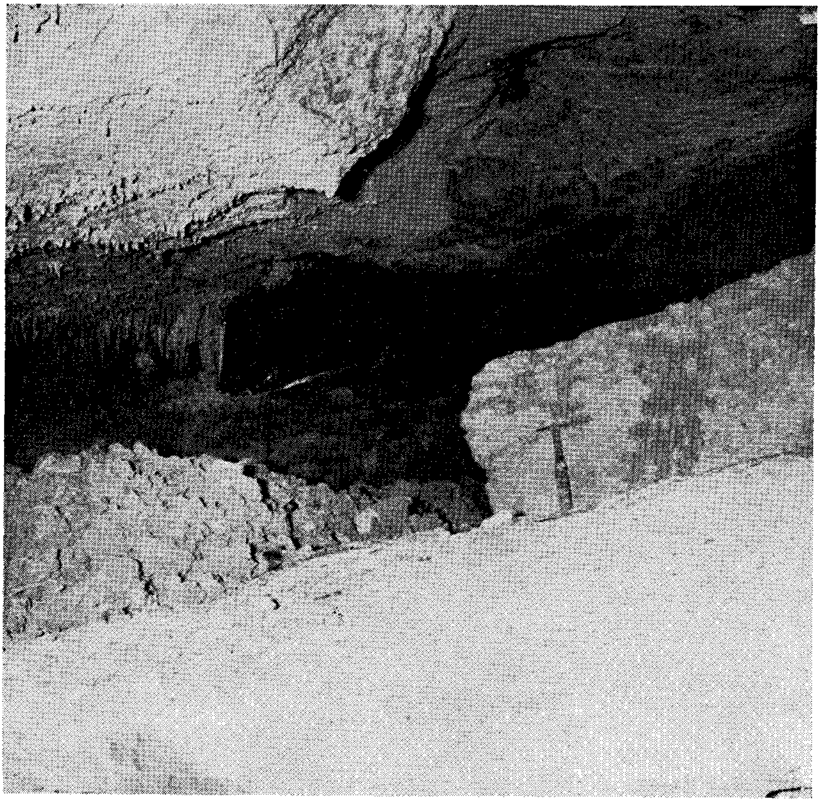
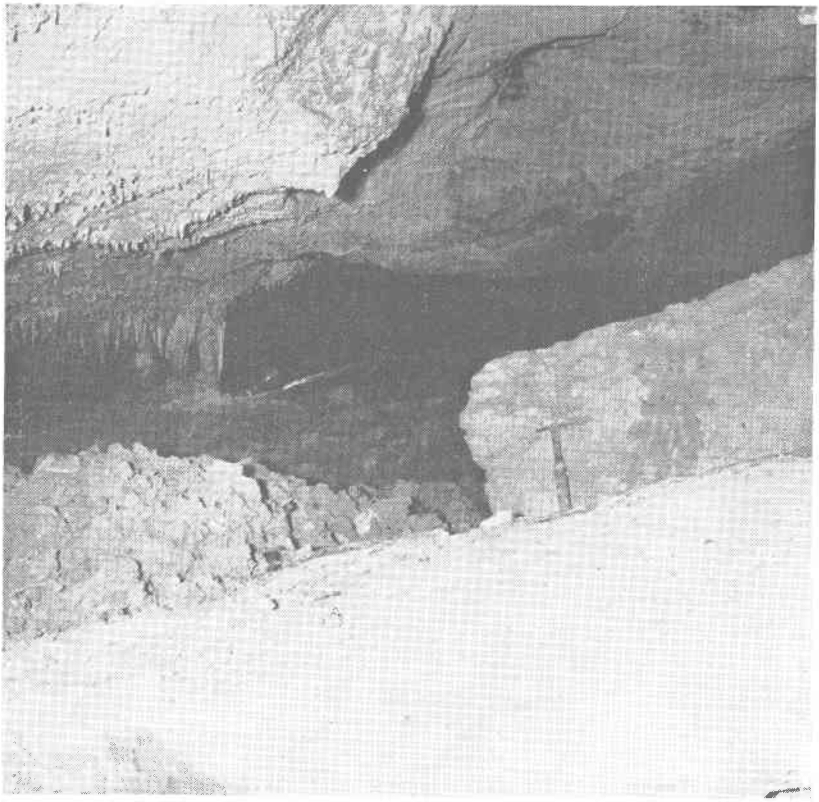


Figure 10. View of layer of reddish brown clay that floors low room at the southern end of the Chasm. Hammer rests against the clay layer. Note niche in ceiling above the hammer. Material at left is artificially disturbed.

by the cement walkway. Two prominent cones are found at the southeastern end of Morrison's Hall. Leaves and twigs have been found in one of these, indicating a connection with the surface.

Stratified deposits of mud are found in some parts of the cave. They occur where cave mud has oozed down or been transported by trickling streams of water into ponds or stagnant pools. Giants Hall and the Ballroom, as shown in the cross sections (Figure 2), have a flat floor at the same level, and both rooms are underlain by laminated silt and clay, typical



