A Guide to the Selection of 
LIMESTONE CAVERNS AND SPRINGS 
in the 
UNITED STATES 
as 
NATIONAL LANDMARKS 

prepared for the 
NATIONAL PARK SERVICE 
by 
Richard L. Powell 
Indiana Geological Survey 
Bloomington, Indiana 

1970
December 1, 1970

Mr. Chester C. Brown, Chief
Division of National Park System Studies
National Park Service
Department of the Interior
Washington, D. C. 20240

Dear Mr. Brown:

The following report, entitled "A Guide to the Selection of Limestone Caverns and Springs in the United States as National Landmarks," is submitted as fulfillment of your contract number 14-10-9-900-117. Twenty copies of this report are provided to the National Park Service by the Indiana Geological Survey.

Respectfully submitted,

Richard L. Powell
Geologist, Coal Section
A GUIDE TO THE SELECTION OF
LIMESTONE CAVERNS AND SPRINGS OF THE
UNITED STATES AS NATIONAL LANDMARKS

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National Park Service

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Acknowledgements

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Plate 1 Map of the United States showing location of caverns and areas discussed in this report.
The Origin of Limestone Caverns: A Historical and Geological Approach

The exact beginning of significant contributions to the theory of the origin of American caverns is very difficult to determine because of the complex inter-relationships and gradual evolution of the presently accepted theories; for the theories accepted at the present time have evolved from publications spanning nearly a century. In fact, no one theory has yet won universal acceptance. In addition, many ideas have been absorbed from foreign workers, primarily those in Europe. The following is a summary of the primary contributions or ideas advanced by various authors, including the classical works on the origin of limestone caverns in America. Although no effort has been made to repeat what are now considered ridiculous theories, considerable effort has been made to include in chronological order, each contribution that involves cavern development in the various karst areas in the United States.

One of the first explanations of the origin of limestone caverns, and certainly one of the first to be widely read, is that of Horace C. Hovey in "Celebrated American Caverns, especially Mammoth, Wyandot, and Luray," published in 1882. Hovey had visited many of the larger and well known caves known at that time. His field of reference was primarily the eastern United States. Hovey (1882, p. 15-17) states, "Rain-water falling amid the leaves and grass, and sinking into the soil, absorbs large quantities of carbonic acid. On reaching the under-lying limestone, the latter is instantly attacked by the acidulated water in which it is dissolved and carried away."

Hovey explains the streamless conditions of some limestone areas as undermined by subterranean drainage. All the smaller streams "are swallowed by what are called 'sink-holes,' that is, circular depressions, sometimes expanding into valleys, but leading down to no true channel; only to a crevice or pit, connecting the sink-hole with a cavern below, in which is the real gathering bed for the accumulated waters."

"The streams, flowing down through the sinkholes, carry pebbles in with them, to be used as teeth for cutting through the successive floors of the cavern, and thus enlarge its dimensions. This is generally done in longitudinal channels, resulting in long avenues, whose walls retain horizontal projections marking former levels or galleries."

"Occasionally the whirling pebbles cut a vertical shaft completely through from the uppermost chambers down to the drainage level. Surprising effects are thus produced, in opening great pits or 'domes,' as they are often called."

Hovey recognized that the cave streams emerge from hillsides as springs, and that mud and sand are swept into the cave. He also realized that the water that seeped into the cavern through the limestone would evaporate and leave dripstone deposits.

N. S. Shaler (1889, p. 103-109), relying on this knowledge of Mammoth Cave and the Kentucky Karst region, presented a popular account of the origin of caverns in which he described surface flood waters sinking into sinkholes and eroding vertical and horizontal passages down to resistant beds where the water stood in pools and then flowing out to open streams. Shaler (1898, p. 253-255) still credited the development of vertical shafts to falling water and erosion by gravel swirling in the bottom of the shaft as it bored downward,
but he attributed the development of levels or horizontal galleries to "solvent" action by carbonated waters on the limestone." Shaler continued to consider resistant beds as the floors of cavern levels.

An early paper published in the United States by a European, "The Genesis of Ore Deposits," by F. Posepny in 1894 discussed relation of ground water to the development of caverns in soluble rocks. The definition of the term "vadose" is particularly significant, for later confusion in ground water terminology has hampered a true understanding of the origin of limestone caverns. Posepny used the term in direct association with cavern development, which he studied in the karst classical region of Yugoslavia.

Posepny (1894, p. 212-216) noted that a portion of the atmospheric precipitation sinks through open fissures or directly through permeable rock and fills them to a certain level, called the water level or ground water level. This level is actually an inclined plane sloping towards the lowest point of the surface topography or to where impermeable rock crops out. This water is not stagnant, but moves towards a surface outlet at a rate depending upon the height it stands above the outlet and the size of the intervening openings. The lateral movement is only apparent, and motion is actually downwards. "For the part of the subterranean circulation, bounded by the water-level, and called the vadose or shallow underground circulation, the law of the descending movement holds good in all cases, even in those complicated ones which show ascending currents in parts. The total difference in altitude between the water-level and the surface-outlet is always the controlling factor" (Posepny, 1894, p. 213).

"Peculiar conditions are created by the occurrence of relatively soluble rocks, such as rock-salt, gypsum, limestone and dolomite, in which, by the penetration of meteoric waters and the circulation of the ground-water, connected cavities are formed, constituting complete channels for the vadose circulation." ..."The water flowing at the bottom of a cave in limestone is unquestionably ground-water; and it follows that the whole complex group of cavities has been eaten out by it. If in another limestone cave we see no flowing water, the current must have found some lower outlet; and the cave represents for us an ancient ground-water channel," (Posepny, 1894, p. 214).

Caverns are formed in limestone, as well as other soluble rocks, when a route of maximum circulation exists between the entrance of water into the limestone and above the exit. The circulation follows open fissures, enlarging them by solution, not necessarily along a parabolic course as with homogenous materials, but influenced by stratification, unequal solubility, or intermixture of impermeable rocks, causing a change in direction, even an upward inclination in places. A change in the position of the outlet, such as progressive erosion of valleys, can cause a change in level and direction of the new channel (Posepny, 1894, p. 216).

One of the first American authors to explain the origin of caves in limestone for mining purposes was of A. G. Leonard in 1897 who was concerned with the origin of lead and zinc deposits in cavities and crevices in the vicinity of Dubuque, Iowa. Leonard (1897, pp. 30-63) described several of the caves, which he considered to have been crevices (joints) enlarged by the dissolving power of freely circulating subterranean drainage derived from surface water. Although he admitted that the water might traverse the crevices in any direction, primarily down or laterally, he indicated it could rise from
below (suggesting a rising ground water level) (p. 61-62), but did not believe that it ascended from great depths (p. 63). Leonard also recognized levels, apparently stratigraphically controlled, but failed to state their cause.

"Indiana caves and their fauna," by W. S. Blatchley (1897), one of the first state cave surveys, included a brief explanation of the origin of sinkholes and caverns. Blatchley (1897, pp. 121-123) said that weak carbonic acid was formed by rainwater that absorbed carbon dioxide from the atmosphere, and humic acids from decaying vegetal matter, entered joints in the limestone and dissolved the limestone as it seeped or flowed along the openings. He also indicated the classical formulas: $\text{H}_2\text{O} + \text{CO}_2 = \text{H}_2\text{CO}_3 + \text{CaCO}_3 = \text{Ca}\text{H}_2(\text{CO}_3)_2$, in which the rainwater plus carbon dioxide becomes carbonic acid and then the carbonic acid reaction with limestone (calcium carbonate) yields calcium bicarbonate in solution to be carried away by the cave stream.

Blatchley claimed that the rainwater descended joints to a lower stratum along which it formed a passage immediately below the surface. The passages enlarged more rapidly as they allowed more surface water to enter, especially as erosion or abrasion was added to the dissolving action of the cave stream. He recognized the dependent nature of the relationship between cavern development and sinkholes.

M. N. Elrod (1899, p. 261) in a study of solution of various types of limestone in Indiana made several conclusions now considered erroneous, but he did differentiate sinkholes formed by solution on the bedrock surface and collapse sinkholes formed by failure of cavern roofs.

S. Calvin and H. F. Bain (1900, p. 523-527) added to the earlier work of Leonard on the lead and zinc caves and crevices of Dubuque, Iowa. They credited acidic surface water with the initial solutional widening of the crevices, but added that collapse of the wall rock into the crevice where it was then dissolved aided the process of enlargement. Their cause for the formation of openings at levels was the development of stages of levels of underground drainage, although they could not refer to the levels as stream grade levels because they closely followed particular beds in spite of the fact that little difference in solubility of rock was noticed. The larger caverns were thought to have formed above the level of adjacent drainage levels to permit free water circulation. The fact that some caverns were water filled was due to rise of water level in the bedrock in openings that had formed as tributaries to the Mississippi River bedrock valley, which was known to be as much as 130 feet below water level in the river.

W. D. Johnson (1901, p. 712) discussed slumping of overlying bedrock into solution cavities in gypsum. The gypsum caves had developed as subterranean streams tributary to deeply incised surface streams. His work in southwestern Kansas included a map of one of the caverns from entrance to exit and showed the junctions of several small subterranean tributaries that drained surface areas (Plate 42).

Further study by Bain (1901) in the lead and zinc mining area of the Ozarks resulted in the application of several principles of hydrology to the origin of both open and mineral-filled caverns. He indicated that the open joints in the bedrock had been filled with groundwater slowly moved by gravitation and indicated that this water was acidic water derived from the surface.
The position of the top of the ground-water level changed from time to time, depending upon the precipitation, and was subject to changes as a result of downcutting by neighboring streams. The groundwater conformed to the surface topography and was greatly influenced by geologic structure, especially pervious and impervious beds. Bain stated that groundwater was a complex of weak acids and bases, and emphasized that "mixed solutions of two or more salts will contain all the salts that can be made by the combination of the ions of the original salts together with the free ions" (Bain, 1901, p. 96-103).

G. I. Adams (1905) in a study on the springs of the Ozarks in northern Arkansas, stated that solution channels and caverns were formed along the bedding planes and joints in limestone above an impervious bed and updip from the outcrop, where the subterranean water issued as springs.

E. R. Cumings (1906) noted that limestone in the sinkhole area of Indiana were transected by two sets of joints and that those extending downdip were commonly greatly enlarged. He stated that solution by water was favored in the past by heavy forests that prevented rapid surface runoff and that free egress at lower levels along deeply entrenched streams was necessary to favor solution.

Isaiah Bowman (1907, p. 10 and 50-51) first used the term "karst" in reference to an area that was characterized by solution of limestone bedrock in the United States when he applied the term to the vicinity of East St. Louis, Illinois. He agreed with Albrecht Penck (1903) that karst water and ground water are not synonymous; normal ground water is somewhat uniformly distributed within a homogenous rock type while karst water (or subterranean water in limestone) is confined mostly to open, clearly defined joints and bedding planes and not within the pores of the rock itself. Thus, karst water probably is synonymous with the vadose water of Posepny (1894, p. 213-214).

E. H. Sellards (1908) presented one of the earliest comprehensive although vague treatment of hydrology in a well developed karst terrain when he discussed conditions in central Florida. He correlated fluctuations of the water level with rainfall slowly percolating downward from the surface (Sellards, 1908, p. 28). He indicated that the water was acidic due to absorption of carbon dioxide from the atmosphere and hydrogen sulphide from the decaying vegetation in the soil, although hydrogen sulphide water was seldom found in shallow aquifers, and he also believed that the amount of carbon dioxide increased in proportion to pressure or depth (p. 19-21, 33). He associated the development of solution sinkholes with solution above the water level and suggested that their bottoms were essentially at the water table or would dissolve the surface rock to that level (p. 56). He believed that solution was most rapid in the zone above the underground water level, and also that solution might take place below the water level (p. 49). This confusing situation resulted apparently because Sellards failed to define either the top of the ground water level or the water table, if he meant two different levels.

Sellards also indicated a relationship between surface water recharge to an aquifer and its movement out of the aquifer, "The large annual in-take of water into the limestone continuing through a long period of time implies an equally ready escape. The natural outlet is through springs," (p. 35).
Myron L. Fuller (1908) described the sheet form of solution along joints and bedding planes, the latter he called ramifying channels, but indicated that tubular openings and caverns enlarged partly by differential solution (p. 12). Fuller defined artesian flow, although in an involved and somewhat confusing text, to cover most geologic situations. His example of artesian flow in solution channels or caverns indicated that the roof, floor and walls of the cavern confined the water and that the gradient of the passage and amount of source water at the head provided the needed pressure for artesian flow (p. 39) (figure 1).

F. C. Greene (1909), describing cavern formation in Indiana, accepted earlier ideas concerning descending acidic surface water along joints and their enlargement by solution. The downward movement of water may be retarded by several factors, including: joints may tighten with depth, the water level may be reached, an impervious or less soluble layer may be reached, or a level corresponding to that of local base level may be reached. Any of these conditions may cause lateral flow along a line of least resistance such as intersecting joints either down along the dip and/or towards the nearest, lower, surface stream. Greene attributed some of the cavern enlargement to abrasion as the opening to the surface allowed the passage of suitable materials, particularly chert fragments. The young caves and some older caves retain the original joint orientation. This classification of age applied to degree of joint control is an apparent confusion of relative size with geologic age. Passage size is not solely a function of its age, although this comparison is frequently used in the concept of "youth, maturity and old age" stages of development, a concept which is of limited validity.

Greene (1909, p. 178) particularly related size and shape of cavern passages to base level of surface streams, suggesting that base level is essentially the same as the permanent ground water level. He indicated that if the surface stream was at a much lower elevation the tributary cave stream would downcut rapidly forming a high, narrow passage. The passage would widen by lateral erosion if the cave stream was nearly on the same level as the surface stream to which it was tributary. Bedding planes in the cave walls are also subject to widening. Lateral erosion or undermining will cause collapse of the walls and roof.

G. C. Matson (1909) published a comprehensive study of the Blue Grass Region of Kentucky which also presented some principles of hydrology that apply to limestone bedrock areas. Matson (1909, p. 39) clearly defined the water table: "The water that sinks into the earth descends until it reaches a level where the underlying rocks are already completely saturated. This level is known as the water table, and its form and depth beneath the surface vary with the amount of rainfall, the relief of the surface, and the resistance which the rocks offer to the movement of the water." In addition he described depression of the water table where it intercepts the surface along stream valleys, generally as a spring or seep. Perched springs are formed where a perched water table, that is, a water table formed above an impermeable material, intersects a valley (p. 40).

"As the belt of rapid solution is restricted to the zone of active water circulation, the formation of caverns takes place largely above the level of the surface streams that receive the underground drainage, but this does not imply that there is no deep-seated solution or that active circulation may not
Section illustrating conditions of flow from solution passages in limestone.

A. Reverted zone due to caving of roof, serving as confining agent to waters reached by well 1; B, silt deposit filling passage and acting as confining agent to waters reached by well 2; C, surface debris clogging channel and confining waters reached by well 3; D, pinching out of solution crevice resulting in confinement of waters reached by well 4.

Figure 1. Example of artesian flow in caverns suggested by Fuller (1908, p. 39).

Figure 2. Diagram to show groundwater zones as defined by Meinzer (1923, p. 23).
extend slightly below the level of the surface drainage," (Matson, 1909, p. 42-43). Obviously the places where water circulates most readily will suffer most loss by solution, commonly along joints and bedding planes, although aided by erosion when the water contains sediment. When the surface streams deepen their valleys, lowering base level, the tributaries in caverns lower their channels along joints. "As long as the lower channel or the passages leading to it are comparatively small the old cavern retains a large part of the drainage. With the enlargement of the new cavities the old channel receives less and less of the original drainage, until it is entirely deprived of its original headwaters except during storms, and at last, when the new channels have become sufficiently enlarged, the old channel receives only the drainage of its local tributaries," (Matson, 1909, p. 43-44), causing abandoned cave passages at different levels, but not necessarily below each other. Matson recognized deep lying solution channels, but noted that they were usually filled with mineralized water and capped with impermeable strata (p. 45). The plane of separation between shallow (fresh water) and deep water (highly mineralized water) coincides roughly with the levels of surface drainage, rising slightly above that level below divides (p. 48).

Matson (1909, p. 48) stated "The slow movement in the underground channel facilitates solution, but when the water enters through open sinks it contains less carbonic acid and the rapid movement of the flood waters does not favor solution."

Several authors had commented on the enlargement of the caverns to the extent that they collapsed to the surface forming sinkholes, usually suggesting the old age of the cavern. H. F. Cleland (1910, p. 327-333) indicated several natural bridges that resulted from the collapse of limestone caverns except for a short segment which remained to span the former cave stream. He also indicated the origin of some bridges by solution along joints and bedding planes at a waterfall.

J. W. Beede (1910) made an early attempt to relate cavern development with surface erosion levels in south-central Indiana, and at the same time categorize cavern and karst development into stages of youth, maturity and old age. Beede’s analysis in most respects parallels that of Matson, except that more emphasis was placed on geomorphic history and an orderly succession of events. Apparently because of his stage classification, Beede described only three surface erosion levels or cycles in an area where at least four cycles are now known.

"The cycle of subterranean drainage may be stated as follows: It begins with surface drainage and in its youth develops subterranean drainage near the points of easy escape for the water. In its maturity there is the maximum of subterranean drainage and the lower parts of the caverns have begun to retreat by collapse while in the uppermost reaches of the stream the transformation from surface to subsurface drainage may still be in progress. Old age is shown by the general condition of collapse and the return to surface drainage. Briefly, it may be stated that the cycle is: surface drainage, partial subterranean drainage, and a return to surface drainage. The final state is peneplanation or base leveling" (Beede, 1910, p. 22-23).
The cycle begins with uplift of the limestone area and rejuvenation of the major drainage routes. The rocks are saturated with ground water, but with an unbalanced static head adjacent to the major streams equal to the elevation of the surface tributaries. Solution sinkholes first develop adjacent to the entrenched main stream at the same time that subterranean drainage is initiated (Beede, 1910, p. 4-5). The development of subterranean drainage then progresses headward along the tributary (p. 6). Beede also recognized that one surface stream is likely to downcut more deeply or more quickly than an adjacent one, initiating subterranean stream piracy if conditions are favored by the dip of the strata or difference in head of the general water table (p. 21-22).

E. R. Cuanings (1911, p. 130) simply emphasized the work of Beede when he stated the idea that the depth to which caverns could develop was limited only by the thickness of the limestone and the elevation to which it was above the main lines of drainage, which in Indiana he said ranged from about 100 to 300 feet.

W. A. Nelson (1912, p. 297), in a descriptive article on Monteagle, Wonder Cave, Tennessee, presented a general theory on origin of caverns. He indicated that the caves were formed in limestone by acidic waters descending through sinkholes. The original bedrock opening is widened first by solution, then enlarged by solution and abrasion as the passage contains an underground stream.


The development of caverns in soluble rocks other than limestone, especially in gypsum, has been noted. One of these is an article on Oklahoma by L. C. Snider (1913, p. 149-150). Gypsum is easily dissolved by ground water, especially along two sets of joints which have developed. Sinkholes develop on the surface and channel the water into the gypsum, which readily dissolves. The water exits at the base of the gypsum beds along the edges of buttes and valleys. The underground channels or caverns apparently extend headward to form other sinks, enlarging in places to cause collapse of shale layers within the gypsum. The gypsum caves appear to resemble limestone caverns in many respects.

H. D. Miser (1914) described the origin of two adjacent natural bridges in Tennessee by the collapse of a portion of the roof of a short cavern. He attributed solution, sapping and collapse as the processes in action.

J. S. Hook (1914, p. 61-64) proposed that some of the phosphate deposits of Tennessee were the residue of solution on the limestone bedrock surface. He described the stages of development of pockets of phosphate as the enlargement by solution of joints in the limestone. The enlarged joints he called "cutters."

N. M. Fenneman (1916, p. 72) noted the solution effects on limestone interbedded with shale in the Cincinnati, Ohio area. He pointed out the origin of solution groves (ramifying channels of Fuller, 1908, p. 12) along bedding planes, especially above an impermeable shale, and the development of solution channels along joints in a confined limestone.
C. E. Siebenthal (1916) recognized the existence of a fossil karst surface in the Joplin region which was an important lead and zinc bearing horizon. Although his paper adds little new information about the origin of limestone caverns, it is most interesting to illustrate the exhumation of a paleokarst landscape of pre-Pennsylvanian age (p. 205).

W. H. Emmons (1917) discussed ground water and its circulation as it concerned mining, with the following general remarks concerning the upper part of the ground water zone in general. He used the terms "water table" and "level of ground water" to describe the upper limit of the zone in which all openings in the rocks are filled with water, but recognized that this upper surface of the zone of saturation is a warped surface adjusted to the topography. Thus, it is shallow below a valley, but rises above that level beneath hills, in general flowing along the path of least resistance from the higher areas to outlets along the valleys. "Thus the water table may be considered a kind of indicator that registers the differences between the loss or leakage from the zone of saturation and the addition from the surface" (Emmons, 1917, p. 46).

"As the country is eroded, the water level moves downward and, within certain limits, it changes with the seasons. In dry years it is deeper than in wet years, and in dry seasons it is deeper than in wet seasons. The difference in elevation between the top of this zone in a wet year and in a dry year is normally greater under the hilltops than on the slopes and in the valleys. In deposits where the ground is open the level of the ground water probably changes with every considerable rain. Consequently there is a zone that is above ground-water level in dry periods but below it in wet periods, and in most hilly county this zone may be of considerable vertical extent. Thus, the water table oscillates, though in general it moves downward with degradation of the land surface." (p. 46).

The surface water which does not run off on the surface or evaporate, but soaks into the ground, passes downward and unites with the zone of saturation. "...a zone that lies above the zone of saturation and may be relatively dry during a dry period but soaked with water after a wet period - includes openings which in a relatively dry time are filled with air; consequently the water that soaks into the ground after a subsequent rain or snow is aerated and thus becomes a more active agent or solution. The downward movement of such water toward the zone of saturation has been termed the 'vadose' circulation. The depth or thickness of this vadose zone is variable, for its lower limit depends on the variable level of ground water." (p. 46) ...... It is, in the main, a zone of solution; consequently its rocks are open and circulation within it is comparatively rapid" (p. 47). Emmons thus defined vadose water as a body of water, with a fluctuating upper saturation level, but then placed its lower boundary at a water level. Perhaps he meant the lower boundary was the top of the permanently saturated zone, which might be nearly synonymous with base level.

The treatment by Emmons was but a beginning of a series of papers that discuss ground water terminology, R. A. Daly (1917) recognized that the phrases "descending water," "acid waters," "oxidizing solutions," etc. could be more useful scientifically than any term in a proposed classification. But he recognized that the value of terms depended upon exact definitions. He used such terms as connate, juvenile, resurgent, and magmatic to denote waters of
sedimentary, artesian or volcanic origin; but used "epigene" or "meteoric" to include seepage waters from the surface. Daly (1917, p. 494) admitted that he had used the term "vadose waters" to include all "seepage waters" or "waters of infiltration." But he now quoted Posepny (1894) as the originator of the term, but added his own words in brackets, as follows: "that part of the subterranean circulation bounded (below) by the water-level (water-table)," claiming that Posepny contrasted it with 'deep underground circulation,' below the water table. "Thus, all seepage waters or waters of infiltration, fresh or marine, are divisible into two physical parts, separated by the water-table: vadose above and phreatic below." (Daly, 1917, p. 495).

Daly accredited Daubree (1887, p. 19) with inventing the term "phreatic" from the Greek expression for "well," which Daly thought meant seepage water and particularly that below the water table, that is, "the infiltrated waters are bounded above by the water-tables," (Daly, 1917, p. 495).

Although this paper is concerned primarily with the American literature on the origin of limestone caverns, it is impossible to entirely ignore foreign works and the influence they have had on domestic authors. E. M. Sanders (1921) translated and over edited a summary of a paper by Jovan Cvijic that described the cyclic development of karst topography and caverns in Yugoslavia. Prior to Cvijic's work two different theories regards the subterranean waters as circulating continuously, all irregularities being explained as due to siphons which force up the water, the stagnant water being regarded as a merely temporary accident. The other theory holds that there is a saturation level in the limestone mass, below which all the crevices of the limestones are filled with water continuously, the only circulation that exists being the descent of the rain that passes through the porous limestone until it reaches the saturation level, after which it is stagnant," (Sanders, 1921, p. 595-596).

Cvijic recognized three hydrographic zones in limestone:

"(1) The zone immediately beneath the surface is composed of channels and reservoirs which transmit water in time of storm but are usually dry.

(2) The next zone is intermittently dry and wet; its caverns and channels may be flooded for considerable periods but not permanently.

(3) The lowest zone, situated immediately above the junction with the underlying impermeable strata, has permanent streams and reservoirs which are always full of water. There are many modifications of the ideal scheme due to geologic structure and other causes." (Sanders, 1921, p. 596-597).

Cvijic established four stages of karst development (Sanders, 1921, p. 597-604):

(1) Youthful - development of imperfect underground drainage causing abundant surface runoff, progressive loss of surface drainage.

(2) Maturity - underground drainage fully developed in a network of caverns and solution channels.

(3) Late maturity - limestone is gradually stripped off the underlying impermeable strata.

(4) Old age - return to normal surface drainage on the impermeable strata with isolated remnants of the original limestone mass in places.
"In the early stages of youth only one hydrographic zone is established; and not until maturity is reached are three zones developed, although toward the end of the period of youth two zones may be distinguished - an upper zone which is flooded intermittently and a lower zone which is always completely saturated" (Sanders, 1921, p. 601).

C. A. Malott (1921) described two instances of surface stream diversion within an area of a few square miles in Indiana, primarily to show two different conditions leading to diversion of surface streams to subterranean routes. In one example the surface stream of a large surface valley, a karst valley, was diverted or pirated down the dip of the strata through subterranean channels into another stream, which he considered to be a case of subterranean stream piracy. The other example was diversion of water from a stream through a limestone meander neck back into the same stream, a case of "self-capture" which he termed as a "subterranean cut-off" (Malott, 1921, p. 207 and 210).

Malott (1922, p. 189-190) repeated ideas similar to those of Greene (1909), Matson (1909), and Beede (1911), however, he expanded the idea that vertical solution channels become sinkholes and perhaps swallowholes for sinking streams; while collapse sinkholes are produced when the cavern passage is enlarged by solution and erosion to undermine the roof of the cave. He also indicated that porous limestone would generally contain poorly defined caverns in comparison to those formed in dense, compact, but well jointed limestones. A limestone plain or plateau that has been uplifted after peneplanation and entrenched by major streams would provide the essential relief to allow water to descent into the limestone and drain out to the surface streams at a lower level.

O. E. Meinzer (1923) published an outline of hydrologic terminology with terms and definitions that he hoped would settle some of the uncertainty that had prevailed in the past. This paper became the standard reference for the United States Geological Survey and many geologic authors in subsequent years, and some of the terminology has been used extensively by researchers on the origin of limestone caverns.

The "zone of aeration," the zone of bedrock in which the openings are not (except temporarily) filled with water under hydrostatic pressure, overlies the "zone of saturation" in which the openings in the bedrock are filled with water under hydrostatic pressure (figure 2). The two zones are separated by the "water table." The water in the openings in the zone of aeration is "vadose water," while water in the zone of saturation is "ground water" or "phreatic water," "Water in transit from the surface to a zone of saturation may for convenience be regarded as passing through a zone of aeration or may be regarded as an irregular and perhaps temporary projection of the zone of saturation" (Meinzer, 1923, p. 22-23). Water that enters the bedrock from the surface as a result of precipitation is "meteoric water" (p. 31).

The rise or decline of the water table, that is, fluctuation of the water table, is the "phreatic rise" or "phreatic decline," or the "phreatic fluctuation." This movement is caused by irregularities of rates at which (meteoric) water is taken into and discharged from the zone of saturation and can be called a "phreatic cycle." Daily, annual, and secular cycles are recognized, the latter covers a period of years that are predominantly rainy and years that are predominantly dry. "The belt of fluctuation of the water table, or the belt of phreatic fluctuation,..., because of the fluctuation of the water
J. Bridge (1924) concluded that the pulsations of ebb and flow springs, or periodic springs, in the Ozarks were caused by natural siphons, perhaps influenced by changes in barometric pressure or air leaks in the siphons.

N. H. Darton and S. Paige (1925, p. 8) described the origin of Wind Cave in the Black Hills of South Dakota. "The cave has been developed by solution of the rock by underground water containing carbonic acid gas and soil acids, which formerly flowed through crevices along the joint planes and gradually enlarged them into tunnels but which now follows other courses at deeper levels."

W. T. Lee (1925), one of the explorers of Carlsbad Cavern, New Mexico, presented a general discussion of solution features in that area. He noted that large amounts of material had collapsed in Carlsbad Cavern, and partly been cemented into place with dripstone following the excavation of the now partly filled original passage. He applied the same theory to cavern zones of active subterranean water circulation along the Pecos River. He particularly noted that surface debris, soil, sand, gravel, etc., was washed into the subterranean openings through the sinkholes by active streams and by slumping.