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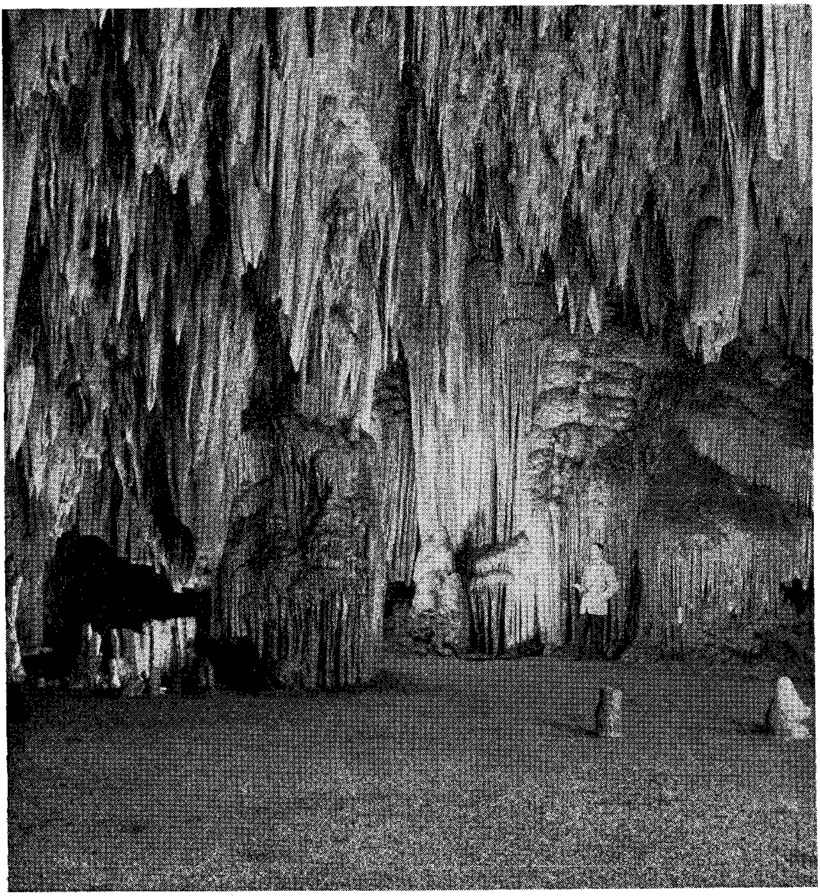
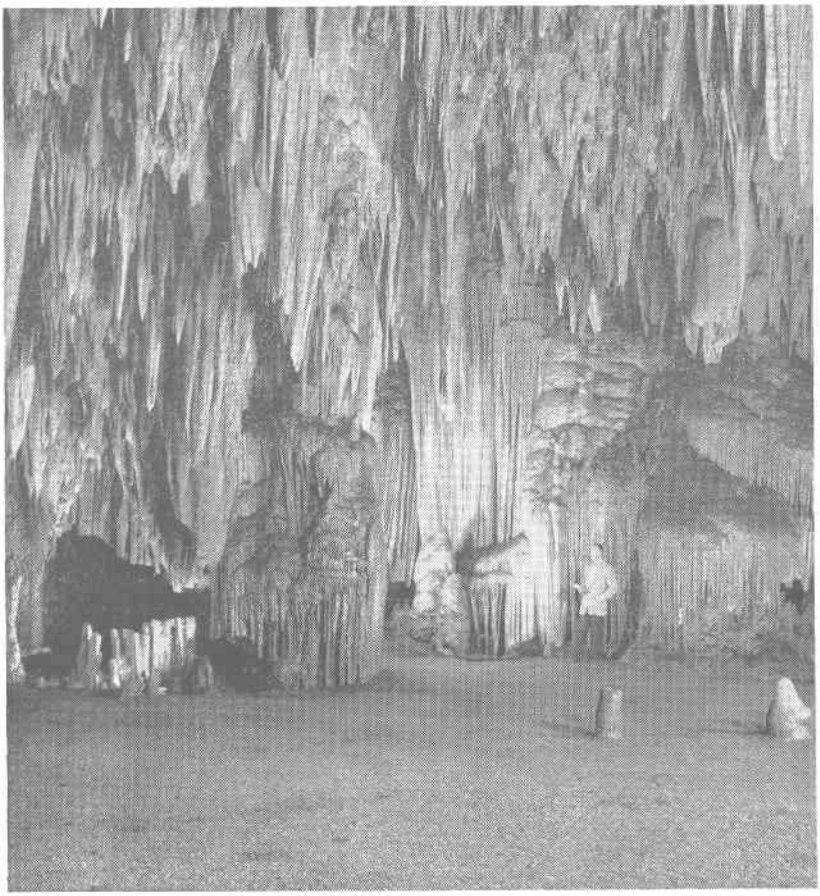


Figure 11. At north edge of Ball Room the ceiling and walls are completely covered by deposits of flowstone and the level floor is probably underlain by laminated silt and clay. (Courtesy of Luray Caverns).

clay is covered with about a foot of crossbedded sand and fine gravel composed mostly of chert fragments. This in turn is overlain in some places by a thin layer of flowstone. Rock surfaces in places in this part of the cave, as well as some of of fine-grained ponded water deposits (Figure 11). A pit excavated in the floor at the northern edge of Giants Hall contains an exposure of 3 feet of this material. The laminated



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clay is covered with about a foot of crossbedded sand and fine gravel composed mostly of chert fragments. This in turn is overlain in some places by a thin layer of flowstone. Rock surfaces in places in this part of the cave, as well as some of the flowstone formations, are deeply pitted and corroded as a result of solution. Other formations however, are unpitted and some stalactites extend to the floor where they merge with very fresh appearing flowstone deposits. These relations suggest that at some time after these two lowest rooms had attained their present shape, the cavern began to dry up and flowstone began to be deposited on the walls and as stalactites hanging from the ceiling. Deposition of flowstone was interrupted by a period of renewed corrosion, when water circulation was greater than at present, and water stood in these rooms to a depth up to 10 feet above the present floor. The water must have been undersaturated in carbonate ion so that dripstone formations as well as the bedrock below the water level were dissolved. At some later time circulation again decreased, the water level lowered and dripstone formation was renewed. This period of increased water circulation may mark a period of cold and moist climate such as might have occurred only 10,000 years ago near the close of the Pleistocene.