A. R. Addington (1926, p. 309-310) noted that abandonment of the now dry passage of Marengo Cave, Indiana, was caused by deepening of the valley into which it was tributary. Accordingly, the cave was formed by the downward and outward circulation of ground water derived from the dissected upland above and adjacent to the cavern. He also noted that collapsed material that falls into the cave stream may be removed by solution.
C. A. Reeds (1926) indicated the origin of Endless Cavern in Virginia by a subterranean stream that had formed two levels related to uplift in the Shenandoah Valley.

G. W. White (1926) conducted a cave survey of Ohio in which he described about a dozen limestone caverns. White very briefly stated that they were formed by acidic water and erosion by a stream. Enlargement of most of the caves ceased with burial beneath drift of Pleistocene age (p. 76).

A. R. Addington (1927) presented a special case for the origin of a solution cavern in limestone when he proposed that a cave in Indiana was formed by meltwater overflow from a glacial lake that spilled into a valley underlain with limestone. The joint control passage developed rapidly while the subterranean passage received more water than it could carry, but later, with a loss of water supply when the lake drained, it contained only a small stream. This paper is one of the earliest to recognize a climatic factor or change concerning the origin of a cavern.

J. M. Weller (1927) prepared one of the first reports on the geology of the Mammoth Cave area in Kentucky. He pointed out that adequate data on the caverns in the area was lacking, but nevertheless he presented some ideas on the development of limestone caverns in the area. Although some of these ideas are not now considered valid, they are of importance in retrospect for the bearing they may have had on subsequent theories.

Weller (1927, p. 42) summarized his more important criteria for the development of underground drainage in limestone as follows:

1. Sink holes and caves are best developed in a thick series of massive, compact, and rather pure limestones which lie high above the main lines of surface drainage.
2. Surface waters diverted underground through sink holes and crevices are carried off through primary channels which are developed at the surface of the ground water table.
3. These primary channels, by both solution and erosion, cut themselves deeper into the limestone and lower the ground water table.
4. Secondary channels develop below the ground water table, which they eventually lower to their level.
5. The positions of streams in primary channels is unstable when secondary channels have reduced the level of the ground water table below them, and they seek new courses at a lower level.
6. The ground water table is continually lowered by downcutting of the primary channels and the development of secondary channels until the local base-level is reached.
7. Complete stability of underground drainage is attained only when the ground water table has been carried down to base level and the underground streams have become adjusted to this level.

Weller considered the development of the secondary channels which were slightly enlarged solution openings in the limestone, as the most important process in the development of great cave systems. The circulation of the ground water is caused by the hydrostatic head or the height which the ground water table stands above local base level.
Weller said that the water which descended into joints in the bedrock was halted either by an impervious bed or by reaching the water table, then moving laterally in either case. An increasing amount of surface water enters the channels as solution enlarges them, thus further enlarging them, solution being aided by erosion as soil is washed into the openings. He also thought that water at the surface of the water table had a tendency to flow laterally, however, with some slow movement downward and outward below the water table. He added, perhaps erroneously, that the slow movement of the water caused greater solution of the limestone because of its more intimate contact. Thus, the channels which offer the freer movement towards an outlet enlarge most rapidly and serve as a line of drainage for the surrounding rock. The channels enlarge further and drain the ground water table down to their level. "As this process progresses the waters flowing in the channels developed at the surface of the ground water table seek new passages downward and the old channels are eventually left dry and deserted above" (Weller, 1927, p. 45-47). Weller indicated that the ground water level may also be lowered by the solution and erosive action of the cave streams which flow in channels at its surface cutting them deeper into the limestone and thus lowering the ground water level to base level. He added, the main subterranean channels can not be reduced below base level. He apparently considered base level to essentially coincide with the groundwater level. Weller made no mention of a fluctuating condition of the ground water level. Thus, it seems obvious that his primary channels at the water table are actually abandoned cavern base levels or perhaps overflow channels for storm waters, causing a rise of the water table, in excess to that which could be accommodated by the secondary channels below the water table.

O. E. Meinzer (1927) reported on the large springs in the United States, including springs issue from limestones, primarily those in Florida and Missouri. Meinzer (1927, p. 6-8) thought that the water that discharged from the large springs was principally meteoric water that flowed at shallow depths, not more than a few hundred feet below the surface. He believed that caverns were formed above base level, if not above the water table, for he states that "Where the land has not subsided and nothing has occurred to raise the level of the streams and the water table, a nearly complete and perfect underground drainage system may be developed, with very cavernous rock above the level of the underground drainage and very tight rock below this level." This drainage system "lacks storage capacity and rapidly discharges its water after a rain. ...Where a limestone country has subsided with reference to sea level, great systems of caverns may be submerged beneath the water table and function as huge subterranean reservoirs that equalize the spring discharge..." Meinzer thought that the subterranean drainage systems that feed the large springs in Florida were formed at a time when sea level was lower. In spite of his general thesis, Meinzer stated, "The limestone must of course, contain large solution channels produced by active and long-continued circulation of ground water."

G. M. Hall (1928, p. 58-59) made a study of a limestone area in the Shenandoah Valley of Virginia where he reasoned that caverns were formed at levels that correspond to erosion levels formed progressively by regional uplift in stages. The cave passages were occupied by ground water which dissolved them near the water table, for most of the carbon dioxide was used up before the water percolated very far. The ground water level dropped below the caverns, but small amounts of water now enters them in wet seasons. The
annual range of fluctuation of the water table varies a few feet in some years, but varied from 50 to 140 feet over a period of a few years (Hall, 1928, p. 56). These differences in water level are generally minor compared to those caused by uplift and rejuvenation.

A. K. Lobeck (1928) prepared a popular account of the physiography of Mammoth Cave at the time it was being established as a National Park, and immediately following Weller's work. Lobeck avoided the complicated theories of Weller and stated that cave levels corresponded to stages of downcutting along Green River, to which they were tributary.

H. T. Stearns (1928 and 1947) prepared a guide to the Craters of the Moon National Monument, Idaho, in which he listed or described 17 caves, actually lava tubes. Lava tubes are formed as the surface of an active lava flow solidifies, but within the flow continues, and as the walls solidify, a tube is formed. Some of these branch and rejoin, depending upon the flow as the inner lava flowed down slope to the advancing lava front. Portions of the roof may collapse to form an entrance or natural bridge (p. 11-12).

O. E. Meinzer (1929) added to his earlier views by emphasizing the low gradients of underground streams developed by solution and not erosion, and that subterranean streams can be compared somewhat to surface streams. "The underground streams, like the surface streams, become adjusted to some base level, such as... a major surface stream, into which they discharge, and they tend to become graded to this base level by the laws of stream gradation. Thus, in a karst region there is developed a sort of underground peneplain which bears close relation in its genesis to a surface peneplain... In so far as a limestone area has a water table, the water table is adjusted to the underground streams, not the underground streams to the water table." (original publication not seen, data taken from Johnson, 1933, p. 35).

R. T. Walker (1928) discussed the origin of limestone caverns by both cold descending waters and hot ascending waters pertaining to the deposition of ores in pre-existing cavities. He claimed that caves formed in the past as well as present time within limestones where suitable conditions prevailed. Walker explained most horizontal caverns and some vertical openings formed as a result of solution by descending and laterally flowing water at the water table, with the greatest volume of water migrating by gravity flow at the water table towards a spring at the surface. The water moves through joints and bedding planes, which he called bedding faults. He placed some importance to collapse of the walls and roof of the conduits, with either removal of the collapsed material by solution if it fell into the cave stream, or the accumulation of debris to form a cave fill or cave breccia. Walker recognized that sediments could obstruct conduits, forcing the water to develop new routes, and that the different levels of cavern passages are related to former water table levels established by surface streams.

A. N. Murray and W. W. Love (1929) studied the effects of organic acids, primarily carbonic acid derived from bacterial decomposition of plants, on limestone and concluded they were very effective, particularly above the water table.

A. C. Swinnerton (1929) abstracted his theory of cavern origin, resulting from studies in Kentucky and Bermuda.
"In the simplest case precipitation passes more or less directly downward through the openings in the rock to the water table and then moves laterally in the fluctuating top of the water table into the surface drainage channels. Insufficient caves may occur both above and below the water table as temporary phases of the adjustment of subsurface flow to the level of the surface streams. But it does not seem possible that continuous systems of caves can develop below the zone of actively circulating ground water - that is, below the water table. The water table is dependent on the level of the surface streams; these in turn depend on the regional base level." Thus, cave levels may develop at several altitudes, but continuous systems representing the lowest level of the main cave stream approximate the base level of the area at the time they were excavated.

Swinnerton failed to account for fluctuations of the water table, a situation which he remedied in 1932.

B. C. Moneymaker (1930, p. 83-85) described the origin of caves in Tennessee by adopting some of the work of Nelson (1912) and Blatchley (1896). Generally he believed that the acidic surface water entered the ground through sinkholes and that the combined subsurface flow, aided greatly by corrosion, formed a cave stream that excavated the cavern.

C. A. Malott and R. R. Shrock (1930, p. 268) reviewed earlier theories concerning the origin of Natural Bridge, Virginia, and made their own field study. They concluded that the bridge was a remnant of a collapsed subterranean cut off that enlarged as a result of stream entrenchment extending along the grade of the cut off.

R. W. Stone (1930, p. 62), in a survey of caverns in Pennsylvania, stated that caves were dissolved in limestone by rain water which carried carbon dioxide derived from the air and soil.

"A cave may be along one general level if it was developed close to a stationary water table, but many caves have several levels. Different levels may be produced by solution working along a more soluble bedding plane high above ground water, the down joints to a lower soluble bed; or after a general level has been developed at ground water level, a deepening of a nearby valley by normal erosion and lowering of the water table would permit development of a lower level. ...The effect of abrasion by circulating water underground is very little in comparison with solution."

W. M. Davis (1930) challenged all the earlier theories concerning the origin of limestone caverns, which basically claimed caverns were formed at or above the water table. Davis said that his theories were based from conclusions derived from reading reports or correspondence of others, although he had been in some caverns around the world, and regretted that he could not study his subject first hand in the field, but he hoped that others would do so.

Davis reviewed the available literature on the origin of limestone caverns citing and restating the older works, and concluded that all of the theories presented postulated cavern development in a zone at or above the water table, and above the local base level. Davis termed this mode of origin the one cycle theory of cavern development, that is, the caves were formed within one epoch.
of regional downcutting. He noted however, that earlier writers had considered caverns to form in two stages, excavation and deposition, and that some major change caused the transformation.

"It is not to be questioned that solution by subsurface water is most active when the water is well charged with carbon dioxide;" but rapid runoff into sinkholes, even in a forested area, is little carbonated. "Not until it has reached the lowest gallery above the water table or has sunk below the water table into a deep-lying, ground water gallery will it have leisure to dissolve all the limestone that it can, even though that may not be much" (Davis, 1930, p. 505). "Moreover, the imperfectly carbonated vadose water may, after its flow is concentrated in enlarged low-level galleries as above explained, run out of them hurriedly before it is saturated with the little limestone that it can carry," (p. 506). ...the concentrated underground stream of vadose water may accomplish more work in the low-level galleries by corrosion than by solution; although solution may still be the chief duty of slowly percolating, non-concentrated filaments of carbonated vadose water above the small, high-level galleries; and it will still be the whole duty of the slow-moving ground water below the water table." (p. 506).

"During the early stages of cavern development when underground joints and partings are in their least opened or embryonic state, solution although acting slowly acts alone. Only as the joints and partings are enlarged by solution sufficiently for trickling streams to follow them will corrosion take a share with solution in their future enlargement. But from that time on corrosion rapidly gains in efficiency until it seems to be the more potent of the two processes," (p. 521). In general he concluded that vadose water was incapable of enlarging caverns by solution because the trickling water became saturated and therefore deposited mineral matter in the cavern.

Davis challenged the concept of development of cavern levels at grade with local base level (1930, p. 517-518). "When it is remembered that large caverns are several miles in length, and that the gradient of graded cavern streams is presumably low because their load is small, the departure of a maturely graded stream from the stratum which initially guided it must be of no insignificant measure; nearly always enough (except perhaps near the gallery head) to permit the development of a mature corrosional branchwork from an original solutional network. Moreover, inasmuch as such departure is greater along the trunk stream than along its branches (except in very old stream systems), a coincidence between attitude of strata and the grades desired by mature streams may be regarded as geologically impossible."

Thus, Davis (1930, p. 517-518) argued that one cycle caverns, as described by earlier workers, or rather his interpretation of their works, were not possible, "for large, first-cycle caverns in dense limestones are unknown," (provided of course that the Davis theory, the two cycle theory, was correct). Davis predicted, however, that if caverns were ever found that had developed in one cycle, they would have a history of development in four epochs, as follows:

1) gradual development of a three dimensional network by solution along joints and bedding planes.

2) development of a branchwork low within the earlier network by erosion by concentrated vadose streams, graded with respect to local base level along local surface streams.
Davis invented a theory based on the assumption that vadose water which reached the water table could not move laterally, owing to a lack of openings there, but rather moved beneath the water table in a deep curved motion, "provided the crevices have been opened enough to transmit hydrostatic pressure within a homogeneous rock" (p. 549). He postulated a two cycle theory of cavern origin, based on development below the water table, with five epochs, as follows (p. 581-582):

1. enlargement by solution of a deep seated network of small water filled shafts (joints) and galleries (bedding planes).
2. enlargement of the network, still water filled, to a network of mature dimensions (caverns).
3. regional elevation and withdrawal of the water.
4. deposition in the dry galleries.
5. degradation of the cavern and surface to a peneplain.

Davis assumed that nearly all cavern development occurred beneath the water table which stood near the surface of a peneplain in a late stage of development, that is, it was approaching a stage of very little relief. The solvent power of the descending carbonated vadose water is not depleted at shallow depths and therefore reacts at greater depths. "Hence the solutional enlargement of a deep-lying network of interconnecting shafts and galleries by ground water, even to the point of widening the galleries irregularly into great chambers in the most soluble layers... It is possible that some corrosional enlargement may also take place when vadose streams descend below the earlier level of the water table" (1930, p. 550-551). The concentration of water movement along certain parts of the embryo network is attributed to differential solution (p. 553). A weak convective force is established by water which has dissolved limestone, therefore, it is denser, for the denser water sinks and is replaced with water which contains less limestone in solution. The solutional attack on the walls and ceiling of the gallery continues, even though exceedingly slow, until the water is well charged with limestone. Some solution will take place even when the imperfectly carbonated vadose water is added to the ground water, for limestone is slightly soluble even in pure water (p. 554). Davis stated that faster moving vadose water and slow moving ground water should be analyzed.

Davis (1930, p. 601-602) claimed that the amount of vadose water available from sinkholes for the development of vertical shafts in limestone is too small, and although he did not fully accept the idea, he thought their formation by solutional convection was possible.

Davis presented a series of discussions of the origins of various caverns that had been described in the literature, quoting statements or paraphrasing ideas, somewhat out of context with the original works, to prove his own theories of the origin of caverns. His continued insistence that a drainage network developed at depth beneath a peneplain was based primarily on work by F. H. King (1899) of which Davis said, "...in an early stage of an erosion cycle, descending vadose water does not turn to a lateral movement on reaching the water table but continues its downward movement..." (Davis, 1930, p. 608). More recent studies, for example Bedinger (1966), show that maximum flow is at shallow depth beneath the water table.
Although Davis noted changes in the level of the water table due to rejuvenation and uplift, especially in relation to stages of development of karst features, he failed to ever mention any aspects of a fluctuating water table due to precipitation, either daily, seasonally or annually.

Davis, however, did not insist that his two-cycle theory be proved correct especially since it failed to account for multiple levels in some caverns, but emphasized that all theories should be considered. "Whatever theory is under consideration, its relation to the general physiographic evolution of a cave district should be clearly defined, and a provisional place should be found under it for every item of observed cave form" (p. 623).

W. M. Davis (1931) summarized his lengthy treatment of 1930, deleting much of the extraneous data which was paraphrased inaccurately from other authors. He presented essentially no new ideas, but was perhaps more concise. He did define the difference between embryonic network passages and shafts and galleries by indicating that the size of the latter was larger than a stove pipe or a barrel (p. 328). Thus, we might consider a cave passage to be any opening large enough to permit passage of a man, even though it may be a tight fit. In view of the fact that his early paper was somewhat long and confusing some of the important points of his summary are reviewed here (Davis, 1931, p. 329-330).

"As with vadose water the movement of ground water must be at first chiefly along intersections of joints with each other and with bedding planes. A complex, angular three-dimensional network of fine crevices will therefore be developed in this case also, but more slowly than by vadose water, because deep-lying ground water is almost stationary; also because deep-descending water will be partly charged with calcite at the beginning of its descent... Unlike the high-level crevices below the water table will be deserted, however small they are, by the withdrawal of water to lower and larger ones. Yet unlike the vadose branchwork, gallery floors here will not be graded; they may ascend and descend somewhat irregularly."

"The time factor here is of great importance. The excavation of deep-lying caverns in a limestone region by ground water solution may continue during an entire cycle of erosion... In the tomb-like stillness of large galleries, solution in slow-moving may be aided by diffusion and also by a slow convection, due to the sinking of saturated water in contact with the roof and walls and its replacement by less saturated water from below...."

Withdrawal of the water from the caverns below the water table could occur in two ways, either by degradation of the valley floors, thus draining the ground water, or by regional uplift, as indicated by Grund (1903) (Davis, 1931, p. 330).

W. M. Davis and C. Killingsworth (1931) abstracted their theory of the solution and deposition of deep seated, slow circulation, part of which is presented here. "If the return of deep-lying ground water to the water-table level involves a considerable ascent with a correspondingly greater decrease of pressure, it may become saturated before reaching the water table; and it should then deposit calcite crystals on the walls of the passages or cavities through which it ascends. The crystal lined caverns of Missouri may thus be explained. ..."
A. M. Piper (1932) concluded, from studies in the Highland Rim Plateau and the Nashville Basin of north-central Tennessee, that if deep circulation could pass through limestone rapidly it could dissolve caverns, in contrast to the slow circulation postulated by Davis (1930), but that such conditions were not known to have existed in Tennessee (Piper, 1932, p. 74). Piper instead tended to accept the fluctuating water table theory and changes of base level indicated by Swinnerton (1929).

Piper (1932, p. 2k) noted that the caverns were not fortuitous but develop a definite drainage system tributary to surface streams. Free circulation is essential so that saturated water in planes in joints and bedding the limestone is replaced by unsaturated water, but mechanical erosion aids the process in turbids waters (p. 71-72). "Where a body of ground water in limestone has a free upper surface or water table, the limestone is presumably dissolved most rapidly in the zone between the highest and lowest positions occupied by the water table in its seasonal fluctuations, for in that zone the ground water percolates relatively rapidly and is most likely to contain natural acids. The limestone is also presumably dissolved above the water table and to a relatively shallow depth below the water table, for there likewise the ground water circulates rather freely. However, the ground water at considerable depth below the water table probably circulates slowly and before it moves a great distance becomes saturated..." (Piper, 1932, p. 73-74).

Piper (1932, p. 78) deemed earlier concepts of stages in the erosion cycle somewhat unsatisfactory, "for they imply that certain minor forms invariably accompany each of the major topographic forms by which the stages are best known. ...It seems more rational to analyze the cyclic history of the surface and underground drainage systems independently, though by analogous stages."

(1) First or youthful stage - solution channels are first developed in the slopes adjacent to deeper youthful surface valleys and then extend headward beneath the uplands. The underground divides may or may not coincide with the surface divides, or they may shift laterally with seasonal or annual variations of precipitation (p. 79).

(2) Second or mature stage - surface valleys are widened and their beds erode down to a profile of equilibrium as they aggrade their lower reaches. Those caverns which collect the largest amount of surface water and those which discharge at the lowest points enlarge the most rapidly, lowering the ground water divides (p. 80).

(3) Third, final, or old age stage - surface drainage at equilibrium parallel by subsurface drainage at equilibrium, a peneplain of solution, resulting in a return to surface drainage by collapse valleys (p. 81).

Piper (1932, p. 82-86) then related subterranean drainage development to the geologic and physiographic history of north-central Tennessee.

A. C. Swinnerton (1932) questioned the conclusions of Davis (1930 and 1931) and Davis and Killingsworth (1931) and the misinterpretation Davis (1930) made of the previous work of Swinnerton. In fact, Swinnerton clarified numerous liberties Davis had taken in incorrectly paraphrasing and inappropriately applying the work of earlier authors to prove his theories. The criticism of the literary larceny and scientific inaptness of Davis by Swinnerton is subdued, but justified.
Swinnerton challenged Davis' major hypothesis when he showed how Davis had missapplied the ground water motion theory of King, (1899, p. 95), which was concerned with the migration of water through porous sandstone, that is, a homogenous medium, which limestone bedrock is not. Swinnerton quoted King, part of which is repeated here:

"The water which enters the ground...moves directly downward until the ground water surface has been reached, when it raises that level and at once augments the pressure. If the land were everywhere level the effect of percolation would be simple to raise the level of the ground-water surface; no lateral movement would be possible except under such conditions as permitted the ground-water level to be lowered more rapidly in one place than in another by surface evaporation aided by capillarity. With the differences of level, however, which are always associated with topographic forms...it is evident that the water which sinks beneath the surface of land areas must tend to accumulate beneath the places where it has fallen until a sufficient pressure has been developed to force it to flow through the soil and rock toward whatever drainage outlets may exist" (King, 1899, p. 95).

Swinnerton then described how Davis had greatly exaggerated rather than modified, the illustration King had prepared to show the motion of deep seated flow, in glacial deposits in Wisconsin (Figure 3). "Davis modifies King's diagram by increasing the depth of deep circulation below the highest point of the water table three times the relief shown, retaining, however, four times the relief as the amount of maximum lateral movement" (Swinnerton, 1932, p. 670) (figure 4). Swinnerton also discussed how Davis had assumed, not proven, the depth to which water could circulate from data that was inferred by Bain (1901, p. 104) in Missouri, which was actually an artesian situation (Swinnerton, 1932, p. 670-671).

Swinnerton contrasted the concepts of ground water circulation of Davis with those of Finch (1904, pp. 193-252) who distinguished three zones: Zone I, the uppermost belt of mobile water; Zone II, the mobile portion of the saturated belt; Zone III, the static part of the saturated belt. Swinnerton (1932, p. 672-673) then quoted Finch, some of which is repeated here:

"The depth of Zone I varies with the topograph, rainfall and the nature of the rock. In low topographic areas it may be zero, in areas of extreme relief it may be hundreds of feet..."

"Zone II embraces that part of the belt of saturation, in any region, which has a means of horizontal escape and discharge. The means of discharge established a continuous condition of gravitative flow."

"The upper limit of Zone II, which is the upper limit of rock saturation or 'water level,' is exceedingly variable."

"Below Zone II, the zone of discharge, the state of underground water is only vaguely understood..."
Figure 3. Diagram to show pattern of groundwater flow (F. H. King, 1899, p. 99).

Figure 4. Pattern of groundwater flow of King modified by Davis (1930, p. 549).
"The top limit of Zone III, ..., corresponds normally to the lower limit of notable mobility in the saturating water body, or the upper limit of static water."

Swinnerton more accurately applied the work of Bain (1901, p. 99-100) which Davis (1930, p. 549) had grossly modified without reason. Swinnerton essentially agreed that hydrostatic circulation is theoretically downward, but the greatest flow is in the direction of least resistance, and the direction of least resistance is along the shortest route to the nearest outlet. Water in limestone is contained within a lattice of intersecting joints. Thus, it is no more confined laterally than downward, and if its descent is impeded it will move laterally (Swinnerton, 1932, p. 674).

Swinnerton noted the importance of the fact that precipitation is sporadic and that the water-table consequently fluctuates, raising at times of heavy rain and declining as the water moved to an outlet (p. 674). He reasoned that more numerous and more open joints near the surface favor increased flow in the upper phreatic zone (Zone II of Finch) compared to circulation deep into the zone of saturation (Zone III of Finch) (Swinnerton, 1932, p. 675-676). "The phreatic water, close to the water table slope adjoining a river valley, must drain toward the stream level, since that is the lowest level in the direction in which the water wall is least supported" (Swinnerton, 1932, p. 676).

Swinnerton also challenged Davis on the basis that the great volume of weakly acidic water that moves through the fluctuating water table zone dissolves more rock than the slowly moving nearly saturated waters in the static saturated zone. He used Matson's chemical data (1909, p. 212-215) to demonstrate that springs discharging from the water table zone were capable of dissolving each year a cavern three by six feet in cross-section and over 120 feet long beneath each square mile of the Blue Grass area of Kentucky (Swinnerton, 1932, p. 678-679). Thus, he concluded that large quantities of water are more effective that Davis (1930, p. 506) thought swiftly moving streams were capable. Swinnerton (1932, p. 683) particularly emphasized that water becomes saturated as it moves through the limestone, thus, it can not acquire additional carbon dioxide no matter how long a time or how far it may move as deep phreatic water.

Swinnerton, having countered some of the major hypothesis of Davis, proceeded to explain the development of limestone caverns within a fluctuating water table (1932, p. 684-686). Generally, as surface streams deepen and cut headward, they cause a withdrawal of water from the adjacent limestone bedrock, draining the joint network to a level at grade with an outlet that is tributary to the surface stream. Abundant rainfall fills the joint network and the water table rises, but the water escapes to the outlet more readily than it descends to the zone of saturation. The more direct openings localize the flow and the larger of these expand at the expense of the smaller ones. The system extends headward as the passages on the outlet end enlarge.

Swinnerton, (1932, p. 688) cited N. Krebs (1929), on the development of the Karst area in Yugoslavia, to indicate that the theories of Grund, cited by Davis, were not universally accepted.

C. A. Malott (1932) prepared a descriptive report on part of the Lost River area in Indiana, in which he outlined the origin of the subterranean system by vadose flood waters. Malott (1932, p. 314) agreed that caverns of
the Lost River system had developed below the water table, as cited by Davis (1930, p. 540-542), but he argued that the chief excavational development took place by diversion of stream waters from the surface rather than during a long period of solutional development below the water table. Malott gave five factors for the development of network system of passages of Lost River.

1. Development of sets of joints in dense and well bedded limestone.
2. Solutional enlargement of joints to form an embryonic network below the water table.
3. The network is maintained above the water table by floodwaters which rise in the system and fill it completely.
4. The water table is lowered as surface drainage downcuts, thus the subterranean system develops slightly lower primitive routes. The earlier well developed passages are filled during high-water periods.
5. Locally, the system may be ponded by collapse, forcing the waters to follow other passages.

Malott applied his theory only to the network cavern passage system of the Lost River area, for which he had pertinent geologic data.

R. W. Stone (1932, p. 125-129), in a revision of "Pennsylvania Caves," modified his earlier views on the origin of limestone caverns and contrasted the highly jointed, steeply dipping limestone of Pennsylvania with the less jointed flat lying strata of Indiana and Kentucky. He recognized some solution enlargement of openings above the water table, but seemed to think caverns were formed by vadose water which had become ground water and flowed through the limestone as sizable streams below the water table. Yet, he states that slower moving ground water is a greater solvent than vadose water, concluding that time and slow circulation to furnish fresh water are important. Stone (p. 130) noted several features of caverns; such as erratic ceiling shapes, projecting soft shaley layers, and inverted ceiling pits; which he assumed were formed by solution, not erosion, at a time when the passage was filled with water.

L. Martin (1932, p. 93-97) mentions 14 caves in the Driftless Area of Wisconsin and concludes that most caves formed prior to glaciation within the glaciated part of the state were eroded away by the ice sheets. He stated simply that caves were formed by groundwater solution.

J. Henderson (1932-33) published a two part generalized work on caverns in which he briefly reviewed the theories of cavern origin. He included a partial catalog of caverns in the world, accompanied by a bibliography. The papers are brief, if not terse, but the data is useful.

W. D. Johnson (1933) in a report on the caverns and ground waters of northern Alabama more or less combined the ideas of Matson (1909) and Meinzer (1923 and 1929), noting that solution is most effective above the water table, and that solution below the water table would be effective only under artesian conditions. Johnson particularly attributed the development of vertical solution fluting to descending vadose water, giving the development of the Natural Well as an example (p. 34-36). Natural Well contains vertical solution openings over 150 feet high. Johnson (p. 48-74) described over twenty caverns, some of which he related to the local geology and special conditions.

W. M. McGill (1933) presented a brief mention of the origin of caverns in Virginia. He related the cavern levels to stages of uplift along the Valley
of Virginia, each level being dissolved and eroded by rain and ground water, mainly along the strike of the steeply dipping limestones.

E. R. Harrington (1934) proposed that the origin of ice of some caverns was due to free circulation of cold air into the cavern in winter and lack of circulation in the summer.

J. H. Gardner (1935) presented the "static water zone" theory of the origin of large caverns, particularly Mammoth Cave, Carlsbad Caverns, Lost River in Indiana, and a sinking stream system in Kentucky. Gardner noted that these larger caverns were formed in limestone that dipped at a rate of 50 feet per mile or less (p. 1256).