SOURCE OF MUD

The mud found on the floor of the cave rooms and in the mud cones is believed to be a residue derived either from the dolomite by solution and erosion in the cave itself or from the soil on the ground surface above the cave. Studies of the carbonate rocks in the Shenandoah Valley, including the Beekmantown dolomite (Carroll, 1959) indicate that the dolomite commonly contains between 1 and 2 percent of insoluble residue and may contain as much as 13 percent. This consists of quartz, chert, clay, feldspar, and a variety of other minerals. X-ray study of the rocks of Cave Hill itself indicates that some of these impurities are present in all the beds sampled; a concentration of only a few percent in the dolomite of Cave Hill could probably account for all of the clay in Luray Caverns. Solution that would produce a room 70 feet high would yield a single layer of mud more than a foot thick. Since leaves have been found in one of the mud cones, the surface soils must be an additional source and the mud probably oozes down through cracks or is carried by streamlets from higher parts of the cave and from the surface itself to the lower levels where it collects in cones or ponded deposits, or is deposited on the floor with flowstone. Mud may also ooze downward to fill fissures and thin galleries from which the dolomite beds have been dissolved.

BREAKDOWN

Breakdown consists of boulders of bedrock and flowstone that may form thick deposits on the cave floor. It results from the collapse of the ceiling or walls of the cave. Breakdown does not form very extensive deposits in Luray but does occur in minor amounts in almost every room. Extensive deposits do occur in the Chaos and in Ruffners Cave. In the latter cave breakdown is the principal deposit (see page 40).

THEORY OF CAVERN DEVELOPMENT

The general basis of the theory of origin of caverns was well expressed in an early report on Luray Caverns by S. Z. Ammen (1882, p. 11-12):

"Caves result from the chemical fact that the carbonates of lime and magnesia are soluble in water containing carbonic acid. This acid abounds in atmospheric air and is one of the products of the decomposition of animal and vegetable matters, so that rain water which has percolated through the soil has usually been enriched with it from both sources. With carbonic acid, then, as the active agent and water as the carrier we are able to account for the disappearance of strata however thick, and whether above or below ground. Above the ground the result is a lowering of the general level, the deposition of a residual stratum of clay (a constituent in a finely divided condition, of the Valley limestone) and the formation of valleys where special causes have favored the disintegration of the stone. "Hard" water flows away, and a clay soil is left behind. Below ground, on the other hand, the result is a cave — if there be a fissure in the strata through which the acidified water may make its descent. In the course of time this fissure is worn larger, and the entering water dissolves and bears away with it bit by bit the stratum through which it passes flowing out at some lower level with its burden lime and magnesia, but leaving the clay behind to plague the adventurous cave-hunter. A cave therefore is a fissure widened by the combined action of carbonic acid and water."

Although Ammen's general statement is still accurate in terms of modern geology, the conditions under which the underground solution took place have been a matter of controversy. The question has centered around the relation of the cavern to the topographic surface at the time of formation, and to the position of the water table. Did the openings form mainly at some time in the remote past when the topographic surface was far above the present one and the openings were entirely below the water table? Or, did the openings form above the water table or at the water table in the vadose zone?

This problem has been discussed in the literature by many authors. A summary of the American literautre, for example, is found in Thornbury (1954, p. 340-349). Until 1930 the prevalent theory in America held that though solution probably went on at all levels, the major part of cavern development occurred above the water table principally by action of water moving from the surface through joints and fissures to the water table where, it was believed, solution activity largely stopped, though some solution did occur below. Enlargement of the fissures occurred both through solutional and mechanical action of flowing water.

In 1930 this idea was challenged by Davis (1930) who suggested, largely on theoretical grounds, that most of the enlargement of caves occurred through solutional activity of ground water in the phreatic zone, below the water table. Davis believed that processes in the vadose zone resulted in the filling of caves and the formation of flowstone and other cave deposits. Davis' theory has been called a two-cycle theory because it involves, first, a period of erosion and cave enlargement and later, as the topographic surface is worn down to the rocks that enclose the cave, a period of cave filling. These ideas were lent strong support by the work of Hubbert (1940) who showed that the flow of ground water beneath the water table is analogous to the flow of electricity, following zones or pathways of least resistance. It is controlled by factors such as the regional hydraulic gradient and the structure and permeability of the bedrock. The position relative to the water table is not necessarily of any importance; for in limestone having many fractures or other openings to render it permeable, the flow of water might be rapid even though the rock were hundreds of feet below the water table. The importance of channelways and flow velocity has been discussed more recently by Kaye (1957).

Today, most geologists probably agree that solution of carbonate rocks may go on at all levels but there is still some disagreement as to the importance of the water table in controlling the position of caves. Bretz (1942) has shown by studies of literally hundreds of caves that the structure of the rocks enclosing the cave is one of the most important factors determining its shape and position. He believes that the prevalence of structural control is strong evidence that the formation of the openings occurred in the phreatic zone, for if the openings were related to the water table they should (according to Bretz) be independent of structure. However, many studies of caves have disclosed evidence that demonstrates the importance of solution in the vadose zone (for example Pohl, 1955) and it is clear that large openings may be eroded by the chemical activity of very small discharges of water.

On theoretical grounds alone the writers believe that the localization of solution within the carbonate rocks is complex and dependent on many factors, of which depth in the earth and relation to the water table, in some caverns at least, may be of minor, rather than major importance. Temperature, hydrostatic pressure, equilibrium conditions in the ground water and their relation to the composition of the rock, porosity and permeability, as well as structure, are all factors of importance.

Physical properties of the enclosing rock are undoubtedly important in controlling the locus of solution. Some beds may be much more permeable than others and permit relatively rapid flow of water through either primary or secondary openings. Research on porosity and permeability in limestone and dolomite has been greatly stimulated by the finding of many valuable oil reservoirs in carbonate rocks in the last 15 to 20 years. This work has demonstrated that most carbonate rocks cannot be regarded as completely impermeable even in the spaces between fractures, and indeed some Tertiary limestones are among the most permeable rocks. It has been amply demonstrated that many Paleozoic carbonate rocks are also highly porous and moderately permeable. In some the permeability is intergranular, especially oölites and coarse-grained crystalline dolomites (Imbt and Ellison 1947 and Hohlt, 1948). This factor may account for the control of solution by the bedrock in Luray, particularly, for there are differences in texture in the dolomite beds of Cave Hill. Some beds, particularly the more coarse grained dolomites, may be much more permeable than others. As circulation of water continues, openings develop and the rate of circulation increases further until a system of openings and tubes develops.