Gardner (1935, p. 1265-1266) questioned the presence of water filled caverns below the water table, as Davis postulated in the two cycle theory, because of his drilling experience in which he found none. Yet, he felt that the simple one cycle theory of Matson and Swinnerton was not adequate to explain truly large caverns. He did not agree with Malott's concept of cavern formation by vadose flood waters (p. 1262).

Gardner (1935, p. 1257) stated that in slightly dipping limestone bedrock ..."where there are underground streams, they flow, in general the direction, with the dipping strata; more rarely, for short distances with the strike but probably in no case for any appreciable distances with the strike but probably in no case for any appreciable distance in the direction of the rise of the beds. ...Subsurface streams follow caverns which they themselves produced, for the two are cogentic." He also stated that caverns are found on the up dip side of valleys, leading to the conclusion that the cavern development was initiated by downcutting into susceptible zones during the process of base leveling. The original water in the soluble zones is connate water, or static water, which is tapped by the downcutting. The open joints and bedding planes are then enlarged at a rate dependent upon the acidity of the vadose or mobile water circulating down the dip of the strata through the soluble, porous zone which is filled during heavy precipitation (p. 1258) (figure 5).

Gardner (1935) indicated that some vertical openings are the result of sapping or piracy of an upper strata by a lower one. He envisioned a separate origin for pits and domes in which they were mostly eroded, rather than dissolved, by falling water (p. 1263).

Gardner (1935, p. 1266) thought that in some places water could be transmitted through permeable, less soluble, strata to lower more permeable and soluble strata. He also was the first person to include climate as important, indicating that most North American caverns probably grew most extensively during wet periods of the Pleistocene epoch (p. 1269-1270).

The work of Gardner, in a sense, could be considered little different than that of Matson or Swinnerton, except that he has placed more stress on deep downcutting by surface valleys and sapping of static zones by subterranean waters. Yet, in some places where deep, rapid downcutting by surface streams has occurred, he may be justified in that the cave system may have developed rapidly under a large area rather than progressively headward and lower with valley deepening, as indicated by Swinnerton and others.
Figure 5. Diagrams to show progressive development of limestone caverns by Gardner (1935, p. 1259).
C. R. Swartzlow (1935) proposed minor differences in the origin of ice in caverns in northern California than that offered by Harrington (1934). Swartzlow did agree, however, that the important factor was settling of cold winter air and lack of circulation in the summer.

M. M. Fidlar (1935) mapped and described a cavern in Indiana in which he recognized small primitive tubes that had been formed along joints and bedding planes, but declared that the larger cavern passage had been enlarged by vadose storm waters derived from a sinking creek in a karst valley (p. 159).

Wm. Von Osinski (1935) discussed the origin of sinkholes by both solution and collapse. He named and described the type "karst window" from Spring Mill State Park in Indiana.

E. R. Pohl (1936) discussed Mammoth Cave, Kentucky and claimed that the sand deposits, which were thought to be about 100 feet thick in some passages, were deposited by rapidly flowing water in solution passages that were formed earlier by slowly moving water. He related cavern development to changes in the rate of downcutting along Green River, which he contended was affected by backflooding of streams that carried melt water from the ice sheets during the Pleistocene to which it was tributary (p. 332). He concluded that the high, narrow cave passages were formed during periods of rapid downcutting and the broad chambers were formed during periods of arrested downcutting and the broad chambers were formed during periods of arrested downcutting. Deposition was caused by backflooding, during at least five periods to correlate with the deposits in the passages (p. 333).

Pohl noted that stream meanders may be the places of discharge of subterranean drainage where they dissect permeable zones beneath a cap rock on the up dip side of valleys. Thus he redefined the static water zone theory of Gardner (1935) as a breached artesian system.

H. P. Woodward (1936) and F. J. Wright (1936) argued that the Natural Bridge in Virginia was not a subterranean cut-off as explained by Malott and Shrock (1930). They explained the origin of the bridges by subterranean stream piracy, that is, a stream flowing at a high level was pirated or captured by another stream at a lower level. The argument concerning the Natural Bridge was not so much the method of development of subterranean drainage, but rather the succession of surface drainage changes through several erosion cycles.

A. C. Swinnerton (1936) studied the vertical shafts at Mammoth Cave and noted that they were each connected at their tops and bottoms with horizontal caverns. He concluded that in each series of domes each dome was formed successively by headward piracy of an upper level stream by a lower one in the course of adjustment to base level. They were partly enlarged at a late stage when they were partly air filled.

P. B. Stockdale (1936) proposed that the development of Montlake, Tennessee, was the result of the collapse of about 800 feet of strata into a cavern at or near the top of the Bangor Limestone. H. S. Sharp (1936) concluded that Mountain Lake, Virginia, which has a similar geologic setting, was not formed by collapse, although he considered the possibility, but rather by a landslide.
E. Steidtmann (1936) analyzed water seeping into a cave in Virginia and determined that the seeping water was most effective in dissolving limestone at the surface where the water first contacts the limestone. The vadose water commonly looses carbon dioxide as it descends, causing deposition where it enters an open cavern. He also concluded that the cave stream enlarged the passage by mechanical erosion, rather than by solution. His data and conclusions apply however only to seeping water, not to vadose flood waters or water within a fluctuating water table.

C. S. Adams and A. C. Swinnerton (1937) presented a compilation of data on the effect of carbonic acid on limestone, which they summarized as follows (p. 507):

"To explain observed ground-water concentrations of calcium carbonate in limestone terranes it is necessary as shown by the solubility-relations of CaCO₃ to account for a higher concentration of CO₂ in ground-water than can be explained on the basis of contact of water with normal atmosphere. This paper has indicated that a richly generating CO₂-environment exists in the soils containing bacteria, vegetation, and decaying organic matter. Water moving through this CO₂-rich zone dissolves CO₂ in accordance with its solution coefficient. It tends to retain its concentration, even though it may enter conditions where it is supersaturated, for several reasons, namely, the high energy required to permit escape of the gas, the slowness of diffusion of the gas to the surface-layer, the endothermic nature of the reaction, the retarding effects of colloidal particles, and the slow rate of decomposition of the bicarbonate ion. Ground-water, with relatively high CO₂-content thus retained, may travel to and through bed-rock crevices and is an effective agent in dissolving limestone, in enlarging openings, and in forming caverns, as well as transporting CaCO₃ in solution."

A. C. Swinnerton (1937) noted the elongation of sinkhole development down the dip in gently dipping strata and elongation parallel to the strike in steeply dipping strata.

R. A. Laurence (1937) noted the presence of several additional deep sinkholes, on the Cumberland Plateau in Tennessee similar to Montlake. He agreed with Stockdale that they were formed by collapse into caverns in the Bangor Limestone.

C. F. Tolman (1937) generally cited the concepts of Davis (1930) in a general discussion of cavern development. He did, however, modify some definitions and concepts. He defined "free ground water" as that ground water moving under the control of the slope of the water table, and "confined water" as that ground water which moves in strata or conduits under control of the head between the intake area and points of discharge (1937, p. 43). "Vadose and ground-water solutions are guided by fractions in the rock which may be gradually enlarged by solution, and a characteristic type of vadose and ground-water flow established in the openings thus formed" (p. 301). Tolman distinguished three types of limestone solution: (1) impervious limestone in flat-lying beds, (2) impervious limestone in inclined beds, and (3) porous limestone.
Tolman specified that less soluble limestone beds or shale layers in flat lying strata would act as barriers to downward movement of waters, and therefore prevent solution below them, but in inclined strata the water table is the most important barrier to the downward circulation and solution (p. 302). He also noted the movement of water through porous strata, such as dolomite and recent (Pleistocene age) carbonate rocks of Florida (p. 308). He attributed acidic vadose water with dissolving the passages, aided by mechanical abrasion. Cavern development is aided by "solution stopping," that is the undermining and collapse by solution of the walls and ceiling of the passages (p. 304). Tolman admitted the existence of openings below the water table, but stated they were not formed below it, they were only larged below the water table after being formed above it (p. 305).

C. A. Malott (1938) agreed that the theories of Swinnerton (1922) and Gardner (1935) present many of the conditions for the development of limestone caverns, but he did not think they gave underground streams diverted from the surface a paramount role.

"Primitive, illy integrated, and somewhat selective three-dimensional passage ways are developed in limestone regions below the watertable. Vadose waters under a flow-head develop underground flow routes from selected parts of the earlier prepared primitive systems. Fairly large streams are diverted from their surface courses into these underground routes. The diverted waters carve out and fully integrate the large caverns at or near the watertable. Th­fully developed caverns bear unmistakable evidence of the streams that coursed through them, though when long vacated they tend to fill with dripstone, be­come encumbered with fallen rock, and loose parts of their stem-carved floors as is well illustrated by the upper galleries of some large cavern systems" (Malott, 1938, p. 323).

Malott obviously failed to visualize the filling of caverns in a fluct­uating water zone by many small openings to the surface that could introduce as much water as a large sinking stream. His theory thus became the "invasion theory" of cavern development.

J. H. Bretz (1938) described several caves in the Galena Formation of the Dubuque, Iowa, area which he ascribed to origin by phreatic water. He believed that all of the caves, except one, had "never had a water-table stream or a direct gravity stream in them" (p. 841). Although all the caves, or mines in most cases, lie above deeply entrenched drainage routes, Bretz (p. 835-836) states that they are in no way related to any deep valleys that could take discharge from them, as was suggested by Calvin and Bain (1900). Yet, Bretz (p. 830, 832, 834, and 838) mentions clay fill, in several caves, which in places contains fallen limestone and galena chunks, that is strati­fied in part - for which he offers no explanation. He explains a high, narrow graded stream passage - in one cave as a vadose occupation of a phreatic cave, yet described numerous clay filled side passages with the contradicting ex­planation that: "There was insufficient volume of vadose water under this upland tract to keep all phreatic routes open, and clay entered with the down­ward-moving waters and filled most of the widened joints" (p. 840). Bretz also mentions a filled cave opening in the base of a cliff but then argued that the open cave beyond had no relation to the valley. "The clay fill con­ceals the egress route of the dissolving water. It descended below present and earlier water tables" (p. 839).
Bretz (1933, p. 833) cited small solution pockets in the roofs of some of the caves as evidence of maximum roof solution. "Solution to make these roof pockets occurred only because the cave was full of water at all times, not as a vadose stream may in flood time fill it to the roof." Yet he claims that similar solution pockets on the walls were dissolved away (p. 834).

Bretz states that, "No cave stream has used the aisles of any Dubuque cave unless it filled them all at the same time and in that remarkable anastomosis, it widened each set of barely open joints to a uniform amount for each system, most for the east-west joints, least for the quarterings. Even one of Swinnerton's water table streams could hardly make this remarkably uniform result" (p. 834-835). Thus Bretz himself implied the east-west enlargement, suggestive of solvent flow in that direction, was toward the entrenched drainage of the area, depending upon which side of the river the caves are located, or perhaps parallel to the dip of the strata. Bretz did not mention bedrock structural relationships of the caverns to the land or river surface.

S. W. Lohman (1938, p. 46-49) noted the solutional and erosional enlargement of joint networks to cavernous proportions in south-central Pennsylvania by subterranean streams that become adjusted to the base level of surface streams to which they are tributary. He indicated that some solution could take place at depth below the water table, but generally within artesian conditions where the limestones are confined between impermeable strata. Water filled solution channels may be caused by rising water tables, but such is not apparently the case in this area, for most streams are actively downcutting their channels. The water table in the past may have been higher, but probably never lower than droughts at the present time.

E. L. Tullis and J. P. Gries (1938) briefly reviewed the two major theories of the origin of caverns in a paper that described ten caverns in the Black Hills. In general, they adopted the concepts of Davis (1930) for they believed that phreatic water circulation could be deep and the caves of the Black Hills exhibited the network pattern as indicated by Davis. They modified the concept, however, to fit known geomorphic history. They postulated that some of the cavern networks were initially enlarged by artesian flow at a depth of several hundred feet, then the networks were filled with calcite, the area was then uplifted and surface streams became entrenched. The present caverns then were formed at or just below the water table (p. 270). The authors include a lengthy discussion on the origin of boxwork and other secondary deposits.

H. M. Fridley (1939) suggested that the water gap south of Cave Mountain, West Virginia, through which flows the South Branch Potomac River, was created by the collapse of a cavern that had previously captured the stream by subterranean stream piracy. It was necessary to accept the Davis theory of cavern development below the water table in order to accomplish the piracy, which is contrary to the tenents of most theories on the origin of subterranean stream piracy.

C. A. Malott (1939) described and named karst valleys. He determined that some surface valleys in limestone were parts of former surface dendritic drainage patterns, but had lost their surface streams to subterranean routes. Commonly the drainage is directed out from under the karst valley to a spring, but is sometimes recovered lower in the same valley.
O. E. Meinzer (1939; p. 676) revised his definition of the zone of aeration. He added that the zone could include water under hydrostatic head temporarily. This condition apparently is not directed at perched water tables which he had already included. Thus, it is questionable just where he would place or what he would call waters within the zone of the fluctuating water table.

C. W. Cooke (1939) discussed the surface erosion and development of caverns and springs in Florida in which he took into consideration the fluctuations of sea level or regional uplift. He indicated that the major topography of Florida was formed by surface stream erosion, but greatly modified by subterranean drainage in limestone areas, as the overlying rocks were removed. Surface water then could circulate freely in the limestone above the water table. Most of the cavern development was at a time when sea level was lower than present, then sea level rose to drown the cavern outlets, or raise the water table (p. 30-32) (figure 6). Cooke described the present water table as one which fluctuates about a mean position dependent upon precipitation and discharge (p. 87). "The growth of caverns takes place most rapidly above and along the water table, where the newly arrived water contains least mineral matter in solution and therefore, is most actively solvent. Once formed, however, caverns may continue to conduct unsaturated water and to grow in diameter even though the water table may have risen to a much higher level, for the descending freshly absorbed rainwater finds access to them through vertical channels etched during an earlier epoch" (p. 89). The water thus flows through the old systems under head and emerges as artesian springs.

K. Ver Steeg (1940) argued that the water gap at the Smoke Hole in West Virginia was not an example of stream diversion by subterranean stream piracy as indicated by Fridley (1939).

M. K. Hubbert (1940) challenged earlier concepts of ground water flow in general, and Swinnerton's (1932) concept in so far as limestone was concerned. Hubbert (p. 930) argued that flow was essentially vertical at ground water divides and arced to decreasing depths between the divide and the outlet (figure 7), with the result that his theory of flow in regard to cavern development is basically little different than that of Davis (1930). Like the King (1899), and Davis (1930) theory, Hubbert assumed that the limestone was uniformly permeable material, which it is not. Thus, all of these theories fail to account for geologic structure and stratigraphic changes in porosity and permeability.

R. W. Smith and G. I. Whitlatch (1940) discuss that origin of the phosphate deposits of Tennessee by the surface solution of a phosphatic limestone. They describe the origin of "cutters," long solution crevices filled with insoluble residue (phosphate not terra rossa) on the limestone bedrock surface. They indicated that the deep weathering and cavernous drainage was formed above the water table (p. 43-47).

J. H. Bretz (1940) presented a lengthy description and interpretation of either a paleo-karst erosion surface or intra-formational solution in a quarry in northeastern Illinois. He indicated that if paleo-karst had been present before the deposition of the overlying shale, it was greatly modified by later artesian or phreatic flow.
Subterranean water system of an artesian spring. Water enters the cavernous limestone through active sinks, flows through caverns, and emerges through sinks that have been submerged by a rise of the water table. The vertical scale is much exaggerated.

Figure 6. Development of cavern levels in Florida as illustrated by Cooke (1939, p. 89).

Approximate flow pattern in uniformly permeable material between the sources distributed over the air-water interface and the valley sinks.

Figure 7. Diagram showing pattern of groundwater flow by Hubbert (1940, p. 930).
S. A. Stubbs (1940) offered brief explanation of the water filled caverns of Florida. He cited Davis (1930) as attempting to indicate that vadose water is incapable of extensive solution of limestone, and he added that the slow circulation in the caverns in the present zone of saturation was performing the greater amount of solution as compared to vadose solution. Yet, he admitted that the caverns were initially formed when the sea level and the water table were lower and have since been flooded and enlarged (p. 160-161).

J. F. Smith and C. C. Albritton (1941) studied the effects of solution on some limestone surfaces in Texas. They concluded that the configuration of the various features was partly a function of slope. A useful bibliography is included.

B. C. Moneymaker (1941) studied solution cavities, mostly crevices, that extended down 100 feet from the bedrock channel of the Tennessee River. The openings were mostly filled with clay, sand, cobbles, and boulders. He stated that the cavities were larger and more numerous above the water table than in the zone of saturation, and cavities in the present zone of saturation were larger above the river level than below it. He contended that the water table had occupied successively lower positions in response to stream downcutting, but preferred to form each cavern level in the zone below each previous water table. Yet, he did not think it possible to determine the amount of solution enlargement in relation to past and present water tables.

R. Rhodes (1941a) also described the deep solution cavities in the bed of the Tennessee River which he thought were formed by solution extending to the depths indicated during late Pliocene or early Pleistocene time, but beneath a land surface that has since been eroded away.

R. Rhodes (1941b) later described artesian conditions along the Tennessee River created by solution channels in the limestone bedrock that were capped by alluvial clays. Water movement was towards the river and its level fluctuated with that of the river.

R. Rhoads and M. N. Sinacori (1941) studied the flow patterns of groundwater in limestones, modifying the results of Davis (1930) and Swinnerton (1932). They, like Davis, assumed that a limestone was uniformly permeable through intersecting joints and that equal flows through equal volumes of rock would accomplish equal amounts of solution along all paths of flow (p. 791). Their main thesis was that deep circulation as postulated by Davis was possible but that deep circulation would decrease as openings in the upper part of the zone of saturation were enlarged by solution and flow thus increased at shallow depths below the water table. The concentration of flow at shallow depths occurs first near a point of discharge, then progresses headward as the master conduits are enlarged by solution. Continued solution lowers the water table.

Rhoads and Sinacori, like Davis (1930), postulated a quantitative theory on the basis of an assumed homogeneously permeable limestone bedrock, which seldom is encountered geologically because of stratigraphic changes and differential deformation. They also failed to account for fluctuations of the water table, other than a lowering brought about by the enchroachment of the cavern into the bedrock.
C. A. Malott (1941) studied the Sloans Valley area in Kentucky which he considered a prime example of the development of a karst valley and cavern system by surface streams invading subterranean openings.

O. D. von Engeln (1942) in a textbook of geomorphology briefly suggested that the irregular shapes of caverns were formed by solution in the upper levels of ground water saturation because there the water would be held in constant contact with the limestone. Gallery levels were thus records of water table change (p. 531). Yet, he recognized enlargement by collapse and solution removal of the collapsed material in the cave stream (p. 583). The text presents a treatment of karst topographic forms and the karst erosion cycle.

J H. Bretz (1942) presented a lengthy paper to differentiate vadose and phreatic features of limestone caverns. He argued that many solution features, such as ceiling, wall and floor pockets, spongework, anastomoses, etc., were proof that the caverns were formed in a zone of permanent saturation, primarily within a deep phreatic zone beneath a peneplain. Although Bretz correctly identified most modern cave streams as too small to have formed the caves, he failed to explain why his phreatic features could not have been formed within the zone of the fluctuating water table during past periods of abundant vadose water. In fact, he fails to discuss the fluctuating water table and changes of the water table owing to climatic changes or Pleistocene age changes in base levels. The features described by Bretz as phreatic were undoubtedly formed below the water table, but there is no proof whatsoever that they can not have been formed by vadose flood waters or waters within the fluctuating water zone. The presence of the features merely indicates that the cave was water filled at times while the features were being formed, but in no way proves that their development was without interruption. Thus they could have also been formed in the zone of the fluctuating water table of Swinnerton, the static water zones of Gardner, or by the vadose flood waters of Malott. Some of the features, namely spongework, most likely could form under artesian conditions.

Bretz (1942, p. 773-776) modified the two cycle theory of Davis (1930) to include a stage of cavern filling with red clay. He argued that the caves were formed deep within the phreatic zone beneath a dissected upland, filled with clay when the upland was peneplained, and then the clay was removed by vadose streams as the area was rejuvenated. He indicated that the fill material was insoluble residue, but admitted that it was impossible to fill a passage with insoluble residue derived from the in situ solution of the limestone from the passage, thus some of the material was washed in from the surface.

Bretz (1942, p. 722-731) noted the arguments by several authors concerning the origin of dome pits or vertical shafts in limestone caverns and offered his explanation. He postulated that vertically grooved and fluted sinuous slots, not joint oriented, and dome pits develop by downcutting along anastomosing channels. The dome pits are produced where headward progression of the downcutting that follows anastomosing channels closes on itself, creating an unsupported core which collapses (Fig. 8). He indicated that some gorge-like dome pits record phreatic development, but that many develop as vadose waters follow phreatic routes that were abandoned as the water table lowered, the vadose waters now descending vertically to a lower level.
idealized developmental stages of a core-block domepit in the Ste. Genevieve formation. (a) Ground plan of the bedding-
plane anastomosis. Vadose water, entering by routes A, B, C, D, and leaving by E, F, G, finds a new escape route down a joint at X.
The initial slot is lengthening in two places at stage (1). Before stage (2) has been reached core block I has been made and presum-a
bly has begun to fall. Block II becomes unstable shortly afterward, and, at stage (4), block III is nearly ready to fall. (b) Blocks I
and II have disappeared, leaving a domepit of dumbbell cross section with sinuous vertical slots leading back to the sites of falling
or trickling water at stage (4). An older, linear chamber has been partially intersected by the domepit.

Figure 8. Diagrams to show development of domepits (Bretz, 1942, p. 724).

Diagrammatic depiction of sequential changes in ground water circulation during evolution of Ozark topography.

Figure 9. Idealized diagram to show the concept of deep phreatic
origin of limestone caverns below a peneplain (Bretz, 1953, p. 21).
Although Bretz labored to prove the theories of Davis (1930) his paper is of great value in differentiating between solution features, erosional features, and depositional features in limestone caverns, and thus, to a certain extent, features indicative of a water filled cavern and those formed by a smaller cave stream.

A. N. Sayre and R. R. Bennett (1942) studied ground water flow in the Edwards Limestone, adjacent to the Balcones Escarpment in Texas, and determined that it was mostly artesian in nature. Most of the water is derived from precipitation, which passes through cavities in the artesian system to issue as springs along the Balcones Fault Zone. The water moves down the dip of the strata, then along the strike to the surface. Water down dip from the fault zone is heavily mineralized and occurs in smaller openings with slower circulation.

A. M. Morgan (1942) reported that solution along the Pecos River in New Mexico has determined the present position of part of the river. The stream has downcut and occupied a series of destroyed subterranean drainage systems. Subterranean drainage is currently developing adjacent to the stream in thick salt deposits where fresh water enters the strata.

A. C. Swinnerton (1942) presented a review and summary of knowledge of hydrology of limestone terranes, emphasizing the effect of local stratigraphy and geologic structure. He basically repeated his theory of cavern origin of 1932, but applied the ideas to indicate the general movement of ground water in limestone. His main thesis can be summarized as having the greatest amount of water flow above the zone of saturation where the joints are periodically filled with infiltration of precipitation. The routes of greatest discharge from the fluctuating zone enlarge at the expense of less favorable routes (p. 665-666).

H. C. Beckman and W. S. Hinchey (1944) cataloged and described the large springs of Missouri, noting that most all of the large springs issued from cavernous limestone or dolomite (p. 27). They recognized that the present drainage systems or permeable strata existed both above and within the zone of saturation, and that the water level fluctuated with storm waters and seasonally. They did not agree with Bretz (1942, p. 751) who stated that the flows were the result of lateral flow in the upper part of the water table and below the lowest drought levels. Instead, they cited the fluctuations of the water table as causing any departure from drought flows (p. 30). They commented on the origin of caverns only that they were formed by ground water.

B. C. Moneymaker and R. Rhodes (1945) described a solution crevice 200 feet deep in the bedrock channel of the Tennessee River in western Kentucky which they thought was originally formed and enlarged by solution below the water table. They indicated that the solution channel predates the river valley, which is of Pleistocene age, and is probably of Miocene or earlier age to present time.

C. A. Malott (1945) briefly described the significant features of the Indiana karst area and repeated his theory that caverns are formed by surface waters that descend into the limestone and most through it to a surface outlet. Large caverns are enlarged by diversion of surface drainage routes (p. 18). He also described karst valleys in Indiana (p. 22-23).
E. L. Krinitzsky (1947) described Goodwin Ferry Cave in Virginia that had developed in two levels oriented along a fault plane. He presented data pertaining to the origin of the cave he studied, and thus, determined the origin of that cave in its geologic setting. He disagreed with the theory of Davis (1930) that caverns were formed below the water table with the theory that the void could not be water filled at all times unless the volume of the cave is at all times equal to or less than the normal flow of the cave stream, and, when the cavern enlarges to a size larger than the volume of the stream, the cave will cease to be phreatic. Krinitzsky did believe that the small, original incipient fissures must have been completely filled, and thus phreatic (p. 114-115). He also noted that the two cavern levels were controlled by earlier levels of New River.

Krinitzsky also did not believe that an application of the theories of Malott (1937) was valid for the cave origin because no surface stream sinks into the surface above the cave and the cave stream does not fluctuate with an influx of muddy water as would a storm water cavern. He did not find rambling patterns which he felt were indicative of caverns formed in a fluctuating water table zone, therefore, he did not accept the lateral flow theory of Swinnerton (1932). He did find, however, that the water supply for the cavern was derived from an overlying conglomerate, therefore, he more or less agreed with Gardner (1935) (Krinitzsky, 1947, p. 113, 116). The conglomerate acts as a perched water table and regulates the flow of water into the cavern. The cave stream follows the dip of the rock and is essentially clear at all times, thus erosion plays no part in its enlargement (p. 113-114).

R. O. Vernon (1947) in a report on the springs of Florida accepted the theories of Davis (1930) and Bretz (1942) to attempt to explain the origin of caverns in the saturated zone. He acknowledged that sea level had been lower, but used this fact to indicate that the caves could not have formed at that time (p. 15-21). Vernon modified the term "artesian" "...it is considered that any water confined or partly confined in an aquifer under hydrostatic head is artesian regardless of the physical character and structure of the rock or of the direction of movement of the water" (p. 15). He apparently accepted the definition indicated by Fuller (1908) (figure 1). Thus, Vernon failed to recognize a distinction between initial development of small openings in relation to rock structure and later enlargement owing to a change in hydrologic and geomorphic conditions.

B. C. Moneymaker (1948) repeated much of what was included in his earlier works on the Tennessee River Valley, but added that his observations lead to the conclusion that fracturing of carbonate rocks was more important than chemical purity of the rock. He again pointed out that solution cavities at depth are generally smaller than those in the upper part of the zone of saturation, and that most of the crevices and cavities below the bedrock valley were filled with various stream deposits. Thus, he claimed the water is forced to seek deeper routes through the limestone (p. 95). He did not explain why the waters could not enlarge the sides of existing crevices at shallower depths, such as is indicated by slumped or collapsed blocks of limestone in the openings.
R. B. Hohlt (1948) studied the nature and origin of porosity in limestone, primarily for application in the petroleum industry. His work reviewed the pertinent classifications of types of porosity, origins of solution porosity, chemistry of solution processes, and made petrofabric studies of limestones. Hohlt recognized two major types of porosity: primary porosity, which is due to deposition, such as voids between particles, crystals, fossils, and bedding planes; and secondary porosity, post depositional features, such as joints caused by contraction of sediments, crustal movement (deformation), and mineral-ogic changes, intercrystalline changes and solution openings related to present or former erosion surfaces (p. 9-10).

Hohlt (1948, p. 11-16) related the production of organic acids from vegetation to solution along joints in limestones and also the relationship of paleo-karst erosion surfaces to unconformities. He did not entirely disagree with the theories of origin of caverns of Davis (1930) and Bretz (1942), for he could find some evidence of solution within artesian conditions, however, he contended that solution below the level of the water table is the exception rather than the rule (p. 15 and 22). Hohlt apparently did not consider the effects of a fluctuating water table, nor did he express interest in geologic structure, however, he did stress the importance of solution along vertical joints (p. 17).

J. M. Berdan (1948) studied cavern development in Schoharie County, New York and believed that solutional openings may have been initiated below the water table, but the greater part of their enlargement was by free-surface vadose streams along joints. Phreatic features described by Bretz (1942) are not present.

W. O. George (1948, p. 506-507) believed that the cavernous, artesian systems in the Edwards Limestone of Comal County, Texas, were partly formed before later sediments were deposited. The present artesian system has been caused by faulting and enlarged somewhat by solution.

D. K. Hamilton (1948) studied some surface solution features and caverns penetrated by wells in the Blue Grass Region of Kentucky. He related the geomorphic history of the deeply entrenched Kentucky River to the perched water tables of the Blue Grass Region, noting that caverns and surface streams were hanging well above the present drainage of the Kentucky River. Hamilton assumed that the water table coincided with the local topography rather than adjusted to local stratigraphy and geologic structure. He also determined that solutional openings were present only to a depth of about 80 feet, and that these openings were developed along sets of joints with the greatest solutional enlargement occurring along the line of flow. The deepest zone of solution underlies the upland valleys which receive the drainage from the adjacent higher areas.