The chemical composition of the rock may also be a controlling factor in the solution. Formulas commonly given to represent the equilibrium conditions in a solution in limestone are the following (Gilluly, Waters, and Woodford, 1954, p. 107):

$$H_2O + CO_2 \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

$$CaCO_3 \rightleftharpoons Ca^{++} + CO_3^{--}$$

$$H^+ + CO_3^{--} \rightleftharpoons HCO_3^-$$

It can be seen from these formulas that the amount of calcium carbonate dissolved must depend on the number of hydrogen ions in solution. This will depend on part on the nature of the bedrock itself. The presence of carbonates other than calcite or other compounds will strongly affect the equilibrium. The conditions in dolomite will, of course, be more complex than in pure limestone. It is possible that a solution may be in equilibrium in one bed and be out of equilibrium in another. Ground water, therefore, can conceivably percolate through many feet of rock without dissolving any of it, but then dissolve a particular bed that has a slightly different composition.

The condition of the ground water is of paramount importance and, as shown by several modern treatises on the geochemistry of carbonates, the equilibrium conditions that affect solution and deposition are complex. Garrels and Dreyer (1952), as a result of experimental work, conclude that the solubility of calcite depends principally on five variables. In general the amount of calcium carbonate that can be carried in a solution in equilibrium increases with increasing pressure, pH, added salts, and amount of carbon dioxide in the solution. It decreases with increasing temperature. Considering the conditions in caverns it is probable that pressures may change as solutions migrate through the rock, thereby altering the equilibrium in the solution and causing deposition or erosion. For example, a solution under moderate hydrostatic pressure may precipitate calcium carbonate on entering a room that is not completely filled with water, especialy if it has a connection with a larger cavern system. A climatic change that caused the cavern temperature to be lowered might affect the system so as to bring about a change from the deposition of flowstone within a cave to renewed solution. Temperature conditions may change with depth in the rock, or as a consequence, the pattern of air circulation, so that a solution from which calcium carbonate has been deposited in an open room, may be undersaturated in slightly colder rocks below.

The discharge of water through a cave must also affect the occurrence and rate of solution. Presumably it takes time for the ground water to reach equilibrium with the rock through which it flows and, if it passes rapidly through open tubes or fissures as in an underground stream, it may never reach equilibrium. Thus the water entering a cave at a certain place may be saturated in carbonate, in which case it might deposit flowstone, or it may be undersaturated, in which case it might erode a niche, dome, or other solutional feature. The discharge entering a cave may of course be different in different parts of a cave, but it also may change through time either because of a climatic change, or a change in the relation of the cave to the topographic surface. A cave which is located deep in the rock strata might be expected to have more water discharged into it and through it than a cave like Luray which is close to the surface and at the present time directly under the crest of a hill which sheds most of the water to rock strata below the level of the cave.

Stoping is a process that may play a part in the formation of some caverns, especially where the rocks are so thin bedded that they cannot support heavy loads. This process acts when weak beds are undercut by solution activity. Large blocks then fall into the opening beneath. The stoping process may proceed piecemeal upward in certain kinds of rocks, forming long vertical pipes or domes filled with breakdown. Stoped blocks in some cavern rooms may be dissolved on the floor of the room because of greater discharge of water there.

ORIGIN OF LURAY CAVERNS

Luray Caverns contain many features that permit an evaluation of some of the factors that formed the cave. Probably the most striking is its unusual plan. Whereas many caves are systems of long tubes or tunnels, or follow a reticulate pattern of fissures, Luray consists of a series of large open interconnected rooms, many with very low ceilings. They show no evidence in their plan of having served as conduits for moving water and many of the rooms are as wide as they are long. The structural control of the cavern plan, however, is plainly evident, for the solution in much of the cave occurred at one or two stratigraphic horizons (Figure 7). One of these is quite obvious in the eastern part of the cave. In the western part the solution occurred in a thicker sequence of rocks but is still rather thinly confined as compared with the height of the hill and the large horizontal extent of the cave. Some of the passages are narrow hall-like rooms reminiscent of the rectilinear pattern so common in caves controlled by joints. In the narrow rooms the joint control is obvious and, as the cross sections show (Figure 2), some of the rooms have a considerable height showing that solution was localized in places along vertical or near-vertical cracks or fissures.

The close structural control of the rooms is not necessarily evidence of solution in the phreatic zone. Because the solution is in large part related to certain beds, the properties of the rock itself are probably the most important factor controlling the form of the cave. The rocks of the hill are all dolomite and no important mineralogical differences are revealed by X-ray examination. Chemical control of solution, therefore, can probably be ruled out. Study of the rocks in the hill, however, indicates that nearly all the solution is in rather massive, coarse-grained dolomites in which there has been in the past a considerable circulation of water that deposited both silica and calcite in veins and vugs. The finer grained, banded rocks above and the dark-colored more thin bedded dolomites below do not seem to have dissolved as extensively. The dark-colored rocks, however, do enclose the lower part of Giants Hall, as well as all of Ruffners Cave. The relation of the maximum solution to the coarser rocks suggest that permeability of the dolomite was probably an important factor controlling the formation of the cave. This includes intergranular permeability in the coarse-grained beds themselves as well as a secondary permeability caused by joint cracks and other minor structures.

A brecciated zone composed of coarse-grained dolomite in which the interstices are filled with calcite was found at several places along the marker horizon. The most accessible outcrop is in the tunnel between the Entrance Room and Morrison's Hall between sections F and G (Plate 1). Breccia also crops out in the Chaos where, in addition to breccia, several thin beds of flowstone crop out in the walls of the room. This suggests that there has been circulation of water at this horizon long before the present cave was formed. Solution was followed by collapse and deposition of calcite. There is, however, no evidence to indicate when this earlier solution occurred and it may have been at any time after the rock was consolidated.

The flowstone veils, mentioned on page 23, are evidence of lateral circulation of water in certain beds. The veils are particularly well developed along the main marker horizon where presumably much of the solution was localized, and they are best developed in the Entrance Hall (Figure 9). The veils consist of bulbous accumulations of flowstone that drape over the lower part of the wall of a room. In some places they look like spectacular frozen cascades emerging from a row of niches or from a bench at some height in the wall. Two cross sections of rooms with typical veils are shown in Figure 5 (Giants Hall and Ball Room). In addition to the marker horizon, veils are particularly well developed in Giants Hall where they appear to emerge from a secondary horizon at which solution was localized about 30 to 40 feet stratigraphically below the marker horizon (Figure 12). A prominent bench is formed at this horizon at the Big Column and between the Palace of Splendors and Giants Hall (Figure 5). The veils are believed to be good evidence that ground water at one time emerged from the bedding planes in the walls of the rooms.

Niches are another feature characteristic of the rock walls and ceilings. The niches are crudely semicircular in cross section and as revealed where there are large expanses of bedrock wall, they are confined to certain beds. They seem to be

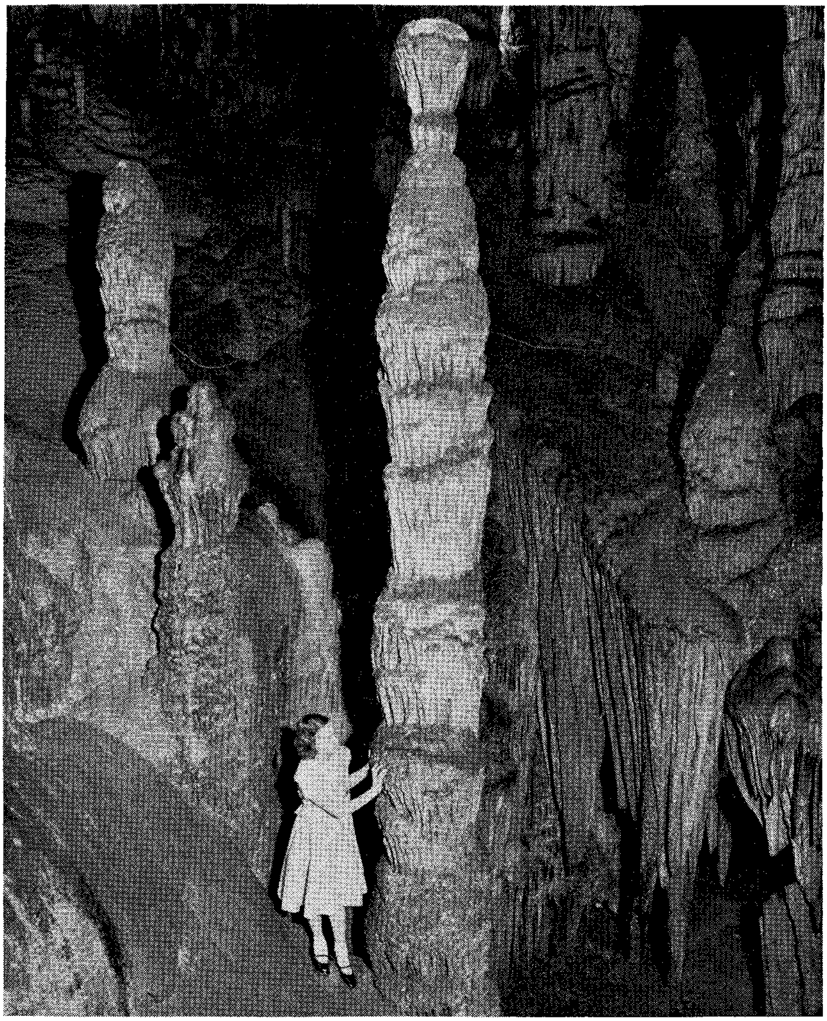
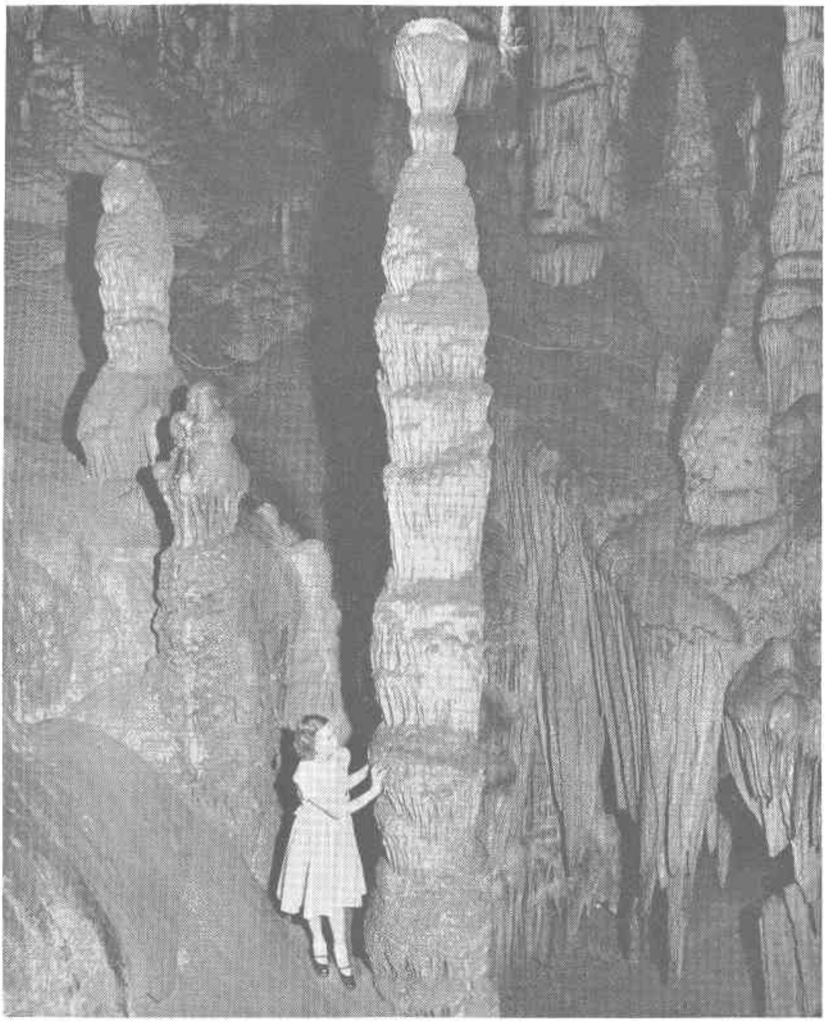