Hamilton did not explain the relationship of the water table to solution at this time, other than to state that they were perched, but does explain further later (Hamilton, 1950).

C. A. Malott (1949) reported on Hudelson Cavern, in the Lost River System of Indiana, and again concluded that although the original joints may have been enlarged by phreatic water, the passage grew to cavernous proportions by surface waters and stormwaters that diverted into them, flooding them temporarily.
P. E. La Moreaux (1949) discussed vertical drainage in limestones of northern Alabama and he compared subterranean drainage to surface drainage in that it is above the water table and local base level, to which level it will adjust by solution and abrasion in time. He indicated, however, that the caverns lie within a zone of fluctuating water, depending upon precipitation and seasonal ground water levels.

R. W. Stone (1949) repeated essentially his earlier theory of 1932 and in addition quoted Davis (1930, p. 623) to the effect that more study is needed to gain a successful theory of the origin of limestone caverns.

J. H. Bretz (1949) presented evidence claimed to prove that Carlsbad Caverns and several other caves in southeastern New Mexico were formed under completely saturated conditions beneath a peneplain. He indicated that widespread occurrences of spongework in various caves was indicative of solution below the water table, and that the present vadose stream present in Carlsbad could not have formed the cavern. Bretz proposed that solution of stalagmites and gypsum deposits indicated a second period of phreatic water conditions after they were deposited in the vadose zone. His prime evidence that the caves were formed beneath a peneplain is the fact that the caves are now dissected by surface valleys, thus the caves pre-date the present topography. He assigned pre-Pliocene age to the peneplain and caverns, which is capped or contain gravels of the Ogallala Formation. Yet, he described the Ogallala Formation resting on a surface with over 1000 feet of local relief, suggesting that the present topography is resurrected. "A pre-Ogallala scarp must have been canyoned, and Ogallala sediment must have been deposited in such canyons. Relocation of modern canyons on old canyon sites appear to have destroyed the record of this. If it ever is found, the concept here advanced will become unassailable" (Bretz, 1949, p. 462). Thus, Bretz describes relief sufficient to allow vadose circulation at the time he claims the caverns were created, but calls the deep erosion surface a peneplain. His bias to support Davis (1930) is evident, "Caves are destroyed under vadose conditions, rarely made" (Bretz, 1949, p. 460). This paper was one of four presented together by Bretz and L. Horberg (1949) to attempt to prove the existence of a peneplain in southeastern New Mexico.

L. Horberg (1949) supported the work of Bretz with a study of erosion surfaces in the Carlsbad Area. He noted the occurrence of Ogallala gravels within a vertical range of 2,200 feet, but suggested that the lower deposits rested on erosion surfaces and had been reworked from higher deposits. He claimed that evidence of pre-Ogallala valleys was lacking. Horberg did not adequately explain the age or extent of the erosion surfaces below the so-called peneplain. He did, however, describe several depositional terranes in the Pecos River Valley that he claimed were of Pleistocene ages. He repeated the idea of Bretz that the caves of the Guadalupe Range were formed in a phreatic water zone beneath a peneplain, prior to the development of the present topography. Both Horberg and Bretz claim that the caves were formed prior to the development of the present topography, but their assumption that there was no topography prior to origin of the caves is denied by their own evidence. The canyons that dissect the caverns are probably Pleistocene age expansion of a pre-existing drainage pattern.
W. E. Davies (1949, p. 25-29) prepared a survey of the caves of West Virginia, describing about 400 caves, in which he reviewed the theories of origin of caves. He considered all the theories to apply to strata with low dip, but he indicated the theories of Davis and Bretz to best fit the steeply dipping strata of West Virginia. However, he indicated that the caves developed at specific levels in the phreatic zone that were controlled by local or regional base levels. He also stated that the clay fills in caves were deposited in running streams as well as still water, rather than only in still water as postulated by Bretz (1932). He then related cave levels to river terraces and erosion levels, stating, "If the maximum enlargement of passages is related to the water-table at the time terraces or erosion levels develop, the age of the cavern is that of the terrace (Davies, 1949, p. 29).

W. E. Davies (1950, p. 7-9) repeated his earlier summary in a survey of the caves of Maryland, which described about 50 caves. The survey was reprinted the same year with an appendix including seven more cave descriptions.

D. W. Mead (1950) briefly mentioned some hydrology problems in limestone and summarized the origin of caverns. "In general, the formation of caverns by solution is limited to the rock mass above the outlet water level although the rock structure may occasionally produce lower lines of flow and consequent cavernous conditions far below the outlet water levels. In other caves cavernous conditions may have been produced in the rock of valleys that have later been filled with glacial, lacustrine or alluvial deposits, or diastrophic movements may have lowered the cavernous rock far below the present water plains" (Mead, 1950, p. 462).

P. Merriam (1950) reviewed the origin of ice in caves and concluded the necessary factors are good winter circulation through numerous crevices and adequate shade in the summer. She included an excellent bibliography concerning ice caves.

R. H. Jordan (1950) reviewed the data on rock structure and the piezometric surface of Florida and stated that artesian flow circulated at great depth and in places is up-dip or across the thick limestone strata. He indicated that the artesian conditions existed in caverns and were possible because of extreme permeability in the caverns rather than restriction to permeable layers, and that an impermeable cap rock was not particularly necessary (p.263). He acknowledged that no known sinkholes extend to a depth below 175 feet, well above a lowering of sea level of 300 feet, but cited examples of cavities at depths of several thousand feet to indicate deep circulation, which was mostly mineralized water (p. 264-266). He concluded that sinkholes are formed by both vadose circulation above the water table and artesian conditions extending upwards, although the latter methods commonly produces springs. But he postulated that the caverns of Florida, now air filled, were formed when sea level was higher than at present (p. 267-268).

D. K. Hamilton (1950) expanded somewhat his treatment of the Blue Grass Region of Kentucky of 1948, primarily to explain the origin of limestone caverns. He argued that vadose solution was inadequate to produce vertical open joints opening into caverns, but would instead produce greater solution at the surface and produce joints that narrow with depth, which he claimed was lacking in the Blue Grass Region. He also contended that horizontal fluting did on cave walls did not match across the joint planes, thus did not indicate
differential solution, but rather did indicate lateral circulation beneath the water table (p. 26-27). He then indicated that since there was no water storage above the water table, no sustained flow could be maintained. Hamilton stated instead that, "the water table would be lowered at a nearly uniform rate by the solutional enlargement of joints in the bottom of the saturated zone" (p. 27).

Hamilton offered several conflicting lines of evidence. He claimed that the ground water of the area was seldom found below 80 feet from the surface, and that a zone of solution existed that paralleled the surface topography and was a perched water body. The zone of solution, synonymous with the saturated zone, beneath the valleys (p. 27-29). He states "... the solutional process is the medium of land reduction today. If the process is carried on only at and above the water table, then no openings of any size can be developed below the water table to allow its lowering. Without lowering the water table, further reduction of the land surface would be limited to a few feet - the vadose zone - leaving then a plateau rising several hundred feet above the local base level, the Kentucky River, a land area unique in that it would exist in the nearly complete absence of any effective erosional agent." Yet, he claimed next that, "Along the walls of the Kentucky River gorge, many large solutional openings are seen. As these caves are entirely above the present water table and river level, and appear to have no counterpart below the water table in that area, they have not been given attention in this study" (p. 28). However, he later states that some ground water discharge from the upland is through springs high along the walls of the Kentucky River (p. 43).

He thus apparently confirmed the existence of a vadose limestone upland, but failed to relate it properly to any past or present water table that formed the cavernous zone, or to any base level that may have existed at their level. Hamilton also failed to mention any seasonal changes or precipitation effects of water levels.

J H. Bretz (1950) described and postulated an origin of sinkholes, caverns and circle deposits in Missouri that are filled with water sediments. Some are capped with Pennsylvanian age sediments, thus indicating a pre-Pennsylvanian erosion surface, but Bretz concludes that they enlarged during post-depositional times.

W. J. Wayne (1950) described a karst valley in Indiana, previously cited as an example of subterranean piracy by Beede (1910), and indicated the geologic relationships. He failed, however, to show the cavernous drainage routes.

C. E. Hendrix (1950) published the "Cave Book" in which he included types of caverns somewhat according to their physical shape, geographic or geologic locality, and hydrology. He contrasted the two cycle theory of Davis with the one cycle theory of Swinnerton, indicating that each has its applications (p. 34-41).

C. A. Malott (1951) indicated that Wyandotte Cave in Indiana was formed by subterranean streams diverted from Blue River which possesses a hydrostatic head of 50 feet or more. The changes in levels were caused by downcutting of the Blue and Ohio Rivers. Recent study (Powell, 1968) proves that Wyandotte passage levels formed at base levels along Blue River, but not as a result of subterranean stream diversion.
W. E. Davies (1951) discussed the mechanical laws governing collapse of cavern roofs, emphasizing sagging of strata, tension domes, and stress and strain. He described two types of collapsed material, block and slab breakdown.

J. H. Bretz (1952) applied his phreatic theory of cavern development to Alabaster Caverns in Oklahoma, a gypsum cave. He determined that the cave experienced two phreatic and two vadose cycles or stages of development. The cavern fill materials were of vadose rather than phreatic origin, and he noted the upward solution by the vadose stream to form upside down meanders in the ceiling.

C. A. Malott (1952) presented a detailed description of the karst topography and hydrographic features of the Lost River area in Indiana. He explained the initial lowering of the water table as producing vertical openings along the entrenched downstream portion, then subterranean drainage developing headward, producing small tubular routes that drained the surface through sinkholes. Surface streams that were diverted through some of the small openings have enlarged the openings to cavernous proportions (p. 228-230). Malott considered the Lost River area to depict a cavern system just developed, however, the system is actually one which is ponded by backwater deposits and alluviation in its lower reaches.

C. F. Lane (1952) described the development of Grassy Cove, a uvala or valley characterized by subterranean external drainage, in Tennessee. In general, he explained its origin by surface erosion, subterranean drainage by groundwater solution in stages caused by uplife, and collapse of caverns.

A. Livesay (1953) briefly outlined a vadose origin of Mammoth Cave in Kentucky, noting especially that solution would be limited below the water table where slowly moving water becomes saturated with calcium carbonate. She indicated that abrasion would become increasingly important as an aid to solution as the cave stream increases in size, but that solution continues regardless.

W. E. Davies (1953, p. 7-8) claimed to adopt the theories of Davis and Bretz to explain the origin of caverns in Pennsylvania, with a major modification that the cave levels are closely related to Pleistocene age river terraces. Thus, he thought that the levels were developed immediately below the water table during the period when straths or local base levels were formed rather than at random depths below a peneplain. He also noted that the cave fill cycle of Bretz did not apply, the fills in Pennsylvania he considered to be of alternately vadose and phreatic origin. Thus, Davies really does not agree with Davis or Bretz, except that caves are formed below the water table, but rather his concept would more closely follow that of Swinnerton except that he did not recognize any fluctuation of the water table.

J. H. Bretz (1953) attempted to relate cavern development to surface erosion levels or peneplains in the Ozarks by his three cycle three cycle theory of cavern development (Bretz, 1942, p. 773-776). Bretz claimed that all interpretations of vadose development of limestone caverns were misinterpretation of field data, or lack of collecting the correct data, but that the phreatic development of Davis (1930), the master physiographer, was correctly analyzed by his reading and reinterpreting descriptions that contained no suggestion of the origin Davis proposed (Bretz, 1943, p. 1-2).
The prime basis for deep phreatic circulation beneath peneplained surfaces, emphasized by Bretz (p. 20), was the models suggested by Davis (1930), and several groundwater hydrologists, that demonstrate the flow of water under hydrostatic pressure within a homogeneous permeable rock. He created his own model to illustrate cavern development in relation to the water table, peneplain and erosion levels (Figure 9). Bretz indicated that deep phreatic circulation extended to depths of several hundred feet during the original stages of cavern development, but are now at shallower depths because of subsequent peneplaination and stream rejuvenation. He denied that there was any relationship between observable erosion levels and cavern levels, in fact, he denied particularly that erosion during the Pleistocene was capable of forming the caves, although it did form the entrenched surface topography which he claimed has since dissected the phreatic cavern routes (p. 22-23). He failed to mention that streams that have subterranean tributaries in the Ozarks are in places deeply alluviated burying earlier lower base levels, probably equivalent to a "deep stage," which he claimed did not exist (p. 18). He also ignored differences in stratigraphy which assure that the bedrock is not a homogeneous unit, therefore, it is not capable of the deep circulation he described.

P. McGrain and O. L. Bandy (1954, p. 69-70) discussed the origin of caverns in rather thin limestones which serve as aquifers for groundwaters derived from overlying permeable sandstones which collect precipitation. The waters descend from the sandstone into joints in the limestone, and then laterally to the outcrop at the base of the limestone which is on an impermeable shale. The joint controlled caverns are enlarged by solution.

Elements of this theory were apparent in the earlier works of Gardner (1935) and Krinitzsky (1947) who both discussed transmission of waters from non-carbonate rocks into a soluble limestone to produce caverns.

W. D. Thornbury (1950) in general reviewed the theories on the origin of limestone caverns, as well as karst features, and cited Matson (1909), Davis (1930), Bretz (1953), Swinnerton (1929), Gardner (1935), and Malott (1937) as presenting the major viewpoints. He indicated that each theory had some application within the area for which it was formulated.

T. H. Black (1954) discussed the geomorphic history of Carlsbad Caverns and their origin. He claimed that small passageways and spongework were formed within the phreatic zone as suggested by Davis (1930), but that definite levels were created within the spongework at or immediately below the water table as proposed by Swinnerton (1932). Considerable collapse was associated with the water table enlargement, as well as with later vadose, small, streams that flowed through the passages. The secondary carbonate deposits, dripstone, etc., and the clay fills were associated with vadose deposition, suggested at times during the late Tertiary and Pleistocene. The article includes a discussion of development of secondary deposits.

P. McGrain (1954) described several caves in the Carter Caves and Cascades Parks in Kentucky, which he indicated were developed by diverted surface storm waters.

E. R. Pohl (1955) noted the location of vertical shafts along edges of ridges in the Mammoth Cave area of Kentucky and concluded that their development was separate from that of horizontal cavern passages which they intersect. The
vertical shafts are formed entirely by solution above the water table by water descending from the surface where the protective cap rock has been eroded away. The horizontal caverns they transect are of earlier phreatic origin, except for drainage away from the bottoms of some shafts. Pohl failed to explain the origi of shafts that integrate cavern levels, or lie deep within ridges that are capped with non-carbonate strata, that have been formed by diversion of water from one level to another.

J H. Bretz (1956) published a survey of 437 caves in Missouri within which he essentially repeated a summary of phreatic features (Bretz, 1942) and the origin of caves in the Ozark area (Bretz, 1953). He did, however, provide a new diagram to illustrate his three cycle theory of cavern development (Figure 10). His continued insistence that ground water moves in a deep path in a homogenous bedrock is apparent, but contrary to fact. The bedrock is not homogeneous, but consists of strata of varied lithology, and if the bedrock is homogeneously permeable, as Bretz indicates, lateral escape of groundwater is as important, if not more important, as deep circulation, as Bretz indicates on figure 10-A with shallow curves. He also discussed types and origins of secondary carbonate deposits in caves.

B. F. Latta (1956, p. 13) assumed that caverns in Virginia were formed by swiftly moving streams, aided by erosion, above the water table.

E. H. Walker (1956, p. 26) studied the groundwater resources of the Hopkinsville Kentucky area and demonstrated the decreasing abundance of solution enlarged cavities and joints with depth and indicated the fluctuations of seasonal water levels within the network of openings. He also noted bedding plane solution, particularly above shale beds, and that solution occurs where the groundwater circulation is the greatest.

C. F. Lane (1957) cited the Grassy Cove and Sequatchie Valley of Tennessee as an example of headward erosion by surface drainage and underground solution accompanied by sapping and collapse. He indicated the process was applicable to some anticlinal valleys of the Ridge and Valley Province.

B. T. Gale (1957), in a discussion of the origin of Carlsbad Caverns, essentially repeated much that had been postulated by Bretz (1949). Gale, however, stated that the cavern levels were formed at a shallow depth within the phreatic zone, prior to downcutting by the Pecos River in stages, and that the fill materials in the caverns were deposited by later vadose streams, and still later were partly eroded.

J. M. Good (1957, p. 19-22) attempted to verify the conclusions of Bretz (1949) by a study of the sediments in Carlsbad Caverns, that is, the cavern was not produced in the present erosion cycle, but is of pre-Pliocene age. Good, however, asserted that the cave passages formed at definite levels within the upper part of the zone of saturation where acidic vadose waters united with the top of the phreatic zone to create a zone of greater acidity (p. 20), rather that at random at depth. Good indicated that the levels in Carlsbad should correlate with the geomorphic history of the area, prior to the present erosion cycle, since Bretz (1949) indicated that the cavern system antedates the reef scarp. Good also indicated that he, like Bretz (1949), attributed all the events of the Pleistocene to the present cycle. Yet Good also indicated that the Pecos Valley stood at an elevation just below the present level of the
The water table almost coincides with the surface of the land. Subterranean circulation is almost at a standstill, and the cave becomes filled with red clay from the deep residual soil. Liston Neely, del.

Early maturity of the present erosion cycle has been attained. The cave is now entirely in the vadose zone; may have a free-surface stream on its floor, dripstone and flowstone deposits, and sinkholes in its roof. It very probably still contains remnants of the red clay fill. Liston Neely, del.

Figure 10. Diagrams to show groundwater conditions during stages of cavern development and later dissection as conceived by Bretz (1956, p. 27).
Big Room at the time sedimentary deposits were being washed into the cave, and acknowledged the existence of various levels of Pleistocene age along the Pecos River Valley, thus apparently contradicting himself and Bretz.

C. A. Kaye (1957) determined that the greater the velocity of acidic water within limestone, the greater the rate of solution. He then indicated that an integrated system of solution channels would enlarge rapidly to caverns and consequently cause a steady fall of the water table and draining of the conduits Kaye considered Swinnerton's (1932, p. 682) idea, that large volumes of water dissolving small amounts of limestone are more effective than a small volume of water dissolving an equal amount of limestone, as valid. Kaye considered his work proof that the Davis (1930) concept of prolonged contact was not acceptable because slowly moving groundwater would not be effective in dissolving limestone. Kaye described primary openings, joints and bedding planes, as a highly complex tabular, partly integrated, gridwork. Solution along the gridwork enlarges the openings, with the water flowing through the system according to hydraulic principles similar to those of a tube-like system. Those conduits that collect and move the most water to an outlet will be enlarged most by solution. Kaye then explained the relevance of the system to the water table, "In order to maintain a constant water table in a system of expanding conduits like that postulated here, it would be necessary steadily to increase the recharge. We may assume, therefore, that under relatively constant conditions of recharge the expansion of the conduit system is accompanied by a falling water table. A falling water table will gradually uncover one enlarged conduit (cavern) after another, and Davis' (1930) second epoch, or cycle, of cavern formation will thereby be realized automatically without recourse to diastrophic movements or a radical lowering of base levels by erosion, which were the processes favored by that writer to bring about the required condition. The fact that the overwhelming majority of caverns studied by Bretz (1942) show good evidence of having been excavated under phreatic conditions suggests that a process more ordinary and less demanding, tectonically, than that of regional uplift is probably responsible for the draining of many caverns" (Kaye, 1957, p. 44).

The maintaining of a constant water table, as indicated by Kaye, is not necessary, but periodic recharge would occur with each precipitation, thus the conduit system would grow at a rate commensurate with climate, fluctuating by filling and emptying the system, and become drained with a change to dryer climate, attainment of a large size, and perhaps a change in base level.

A. C. McFarlan (1958, p. 47) briefly outlined the development of caverns in Kentucky as forming near the water table by water moving through limestone to a surface outlet, primarily by solution, then followed by normal stream erosion. He stressed the down-dip drainage through well jointed limestones into entrenched Green River as the essential conditions in the Mammoth Cave area (p. 50-52).

R. C. Gardner (1958) studied the Cave of the Winding Stair, California, and concluded the vertical cavern passages were developed by subterranean streams at the water table cutting deeper as base level lowered. The original passages were small phreatic tubes.

A. L. Lange (1958) described several caverns and their hydrology in the vicinity of Lehman Caves National Monument, Nevada. He concluded that the caves were formed by subterranean stream piracy of surface drainage, partly as the result of moraine valley damming. Some of the caverns still flood.
W. A. White (1958, p. 87) discussed the hydrology and origin of sinkhole lakes in central Florida and indicated that most of the surface karst features were a result of a shallow groundwater solution. The deep circulation cited by many authors was artesian circulation within buried stratigraphic units of several ages or cycles.

W. E. Davies (1958) revised his survey of the caves of West Virginia, adding about 100 caves to make the total about 500 caverns (A supplement published in 1965 added about 140 new caves). Davies (1958, p. 23-29) essentially repeated his earlier work (1949, p. 25-29), but he added that the distinct levels separated by uniform spacing in most caves in West Virginia nullified the Davis (1930) and Bretz (1942) concepts of random solution deep beneath a peneplain. He then indicated that small, nonintegrated tubes and pockets develop at random in the phreatic zone, but that graded cavern passages develop by solution directly below the water table at a time when it is fluctuating least during stages of lateral planation by major surface streams. Vadose stream enlargement was ruled out because phreatic conditions were necessary to create some of the features present, but the caves were later partly filled with sediments derived from initiation of vadose conditions which occupied the caves after they had been uplifted or rejuvenated. Yet Davies claims the fills have since been partly removed by the vadose streams. He more or less correlated the cavern levels with Pleistocene terraces, yet he did not mention climatic conditions during the Pleistocene.

J. Vineyard (1958) studied the hydrology of Cave Spring—Wallace Well Cave System in Shannon County, Missouri, by entering the cave system that fed the spring. Bretz had indicated that such systems were phreatic, thus flooded, but Vineyard proved the existence of a fluctuating water table condition within the system. Muddy storm waters are impounded within the open cavern system, raising the water table, by constricted outlets somewhat below the normal water table. The decreased velocity of the storm waters causes sedimentation within the systems and discharge of clearer waters. Additional water is derived from the porosity in the adjacent bedrock, depending upon the position of the water table.

W. S. Motts (1959) stated that meteoric (vadose) water is still dissolving limestone below the lowest level of Carlsbad Cavern and that the cave was formed as waters discharged into the Pecos River during successive stages of downcutting. Motts essentially contradicts the work of Bretz (1949) and Horberg (1949).

G. W. Moore (1960), in an introduction to a symposium on the origin of limestone caverns, noted the horizontal network pattern of most caverns and concluded that they must have formed by solution in a zone of saturation, but were controlled by a piezometric surface rather than at random depths. He did not feel that greater water flow directly below the water table was solely responsible for cave passages, but added that oxidizing and production of sulphuric acids in a shallow groundwater zone aid the process.

Moore's indication that most caverns consist of a network is totally erroneous, as is his use of the term piezometric which is applicable only to artesian aquifers. Moore noted that water moving downward from the surface would carve dendritic channels, in contrast to a network formed by lateral moving waters, and contrary to his opinion, more caverns do have a linear or dendritic pattern rather than a network.
W. R. Halliday (1960) proposed that theorists concerned with the origin of limestone caverns devote more effort to adequately describe water table levels and groundwater flow conditions, rather than using general phrases such as "one-cycle," "two-cycle," "vadose," and "phreatic." He implies that Wm. M. Davis (1930) was referring to geomorphic cycles when he proposed a two-cycle theory of cavern development, but that subsequent authors have misconstrued the concept to indicate stages of development. Halliday pointed out that Davis mentions cases of multiple epochs of cavern development within a cycle, and that Bretz (1942) carefully used the term epoch to avoid connotations placed on the use of the word cycle. He also indicated that the concept of phreatic and vadose features suggested by Bretz has led many authors to simply designate cavern development as either above or below the water table, as if it were a simple or easily defined surface, which it is not. Halliday recommended that speleologists study the stratigraphic, structural, and geomorphic conditions in each geographic area to determine the exact solutional and depositional history of the caves in the area. "Inasmuch as the surfaces of these areas have not all had the same geomorphic history, it does not appear logical to expect the history of their caves to have been necessarily identical" (Halliday, 1960, p. 26). He concluded by indicating that, "only in the broadest sense can it be said that all limestone caves develop in the same way - or in one of two ways - and terminology which suggests that this is true should be replaced by descriptive data based on the individual speleogenetic sequence observed in each case" (p.28).

Although the concept of cycle may be clear to Halliday, it has not been understood by most geologists because of the different ways it has been used by Davis and Bretz, who both used the term for variable epochs or stages.

W. E. Davies (1960) discussed development of caverns in folded strata, repeating many ideas from his earlier papers. He also noted the relationship between small passages in headward portions of caverns emptying into larger passages and large caverns serving as tributaries to large surface valleys at levels that correspond to surface erosion levels. Davies claimed that the cavern levels, which followed the strike of the strata or cut across the dip, were developed within a narrow zone of saturation immediately below a stable piezometric surface, citing the work of Bretz (1942). He further claimed that the stable condition was during an arid climatic time, evidenced by sulphide minerals in cavern fill materials that were washed into the cave during unstable times following cavern development.

The erroneous use of the term piezometric, used by Davies to designate the water table, in no way validates a concept of stability of groundwater deemed so necessary to produce the so-called phreatic features of Bretz. In fact, it is difficult to conceive of any stable groundwater condition in an arid climatic cycle capable of flow and solution, for even arid zone topography is primarily the result of intensive, although sporadic, stream erosion.

G. H. Deike (1960) proposed that Breathing Cave, Virginia, had an early artesian origin, but was also enlarged later when the water table stood at several different levels at different times within the cave. Deike indicated that the original cave was formed at a time when artesian conditions existed and that the cave waters moved either around or under the synclines and anticlines of the confined shaley limestone within which the cave developed. He noted that the cave network trended along the strike of the strata, yet he
also claimed it followed the dipping flanks of an anticline. Deike stated that the system had its outlet about two miles eastward where it emerges in an area that contains several caverns that have horizontal passages, that cut across structural features, which formed at the levels of river terraces.

W. B. White (1960) suggested that papers within the past 30 years have indicated that caverns are formed in the phreatic zone, but that whether the development is deep or shallow phreatic has not been settled. He indicated that caves in the Ridge and Valley Province, mostly in steeply dipping strata, are of a horizontal nature and either follow the strike or cut across the dip of the strata. He concluded, "The caves have the appearance of being part of a subterranean drainage net in which subwater-table streams moved under a finite flow velocity. There is almost no evidence for an earlier spongework or network extending along the bedding toward the surface or deep into the rock as predicted by the deep phreatic theory" (p. 51).

J. V. Thrailkill (1960) indicated that Fulford Cave, Colorado, was an exhumed cavern in Mississippian age limestone that was filled with Pennsylvanian age sediments, however, the present cave was initiated in the deep phreatic zone by slowly moving ground water from the end of Cretaceous until late Pleistocene time, when the successive levels were formed suddenly by water-table streams (figure 11). Each level was enlarged within the upper part of the phreatic zone (shallow phreatic) by streams moving along the water table slope. The streams were fed directly by vadose waters descending from above. Each successive level was formed by a lowering of the water table and readjustment of the water table, with a corresponding adjustment by vadose waters descending to the active water table passages. Thrailkill claimed the phreatic features of Bretz (1942) could be divided into deep phreatic and shallow phreatic features. He made his case for Fulford Cave in a shallow phreatic zone primarily because of the horizontality of some of the passages and because he believed the carbon dioxide content of the groundwater would be higher within that zone. Thrailkill indicated that the distinction between laminar flow and turbulent flow, the latter indicated by scollops or flutes on cave walls, should indicate the line between the deep and shallow phreatic zones, respectively. He indicated that scollops and flutes could also be formed by vadose waters.

Thrailkill thus recognized the need of acidic vadose waters to dissolve cave passages at levels related to the water table, but he failed to note fluctuations of the water table or any change in stream nourishment and regimen. His shallow phreatic zone would probably be within the zone of the fluctuating water table.

P. E. LaMoreaux and W. J. Powell (1960, p. 368) studied the groundwater conditions in a limestone area at Huntsville, Alabama, and determined that the underground cavernous drainage system was somewhat comparable to and subject to some of the same laws of flow and base level as surface streams. Their study showed that the water table becomes adjusted to the profiles of the subterranean channels, which in turn are regulated by the base level of the major surface drainage, near the Tennessee River.

G. K. Merrill (1960) supplemented the work of Pohl (1955) on the origin of vertical shafts in the Mammoth Cave area. He generally considered domes pits to have no genetic relationship to cave passages, but are formed by continual seeps and flows of water from above a porous caprock. He noted that resistant
Evolution of the cross section of two strike passages of a hypothetical cave whose history was similar to that of Fulford Cave: (a) solution along joints and bedding in the deep phreatic zone; (b) solution and fill in the shallow phreatic and deep phreatic zones (tubular conduits at A and B); (c) breakdown (C) and solution in the vadose and shallow phreatic zones (tubular conduits at A and B and water-table stream cutting downdip at D); (d) shifting downward from E to lower passage and further cutting in vadose zone to F caused by sudden lowering of the water table (breakdown at C and speleothems at G; some remnants of phreatic fill are present).

Figure 11. Diagrams showing the progressive development of caverns and lowering of the water table (Thrailkill, 1960, p. 60).

This figure not only orients the cave-favorable environment between the original land surface and its water horizons (A) and those following cave formations (B), but also locates the time span of the true speleogenetic process (S). The latter commences when the steep gradient between X and Z is created, and ends when the new water table (II) and its supporting levels have become graded and stable. The vertical arrow at the right indicates the approach of the cave toward and above the new ground surface, and represents what many previous authors have regarded as "uplift." The descending arrow at the left shows the direction pursued by speleogenesis in relation to the original land surface. The inclined central horizons represent the flow of kinetic energy. As indicated here the cave itself is a transient, non-permanent phenomenon to be eliminated as its horizon approaches and ultimately rises above the ultimate land surface.

Figure 12. Diagram to show the relative position of the water table during cavern development (Woodward, 1961, p. 46).
ledges, rather than the water table, halts the downward development of vertical shafts, but that they also may develop below the resistant strata which acts as a caprock.

Neither Merrill nor Pohl explain the occurrence or origin of vertical shafts in the Mammoth Cave area which lie well beneath the capped ridge where the caprock is intact. Similarly, their explanation does not apply to all other areas where shafts are encountered.

G. W. Moore (1960) discussed the origin of Carlsbad Caverns in the top of the zone of saturation, somewhat the same as Good (1957). He indicated the levels in Carlsbad formed at stands of the water table. "It was only following uplift and denudation of the area that the top of the zone of saturation was lowered to the level of the caverns and extensive cave development could take place" (p. 14). He was not able to correlate three definite levels in Carlsbad with surface erosion levels, in fact, he claimed it has not been possible to correlate the cave levels with Pleistocene levels along the Pecos River. "Limestone caves are formed as one phase of the destruction of a landscape by erosion, hence they themselves tend to be ephemeral and do not have a long geologic history" (p. 13). He indicated that the thick sediments in the cave were partly derived from the surface and deposited as the passages changed from water-filled to air-filled conditions, but that small streams have since cut into the sediments.

Although Moore claims that the cave is one phase of the erosion of the surrounding landscape, he admitted that there were several stages of cavern development, but he failed to show a correlation of cave levels with known surface erosion intervals.

H. P. Woodward (1961) presented a stream piracy theory of cave development based on his knowledge of caves in steeply dipping strata. His work is internally repetitious, and therefore somewhat unorganized, but contains many worthwhile ideas. Woodward claimed that all caves were formed by the sudden or abrupt diversion of surface waters from an upper stand of the water table towards a lower position, both of which mark the positions of local base levels (figure 12). He indicated that pre-cave stage solution below or above the water table could form non-integrated openings, but that a cave is formed only when free-flowing water moves from one level to another. He stated that groundwater moves too slowly to dissolve caverns, but that it serves to capture surface drainage which enlarges the cave by abrasion, owing to its high velocity. He claimed that the fluctuations of the water table were independent of the cavern level, but that they could modify the passage by solution if the water raised to flood the cave.

Woodward's theory is little different than that of Malott (1952), but it is presented in considerable detail, especially in regard to geomorphic concepts of stream piracy and base level. Woodward indicates that downcutting rather than uplift is the more common cause of change of base level (he suggests changing climate as a cause for downcutting), and sedimentation is a cause of raising base level. He failed to directly correlate climatic changes with stages of cavern development, but his work suggests that such may be the case. His insistence that all caves are formed by stream piracy or abrupt diversion of surface drainage is not supported by known relationships of most caves to their respective landscapes.
J H. Bretz and S. E. Harris (1961) published a survey of the caverns of Illinois, listing over 60 caves, in which the earlier theories of Bretz on the origin of caves was included. Although they continued to claim that the caves were formed at random within the phreatic zone, they recognized five stages of development; solutional excavation, clay filling, vadose erosion, vadose gravel filling, and vadose rejuvenation. The earlier diagram of Bretz (1953) was redrawn to show abandoned cave levels (figure 13).

R. L. Powell (1961, p. 23-25) presented a survey of 398 caves in Indiana within which he reviewed the more acceptable classical theories of cavern origin. He indicated that the infiltration of water from the karst surface entered the limestone and enlarged openings by solution along a route to a surface outlet. The filling of the cave by storm waters that dissolve the cave ceilings and normal flow and drought time stream conditions were noted, as well as was the high velocity of flood waters and their increased solvent effect. The establishment of cave levels was attributed to establishment of progressively lower base levels due to surface erosion.

Powell failed to describe adequately the flood water invasion of passages and fluctuations of the water table due to general vadose infiltration, of which the latter condition is more common. He also neglected to emphasize the changing climatic conditions which have effected present and past water table fluctuation and surface stream erosion during Tertiary and Pleistocene times.

J. T. Hack and L. H. Durloo (1962, p. 30-32) believed that Luray Caverns in Virginia were formed as a result of selective solution of dolomite beds, first below the water table and later by vadose streams. They suggested that groundwater could flow through one bed with which it is at equilibrium, but then pass into another bed of different composition and dissolve within it, particularly the coarse grained dolomites at Luray. Stopping, or collapse, aids in the enlargement by dropping rocks into active streams.

W. R. Halliday (1963) prepared a survey of about 110 caves in the state of Washington, describing both limestone caverns and lava tubes.

Wm. H. Matthews III (1963, p. 14-19) claimed that Longhorn Cavern in Texas was mostly enlarged by erosion by running streams above the water table, but within openings that had originally been developed by solution. Inverted potholes or domes in the small ceiling were suggested to have been formed by solution by swirling waters when the passages were filled by swiftly flowing streams. Water now flows from surface sinkholes into the lower cave level only during exceptionally heavy rains, but in the past streams carried in sediments which nearly filled some of the passages.

R. L. Powell (1963) proposed that several large karst springs or artesian springs in Indiana are actually former cave springs which have been alluviated by sedimentation of Pleistocene age. The caverns developed by gravity flow at grade with deep stages of erosion and were later buried but managed to maintain flow through the system by hydrostatic flow.

G. W. Moore and Bro. G. Nicholas (1964) presented a theory they claimed to account for the origin of most caves in the United States, which they erroneously claimed were usually in the form of a network. They also stated that experts believe that caves are formed by slowly moving water in a zone
Generalized cross section showing relations of caves to water table in horizontally bedded, vertically jointed rock.

Streamless caves in wet weather may receive water from sinkholes, but they have ceased to grow and are deteriorating. Dripstone may be accumulating. Mouths are likely to be blockaded with surface waste.

Caves with streams on the floor will have perennial flow if they are so located that they can tap the saturated zone. By doing this, they lower the water table in adjacent rock. Little increase, if any, in capacity is occurring. Dripstone may be deposited.

Tube-full caves, below the water table, are growing caves. No dripstone is possible. At the mouths large springs rise against gravity.
below the water table (p. 10), which is certainly seriously doubted to be true. They indicated that the production of sulphuric acids accelerates solution at a greater depth below the water table, enlarging joints to a critical size (\( \frac{1}{2} \) inch in diameter), after which flow in the openings becomes turbulent, therefore, increasing solution. "When turbulence begins in a channel, it robs nearby fractures of part of their flow. The channel, being enlarged in an accelerating rate, ultimately grows into a cave passage, while its surviving neighbors never exceed a quarter of an inch in diameter" (p. 13).

They noted that the network of cave passages are horizontal, even in steeply dipping limestone strata, and accepted the idea of Davies (1960) that they formed in a relatively thin zone directly beneath the water table (p. 14). They excluded cave development in the vadose water zone because the water is not in contact with the limestone long enough for solution to take place, consequently they favored solutinal enlargement just below the water table because the carbon dioxide content is higher there. The water movement is greatest along the gentle slope of the water table toward a surface outlet along a stream valley. A lowering of the water table, caused by surface erosion, drains the cave (p. 16). They correlated the presence of scallops on cave wall with fast moving streams above the water table and smooth walls lacking scallop with slowly moving water below the water table (p. 11).

S. M. Herrick and H. E. LeGrand (1964) reported conditions for subsidence of a limestone area in southwestern Georgia that was caused by solution and collapse. They assumed that groundwater circulation prior to the development of solutionally enlarged openings would be somewhat as proposed by Davis (1930) but that the greatest amount of solution takes place at shallow depths below the water table, developing secondary permeability, as expressed by Swinnerton (1932) and Rhoades and Sinacori (1941). "...greater quantities of water pass through a unit volume of limestone near the points of discharge into streams than through the same volume of limestone at points remote from the stream during the same unit of time. This increased circulation leads to increased solution and the development of good secondary permeability in the shallow zone just below the water table and near the stream. ...The amount of dissolved matter in water exposed to soluble rock tends to increase with time, but the increase tends to lessen as the water approaches a limit of saturation insofar as the ability to dissolve more rock is concerned. It is thus evident that vigorous circulation is necessary to accomplish large-scale solution in a short time" (p. 31). They then indicated that cavern development at shallow depths induced collapse of the land surface as well as related directly to development of solutional landforms, but that solution at depth below the surface, below a deep water table, might not extend to the surface by collapse. They related the three stages of karst development - youth, maturity, and old age - to degree of development of solution and collapse features in limestone and concluded that they progress from old age features at outlets to youthful features in the subterranean headwaters, essentially migrating upstream (p. 35). "The direct relation between solution and secondary permeability is fundamental to the development of karst topography and to the development of contrasting zones in limestone formations" (p. 31).

G. E. Hendrickson and R. A. Kreiger (1964) analyzed the groundwaters of the Blue Grass Region, Kentucky, and established that the depth of effective solution is limited to the depth of abundant groundwater circulation, and the depth of abundant groundwater circulation is controlled by the topography and
bedrock character. Shale beds restrict downward circulation to shallow depths (p. 15) (figure 14). They noted the solubility of limestone in cold acidic water and cited the following chemical reactions (p. 54):

\[
\begin{align*}
H_2O + CO_2 &\rightarrow H_2CO_3 \\
H_2CO_3 &\rightarrow H^+ + HCO_3^- \\
HCO_3^- &\rightarrow H^+ + CO_3^{2-} \\
H_2CO_3 + CaCO_3 &\rightarrow Ca(HCO_3)_2 \\
H_2CO_3 + MgCO_3 &\rightarrow Mg(HCO_3)_2
\end{align*}
\]

They also noted a reaction with iron sulphide in the bedrock to produce sulphuric acid and hydrous iron oxides, by some of the following reactions (p. 58):

\[
\begin{align*}
FeS + 2 O_2 &\rightarrow FeSO_4 \\
2 FeS_2 + 2 H_2O + 7 O_2 &\rightarrow 2 FeSO_4 + 2 H_2SO_4 \\
4 FeSO_4 + 10 H_2O + O_2 &\rightarrow 4 Fe(OH)_3 + 4 H_2SO_4
\end{align*}
\]

And they indicated that the sulphuric acid reacts with the limestone to produce gypsum and carbonic acid:

\[
H_2SO_4 + CaCO_3 + 2 H_2O \rightarrow CaSO_4 .2 H_2O + H_2CO_3
\]

thus suggesting that solution can take place at depth as well as in shallow zones, but more slowly than within a zone of active circulation (p. 61). They explained the fluctuations of the water table and solution of the limestone as follows; "In late winter and early spring, when increased recharge raises the water table, the slope of the water table toward the streams steepens and ground-water discharge increases. At this time, much of the ground water is moving at a relatively rapid rate and through relatively large openings. Consequently, the ground-water discharge to the stream is relatively low in dissolved solids. In late summer and early fall, the water table is relatively low, the slope of the water table to the streams is less steep, and ground-water moves more slowly and through smaller openings. The ground-water discharge to the streams at this time is relatively high in dissolved solids (p. 65).

Thus, they appear to support the view of Swinnerton (1932) that large amounts of water only partly saturated remove more limestone by solution than small amounts of water that are completely saturated. It is not understood, however, whether they meant that small openings or fewer openings (less volume) would be filled in the dryer period. The latter condition is most likely, inasmuch as the solution openings will not decrease in size.

W. W. Varnedoe (1964) studied the origin of Anvil Cave, Alabama, a vast network of maze passages (figure 27). He suggested that artesian flow followed a gradient through a meander loop of Casper Limestone which was capped with Hartselle Sandstone. The surface stream later downcut its surface channel and recaptured its water from the cave, leaving the cave passages silted up and abandoned.
Generalized diagram showing typical movement of ground water in the Blue Grass region, Kentucky.

Figure 14. Diagram showing groundwater movement as conceived by Hendrickson and Kreiger (1964, p. 12).

Section through a limestone aquifer showing approximate flow lines with multiple discrete sources. Vertical exaggeration 10 X. Shaded areas indicate zones of solution. See text for discussion.

Figure 15. Diagram to show paths of groundwater flow as conceived by Thrailkill (1968, p. 39).
H. H. Douglas (1964) recorded 1790 caves in Virginia, but did not include a chapter on their origin, although the book provides much valuable information for such a study.

T. E. Wolfe (1964) studied cavern development in an area in West Virginia to determine the extent that former erosion levels, the water table, impermeable layers and rock structure control and development of horizontal passages. He easily determined that the caves cut across the geologic structure in most places and that the present water table had no effect, as would be expected. Some passages contain vadose streams as perched water levels on impermeable strata, but they descend steeply to a lower water table, where the strata are breached. He concluded that most of the passages occurred at levels within a 300 foot interval that correspond to the Harrisburg Peneplain, and that they formed there during time of water table stability.

Wolfe does not explain how a water table can maintain stability within a 300 foot interval and produce at least two horizontal passage levels within this range, excluding modern vadose connections with a third, lower, modern level.

L. C. Brod, Jr. (1964) postulated that some vertical pits and small caves in an area in eastern Missouri were formed by ascending artesian water from a sandstone that underlies the limestones. His theory parallels and concepts of Bretz in that he claims the solution occurred prior to the development of the present landscape and that much of the evidence to support his claims is indirect. Like Bretz, Brod included a stage of mud filling beneath a peneplain and claimed that the present topography has downcut into the system. None of the fissures is shown to penetrate more than 20 feet into a dolomite about 100 feet thick that overlies the sandstone, thus Brod has not one cave that he can prove intersects the underlying sandstone.

A. N. Palmer (1965) re-evaluated some ideas concerning the occurrence of groundwater in limestone and concluded that groundwater flow patterns are determined by geomorphic history, geologic structure and stratigraphy. The initial permeability of the limestone may be primary or secondary, or both, but most caverns are formed along joints and fractures. The network of openings may act as a reservoir or a conduit, or both, depending upon the relationship of the water table and groundwater movement to joints and solution channels. Groundwater solution is initially slow, but increases with increased flow velocity. As some conduits are enlarged, other smaller channels are robbed of their flow. If recharge is by slow infiltration over a large area the active zone of solution is just below the water table, but if sinking streams are diverted from the surface enlargement is in the zone of the fluctuating water table. Groundwater movement is greatest adjacent to and updip from entrenched surface drainage and develops progressively headward, flattening the water table as solution channels develop. The groundwater tends to follow the strike of the rock to an outlet if the dip is steep. Groundwater flow in anticlines and synclines is at their crests and keels where fracturing is greatest. An impermeable layer in limestone above adjacent surface drainage forms a base level of solution.

Palmer indicated that rejuvenation may produce strath terraces and new solution levels, perhaps temporarily suspending subsurface drainage levels for a length of time inversely proportional to the volume of groundwater flow.
R. A. Watson (1966) discussed the hydrology of the Mammoth Cave area by integrating surface drainage and solution with water level fluctuations within the lower levels of the caverns and flood levels along Green River. Watson indicated that much of the dissolved carbonate in the cave waters is derived from the limestone bedrock surface, as well as that dissolved from cave passages. He also indicated that the sediments were derived from the soils and mantle of the Pennyroyal Plateau and the Mammoth Cave Plateau by storm waters, and not from back flooding by Green River as suggested by Collier and Flint (1964). Watson mentions the flooding of the lower cave systems and consequent fluctuations of the water table in relation to flooding on Green River, and relates the discharge of the subterranean passages to release of groundwater from integrated voids remote from the cave size passages. He also noted that flooded cave passages, caused by sedimentation in Green River, exist below the open stream levels.

R. L. Powell (1966) proposed that some caverns in Indiana are formed in some thin limestones that are overlain by sandstone by drainage from the permeable sandstone into joints in the relatively impermeable limestone. Perched water tables exist within the sandstone between the outlets along joints in the limestone. The flow is regulated by recharge to and rate of discharge from the sandstone. The limestones are thin and overlie impermeable shales which create perched water tables within the open joints within the limestone.

V. T. Stringfield and H. E. LeGrande (1966) presented a study of the hydrology of the limestones of the Coastal Plain of the southeastern United States. They demonstrated that a water table circulation system occurs where the limestones are the surface rocks and that a homoclinal artesian system occurs where the strata are conlined beneath younger impervious beds. They indicated that a karst development similar to that of the Mammoth Cave area formed here when sea level was lower during Pleistocene time when sea level was lower. Much of the karst is now buried beneath Pleistocene age sediments. Solution cavities at depth in older strata underlie unconformities, and are not proof of solution initiated at depth (p. 2, 22, 25, & 39-40).

Stringfield and LeGrande indicated that in the early stages of karst development water descends in the zone of aeration to the water table, forming vertical tubes and shafts, then flows at shallow depth within the zone of saturation to dissolve and enlarge caverns, with the path of greatest flow being the place of greatest enlargement. The solution increases the permeability, thus lowers the water table if there is no increase in recharge. Recharge is derived from fresh precipitation, raising the water table, and flows toward areas where the water table is low (p. 23-26).

R. K. Hogberg and T.N. Bayer (1967) presented a guide to several caves in Minnesota. They suggested that subsurface streams at or near the water table enlarged fractures in the limestone. The caves were later drained when surface streams downcut in Pleistocene times.

R. L. Powell (1968) correlated the levels of development of Wyandotte Cave, Indiana, with surface erosion levels of late Tertiary and early Pleistocene age. The upper level formed as a tributary to Blue River within a fluctuating water zone which derived drainage from the hillsides above the cave. As surface valleys deepened, the drainage descended deeper into the limestone and established a new water table level. The lower level in part diverted water from the upper
level by vertical openings, in places creating a perched water table above a shale, but may also have enlarged by surface stream diversion through a subterranean cut-off. Sediments within the cave passages were caused by multiple stages of backfilling due to aggradation or glacial lake ponding in the valley of Blue River.

J. Thrailkill (1968) presented a laborous discussion of several factors to answer three questions concerning the origin of limestone caverns; how valid is the application of flow concepts for homogeneous aquifers, what is the source or cause of undersaturation of groundwater, and why is cavern development localized in the shallow phreatic zone. He reviewed earlier theories concerning flow of water in limestone and much technical data concerning the chemistry of solution of limestone.

Thrailkill indicated that although the flow concepts developed for granular homogeneously permeable materials appear valid, limestone aquifers are seldom homogeneous (p. 42). He postulated that descending vadose waters loose their solvent ability at the limestone land surface before they reach the water table, therefore, solution below the water table is caused by effects of temperature change, mixing of dissimilar waters, and floods in surface streams which cause undersaturation. He argued that caverns are volumetrically insignificant, therefore, only slight changes in saturation could cause their development (p. 36 & 42). He then postulated that vadose waters, although saturated, flows horizontally after reaching the water table toward a surface outlet, dissolving the limestone because of mixing, temperature change, or its flow rate which makes the water undersaturated. He suggested that saturated water would be forced to follow lower paths of flow because it is denser and would also be forced down by descending fresh water (p. 42). He stated that water from surface sources close to the outlet would follow a path close to the water table, but that waters from more distant sources would be forced to follow deeper flow paths (p. 39) (figure 15).

Thrailkill (1968, p. 43) concluded that cave excavation would progress most effectively during floods. "Although the earlier discussion of the nature of limestone aquifers apply to any steady-state aquifer, a flooded aquifer probably seldom attains a steady-state. Under nonsteady-state conditions, the water table will exhibit marked elevation differences whose magnitude and position will vary rapidly with time (flood waves), as will the head and the flow patterns of the underlying aquifer. ...It is, of course, possible to consider the region between the low water table and the flooded water table as a zone of flooding in the vadose zone. ...It is not known why cave excavation should be so sharply limited downward, but if the floor of the cave is determined by a low water table, it may eventually be convenient to separate the zone of flooding (shallow-phreatic zone?) from the rest of the aquifer. In any case, it seems best to consider the upper limit of the shallow-phreatic zone as an average, steady-state, flood water table."

Although Thrailkill admits that deep circulation is not probable, he illustrates deep movement on his illustrations. His indication that saturated waters are forced to follow deep paths by additions of fresh water are contradictory to his own suggestions and with facts. He claims that vadose floodwaters infiltrate into the limestone, but that they lose their acidity before reaching the water table and that they flow in layers rather than stacking up and raising the water table. Yet he admits that the water table fluctuates. His reluctance to accept the fact that infiltrating waters retain more acidity that is produced by temperature change, mixing or whatever he means by flooding, is not proven by his involved chemical discussions. Much of his data was obtained by analysis of small seeps and not with actual infiltration of large amount of vadose waters.
Conclusions

The early concepts of origin of limestone caverns could be summarized as infiltration of acidic precipitation and runoff into the joints and bedding planes of limestone bedrock where it descended to a level, then the waters flowed out to a surface stream as a subterranean tributary. Many workers indicated that the cave streams were tributaries, but few mentioned their relationship to the water table, although some authors related cave levels to base levels. Many theorists related flood waters to cavern development, but only a few specifically indicated that diverted surface streams were the prime excavator of caverns. Most theories cited solution to be the primary process of enlargement, although abrasion was considered as an important secondary process in some theories, particularly if the cave was large enough to contain a stream and sediments from the surface. Some workers acknowledged that the water table fluctuated in limestone areas, and that there was a zone of permanent saturation below and a zone of aeration above, but no one argued the relationship of the water table to cavern development. Apparently they logically assumed that descending vadose waters became united with the zone of saturation, producing a fluctuating water table dependent upon precipitation, and perhaps they assumed that caverns formed at a level compatible with the water table and base level, the two being considered somewhat synonymous.

Controversy arose with the theory of W. M. Davis (1930) who suggested that caverns were formed at depth below the water table within a homogeneously permeable limestone bedrock by deeply circulating waters, and were drained by later stages of surface stream downcutting. The Davis theory was challenged by A. C. Swinnerton who proved that the basic theory of deep seated circulation was erroneous, primarily because Davis exaggerated the depth to which the water would circulate and ignored the lateral flow component that would function if the rock were uniformly permeable. Swinnerton indicated that some of the Davis examples of deep circulation were artesian. J. H. Bretz (1942, 1953 & 1956) followed the Davis theory, attempting to prove that caverns were formed in a deep phreatic groundwater zone of permanent saturation below old erosion surfaces, with no relationship to present topography other than being drained and dissected by recent surface drainage entrenchment. The work by Bretz on cavern features of vadose and phreatic origin is commendable, however, his phreatic features are indicative only of origin below water and not of development in a zone of permanent saturation as he claims. The theoretical works of Davis and Bretz should have been ignored simply for the reason that they assumed a homogeneously permeable limestone bedrock, if for no other reason, for both carbonate strata and its joint patterns vary vertically and laterally. The fact that Bretz ignored correlation of cavern levels with recognized stages of surface erosion is difficult to justify. The papers of Davis and Bretz were perhaps of their greatest value because they included much information about caves in various parts of the United States that were previously scattered in many publications, although their conclusions as to origin were frequently not that of the various authorities from whom they obtained data.

The works of Davis (1930) and Bretz (1942) had a pronounced effect on theory of cavern origin in that they proved that caverns were basically developed below the water table, a concept that had not been sufficiently emphasized by earlier authors. But neither of the two defined the water table as well as Swinnerton (1932), who recognized its dynamic character. Swinnerton should be credited with combining earlier theories of cavern origin, that were presented by many competent geologists, with a practical description of the water table.
A few geologists accepted the theory of deep seated origin of caverns, but most began to indicate that cavern development occurred below the water table. Some workers noted the coincidence of cavern levels with erosion levels and postulated corresponding previous positions of the water table, but nearly all considered this water table as stable, rather than as fluctuating. Several papers have specially correlated cavern development with levels of erosion of Pleistocene age. Yet only a few papers have barely mentioned changes in climate with corresponding changes of landscape known during Pleistocene time.

Numerous authors, mostly petroleum geologists, have noted the existence of buried karst erosion surfaces and caverns, for the most prolific petroleum production in the world is within paleo-karst reservoirs. Yet, some speleologists continue to confuse paleo-karst erosion features with modern deep seated cavern formation, mostly because some artesian waters may now occupy the system. Others have failed to visualize raising of base level or the water table which in effect creates somewhat artesian conditions within cavern systems formed at base level, but further enlarges them to the present time. But, the general failure of nearly all speleologists has been to describe cavern development in the present tense, citing examples of present chemical analysis and physical conditions of subsurface drainage flow, when cavern development should be related to the conditions at the times the caverns were formed. That is, since most caverns in the United States appear to have developed at grade with Pleistocene age erosion levels, during Pleistocene climatic conditions, their origin should either be explained as relicts of the past, or similar conditions should be sought in the world for active development. No known examples can be given at this time for active cavern development within the United States that would approximate the scale of excavation of caverns comparable to those of Pleistocene time.
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Cave areas of the United States:

Most of the caves in the United States are found within several major physiographic provinces. The geologic conditions, stratigraphy, structure, topography, hydrology and geomorphic history, of the different regions generally effects cavern development for most of the caves in each region and somewhat differentiates types of caverns from region to region. The following regions have been delimited to grossly include similar caverns formed at similar times within strata of similar age, and areas of similar structure, hydrologic, and topographic conditions.

Southeastern Coastal Plain Province

The southeastern part of the East Gulf Coastal Plain Section and the northern part of the Floridian Section of the Coastal Plain Province (Fenneman, 1938, p. 65-83 and p. 46-55), contains few enterable caverns and springs (figure 16). The subterranean drainage and karst topography is developed in limestones of Tertiary and Pleistocene ages within a region where the total relief is generally less than 300 feet. The area is in part drained by numerous surface streams, principally the Withlacocchee, Suwannee, and Apalachicola Rivers and their tributaries. Most of the water filled caverns were developed parallel to the dip of the strata, which is generally towards the Gulf of Mexico, at times during the Pleistocene Epoch when sea levels were lower than at present. Some of the caves and part of the karst area contain or are covered with sediments that post-date the origin of the solution features (figure 17).

References:


Additional data on Florida physiography on pages 266-267.
Location of large springs. Florida springs from Ferguson, Lingham, Love, and Vernon (1947); Georgia springs from Callahan (1964).

Figure 16. Map of part of the Southeastern Coastal Plain Province showing locations of large springs (Stringfield, 1966, p. 177).
Figure 17. Map of the Southeastern Coastal Plain Province showing principal artesian aquifers (Stringfield, 1966, p. 96).
Ridge and Valley Province:

The middle and Southern sections of the Ridge and Valley Province (Fenneman, 1938, p. 195-278) probably contain more known caverns than any other single homogeneous region in the United States. The region is characterized by plunging anticlines and synclines that have been truncated and eroded into a series of elongated valleys lying between parallel and echelon ridges extending from Pennsylvania, through Maryland, Virginia, West Virginia, Tennessee, and Georgia to Alabama (figure 18). Most of the caverns have developed in moderately to steeply dipping limestones and dolomites of older Paleozoic age (Cambrian to Devonian) (figure 19).

The local relief of the region varies from several hundred feet to more than 1000 feet. The major surface streams are the southward flowing Tennessee and Coosa Rivers in the south and the northward and southward flowing segments of the Roanoake, Potomac and Susquehanna Rivers in the Middle section. Several stages of erosion and deposition have been postulated by King (1949) and the development of caverns with stages of surface erosion have been indicated by Davies (1960).

In general, the caverns tend to follow the strike of the strata more frequently than in other parts of the country, and network patterns are probably present in more caverns, but not as well developed as in some other parts of the United States. Although some cavern development has been by artesian circulation, most caverns are horizontal passages that cut across geologic structure at grade with surface erosion levels.