Figure 12. Veils of flowstone and spectacular stalagmites along the western margin of the cave in Giants Hall. (Courtesy of Luray Caverns).

especially common at the marker horizon (Figure 13). Their relation to particular beds is convincing evidence that they were not formed simply wherever circulating water impinged against the walls. They are probably the result of differential solution like the niches common on rocks in arid regions (Bryan,



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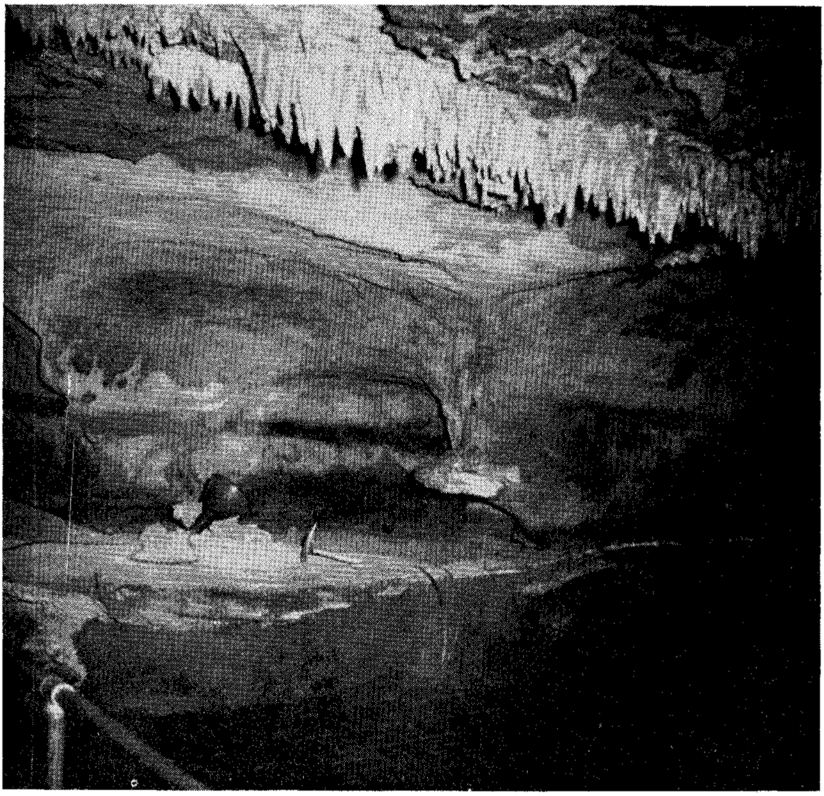

Figure 13. Large niche in dolomite at the edge of the Elfin Ramble.

All the features so far described could have been produced in the vadose zone, or at a time when the cave was not completely filled with water. The only condition necessary was that the water discharged into the rooms from the bedding planes and from the cracks and fissures in the ceiling be

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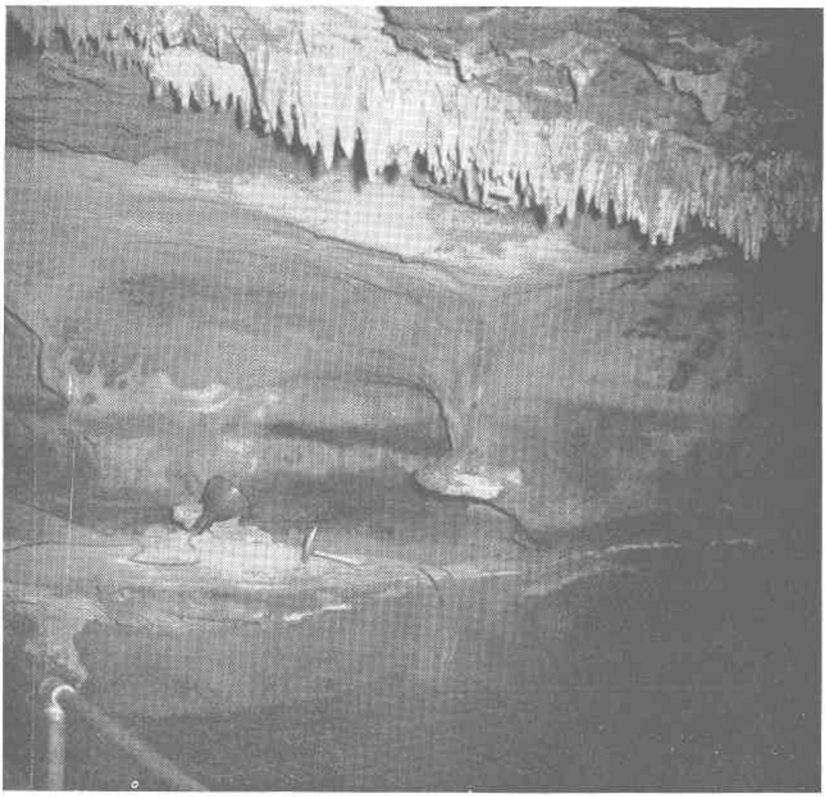

Figure 13. Large niche in dolomite at the edge of the Elfin Ramble.