References:

Figure 18. Map showing the physiographic provinces that contain the majority of the caves in the United States (U.S.G.S. Prof. Paper 580, p. 38).
Figure 19. Map showing general distribution of caverns within the Appalachian Region (U.S.G.S. Prof. Paper 580, p. 47).
Appalachian Plateaus Province:

Numerous caverns are found in some sections of the Appalachian Plateaus Province (Fenneman, 1938, p. 279-342), particularly in the Cumberland Plateau section of Alabama, Tennessee and Kentucky and the Allegheny Mountain sections of Pennsylvania, Maryland, and West Virginia (figures 18 & 19). The eastern margin of the province, which borders on the Ridge and Valley Province, is generally an eastward facing escarpment 500 to 1000 feet high. The Paleozoic age strata of the Appalachian Plateaus Province are similar to those of the Ridge and Valley area, but they are not as intensely folded, in fact, they trend toward flat lying strata in a westward direction.

The Allegheny Mountain section includes open anticlines and synclines that are not as deeply dissected as those of the Ridge and Valley section. The section is drained mostly by the Monogahela and Susquehanna Rivers. The caverns have developed primarily in limestones of Mississippian age.

The Cumberland Plateau section is basically a flat lying thrust block of Paleozoic strata, although structural features occur. Most of the caverns of this section have developed in limestones of Mississippian age as headwater tributaries to the Black Warrior, Tennessee, Cumberland, and Kentucky Rivers. The local relief is generally from 500 to 1000 feet, and several of the deepest pit caves in the United States have developed in thick limestones in this section.

References:


Interior Low Plateaus Province:

The various sections of the Interior Low Plateaus Province (Fenneman, 1938, p. 431-448), including small areas intruding into the Till Plains Section of the Central Lowlands contain caverns probably nearly equal in number to the Ridge and Valley Province. The two longest known caverns in the United States are within this province, which is characterized by well developed karst topography, and long caverns, developed on nearly flat lying to moderately dipping limestone strata that is mostly of Mississippian, Devonian and Ordovician ages (figure 20). Nearly the entire area included here is within the drainage basin of the Ohio River, with a local relief up to several hundred feet.
Interior Low Plateaus Province, which lies south of the limit of glaciation and along the axis of the Cincinnati Arch. The Province is divided into four sections. North is the Lexington Plain, corresponding to the bluegrass area of Kentucky. South is the Nashville Basin; the Plateaus around it make up the Highland Rim. The remainder of the province is low, dissected plateau. Areas of limestone sinks (karst topography) on the Highland Rim and dissected plateau are indicated by stippling.

Figure 20. The Interior Low Plateaus Province (Hunt, 1967, Physiography of the United States, p. 216).
The Highland Rim Section is here defined as all the upland or plateau area developed on limestones of Mississippian age, including the Mitchell Plain of Indiana, the Pennyroyal Plateau of Kentucky, and the Shawnee Hills of southern Illinois, as well as the Highland Rim of Tennessee and Alabama. The major portion of the area is drained by the Tennessee, Cumberland, Green and Ohio Rivers, which flow through deep valleys in the limestones and in many places are fed by subterranean streams from caverns. The caverns commonly are found at levels that correspond with erosion levels of Tertiary and Pleistocene ages. Many of the larger and longer caverns have developed at several levels.

The Nashville Basin Section, drained by the Cumberland and Duck Rivers, contains caves in Ordovician and Devonian age limestones. The relief of this section is generally less than 200 feet, in contrast with the Highland Rim Section which surrounds it at elevations generally several hundred feet higher. The strata of this section are sloping away from the top of the Nashville Dome, to extend beneath the Highland Rim.

The Blue Grass Section, drained by the Ohio, Kentucky, Licking and Salt Rivers in Kentucky, is here expanded to include caverns in Indiana within the drainage basin of the Ohio and Muscatatuck Rivers. The caverns are developed mostly in Ordovician, Silurian, and Devonian age limestones which dip slightly off the Jessamine Dome. The northern part of the area, approximately along the Ohio River, has been glaciated. The relief is up to several hundred feet where the streams flow through limestone gorges, and many of the caverns have levels hanging above present stream levels.

References:

Ozark Plateaus Province:

Numerous caverns occur in limestone and dolomitic strata of the Salem Plateau and the Springfield Plateau Sections of the Ozark Plateaus Province in Missouri and Arkansas (Fenneman, 1938, p. 631-662). The local relief along the major streams in the region is generally several hundred feet, less on the undissected uplands. Caverns in the Salem Plateau Section have developed primarily in limestones and dolomites of Ordovician age, although some caverns in other lower Paleozoic rocks exist. The Salem Plateau is separated from the Springfield Plateau by the Burlington Escarpment, one of several escarpments or cuestas formed on the updip crops of strata sloping off the Ozark Dome (figure 21). The Springfield Plateau is underlain predominantly by strata of Mississippian age. The province is drained primarily by the Osage, Gasconade, Meramec, White and Black Rivers, as well as by the Mississippian River along the east boundary of the area. Numerous large springs flow into the rivers, and many cave entrances open along the stream bluffs, probably at grade with several erosion levels of Tertiary and Pleistocene ages.

Some caverns are known within the Boston Mountains Section, but little is known generally about the caverns of Arkansas, which have been barely mentioned in publications. Caves in the section would be in limestones of Mississippian age.

References:


Additional data on Ozark physiography on pages 274-275.
Figure 21. Map and cross sections of the Ozark Plateaus Province (Adams, 1901, p. 23, 93 & 94).
Upper Mississippi Valley Lead and Zinc District:

Numerous caverns, generally small, long, fissures, occur in dolomitic strata of Ordovician age generally within the Driftless Section of the Central Lowland Province of Fenneman in Wisconsin, Illinois and Iowa (figure 22), but do extend beyond the glacial boundary, therefore, they are here given the name of the mining district, with which they are closely associated. The area is drained principally by the Mississippi, Galena, and Wisconsin Rivers, with a local relief of several hundred feet. The caves have in part been places of deposition for sulphide minerals, therefore, many mines have been opened to excavate the minerals from the original passages.

References:


Great Plains Province:

Black Hills Section:

The Black Hills Section of the Great Plains Province (Fenneman, 1931, p. 79-86) contains a grouping of caverns in South Dakota formed mostly within the Pahasapa Limestone of Mississippian age. The limestone crops out as a plateau that surrounds the central core of the Black Hills (figure 23). Local relief is on the order of several hundred feet in the vicinity of most of the caverns. Numerous streams drain the area, all tributary to the Cheyenne River. The notable caverns include Wind Cave and Jewell Cave, both of which exhibit a maze or lattice-like network of cave passages. These caverns have been indicated to have had artesian conditions governing their development.

References:

Figure 23. Map and cross section of the Black Hills Section (Meinzer, 1923, Water-Supply Paper 489, plate 23).
Edwards Plateau and Central Mineral District:

The Edwards Limestone and associated strata of Lower Cretaceous age contains caverns in south-central Texas. The generally flat-lying Edwards Limestone caps the Edwards Plateau where minor karst features have developed, but the strata have been much dissected in the Central Mineral District or the Llano-Burnet area (Thornbury, 1965, p. 309-319) (figure 24). The two areas are bounded on their arcing southeastern margin by the Balcones Fault Zone, a zone of artesian water supply, and separated from the Gulf Coastal Plain by the Balcones Escarpment, which is from about 300 to 1000 feet high from north to southwest (Fenneman, 1931, p. 50-59). The areas change character to the northwest as younger sediments overlie the Edwards Limestone. Local relief within the sections in the vicinity of the caverns is a few hundred feet, up to several hundred feet along the major streams that drain the areas, the Colorado, Guadalupe, Medina, and Nueces Rivers. Most of the caverns are probably of Tertiary and Pleistocene ages.

References:


Additional data on Texas physiography on pages 280-281.

Colorado Plateau Province:

Grand Canyon Section:

Numerous limestone caverns and springs have been briefly mentioned in literature concerning the Grand Canyon area, but detailed data is generally lacking. The caves in the area have formed in the Redwall, Muav, and Kaibab Limestones as the Colorado River downcut its mile deep canyon during Tertiary and Pleistocene and Recent times. The limestones in the area are thick, moderately to steeply dipping, and transected by several large faults. The more well known features include a large karst valley on the Kaibab Plateau between Jacobs Lake and the North Rim; Redwall Cavern and Cave of the Domes; and some of the springs, such as Roaring Spring on the North Rim and Vasey's Paradise on the Colorado River at river mile 31.9.

References:


Figure 24. Physiographic landform map of the Edwards Plateau and Central Mineral District of Texas (taken from Lobeck).
Basin and Range Province:

Sacramento Section:

Notable caverns occur in limestones and dolomites of Permian age in the Sacramento Section in New Mexico and Texas. Carlsbad Caverns is one of these caves that has developed within a thick sequence of carbonate rocks deposited as a reef. The local relief of the region, which is drained by tributaries of the Pecos River, is generally about 1000 feet or slightly more. The east edge of the Guadelupe Mountains, within which many of the caves are located, is a reef escarpment, with the dip of the strata sloping generally to the east-northeast (figure 25). Consequently, some of the subterranean drainage now resurges in the Pecos Valley. Multiple erosional and depositional terraces of Tertiary and Pleistocene ages along the east front of the Guadalupe and within the Pecos Valley probably correlate with stages of cavern development in the Guadalupe Mountains.

References:


Snake River Plain Section:

Numerous lava tubes occur in the late Tertiary and Pleistocene age lava flows of the Snake River Plain Section in the vicinity of the Craters of the Moon National Monument (Fig. 42).

References:


Rocky Mountain System:

Caverns occur in rocks of several ages within the divisions of the Rocky Mountains, but no concentrated areas of major cavern development are here recognized.

Cascade - Sierra Mountains Province:

Several groupings of caverns are known within this province.

Numerous lava tubes are known within the lava flows of late Tertiary and Pleistocene ages in the Mount Shasta and Lava Beds National Monument and vicinity in northern California and southern Oregon.
Figure 25. Map and cross sections of the Sacramento Section (Horberg, 1949, p. 465, and Darton, 1928, p. 223 & plate 50).
Another group of lava tubes, including Ape Cave which is the longest tube in the United States, is located in the Cascade Range in southern Washington, generally southeast of Mt. St. Helens.

A grouping of caverns is known in the vicinity of Sequoia and Kings Canyon National Park in the Sierra Nevada Range of California. The caverns have developed in limestones and marbles of Paleozoic age, probably in accordance with Tertiary and Pleistocene age erosion surfaces.
Cavern Features and Deposits

Descriptions of different limestone caverns generally sound very similar, for they are usually written within a limited framework of descriptive terms, however, no two caves are exactly alike, thus the writer is forced to the use of common descriptive adjectives and to make comparisons of known similar features in different caverns. Many caverns are noted for some particular feature, such as a large, deep or long passage or an unusual dripstone deposit, thus they are more easily characterized.

Descriptions of caverns usually commence with classification of the entrance type, which genetically can be considered either a water inlet or outlet, or a collapse of the cave roof to the surface. Outlets for cave streams are called springs, spring caves if the cavern is enterable at that point, cave springs if not enterable but one wishes to classify the type of spring. Spring cave openings vary in size from small tubular or rocky crawlways to those large enough to accommodate a truck or larger. The entrance to Carroll Cave in Missouri is an example of a large spring cave opening. Former spring cave openings, now abandoned by the cave stream and thus dry, serve as entrances to some caves. This latter type, as well as some of the entrance passages which actively carry a stream, are often collapsed upward into the actual cave passage that was formed by the cave stream (Greene, 1909, p. 181, and Weller, 1927, p. 59 and fig. 19). Many cave streams are capable of removing the collapsed material, either by mechanical erosion or solution, resulting in an alcove or gorge that extends into the hillside wherever the passage has collapsed to the surface. These topographic indentations are commonly called steepheads in Florida and spring alcoves in other parts of the United States (Sellards, 1918, p. 27; Stearns, 1936, and Malott, 1945, p. 18). Spring caves which have been buried by sediments, but which continue to function as artesian springs, are called alluviated cave springs (Powell, 1963). Springs which have been submerged by rising sea level are known, particularly along coastal Florida, as submarine springs (Vernon, 1947, p. 9-10).

Caverns may also be entered at large openings where the water flows into the limestone bedrock such as sinkholes or swallowholes, or where the roof of the cavern has collapsed to form a collapse sinkhole. Most sinkholes are surface depressions formed by surficial solution of the limestone bedrock by precipitation and run-off. Commonly they are formed above and along a set of joints in the limestone bedrock, but they also occur where the limestone is not jointed and in places where it is dissected by many joints. The enlargement of the depression by solution is usually aided by varying degrees by collapse and mechanical erosion, depending upon the specific type of carbonate bedrock and the amount of water which passes through the opening. Sinkholes caused by solution are a type in direct contrast to collapse sinkholes caused by failure of a cavern roof to support itself. Collapse sinkholes are of several types, ranging from those that open into the side of the cave passage or even allow entry into both ends of the cave passage.

Sinkholes also frequently overlie vertical pits and domes in caverns, which serve as cave entrances when they are open to the surface. A collapsed sinkhole above a vertical pit formed by solution is a pit, or if it opens into cavern passages it is a pit cave, a type that is presently popular with climbing enthusiasts or pit cavers. Grapevine Cave in West Virginia is a good example of a pit cave entrance.
Most caverns are named in accordance with the name of the landowner at the time of discovery. Many others are named for physical, historical or biological features. A few are named for the discoverer. The proper name is commonly followed by a descriptive term related to the character of the cave or entrance; i.e., Carlsbad Caverns, Natural Well, Floyd Collins Crystal Cave, Blue Spring Cave, Bat Cave, Ezell Cave, etc.

The size and shape of cave passages, other than by numerical descriptions, is commonly expressed in terms related to humans traversing the passage; i.e., crawlway, stoopway, walking passage, crevice passage, chimneying, etc. The character of the passages in terms of dampness (wet, muddy, slimy, dusty, dry, etc.) is commonly combined with other terms to make place names within caverns. Passages, rooms, galleries, halls, avenues, crevices, squeezeways, tubes, pits, domes, stream passages, underground rivers, etc. are commonly named for their discoverer or some prominent feature within the passage.

Passages within caverns vary greatly in shape and size, depending greatly upon the solubility and erodability of the carbonate and non-carbonate rocks present and the amount of water or length of time the cavern has required to develop. Cavern passages commonly follow vertical joints in the limestone bedrock resulting in high and narrow passages, but passages widened along or developed totally along bedding planes are common. However, the recognition of simple joint or bedding plane cavern passage development is frequently confused as a result of passage enlargement by solution and collapse and filling with sediments and other deposits to the extent that the original passage form is changed or masked.

Solutional features in caverns have been described by many authors, some descriptions bearing only on unique conditions that exist in one place, other descriptions bearing upon similar features that are seen in many different caverns. Most solutional features have been named either for their mode of origin or their shape, but the supposed mode of origin for some features has been found erroneous although the feature retains the original name.

The walls of cave passages are commonly scored with vertical or horizontal groves, flutes or scollops, and other solutional features that indicate the direction of water movement. The relative sizes of these features are an indication of the amount and velocity of water, and the length of time involved, required to form them (Moore and Nicholas, 1964, p. 10-11).

Some cave walls, mostly commonly in dolomitic bedrock, are complexly hollowed out with twisting, irregular, and bifurcating, small tubes, slots or holes called spongework or honeycomb which extend laterally and upwards from the cave passage (Bretz, 1956, p. 15). Although these openings have been described as evidence of cavern development below a permanent water table, they more likely have formed by ground water descending freely through the dolomite into the passage or towards a primary opening.
Wall or ceiling pockets are larger than spongework and consist of somewhat circular, short, dead end pits, tubes or domes in the walls and ceiling of cave passages. They have commonly been attributed to differential solution of the limestone by eddies or whirlpools in water filled passages, but the actual existence or cause of the unusual current is unknown (Bretz, 1956, p. 16). The origin of ceiling pockets, or "bells" has been suggested to represent unsaturated water seeping into the cave at this point, and also by solution owing to mixing of seepage water and cave stream water (Bogli, 1965, p. 130). The later process commonly results in a slot-like cavity which has enlarged along a joint.

Large cavernous passages have enlarged from smaller conduits, usually by lateral and downward solution and minor erosion. An inverted trough is sometimes preserved in the roof of the cave as a ceiling channel if the passage has essentially been downcut since development of the original small conduit. Anastomosing channels is the ceiling of a passage are simply an agglomeration of ceiling channels and pendants, and usually smaller in size.

Bedding plane anastomoses are bifurcating solution channels or networks which are oriented along bedding planes. They range in size from very small tubes to inverted channels to those large enough to enter. Anastomoses represent solution along bedding planes, supposedly below the water table (Bretz, 1942, p. 708 and Ewers, 1966), but their actual relationship to a fluctuating water table has not been established. Anastomoses clearly predate most cavern passages along which they are found, in most cases the cave passages as well as the anastomoses are associated with a solutionally enlarged joint.

Anastomosing channels and meandering ceiling channels are passages around cores of limestone bedrock. The bedrock cores commonly remain as pendants as the passage enlarges within the underlying stone or if the underlying rock collapses into a subsequent passage.

Maize or network patterns occur in some cave passages wherein numerous joint controlled passages transect each other; i.e., Anvil Cave, Mark Twain and Cameron Caves, Wind Cave, Jewell Cave, etc. These networks have been attributed to water filling of all the passages simultaneously below the water table (Bretz, 1956, p. 17), but they may also result from filling of joints by storm waters backflooding upstream from an obstruction in the main passage (Palmer, 1969, p. 39 and 74).

A striking feature of limestone cavern passages are those that are essentially vertical shafts ranging from a few feet to tens of feet in diameter and varying in depth from several feet to several hundred feet; i.e., Ellison Cave, in Georgia, contains a shaft 510 feet deep, one of the best and most accessible illustrations of a vertical shaft is the Natural Well in Alabama. Horizontal, or nearly horizontal cavern passages intersect these shafts, which are called pits when viewed from the top, domes when entered from the bottom, and dome-pits when breached somewhat in between. The origin of vertical shafts has been discussed by several authors (Bretz, 1942, p. 722-731, Pohl, 1955, and Merrill,1960), best summarized as owing to nearly constant seepage of water from a perched water body down the walls of vertical joints and fissures until it flows laterally along a more impermeable horizon.
The development of limestone caverns by solutional enlargement is generally accompanied with an increasing amount of collapse of the bedrock ceiling and walls as the passages expand laterally to undermine spans of strata. Slabs and blocks of collapsed strata, commonly called breakdown, may fall into the cave stream and partially or totally removed by solution or erosion, or they may accumulate on the floor of the passage or become wedged between the walls. The collapse may extend to the surface as a collapse sinkhole or karst window, but more commonly it results in irregular passageways floored with broken rock that are somewhat above the level of the solutionally developed cavern passage. Many cave entrances are through inclined tunnels that are floored with debris slopes of breakdown caused by progressive upward roof collapse owing to frost action and weathering adjacent to the entrance. More than a few caves contain a large room partly filled with breakdown that are tritely named the "Mountain Room". A large Mountain Room is found in Sauta Cave, Alabama.

Deposits in caves may be classified many ways, but they generally fall into two distinct groups, mechanical deposits and chemical deposits. Mechanical deposits include breakdown and various alluvial, colluvial and lacustrine sediments that are stream deposited within cave passages, commonly called cave fill. Chemical deposits are commonly the dripstone and flowstone deposits of calcite and aragonite formed by chemical precipitation, but includes secondary crystalline growths of many types and of numerous mineral species.

Little can be stated concerning cave fill or sedimentary deposits of boulders, pebbles, sands, silts, and clays, other than they are materials usually derived from surface erosion and washed into the cave passages by streams, for little study has been made to date. The cave fill commonly is associated with active cave streams, as well as being present as sediments in abandoned stream passages. Many passages are blocked by sediments that have accumulated up to the cave ceiling, while others are blocked with soil and debris that has washed down from an opening to the overlying surface. These sediments are sometimes of great interest if they are found to contain artifacts of historic and pre-historic ages or fossil material. Most of the cave deposits of the United States are of Pleistocene and Tertiary ages.

Cave fill present along active cave streams is generally called mud banks, provided of course that the material is mud. The banks of cave streams are generally subject to flooding much the same way as surface streams.

Chemical deposits in caverns, called dripstone or flowstone, have received considerable attention by both the layman and the mineralogist, for they account for the beauty aspects of some caves. The size and shape of these deposits, as well as their exact mineralogy and mode of origin is very diverse.
The dripstone, flowstone and rimstone deposits in caverns, sometimes called speleothems, are secondary sedimentary rocks, that is, they are calcium carbonate precipitated from calcium bicarbonate derived by acidic groundwater descending through limestone into cave passages. The calcium carbonate is precipitated owing to a loss of carbon dioxide which is caused by aeration, evaporation, or changes in temperature or pressure, and rarely by bacterial action. The calcium carbonate is deposited most commonly as layers of calcite and aragonite, superposed with the youngest increment overlying older layers, commonly resulting in a banded appearance. Impurities, such as mud layers or impure carbonate deposits, commonly cause alternating dark bands between cleaner carbonate zones. This banding resembles that of tree rings, especially in stalactites and stalagmites which have concentric layering, however, they are not annual or seasonal growth rings and no dendrochronology is known, although superposition allows establishment of a sequence of deposition. The growth rate of dripstone deposits varies greatly from place to place within a given cave as well as throughout geologic time and with climatic changes from region to region.

Perhaps the most common form of secondary calcium carbonate is that of flowstone, the sheet like layers that cover broad areas of limestone cave walls and floors, breakdown blocks, and mud banks. Flowstone is deposited in sheets or layers by water seeping across broad areas, resulting in material that resembles flowing stone, although continued seepage may build a thick deposit that grades into a somewhat stalagmitic form.

Stalactites and stalagmites are forms of dripstone that are commonly known to laymen, although dripstone deposits also include several other forms.

Stalactites commonly consist of concentric layers of banded calcite or aragonite, with an ice cicle shape, usually pendant from the ceiling, and sloping upper walls of cave passages, but may also form on ledges and under blocks and slabs of breakdown. The typical ice cicle type appears to have formed originally as a soda straw-like form, but later enlarged laterally by accumulation on the outside owing to water seeping down the outer surface as well as growing lengthwise by seepage through the hollow core. The central core of many stalactites becomes blocked by crystalline growth or sedimentation, forcing the descending seepage to breach the stalactite at its base near the ceiling and resulting in growth on the outside or the formation of a new stalactite.

Soda straws are very thin-walled, generally hollow, long stalactites, that grow almost exclusively by addition of calcium carbonate at the tip. They are commonly about a foot long, but lengths of several feet are known. They are very delicate and easily broken.

Draperies or bacon rind are common names for two forms of leaf stalactites. Bacon rind is a ribbon-like projection which is attached to sloping cave walls, commonly translucent with a banded appearance, especially when illuminated by back lighting. Bacon rind grows by water seeping or trickling along the sloping wall, adding precipitated carbonate to the trailing edge of the deposit, much resembling water spilling over the edge of a wash pan and running down the sloping outer side. Draperies resemble bacon rind in origin and shape, except that they are commonly free hanging and therefore resemble stalactites.
Helictites are generally small, twisted forms of crystalline calcite or aragonite which have been called "eccentric stalactites." The calcite forms generally have a very small central tube which allows seepage of water towards the tip where a crystalline rhomb of calcite or an accumulation of acicular aragonite crystals forms. The best example of calcite rhomb type helictites are in the Caverns of Sonora, Texas, while the more common type of aragonite helictites occur in many caverns, notably Carlsbad Caverns.

Somewhat similar to helectites, helagmites are eccentric forms which have grown upwards from the floor or walls of cave passages. Helagmites are not a true stalagmitic form because dripping water is lacking, but rather they are evidence of the importance of the central tube and accumulation at the tip of the helictite form of stalactite. Helagmites are abundant in the Caverns of Sonora, Texas.

Stalagmites are the dripstone deposit that forms as a mound or pillar, usually beneath stalactites, where water drops from the ceiling or upper walls of cave passages. Stalagmites are nearly always layered and concentrically banded like stalactites, but they grow primarily by accumulation to the exposed surface much like flowstone. Many stalagmites grade laterally into sheets of flowstone. Stalagmites generally lack a central core or tube, but some possess a shallow splash cup at their summit which in cross section of the stalagmite may be similar to a central core or channel. Stalagmites range in outward appearance from low mounds to totem-pole like columns, and they range in size from small pimples to the massive monoliths of Carlsbad Caverns and Kickapoo Cave, Texas.

Stalactites and stalagmites which grow together are commonly called pillars or columns, but they may also be caused by just the growth of either a stalactite or a stalagmite.

Compound forms of stalactites and stalagmites, and other forms of dripstone and flowstone are common, with which it is sometimes difficult to distinguish a particular form or forms. Such masses are usually called simply flowstone, but sometimes flowstone columns.

Not all notable secondary decorations in caverns consist of forms of calcium carbonate. Many other minerals occur in caverns, some forms of some minerals are known only from caverns (Moore and Nicholas, 1964, p. 54-55).

Gypsum, (calcium sulphate) particularly the variety known as selenite, occurs in dry passages in numerous caverns, particularly those in Mammoth Cave National Park. Gypsum flowers are a common form which appear to extrude from the walls of cave passages forming a rosette, but the twinned crystal form, known as a fishtail twin, are found in clayey sediments in some cave passages. Needles of selenite ranging from very small to over a foot in length are known in American caverns. Gypsum most commonly occurs in caverns as a crust which forms on the cave walls and ceiling. This crust may be multilayered and sometimes has fallen off the walls.
Epsomite, \((\text{MgSO}_4 \cdot 7 \text{H}_2\text{O})\) commonly called epsom salts, occurs in several caverns, notably Wyandotte Cave in Indiana and Ellison Cave in Georgia. The "angels hair" in Cumberland Caverns, Tennessee is probably also epsomite. Mirabilite, \((\text{Na}_2\text{SO}_4 \cdot 10 \text{H}_2\text{O})\), is similar in general appearance to epsomite, but tastes salty rather than bitter, and occurs in some cave passages.

Moon milk is a form of hydromagnesite found in a few caverns. This material usually has the appearance of a milky paste seeping down the wall of cave passages and domes. Some moon milk is a hydrous form of calcite (Davies and Moore, 1957, p. 26).

Secondary calcium carbonate deposits are also deposited in cave streams or pools of water. Aeration of carbonate saturated waters, such as across a riffle in a cave stream, can cause deposition of material in the form of a rimstone dam. These dams are commonly arched across the cave stream in a downstream direction, and also arched over the pooled water in an upstream direction. The dams apparently usually grow by accretion of material at the inner or upstream lip of the dam where ever the flow is greatest, thus constantly building up low places to more or less maintain an even flow across the entire rim. Small rimstone dams, called gours, are sometimes found in flowstone masses. Aragonite rafts and calcite bubbles rarely occur in pools of water in caves, most generally in rimstone damed pools. Aragonite rafts form as carbonate crystals which float as a result of surface tension in the pool. Calcite bubbles probably form as the result of surface tension of a bubble formed by gas or the slash of a drip. Both forms of carbonate usually exist as accumulations in the bottoms of pools when they are found.

Cave pearls and cave concretions are spherical and sub-spherical nodules of carbonate which are sometimes found in pools or drip basins. Both forms may have a foreign nucleus and consist of somewhat concentric bands, but the cave pearl has a smooth appearance, where as the concretions are often rough and interlayered with muddy bands.
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Selected Significant Caves of the United States

Ninety-seven caves, groups of caves, or karst areas, selected as being among the most significant such features in the country are described in the following pages. For the purposes of selection and description the caves were considered significant under one or more of the following headings: 1) geology and hydrology, 2) paleontology, history, and archaeology, 3) biology and 4) scenic. The placing of a cave or group of caves into one or more of these groupings provides a means for comparing unique caverns with somewhat similar assets, and makes quick reference to the significant features of a particular cave possible.

The placing of a significant cave into any one of the four major groups was in a few cases an arbitrary decision, and was based primarily on published descriptions of the caves, personal communication, or first hand knowledge of the cave. The descriptions presented here are in most cases summaries of the significant features of the cave. Even within a particular grouping of caves, direct comparisons of the significant features of different caves are very difficult. In most cases direct comparisons were not attempted. Thus, these groupings should be treated only as a listing of U.S. caves which were considered among the most significant in the country. No effort was made to rank them in any particular order other than under each major heading they are listed as merely primary and secondary significant.

Caves described under the heading of geology and hydrology make up the great proportion of the caves selected. Geological significance covers a wide range of cave related features. In most cases geological significance is related to an unusual geologic occurrence connected with the cave, or to a geologic feature which is well illustrated by the cave. Caves of great length and size were often considered as geologically significant.

Hydrologic significance was in general reserved for caves which presently serve as major routes for karst groundwater circulation. Caves illustrating unusual or typical hydrologic phenomena are also described under this heading.

Paleontological, historical, or archeological significance was credited to caves in which major archeological and paleontological finds have been made. Also described under this heading are caves which have local or national historic significance, such as Cave-In-Rock in Illinois, or the well known saltpeter caves of West Virginia such as Haynes and Greenville.

Great caves in the history of American speleology are also given historic significance. Such is the case with Schoolhouse Cave in Germany Valley, West Virginia, in its day one of the toughest and most difficult caves to be attempted by American cavers.