All the features so far described could have been produced in the vadose zone, or at a time when the cave was not completely filled with water. The only condition necessary was that the water discharged into the rooms from the bedding planes and from the cracks and fissures in the ceiling be undersaturated in carbonate ions. It is even possible that dolomite could have been dissolved at some places while calcite flowstone was being deposited in other places. On the other hand, the major period of cave solution may have occurred before the major period of deposition and a decrease in the amount of water discharged into the cave caused a change from erosion to deposition.

The cave deposits including the mud and fine gravels could all have been locally derived within the cave itself, or from openings immediately above it. None of them indicate that the cave contained any large stream of water or was a part of any large continuous cavern system.. We could find no evidence in the cave today to indicate that any major part of the present cave was ever filled with water. This, of course, is perhaps because so much enlargement as well as deposition has occured in the vadose zone that all evidence of solution in the phreatic zone has been destroyed. It is quite likely that the initial stages of cavern development did occur at much greater depth in the rocks, in the phreatic zone.

The writers' ideas about the conditions that exist at the main solution horizon are illustrated in Figure 14, a hypothetical cross section showing a room developed in a particularly permeable bed.

Although there is little breakdown in Luray Caverns the height of some of the rooms in the western part of the cave, such as Giants Hall, suggests that stoping may have contributed to cave formation. The stoped blocks were perhaps later dissolved from the floor of the room, where they may have been completely immersed in water. That at least some stoping occurred is evident at Titania's Veil (Figure 8), where the floor of a bench covered with thick flowstone has collapsed, to produce a pile of breakdown visible in the foreground of the figure. The stoping at this place must, of course, have occurred in the vadose zone since it involved flowstone formed above the water level.

We believe that the evidence in Luray Caverns and the theoretical considerations presented above indicate that the cavern began to form long ago at a great depth in the earth. Part of the open space may have formed at this time. Most of the

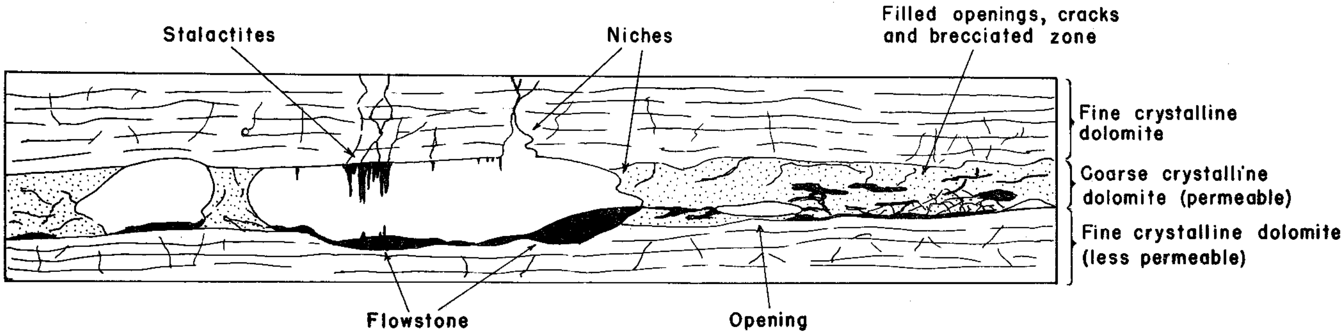

Figure 14. Hypothetical cross section through part of the principal rock layer in Luray involved in the solution. The diagram illustrates the conditions that are believed to exist in this layer and the evidence for repeated solution and deposition.

features that are now exposed to view, however, developed either close to or above the water table, with the rooms growing laterally by solution and weathering as the water emerged from the more permeable beds or from open bedding planes or joints. Most of the dissolved carbonate was carried out of the cave system but some may have been redeposited as flowstone, later to be redissolved or to collapse as further solution occurred. Solution must have dominated the early stages of development. In later stages as the topographic surface was worn down close to the cavern level and the ground-water circulation diminished, the water entering the cave in most places was saturated with carbonate ion and deposition dominated. The solution pits in the flowstone in Giants Hall and the Ball Room are an indication that the circulation of ground water as well as its ability to dissolve carbonate have fluctuated in the recent geologic past, perhaps in response to Pleistocene climatic changes.

ORIGIN OF RUFFNERS CAVE

The data on the rock structure in Cave Hill indicate that Ruffners Cave must be in rocks that are stratigraphically below the rocks of Luray Caverns as shown in Fugure 7. The rocks in Ruffners consist of a thick section of coarse-grained very dark gray dolomite. Luray Caverns contain rocks of this kind only at the base of the section as exposed in the Chasm.

Ruffners Cave is fundamentally different from any part of Luray in its structure. It consists essentially of a single dome-shaped opening that is more than two-thirds filled with breakdown or fallen angular blocks of dolomite. The dome is surrounded by a network of small peripheral solution tubes that penetrate a short distance into the rock. The structure of the cave resembles closely the very familiar dome-shaped rooms in Mammoth Cave, Kentucky, and in Wyandotte Cave, Indiana, that are partly filled with piles of boulders.

Evidently the cave formed by a sort of stoping process. Openings in the rocks first formed at lower levels in the dolomite and as the opening enlarged, the roof collapsed. The peripheral tunnels and rooms that surround the debris pile are solution tubes. As shown in Plate 1, they have a rectilinear pattern indicating a control by joints. The collapse probably took place piecemeal as the rocks in the lower part of the cave dissolved and the roof and wall area enlarged.

CONCLUSIONS

Luray Caverns is an unusual cave in that it consists not of a network of narrow solution tubes, but of a group of closely connected rooms of large area. The rooms are dissolved out of a relatively thin group of beds and it is evident in the eastern part of the cave, at least, that solution was most active in coarse-grained crystalline dolomites that also contain silica and calcite in intergrowths and secondary veins. Solution does not appear to have been active in the fine-grained rocks. The evidence of the cave deposits indicates that although part of the solution probably occurred long ago in the phreatic zone, some if not much enlargement of the cave probably occurred close to the surface at and above the water table.