Biologic significance was reserved for caves illustrating ecological relationships between cave inhabiting animals. In some cases the cave was considered biologically significant as the "type locality" of one or more cave inhabiting species. Although most caves contain animal life of some form, the selected caves either have large populations of a single species, many different species, or in some cases represent one of the very few caves where a particular species is found.
Scenic significance covers a wide spectrum of cave related features. Many commercially developed caves are listed under this heading because of the large, abundant or rare speleothems (dripstone and flowstone deposits) which they contain. Scenic significance was also applied to caves containing rooms, shafts, or passages which are comparatively large and impressive.

This study also describes 5 karst areas which were selected because many features associated with caves and karst development are present in a relatively small area. For convenience these areas are also listed under the major headings. Maps of each area are provided with known caves located on the maps. In addition the major caves of each area are described and in many cases maps of these caves are included. Some of the karst areas lack any truly significant caves but the combination of many caves in a small area and associated surface karst features make each area outstanding.

It should also be mentioned that no effort was made to obtain a geographically uniform distribution of caves. The caves described in this report are mostly concentrated in certain areas of the country. These areas correspond to the major karst areas of the U.S., as are described in the Cave and Karst Regions section of this study. No effort was made to choose a cave just to obtain an even geographic distribution of caves among the contiguous 48 states. Likewise, no importance was attached to simply determining the longest, deepest or most scenic cave in every state.

The cave maps accompanying this report were taken from various sources, mainly published state cave surveys. The quality and accuracy of these maps vary greatly. In many cases no accurate map of a described cave could be found, and in other instances the maps were of such poor quality as to be useless for the purposes of this report. The report contains many comprehensive and high quality maps which accurately delineate the trends of the cave passages, and supply other data as related to the character and configuration of the cave. Examples of excellent cave maps include Blue Spring Cave (Fig. 31), and Ellison's Cave, (Fig. 46). In many cases better maps of caves exist than those that appear in this report, but they were unavailable for inclusion in the report or were too large for suitable reduction.

The length of a cave given in a description is in almost all cases its surveyed length. This figure may be too small in some cases, as accurate surveys of the cave may still be in progress. Figures taken from older literature may also be questionable. Pages 284 to 286 at the end of the report contain an up to date listing of the longest caves in each state over 2km. in length.

Symbols used on cave maps vary greatly from area to area and map to map. Certain symbols however are standard on most maps and are the ones used in the report (Fig. 26).

The caves described in the report are listed alphabetically by state in the following tables. The basic significant features of each cave are listed as well as its latest known status. Map number refers to the number representing the location of the cave on Plate 1. Numbers in the reference column refer to the list of basic references immediately following the tables. The basic reference list is a general collection of published material covering all or parts of cave areas in the United States. The basic reference list is merely a collection of readily available literature, and does not necessarily contain the best reference concerning an individual cave. A more complete list of references is given with each description of a selected cave.

Uncapitalized cave names are those caves originally considered for national significance but not described in the final listing.
Figure 26. Cave map symbols as used in this report.

I. Passage configuration

- Passage outline (ceiling height in feet).
- Underlying passages (in descending order).
- Unsurveyed passage.
- Abrupt drop in passage floor (drop in Feet).
- Slope in passage floor (opening down slope).
- Abrupt drop in ceiling in splayed direction.
- Domepit (height/depth-in Feet).
- Passage intersecting bottom of a dome.
- Passage intersecting top of a pit (drop in Feet).
- Undercut Wall.

II. Cave features

- Flowstone - rimestone.
- or stalactite, stalagmite column (dripstone undifferentiated.)
- Stalagmite
- Stalagmite
- Column.
- Crevice in floor.
- Slot in ceiling.
- Mudbank.
- Ledge.
- Breakdown.
- Passage ending in fill.
- Stream.
- Water depth.
- or Standing water.
Uncapitalized cave names are those caves originally considered for national significance but not described in the final listing.
<table>
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<tr>
<th>Map No.</th>
<th>Cave Name</th>
<th>Page This Report</th>
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<th>Paleontology</th>
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<th>Historic</th>
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1 total of all surveyed caves in Newsom Sinks.
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1 many small lava tube caves located within the monument.
2 contains the two deepest vertical shafts known in any U. S. cave.
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1 many small lava tube caves located within the monument.
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1 the longest known cave system in the world.
2 the third longest known cave system in the world.
3 two entrances, both entrances commercial.
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**MISSOURI**

**MONTANA**

| 48     | BIG HORN Caverns                  | 123  | 37        | x                     | 2.0            | Gated        |

**NEVADA**

| 49     | DEVIL'S HOLE                      | 149  | 22        | X X                  |                | Gated, N.P.S. |
| 50     | GYPSUM CAVE                       | 223  | 18        | X X                  |                | Undeveloped  |
| 51     | LEHMANN CAVE                      | 255  | 31        |                      | 1.52           | Lehman Caves Nat'l. Monument |

1 two separate but genetically related caves totaling 6.2 miles in length.
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1 recent discoveries may have extended the depth of Carlsbad past the 1070 ft. figure, possibly making it the deepest known cave in the U. S.

2 total mapped in Dry and Endless Caves only.
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<td>3.4 sq.</td>
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1 second deepest cave in eastern U.S.
2 Grassy Cove Saltpeter Cave only.
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**TEXAS**

72  CAVERNS OF SONORA  27

73  DEVIL'S SINK HOLE  250

74  EZELL CAVE  23

75  FRIESENHAHN CAVE  222

76  INDIAN CREEK CAVE  177

77  KICKAPOO CAVE  253

78  NEY, Frio, BRACKEN CAVES  239

79  POWELL CAVE  201

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1 an estimated 9 million bats inhabit Frio Bat Cave.
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1 possibly the deepest known cave in the U.S.
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Caves of the Great Savanna
(The Hole, Luddington's, and McClung's Cave)

1 longest and deepest lava tube known in the U.S.
2 very scenic area, containing a few former and one present commercial cave.
3 3 separate but hydrologically related caves.
<table>
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<td>250+</td>
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1 currently the deepest cave in West Virginia and one of the deepest in the Eastern U.S.
Basic References Cited


5. ------, and Harris, S. E., 1961, Caves of Illinois, Ill. Geol. Sur., Rept. of Inv. #125.

6. California Caver, publication of the California Regional Association, NSS, Fresno, California.


16. ------, 1962, Caves of California, mimeo.


32. Texas Caver, published monthly by the Texas Speleological Association, Austin, Texas.

33. Thompson, James, Geology of Jewel Cave, Jewel Cave National Monument Natural History Association, 18 p.


37. Personal communications from various sources, including members of the NSS Committee on Outstanding Caves, Jerry D. Vineyard, and William W. Varnedoe.
### Caves considered significant primarily for reasons of geology and hydrology

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Anvil Cave is located in Morgan County south of Decater, Alabama. Anvil Cave is of hydrologic and geologic interest as it is the most complex maze cave in the United States (Fig. 27). Anvil Cave contains 12 miles of mapped passages, but lies entirely under a ten-acre hill overlooking Flint Creek, in Morgan County. The cave has 7 entrances and a trip to the farthest separated of these can be made in about 30 minutes. The majority of the passages in the cave are of walking heights, although there are several rough breakdown areas especially in the northern part of the cave. The cave contains no running streams of water but several small pools contain troglobitic fish.

The cave is developed in the Middle-Mississippian Gasper Limestone although the cave passage often extends upward to the overlying Hartselle Sandstone which forms the ceiling. A theory concerning the development of the cave by artesian flow appeared in Vol. 35, No. 4, 1964, of the Alabama Academy of Science. While not the only maze cave in the United States, anvil is indeed the most complex.


Ape Cave is the longest unitary lava tube in the United States. It contains many interesting geologic features such as splash holes, calcareous formations, rippled lava, chockstones wedged between levels, lava springs, and lava stalactites and helictites. The passage in the tube is 11,215 feet long, with a depth change of 700 feet, (Fig. 28).

The cave has two entrances connected to short upper levels from which one may reach the level of the main tube. Water enters from several large breakdown domes very close to the surface. Dripping from these domes has eroded the sand deposits on the lava floor to miniature "badlands" like those of Cathedral Gorge, Nevada.

Bats of different species inhabit the cave, indicating a range overlap in the area. Some large Ambystoma and interesting lava tube molds and slime are present in several areas.

Figure 27. Map of Anvil Cave, taken from NSS News, vol. 21, no. 10, Oct., 1963.
Figure 28. Map of Ape Cave, taken from Halliday, 1963, plate 2.
Big Horn Caverns

Big Horn County, Montana

Big Horn Caverns also known as, Glory Hole, Big Horn County, Montana, is the largest cave in the state. It is a complex cave with many varieties of speleothems and fossils. The entrance to the cave is a 65 foot pit which connects with 1 mile of mapped passages with an estimated 3 miles more remaining. Large passages, 20-30 foot wide and almost as high, are covered with about every type of speleothem imaginable. Besides the more common formations, aragonite, snow-white gypsum, gypsum rosettes, gypsum flowers (up to 8 in. in length), calcite rafts, gypsum stalactites and stalagmites, aragonite anthodites, and angel hair are found in the cave. Many fossils exist in the cave, exposed by solution of the surrounding limestone. Some have been completely freed of the walls and are found in the silt on the floor. The most commonly found fossils are syringopora, horn corals, and various brachiopods. The cave is developed in the Madison Group, primarily in the Charles and Mission Canyon formations.

Personal communication, Mike Kaczmarek.

Big Ridge Cave

Mifflin County, Pennsylvania

Big Ridge Cave, Mifflin County, Pennsylvania, is the deepest cave in Pennsylvania. By various drops and slopes one cave descend in this cave to 310 feet below the surface where many passages and dome pits form a maze-like terminal complex which has not yet been penetrated for much more than an additional 50 feet, making the total depth of the cave about 360 feet. At the 310 ft. level are perfectly preserved bone deposits. Formations in the terminal complex are white and floored with white crystalline material. About 200 ft. below the entrance dates of the 1860's and 70's were observed. This cave is unusually large, complex, and deep for the Pennsylvania area.


Black Chasm Cave

Amador County, California

Black Chasm Cave, in Amador County, California, is the site of many diving experiments and biologic and geologic surveys. The mapped extent of the cave is small (Fig. ). Because it is a nature preserve leased by the Nature Conservancy, it has been kept from vandalism and interference with the natural state and physical systems operating in it. Black Chasm has several areas with formations, especially helictites. The lake in the lower part of the cave has been studied repeatedly for information concerning sediment deposition and source of the water. Dives have been made to explore a 70 foot deep hole in the bottom of the otherwise relatively shallow lake. Various crevices and underwater passages are being pushed, with some interesting discoveries. Exploration by boat on the surface of the lake resulted in the discovery of a rather large room with white flowstone and helictites.
The Black Chasm
Amador Co., California

Figure 29. Map of Black Chasm Cave, modified from California Caver, vol. 4, no. 3, op. p. 20.
Samples of the water have been taken for the nearby town of Volcano, which hopes to get its water supply from the lake.


Blanchard Springs
Rowland Cave
(13 and 15 on Plate 1)

Blanchard Springs Cave, also known as Half-mile Cave and Great Stone Caverns, is a large cave in northern Arkansas. Explorations have found many huge rooms. Entry into the cave is gained through a 70 foot pit. At the bottom is a 300 foot long stream passage which floods. Beyond this is a corridor 90 feet high and 60 feet wide, with many speleothems. A huge flowstone mass nearly blocks the passage, beyond which is a room 450 feet long, 125 feet wide, and 90 feet high. Additional passages lead to a large room "several hundred yards long" and 150 feet wide with many glittering formations. Along part of one wall is a sparkling flowstone deposit 200 feet long, one of the largest speleothems known. The huge Stadium Room was mapped at a length of 600 feet. In the Hall of Giants were huge stalagmitic pillars 75 feet high, as large as anything in Carlsbad Caverns. National Speleological Survey members Hugh Shell and Hail Bryant explored and discovered most of the cave. They were mapping, with 7000 feet mapped and 13 miles sketched and hopes of connecting with nearby Rowland Cave when the government, for some unknown reason, refused to let them continue their work. The United States Forest Service now owns the cave and has plans for commercializing it.

Rowland Cave is a commercial cave about 2 miles from Blanchard Springs with a half mile mapped passage and many thousand feet of passage explored. The Blanchard Springs-Rowland connection would form one of the largest of all United States caverns.


Blowing Cave
(81 on Plate 1)

Blowing Cave, Bath County, Virginia, is an historic cave which provides a good example of a complex blowing phenomena. It was one of the first caves known in this country; Thomas Jefferson became intrigued with its blowing behavior and wrote to some degree on the subject. The blowing of this cave is fairly typical of caves with two entrances, each at a different elevation. Changes in pressure and temperature induce an influx of air at one entrance and blowing activity at the other. The known entrance of Blowing Cave exhaled air in the summer and inhaled in the winter. Exploration in the cave were producing interesting observations, such as a stream flowing...
away from the nearby Cowpasture River and 13 feet below its level, when testing of explosives by the U. S. Army in the entranceway during WWII collapsed the entrance. It is believed that re-entry into the cave would not be too difficult. At the time of entrance collapse, over 1,500 feet of cave had been mapped.


Blue Spring Cave
(27 on Plate 1)

Blue Spring Cave is located 5 miles south of Bedford, Indiana, on the south side of White River. Over 19 miles of passages have been mapped in the cave, making it the fourth longest cave in the United States (Fig. 30). Blue Spring has four entrances, two of which open into the two mile long main stream passage. The main stream passage of Blue Spring varies greatly in size with maximum dimensions of 50 feet wide and 40 feet high at its upstream end, near the "Mountain Room." The stream passage is a "trunk" passage which carries a great deal of water and completely fills its downstream section during flood periods. A boat is needed to traverse the stream passage and numerous blind fish and blind crayfish may be seen in the water.

Several major discoveries were made in the cave during 1963 and 1964. These included the opening up of the "First", "Second", and "Third" Discoveries' as well as the "Sand Passage." Later exploration in the First Discovery section lead to the discovery of two new areas, the "Fourth" and "Fifth Discoveries," (Fig. 31).

The "Second Discovery" is generally regarded as the most scenic part of the cave. The total mapped length of passages in the "Second Discovery" is about 5% miles. Of interest in this section are the King’s Hallway, a % mile long dry upper level passage, the Helictite Room containing an excellent display of helictites, two large columns, and a large pure white flowstone mass.

Most of the passages in the cave are of walkable size, and contain active streams. Blue Spring is of geologic interest, being an excellent example of cavern development beneath a sinkhole plain. The cave is quite scenic in places, and is comparable to Carroll Cave in Missouri, although somewhat larger and dryer.

The Lucifigus Newsletter, vol. 11 No. 6.
Figure 30. Topographic map and line drawing of Blue Spring Cave, topography from USGS Bedford West Quadrangle, 1:24,000.
Figure 31. Map of Blue Spring Cave, taken from Palmer, 1969, plate 4.
Breathing Cave, Bath County, Virginia, is a large cave which is of geologic and historic interest. The cave is developed in the Keyser (Helderberg) limestone. Under the flank of a large synclinal valley, (Fig. 34) Breathing was considered the largest cave in Virginia until the Butler-Sinking Creek System was discovered. During the Civil War it was mined for saltpeter. The cave has many of the commoner types of speleothems. Geologically, the cave is significant because it trends deeper and deeper from the entrance, instead of leveling off, as certain theories would require it to (Fig. 32). "Burton’s" phenomenon, almost peculiar to this cave, has been studied repeatedly. This is the breathing activity of the cave, in which air is inhaled for four minutes, then exhaled for a comparable period. The reason for this unique behavior is not completely known. At present the cave is part of a large system associated with Butler-Sinking Creek Cave to the south.


Bull Cave is located a few hundred feet inside the boundaries of Great Smoky Mountain National Park in Tennessee. The entrance to the cave is located on the southeast side of a large uvala on the crest of Rich Mountain near Townsend, Tennessee.

Bull Cave was first explored in 1955, and subsequent exploration proved it to be the deepest cave in the Eastern United States. The cave was mapped through a series of pits and crevices to a depth of 796 feet below the lip of its gaping entrance sink (Fig. 33). The cave consists of several narrow fissures, steep pitches and 2 large vertical drops. The first of these is 170 feet deep, and opens into an impressive breakdown chamber, 100 feet high, 30 to 85 feet wide, and 260 feet long. The second major drop is 105 feet deep, and is the last major pitch encountered in the cave. The passages between the entrance and the major drops are generally high and narrow and have steeply sloping floors. The cave can be considered to be very difficult, and has many very wet and difficult climbs.

Figure 32. Map of Breathing Cave, modified from Douglas, 1964, p. 133.
Figure 33. Map of Bull Cave, taken from Speleotype, vol. 4, no. 3, op. p. 48.
Butler-Sinking Creek System

Bath County, Virginia
Williamsville Quadrangle
38°11'17" N Lat., 79°39'00" W Long.

The Butler-Sinking Creek System, Bath County, Virginia, is the largest cave system in Virginia, of which over 50,000 feet have been mapped. Between Jack Mountain and Chestnut Ridge lies the syncline in which the system is developed. Butler-Sinking Creek ascends both flanks of this syncline, at one point coming within 800 ft. of Breathing Cave. Dye connection has been established with Aqua Cave, as an air connection has been made between Butler and Boundless Cave. These possible connections, all definitely in the same system, along with further exploration, may one day produce one of the largest cave systems in the United States. The cavern also has many beautiful formations including more common formations, a passage with a solid calcite floor, unusual kinds of sulfate crystals and gypsum flowers, and large doubly-terminated quartz crystals. At one place, a partially fossilized human bone, tentatively identified as part of the femur of a young Indian, has been found (Fig. 34).

W. E. Davies, 1958, Caves of Virginia, Virginia Cave Survey, pp. 135-146, map, pp. 136-137.

Carroll Cave

Camden County, Missouri
Conns Creek and Stoutland Quadrangles
NE¼ NE¼ NW¼ SW¼ Sec. 18, T. 37 N., R. 14 W.

Carroll Cave is a large and complex cave system in the northern slope of the Ozarks in central Missouri (Fig. 35). The cave is one of the longest known caves in Missouri, and contains more than 10 miles of surveyed passage with at least another 10 miles unsurveyed. The passages of Carroll Cave are generally quite large and wet. Carroll Cave is very scenic in that it has many impressive dripstone displays, large rooms, passages, and a waterfall. Carroll River, one of the two main streams in the cave contains blind fish and numerous other forms of cave life. The cave is interesting geologically in that it forms part of the drainage net of a large Missouri spring, Toronto Spring, located 4 miles north of the entrance to Carroll Cave. Carroll is also of interest to paleontologists because of the Pleistocene bone deposits that have been found in the cave. The cave is also the type of location for an unusual speleothem called the spathite.

The cave is developed in the upper part of the Gasconade Dolomite of Ordovician age. The entrance to the cave is a low arch, 60 feet wide and 12 feet high on the west side of Mill Creek Valley. A small stream, Carroll River, flows from the cave entrance. The stream is ponded for the first 1000 feet of cave passage. This passage is flooded during heavy rains. The cave may be divided into 3 main parts, each of which contains a small stream. The first section of the cave, the Carroll River passage, is 13,000 feet long. The Mountain Room, located in this passage about 1000 feet from the entrance is the largest room in the cave. The Carroll River passage splits at the "Bridge" into the Upper and Lower Thunder River Passage. The Upper Thunder River Passage is 8,800 feet long. This passage ends in a large collapse through which Thunder River enters the cave. The downstream end of Thunder River is the Lower Thunder River. This passage heads generally northwest.
Figure 34. Topographic map showing cave pattern of the Butler-Sinking Creek Cave System, topography from USGS Williamsburg Quadrangle, 1:62,500.
Figure 35. Map of Carroll Cave, modified from Helwig, NSS Bulletin, vol. 27, no. 1, p. 13.
and is 12,800 feet long. Lower Thunder River passage has many major side passages extending from it, and is relatively void of formations. The water from Thunder River emerges at Toronto Spring, 3 miles from the Terminal Siphon of Thunder River.

Carroll Cave is interesting geologically because of its complex hydrology. Two separate stream systems currently occupy the cave. The geology of the cave was studied by James A. Helwig in 1962 and 1963. At the present time the cave is gated.


Cass Cave Pocahontas County, West Virginia
West Cass Quadrangle
(87 on Plate 1) 38°23'59" N Lat., 79°56'49" W Long.

Cass Cave has become one of the most visited as well as spectacular caves in West Virginia. The entrance to the cave is a stoopway which leads for 700 feet to the prime attraction of the cave, the Big Room (Fig. 36). The room is 180 feet high, 900 feet long, and 20-40 feet wide. There is a sheer drop of 150 feet from the entrance passage to the bottom of the Big Room. A waterfall cascading over the lip of the room falls for 130 feet to the bottom. Formations are also numerous and include domes, spattermites, and rimstones. Flowstone and columns occur up to 20 feet high. Geologically interesting is the Gargoyle Dome, which has projections sticking out two feet from the sides. These projections were caused by complex erosion and different solubility. Also occurring are gypsum crystals, snow, and cave pearls. The cave pearl nest of particular interest lies under drippage which falls nearly 100 feet. Of a zoological interest are several skeletons of small carnivores on shelves 50 feet above the floor. The total length of the cave is over 2 mile

Personal Communication.

Caves of the Bells Santa Cruz County, Arizona
Mt. Wrightson Quadrangle
(10 on Plate 1) SW¼, NE¼, NW¼ Sec. 1, T. 20 S., R. 15 E.

The Cave of the Bells is of geologic interest primarily because it is an extensive maze located in the Santa Rita Mountains. It contains a complex series of passages which have developed randomly. Speleothems are present and include aragonite crystals and anthodites in fabulous displays in the newly discovered Madonna section. The cave is one of several in southeast Arizona where isolated fault block ranges separated by vast basins occur. These ranges offer great possibilities for extensive and deep caves, with enough available limestone to contain the deepest shaft in the world. Although the area has great potential, not much activity was carried on there
Figure 36. Map of Cass Cave, modified from NSS Bulletin, vol. 21, no. 1, p. 23.
as of 1958. The Cave of the Bells is not far from Onyx Cave, a popular and often visited southeastern Arizona Cave.

Personal Communication.

Cave Hollow System

(88 on Plate 1) 30°00'50" N Lat., 79°34'13" W Long.

The Cave Hollow System is one of the longest in West Virginia, containing over 5 miles of passage, (Fig. 37). Several caves link to form the Cave Hollow network. The main cave, Cave Hollow Cave, contains 20,000 feet of passage. In addition, there is a .3 mile passage in the adjoining Manhole Cave. The Ribcage-Vampire Pit complex also connects with the system. In total there are five entrances to the cave. Inside the five miles of passage are many speleothems, including helictites, quartz crystals, white flowstone, and blood red flowstone. The passages contain pits, crevices, and waterfalls. Biologically significant were the discoveries of a new species of isopod, and the finding of a previously unknown white planarian.


Cave Spring System

(40 on Plate 1) Round Spring and Lewis Hollow Quadrangles

Shannon County, Missouri Sec. 28, T. 31 N., R. 5 W.

Cave Spring located about 9 miles southeast of Cedar Grove, Missouri Current River, is the resurgence of a large conduit system, which can produce as much as 47,000,000 gallons of water per day. Two caves open into the Cave Spring System, which feeds this large spring. Wallace Well, a short distance uphill from Cave Spring, is a crawlway from which a pit bells out to reach a lake below. The lake is quite deep and spectacular, and connects directly with Cave Spring. Farther back from Cave Spring is Devil's Well, similar to Wallace Well, with a drop of 100 feet to an underground lake 400 feet long, 80 feet wide, and 85 feet deep. Both these wells are openings into one of the huge hydrologic conduits that supply one of Missouri's springs. The Cave Spring System is one of the few places where the supply system of one of Missouri's large springs may be observed, (Fig. 38).

Figure 37. Map of the Cave Hollow Cave System, taken from Davies, 1965, p. 66.
Figure 38. Topographic map showing location of the Cave Spring System, taken from Vineyard, NSS Bulletin, vol. 20, p. 48.

CAVE SPRING—WALLACE WELL CAVE SYSTEM

SHANNON COUNTY

SW1/4, SE1/4, NW1/4, SEC. 21, T.31 N., R.5 W.
Cave of the Winding Stair  
San Bernardino County, California  
Flynn Quadrangle  
Sec. 9, T. 10 N., R. 14 E.

140.

Winding Stair is primarily a vertical cave, both difficult and dangerous to explore. Its total depth lies between 300 and 400 feet. Found in slightly distorted limestone with a local dip about 30 degrees to the east, this cave is a series of tight crawlways with some breakdown chambers, and an interconnected pit system. There are many coralloid speleothems, and in places much dripstone and flowstone. A very deep pit drops 265 feet to the lower levels of the cave. The bottom room has a ceiling height of 120 feet with a huge dripstone curtain, aragonite crystals and some gypsum floors. The cave is to be included in the Mitchell Caverns State Park.


Cemetery Pit  
Dade County, Georgia  
Trenton Quadrangle  
Fox Mountain

The entrance to Cemetery Pit was located in 1961 about 1/3 of the way up Fox Mountain in a 40 foot deep sinkhole (Fig. 39). Since its discovery Cemetery Pit has become the center of much caving activity and is one of the most well known and most frequently visited pit caves in Georgia.

The entrance drop is 154 feet, although only 78 feet of this is free drop. The rest may be descended on foot over breakdown to the stream level. Another pit 450 feet inside the cave is 35 feet deep and leads to the Big Room, where passages branch in all directions. Several of these end in domes or pits. Twin waterfalls were found. A mazework of many short passages was found to connect the major passages and was named the 3-D maze area. Total length of surveyed passaged by 1968 stood at 2.5 miles. There are a few formations in the cave, including stalactites, and soda straws, one of which is 25" long.

Georgia Underground, publication of the Dogwood City Grotto, N.S.S., January-February 1968, Vol. 5, No. 1

Church Cave  
Fresno County, California  
Tehipite Dome Quadrangle  
Sec. 10, T. 13 S., R. 9 E.

This cave has been known since 1907, although its location was lost until 1951. It contains several large chambers; however, most of the cave is extremely difficult, and its appeal is scientific rather than scenic. It has been the scene of several rescues. More than 8,000 feet have been mapped, with four entrances located (Fig. 40). Much of the passage is either narrow or breakdown filled, and not many speleothems are present. The cave contains 6 streams, the largest of which carries 50 gallons per minute, and flourescien tests have shown a connection with nearby Boyden Cave. There is very little life found in the cave.

Figure 39. Map of Cemetery Pit, taken from Georgia Underground, vol. 5, no. 1, 1968.
Figure 40. Plan and section of Church Cave, modified from Caves of the Sequoia Region, California, Guidebook to the 1966 NSS Convention, p. 22 and 24.
Coldwater Cave in Winneshiek County, Iowa, can be regarded as the most significant Iowa cave. Three and one-half miles of main passage has been surveyed in the cave, with upwards of 6 to 7 miles of passage explored, (Fig. 1+1 ). The cave is regarded as being very scenic and for its location, most unusual.

Coldwater Cave was discovered in September 1967, and was until recently unknown to the general public. On the suggestion of several members of the National Speleological Society, who had made the initial explorations of the cave, the area encompassing Coldwater Cave was made a state preserve by the Iowa State Conservation Commission in 1969. Entrance to the cave is currently being controlled by the State Conservation Commission. At present, Coldwater has only a single entrance, as almost ¼ mile of completely submerged cavern passage lies between the entrance and the major portion of the cave, and scuba equipment if necessary to enter the cave. It is possible that a "dry" entrance to the cave could be located.

The entrance to Coldwater Cave is quite scenic and is located in wooded surroundings at the base of high limestone cliff. A short distance inside the entrance passage a sump is encountered, and further exploration of the cave requires scuba equipment. Beyond the submerged section lies by far the major portion of the cave.

The main passage of the cave is a long sinuous conduit which extends more than 3½ miles to the north beneath the rolling Iowa landscape. Portions of the main passage are 30 feet high and up to 50 feet wide. Numerous side passages have been discovered off of the main stream passage and at least one very large domed pit has been located.

The cave is currently (March 1970) still under exploration and it is estimated that a total of 10 to 12 miles of passage may exist in the system. Coldwater contains numerous large and beautiful formations, and remains in essentially its natural state.

ARTICLE: Concerning Coldwater Cave has appeared in Picture Magazine of the Des Moines Sunday Register, Dec. 7, 1969.

Personal Communication: David Jagnow, Iowa Grotto, N.S.S.

Craighed Caverns
Meigs County, Tennessee
Sweetwater Quadrangle
(69 on Plate 1)

Craighed Caverns is operated commercially at the present time under the name of its principal attraction, the Lost Sea. The cave has one very large main passage, averaging 50 to 75 feet wide, 20 feet high, and one-half mile long. The southwest end of this passage terminates at a very large underground lake some 700 feet long, 200 feet wide, and up to 65 feet deep, which has been named the Lost Sea. This body of water is believed to be the largest underground lake in the United States.
Figure 41. Map of Coldwater Cave, modified from map by David Jagnow.
The cave contains a display of large anthodites, also at the southwest end of the main passage in the "New Room." Hundreds of anthodites and calcite needles may be seen in this area of the cave.