Ruffners Cave is enclosed by rocks that have different characteristics from those that enclose Luray Caverns; it was formed by stoping process that resulted in a single dome, the lower part of which is filled with breakdown.

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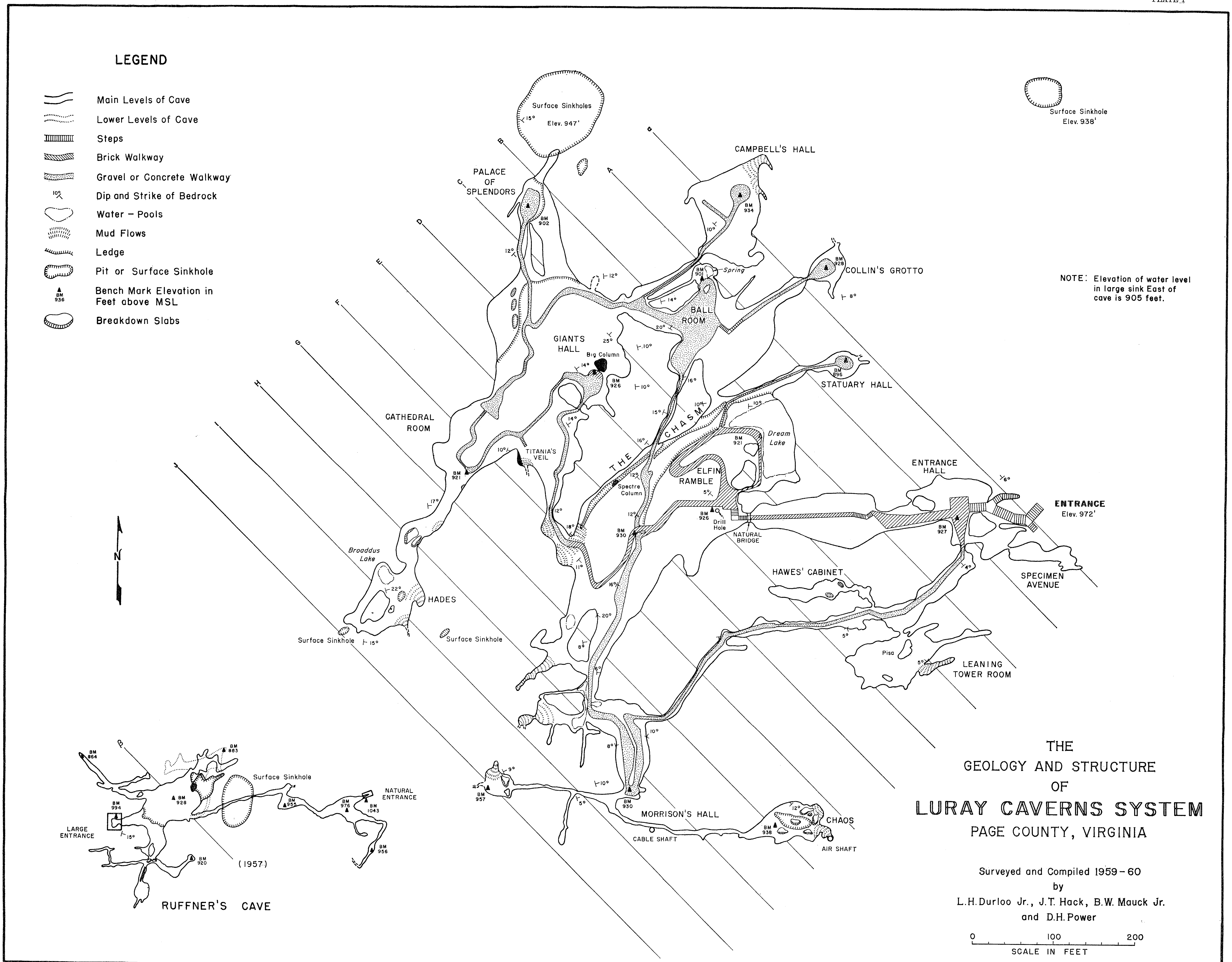

LEGEND
Main Levels of Cave
Lower Levels of Cave
Steps
Brick Walkway
Gravel or Concrete Walkway
Dip and Strike of Bedrock
Water – Pools
Mud Flows
Ledge
Pit or Surface Sinkhole
Bench Mark Elevation in Feet above MSL
Breakdown Slabs
Surface Sinkholes
Elev. 947'
Surface Sinkhole
Elev. 938'
CAMPBELL'S HALL
PALACE OF SPLENDORS
COLLIN'S GROTTO
Spring
BALL ROOM
GIANTS HALL
Big Column
STATUARY HALL
CATHEDRAL ROOM
THE CHASM
Dream Lake
TITANIA'S VEIL
ELFIN RAMBLE
Spectre Column
ENTRANCE HALL
ENTRANCE
Elev. 972'
Drill Hole
NATURAL BRIDGE
SPECIMEN AVENUE
HAWES' CABINET
Broaddus Lake
HADES
Surface Sinkhole
Pisa
LEANING TOWER ROOM
MORRISON'S HALL
CABLE SHAFT
CHAOS
AIR SHAFT
NOTE: Elevation of water level in large sink East of cave is 905 feet.
LARGE ENTRANCE
NATURAL ENTRANCE
(1957)
RUFFNER'S CAVE
THE GEOLOGY AND STRUCTURE OF LURAY CAVERNS SYSTEM
PAGE COUNTY, VIRGINIA
Surveyed and Compiled 1959 – 60
by
L.H. Durloo Jr., J.T. Hack, B.W. Mauck Jr. and D.H. Power
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SCALE IN FEET