Craighead Caverns is one of the largest caves of the area, and has been known for many years. Indian relics have been found inside the entrance of the cave, but it is doubted they explored the cave to any great extent.

In 1939, the lower jaw of a Pleistocene jaguar was found in the bottom of a crevice about 400 feet inside the cave. A skull was also discovered 50 feet above the point where the jaw was found. An interesting set of cat tracks were then found about 1700 feet into the cave, near the "New Room."

Craighead Caverns is noted primarily for its unique lake, and paleontological finds. Recently, a new species of blind fish was found in its lake. Its anthodites and other formations are not spectacular, but the cave as a whole is noteworthy.


Craters of the Moon Butte County, Idaho Craters of the Moon Nat'l. Monument Map
(25 on Plate 1)

There are many lava caves located within Craters of the Moon National Monument, and four of them are of special note (Fig. 42). The largest of the lava tubes, and the one visited by tourists, is Indian Tunnel Lava Tube, 828 feet long, 28 feet high and 50 feet wide. There are five skylights within this cave. It contains the mineral mirabilite.

Crystal Pit Spatter Cone Cave has unique mineralization which includes mirabilite (Na₂SO₄), gypsum, and jarosite. Also occurring are gypsum covered lava stalactites. The entrance to the cave is an 85 foot pit.

Acro Tunnel Lava Tube contains very interesting formations, including ice speleothems, bulbous lava stalactites, and white coralloidal opal. There are small soda straw stalactites covered and tipped with opal, and these may be precipitating opal from capillary waters.

Great Owl Cavern Lava Tube is 480 feet long, 40 feet high, and 50 feet wide. This cave contains ice year round.

Figure 42. Topographic map showing the major caves of Craters of the Moon Nat'l Monument.
Cumberland Caverns is located in Warren County, Tennessee, 1.8 miles west of Shellsford. The cave was discovered about 1810 by Aaron Higgenbotham, and was henceforth called Higgenbotham Cave, until 1956 when the cave was opened to tourists.

Cumberland Caverns is the longest known cave in Tennessee, 16 miles, and has a rich and well documented history (Fig. 43). The earliest date yet found in the cave is 1855. During the Civil War, the cave was extensively mined for saltpeter, and the various leaching vats, tools, and wooden pipes used during the operation are on display in the cave. After the Civil War, the cave became popular with local people. Countless trips were made during this era from the historic entrance to the spectacular Big Room, a grudging 6 hour trip. Of the many names and dates left in the cave from this period the name Shelah Waters and the date 1869 are significant. Waters was a tax revenue officer who may have been the first to venture beyond the early limit of exploration. His name can be seen today in some of the more remote sections of Cumberland Caverns.

Modern day exploration of the cave began in 1945. Following Water's footsteps, these explorers rediscovered the Volcano Room, the Awesome Hall of the Mountain King, the Devil's Quarry, and the magnificent Monument Pillar. In 1953 the magnificent "Great Extension" was discovered. Subsequent exploration has revealed the Crystal Palace, containing fine displays of gypsum florns and selinite needles said to be some of the finest in the United States.

The long hard trip from the entrance to the Big Room was bypassed in 1953 with the linking of Henshaw Cave and Cumberland Caverns. In 1951 the small opening connecting the two caves was enlarged, and the commercial development of the caves was started. Today, the main parts of the historic sections of Cumberland Caverns are now shown on the Commercial tour. Many of the wild sections of the cave are still undeveloped, including the Great Extension. The most significant features of Cumberland Caverns are its large dry rooms and passages, historic significance, and spectacular gypsum displays.

Figure 43. Map of Cumberland Caverns, taken from Barr, 1961, p. 472.
Dante's Descent  
Coconino County, Arizona  
Williams Quadrangle  
NWq Sec. 22, T. 22 N., R. 3 E.

One of the most awesome pits in the United States is Dante's Descent, almost 300 feet deep and 106 feet across (Fig. 44). For years it was forgotten and practically lost. The opening is well hidden among jagged lava rocks. The lava cap rock of the area slopes down twenty feet from the mesa and then drops fifty-five feet in two stages to the prominent Diamond Back Ledge. The ledge extends for about two thirds of the hole's circumference and is ten feet at its widest. The total free drop from the mouth of the pit to the top of the floor is 257 feet. The rest of the descent is over breakdown, which is confined to the northeast and southwest walls rather than being the conventional mound in the center. The bottom of the pit is larger than the top and is not oval like the entrance. The hole was located many years ago and the first explorer went down in a metal barrel with a winch cable. Even today, few people have been to its bottom.

Speleo Digest, 1958, Published by Pittsburg Grotto, N.S.S., p. 2-29, 2-31.  

Devil's Hole  
Nye County, Nevada  
Death Valley National Monument

Devil's Hole is a warm water spring in the middle of the Nevada desert. It is protected by the National Park Service because of its rare fauna. The hole is a spring which contains 93° water. Several dives have been made with the discovery of an air-filled room and many submerged channels and passages. Divers have reached a depth of 240 feet in the hole with no sign of the bottom (Fig. 45). Animals found include rare planaira and fish unique to Devil's Hole, and the cave has been gated to protect them. The depth of the spring adds to its notoriety.


Devil's Icebox  
Boone County, Missouri  
Columbia Quadrangle  
SWq, SWq, NWq Sec. 7, R. 49 N., R. 12 W.

Devil's Icebox, Missouri, is an enterable remnant of one of the large hydrologic supply systems underlying Missouri's karst region. Basically an enlarged joint system, the cavern is similar to concepts of the connecting conduits between such large subterranean reservoirs as Wallace Well and Devil's Well. Exploration in the cave is difficult; rafts are required in several places and the constant exposure to water saps endurance. 29,000 feet have been mapped in the cave, which is still being explored.
Figure 44. Map of Dante's Descent, modified from Speleo Digest, 1962, p. (2-30).
Figure 45. Profile map of Devil's Hole, modified from Halliday, 1966, p. 281.
The first 2,600 of the cave is a water passage which requires rafts. Beyond a low place about 300 feet from the entrance, the passage enlarges to an average size of eight feet high and forty feet wide. The stream here is deep and meanders across the whole width of the passage. Further on, the passage decreases in size until a siphon is reached 19,000 feet from the entrance.

Mapping in the many side passages is still continuing, with the hope of a new entrance. About 60 domes are found in Devil's Icebox, seemingly enabling rain water on the surface 175 feet above to enter the system as quickly as it does.


Ellison's Cave
Walker County, Georgia
Estelle and Cedar Grove Quadrangles
(exact location shown on map)

Ellison's Cave currently has 3 entrances, the Old Ellison's Entrance, the Stairstep Entrance, and a new entrance near the Old Ellison's Entrance which provides easier access to the rest of the cave. Both Fantastic Pit and the Incredible Domepit are difficult to reach. Fantastic Pit has 3 drops above it, 125' 18', and 25' which must be descended before the top of the pit.
Figure 46. Map of Ellison's Cave, taken from Schreiber, Georgia Underground, vol. 7, no. 2.
is reached. The same is true for the Incredible Domepit which has drops of 13', 60', and 85' before the actual 440' drop is reached, some 600' inside the cave. Fantastic Pit and the Incredible Domepit are the only known routes into the bottom cave. Ellison's Cave has gained a reputation as a very difficult cave requiring much endurance and stamina to reach the bottom cave and return to the surface.

The bottom cave consists of several levels of relatively large dry passages containing considerable amounts of breakdown. The upper levels of the bottom cave are developed within a prominent east-west trending fault. Fault control is seen throughout the bottom cave. The lower levels contain several impressive high ceiling domes and passages including the 200+ Snowball Dome. One room, the Hall for the Giants, located at the extreme western end of the bottom cave, is 300 feet long, 80 feet wide, and 50 feet high. Spectacular displays of "moonmilk", gypsum and epsomite are also found in the lower levels of the cave. One newly discovered area, the Angels Paradise, contains a unique display of espomite with some of the long slender crystals reaching lengths of over a foot. It is one of the most spectacular epsomite displays in the United States.

At the present time the spectacular features of the bottom cave are relatively safe from vandalism because of the extreme difficulty in reaching them from the surface. The entire cave, with exception of the long known passages just inside the Old Entrance, is in almost a virgin state, however, increased traffic in the lower cave may damage some of the fragile epsomite and gypsum deposits.

Because of the hazard that Fantastic Pit presents to the unqualified caver, a gate has been installed in the cave, just a few feet from the edge of Fantastic Pit. Entrance to the Lower Cave is now limited to groups qualified in vertical caving, and it is hoped that the gate will also help to protect some of the beautiful and delicate formations in the Lower Cave.

Huntsville Grotto Newsletter, Vol. 10, No. 6, "The Stairstep Entrance to Ellison's Cave, by Richard Schrieber.

Fern Cave
Jackson County, Alabama
Paint Rock Quadrangle
( 2 on Plate 1)

Fern Cave, located in the Jackson County Mountains of northeastern Alabama is the site of the third deepest pit in the United States (Fig. 47). This unique shaft located 500 feet into the cave was discovered in 1961 and quite rightly named Surprise Pit. The pit is spectacular in its dimensions; it is 440 feet deep, 60 feet in diameter at the top, and bells out into a huge breakdown floored chamber at the bottom. A waterfall which enters the
Figure 47. Map of Fern Cave, modified from Veitch, 1967, Caves of Alabama, p. 30.
Figure 48. Profile map of Fern Cave.
Cave's entrance sink flows back into the cave 500 feet at the lip of the pit and plunges the 440 feet down the shaft. Surprise Pit remained the deepest freefall pit in the U.S. until 1968, and the exploration of Ellison's Cave in Georgia (Fig. 48).

Fern Cave is located just east of Paint Rock, Alabama, in Nat Mountain. The cave takes its name from the ferns surrounding its scenic entrance sink in the side of the mountain. The passage back to the pit averages about 8 feet high and 3 feet wide and contains the small stream flowing in from the entrance. The Pit itself is L-shaped in plain view, and is developed in the Bangor Limestone.

Surprise Pit has become the ultimate challenge of "vertical" cavers in the United States. The drop into Surprise Pit is free from any wall and is quite spectacular. It has been suggested that if the pit were ever developed commercially, that a glass elevator in the shaft would offer a splendid view. The pit is so large that the presence of an elevator shaft would be hardly noticeable. Surprise Pit is one of the finest examples of a dome-pit in the United States. The presence of the pit makes Fern Cave extremely interesting to both the cave explorers and geologists alike.


Flint Ridge Cave System  
Edmundson and Hart Counties, Kentucky  
(32 on Plate I)

The Flint Ridge Cave System is located in Mammoth Cave National Park, about 100 miles south of Louisville, Kentucky. Flint Ridge is located just to the northeast of the famous Mammoth Cave Ridge, and contains the world's longest cave (Fig. 49). At present, about 75 miles of cave passage has been surveyed in the Flint Ridge System. The system is now under intensive study in almost all major fields of speleology. Research is being conducted at the present time by the Cave Research Foundation whose primary interest is the complete exploration and study of the Flint Ridge System. Intensive research and study in Flint Ridge has led to a better understanding of the origin and development of large cave systems. Biological surveys have been fruitful in the search for a better understanding of the life in caves. Several papers concerning the geologic, hydrologic, and biologic research in the system have been published, many of which are cited in the references at the end of this description.

Flint Ridge is a largely undeveloped area inside Mammoth Cave National Park. Contained in the ridge are 4 major caves, Unknown, Crystal, Salt's and Colossal which have been linked together to form the system. The passages of Flint Ridge vary from large dry walking passages to small mud-filled crawl-ways. The system is very complex and exploration is far from complete.
MAMMOTH CAVE
and
THE FLINT RIDGE CAVE SYSTEM
Mammoth Cave National Park, Kentucky
Topographic map showing cave pattern

Figure 49. Map of Mammoth Cave and the Flint Ridge Cave System, topographic map showing cave pattern, taken from James F. Quinlan, 1968, personal communication.
The early exploration of the 4 major Flint Ridge Caves has been somewhat obscured by time. The large dry passages of Salt's Cave may have been the first to be explored. Names on the walls of the cave date back to 1845. The spectacular entrance sink to Salt's Cave, and its large dry, breakdown strewn main passage attracted much attention during the latter part of the 19th century. Salt's was also the site of two unsuccessful commercial ventures in the early part of this century. This large cave is noted primarily for its pre-Columbian Indian artifacts. Perhaps the next cave to be discovered was Unknown Cave, sometime late in the 19th century. There are indications that Unknown Cave may have been the first cave in Flint Ridge to be surveyed. An interesting note is a 1903 sketch map of Unknown Cave which showed it as an entrance to Salt's Cave. It is not known if an actual connection between the two caves was really made.

Colossal Cave was discovered sometime before 1900. Exploration revealed Colossal to be the most extensive known cave in Flint Ridge, until the discovery of Crystal, and was the first cave to be accurately surveyed in Flint Ridge. Colossal Cave was operated commercially by the Louisville and Nashville Railroad. The major features of Colossal Cave were Grand Avenue and the huge Colossal Dome.

In 1915 Great Onyx Cave, located in the extreme northwest corner of the ridge, was discovered by Edward Turner. Great Onyx remains today physically separate from the rest of the Flint Ridge System.

Less than two years later, the legendary Floyd Collins opened up a sinkhole near his home, and discovered Crystal Cave. Collins, exploring by himself, penetrated deep into Crystal Cave before his death in Sand Cave in 1925. It took modern day explorers many years to rediscover all which Collins had seen in his exploration.

Systematic exploration of Crystal, and soon other Flint Ridge Caves, began in 1947. Several major discoveries in the late 1950's lead to the connection of Salt and Colossal Caves, and Crystal and Unknown. A small connection found in 1961 united these two great caves into what is now called the Flint Ridge Cave System. The Cave Research Foundation, began its work in Flint Ridge in 1957 and has been responsible for many major discoveries and scientific studies in this most recent era of Flint Ridge exploration.

The Flint Ridge Cave System is truly one of the greatest caves in the world. The brief description and history given here does not at all do justice to this enormous cave system. Several factors, besides its length have made it extremely significant, its largely virgin and completely un-vandalized state, its complex geologic history, its pre-Columbian Indian artifacts, and its colorful history, just to name a few.

The following references should be consulted for a more detailed study of the Flint Ridge System. Numerous articles concerning the geologic and biologic features of the system have been published most of which appear on the master publication list of the Cave Research Foundation.

Fort Stanton Cave

Lincoln County, New Mexico
Near Ft. Stanton
Lincoln National Forest

Fort Stanton Cave is one of the largest caves in southern New Mexico, and has been mapped to an extent of 11 miles. There are still vast areas unmapped. The entrance is a large sinkhole twenty feet across and descent is made through a number of passages and rooms to the main cave passage, a two mile long channel 25 feet high and 20-40 feet wide. Although there is a great amount of breakdown and sediment along the passage, it rarely reaches half the ceiling height. At the end of this two mile passage there are two forks, one of which goes up while the other stays at main passage floor level and permits the flow of the stream to continue. The upper passage has the same ceiling as the main passage, but its floor rises until the passage is constricted into a maze of crawls in tubes. The lower passage continues onward but the ceiling drops to within eight inches of the floor for a short distance before the passage opens back up into the same large size passage which ends in breakdown. The rest of the cave is entered from a T junction in the first two mile passage. This leads to the longest part of the cave with seven miles mapped in it, for a total of eleven miles mapped.

This cave is joint controlled as are other caves in the area. It appears to be developed along a major fault trending north-northeast toward the Capitan Mountains. In addition to the normal speleothems Fort Stanton has a wide variety of gypsum. Many of the crawls selenite needles up to six inches long. Gypsum flakes cover the floor in the extreme northern of the main corridor. There is also gypsum and odd disc-shaped gypsum crystals.

Speleo Digest, 1962, Published by Pittsburg Grotto N.S.S., p. 2-60, from Carpenter and Schluter.
Fossil Mountain Ice Cave

Teton County, Wyoming

43°39'40" N Lat., 110°57'35" W Long.
Elevation 9250 Ft.

When one enters Fossil Mountain Ice Cave he enters a world of glistening fascination. The entrance to the cave lies 1000 feet up the west wall of Darby Canyon from Wind Cave, which has a 140 foot high entrance not easily missed. About 50 feet in from the entrance the limestone floor turns to thick clear ice. The main passage is a tall phreatic solution passage with vadose workings. It is about 400 feet long and is encrusted with hexagonal plates of ice which build thick crusts. At the end of the upper passage is a pit which drops 30 feet to an ice floor. On the opposite side of this room a cascade of ice flows down the side for 40 feet to meet the floor. This thick ice floor forms a balcony over a 45 foot pit on the far side. Two holes in this room 20 feet below the entrance passage lead to a lower passage which runs parallel and directly below the upper entrance passage. There are many ice platelets on the walls and the floor is clear ice. A low room is entered about 200 feet back and is beautiful with ice formations. The passage forks, with the left part ending. The right side leads through a 20 foot long snow crawl and into the most beautiful room in the cave, the Crystal Room. On the floor is deep clear ice. The walls and ceiling are encrusted with ice platelets which hang in pendants. There are also ice stalactites, stalagmites, and columns. The ceiling stone may be seen through the clear ice. The ice formations in this small cave make it one of the most scenic to be found anywhere.

N.S.S. News, Vol. 11, No. 12, p. 11.

Grassy Cove Karst Area

Cumberland County, Tennessee
Grassy Cove Quadrangle

35°50'60" N Lat., 84°56'45" W Long.

The Grassy Cove area of east central Tennessee was selected as an area displaying excellent karst development (Fig.50 ). There are several caves and sinking streams in the area which are very characteristic of a karst area. Although none of the caves are really spectacular, when taken as a group they represent a very significant geomorphic situation.

Grassy Cove is a large crescent shaped uvala roughly 7½ miles long and 1½ to 2 miles wide; it is developed along the crest of a broad symmetrical anticline in the Cumberland Plateau of Central Tennessee. As erosion slowly removed the overlying Pennsylvanian sandstones and shales from the anticline, solution began to rapidly lower the underlying Mississippian limestone surface. The collapse of underlying caverns also added to the development of the cove. A detailed account of the geology and development of the caves can be found in the references cited at the end of this description.

Possibly the most well known of the Grassy Cove area caves is Grassy Cove Saltpeter Cave (Fig.51 ). This cave is about 3 miles long and is the fourth longest cave in Tennessee. The cave is for the most part dry and spacious, and contains some remnants of the saltpeter operations conducted there during the Civil War. Grassy Cove Saltpeter Cave is one of the best known caves in the state of Tennessee, and is located on the east slope of
Figure 51. Map of Grassy Cove Saltpeter Cave, taken from NSS Bulletin, vol. 29, 1967, p. 150.
Mill Cave, (Fig. 52) located in the northwest corner of the cove is one of the largest caves in Middle Tennessee. The entire drainage from Grassy Cove, plus the stream entering the cave from Bristow Cave, flows into the mouth of Mill Cave. This stream may be followed the length of the cave. The entrance to Mill Cave is 10 feet high and 30 feet wide. The main cave passage runs west for 3,500 feet to a second entrance which is 8 feet high and 25 feet wide, and opens high above the stream. Downstream from the second entrance, the passage continues with much larger dimensions about 80 feet wide and 75 feet high. The exact length of passage past the second entrance is not known, but is at least several thousand feet. Mill Cave is popularly supposed to be the headwaters of the Sequatchie River, 7½ miles to the southwest, and 390 feet lower in elevation. Devilstep Hollow Cave, located at the head of the Sequatchie Valley is the source of the Sequatchie River, and according to local stories connects with Mill Cave in Grassy Cove. It is possible that the stream which flows through Mill Cave does indeed have an outlet in Devilstep Hollow.

Brady Mountain, which rims the west side of the cove contains several vertical shafts, 2 of which are well known, Banshee Hole, and the Grouffre (Fig. 53). The Grouffre is one of the most impressive pits in Tennessee, along with Conley Hole described in this report, and the spectacular Mystery Falls on Lookout Mountain. The Grouffre, or Blowhole as it is sometimes called is 235 feet deep, and is located about ½ mile west of the entrance to Grassy Cove Saltpeter Cave. The surface entrance to the pit is quite small, about 23 feet. One descends into a vast chamber which is 200 feet high, 250 feet long and 80 feet wide. There is one very extensive passage leading off from the bottom of the pit.

Other caves are known in the Grassy Cove area including, Milk Sick Cave (Fig. 54), 35°49′21″ N and 84°55′14″ W, and Bristow Cave, 35°20′29″ N, and 85°54′19″ W. Bristow Cave is the only large stream inlet into Grassy Cove. The cave is located on the east side of the cave and has a rather impressive entrance, measuring some 15 feet high and 50 feet wide. The entrance opens into a large room, through which the stream flows. The room is about 80 feet wide, 40 feet high and 300 feet long.

Grassy Cove contains several "good" caves, and is an excellent area to study the development of karst and underground drainage. The area is relatively undeveloped and is quite scenic.

T. C. Barr, 1961, Caves of Tennessee, p. 138-142, (describes most major caves in the Grassy Cove Area).
Figure 50. Grassy Cove Karst Area, topographic map showing cave locations, topography from USGS Grassy Cove Quadrangle, 1:24,000.
Figure 52. Map of Mill Cave, modified from Speleo Digest, 1966, p. (1-180).

MILL CAVE
Grassy Cove
Cumberland Co., Tennessee
Figure 53. Map of the Gouffre, modified from Speleotype, vol. 4, no. 1, p. 11.
MILKSICK CAVE
(Grassy Cove Karst Area)
Cumberland Co., Tennessee

Figure 54. Map of Milksick Cave, modified from Speleo Digest, 1966, p. (1-78).
Greenbrier System
Greenbrier and Monroe Counties, West Virginia
West Ronceverte Quadrangle
Hedricks Entrance
37°41'32" N Lat., 80°26'02" W Long.

The Greenbrier System, located in Greenbrier and Monroe Counties, West Virginia, is a large cave system with great potential to become one of the major caves in the United States (Fig. 55 & 56). The oldest known parts of the system are Organ Cave and Hedrick Cave. Both of these caves boast huge passages, beautiful formations, and vertical drops. Not much cave was generally known until 1948-89, when work in the cave resulted in many major discoveries, extensions, and the connection between Organ and Hedricks Cave. Further work has resulted in the present Greenbrier System's seven entrances - Organ, Hedrick, Lipp, North, Deem, Sivley, and Humphrey Caves. Cavers mapping in the system have mapped 15 miles, with an estimated 15 miles of explored passages remaining. Due to misunderstandings and discourtesies of various cavers with the land-owners, about half of these entrances are now closed to cavers.

Wm. Davies, 1958, Caverns of West Virginia, West Virginia Geological Survey, pp. 92-94.

Germany Valley Karst Area
Pendleton County, West Virginia
(89 on Plate 1)

Germany Valley is an important karst area and cavern complex in Pendleton County, West Virginia (Fig. 57). The valley is known for its many pits and vertically-oriented caves, along with the more usual cave systems. The major caves in Germany Valley are Schoolhouse, Hellhole, Seneca, Nameless, Stratosphere Balloon, Lawrence, and Gypsum Caves, (Figs. 58, 59, 60, 61, 62).

Schoolhouse Cave was once regarded as one of the most difficult caves in the United States, and is one of the old "classics" in American Cave exploration. Much of the cave is vertical; the horizontal cave distance being only about 2,000 feet, but a trip to the end and back requires 12-20 hours. Hellhole is a 180 foot deep pit with a cave at the bottom. Seneca Caverns is a scenic commercial cave. Nameless Cave is a small cave, about 200 feet long, near Seneca caverns. The cave is suffering much vandalism and trash dumping.

Stratosphere Balloon Cave is a former commercial cave. Speleothems are notable, especially a large flowstone formation 18 ft. in diameter and 25 ft. high, for which the cave is named. Lawrence Dome Pit Cave is a small, 700 ft. long, cave containing many formations and preserved bones of animals which fell in the funnel-shaped entrance. Gypsum Cave is a medium-sized cave containing gypsum, anthodites, and several pits and dome-pits.

There are numerous other caves and pits in Germany Valley. A few of these are Hourglass, Dunn's, Judy Spring, Little Hellhole, Groundhog, Coon, Harper's, and Warner's Caves.

The National Forest Service has plans to turn part of Germany Valley into a recreation area (Spruce Knob and Seneca Rocks, R. A.). This could harm the area both on the surface and underground.
Figure 55. Map of Organ Cave, (Greenbriar System), taken from Davies, 1958, p. 113.
Figure 56. Map of the Greenbrier System, taken from Davies, 1958, p. 92.
Figure 57. Location of caves in the Germany Valley Karst Area, Pendleton Co., West Virginia (Speleo Digest, 1959, p. 2-69).
Figure 58. Map of Schoolhouse Cave, taken from NSS Bulletin 11.
Figure 59. Map of Hellhole Cave, taken from Davies, 1958, p. 214.
Figure 60. Map of Seneca Caverns, taken from Davies, 1958, p. 238.
Figure 61. Map of Stratosphere Balloon Cave, taken from Davies, 1958, p. 247.

STRATOSPHERE BALLOON CAVE
PENDLETON COUNTY
West Virginia
SURVEYED 7-12-48
175
0 20 40 60
FEET
Figure 62. Caves of the Germany Valley Karst Area, modified from Speleo Digest, 1959, p. (1-83), (1-85), (1-86), (1-90), and Speleo Digest, 1958, p. (1-170).
Hosterman Pit

Hosterman Pit, with a mapped length of 6,623 feet, is one of Pennsylvania's largest caves (Fig. 63). It requires a total of 630 feet of vertical ropework for exploration. It was initially entered in 1961 when cavers found several large rooms and some passages which could not be entered without more equipment. A return trip was successful in climbing to a lead beneath a flowstone overhang, where a passage containing formations was found. A side passage revealed the first noteworthy formations, helictites and anthodites. Later, blasting opened up a new section of cave now known as the Dynamite Section. More blasting removed the flowstone plug at the end of the Dynamite Section, opening up a small section of caves containing many formations, including anthodites. Several species of bones have been found in one area of the cave, including those of the now-extinct Eastern Elk. The cave is owned by the Bethlehem Steel Corporation and is gated.

Indian Creek Cave

Indian Creek Cave was discovered in 1955 when a Texas hunter noticed a wisp of steam coming up from a crack near the usually dry bed of Indian Creek. The rancher was determined to investigate this and hired two Mexicans to chisel open the crack to a greater width. After a little work they broke into a small room. A hoist was rigged and the rocks and boulders of the small room were removed by the Mexicans. During more chiseling and hammering in the opening, there was a roar and the floor dropped seventy feet into the cave below, leaving the Mexicans dangled from the side on their safety lines. After the cave was opened a geologist visited it and reported sticky red clay and many nice formations. In 1955 Uvalde County decided to use the cave as a recharge for the low water table of the area. About $20,000 was spent to enlarge the entrance and built a 225 foot long concrete dam in front to divert flood waters from Indian Creek. The subsequent large volume of water that poured into the cave after rains scoured out all of the clay and most of the formations were toppled in the front part of the passage. The sound of the flood water roaring into the cave can be heard for a half mile and it vibrates the solid rock (Fig. 64 ).
Figure 63. Map of Hosterman's Pit, taken from 1970 NSS Convention Guidebook, op. p. 67.
Figure 64. Map of Indian Creek Cave, modified from Speleo Digest, 1960, p. (1-179).
The cave is entered through a 120 foot deep sink with five ledges on the way down. At the bottom there are two passages. A passage over a ledge to the northwest leads to a grotesque formation room. The southwest passage leads to the main part of the cave. The flood scoured main passage goes 200 feet to a three way junction, the branches of which rejoin. This passage carries most of the floodwater and is completely scoured. After 900 feet of shallow pools deep water is encountered. There is a side passage with a waterfall and a siphon. The main passage leads to the Sunflower Junction where the passage again forks. One fork leads to large banks resembling sand dunes and then to a formation room where soda straws are three feet long. An alcove contains long columns and a high flowstone cascade. The cave has much more passage and though closed as of November 1967, it is the second longest in Texas with eighteen thousand feet explored. The different formations in the three miles of passage include cave pearls, huge bacon rinds, black stalagmites, helcites, calcite crystals, white popcorn, and some formations resembling those of the Caverns of Sonora.

Speleo Digest, 1960, Published by the Pittsburg Grotto, N.S.S., p. (1-177)-(1-1k) N.S.S. News, Sept. 1962, cover picture.

Jewel Cave Custer County, South Dakota Jewel Cave Quadrangle  
(64 on Plate 1) NE\textsuperscript{4} SW\textsuperscript{1} NE\textsuperscript{1} Sec. 2, T. 17 N., R. 2 E.

Within the boundaries of Jewel Cave National Monument, Jewel Cave is an extremely large cave with 27 miles of mapped passage, with a small portion open to the public as a commercial cave (Fig. 65). There are also plans to open up an area with 100 foot ceilings and long chambers in one of the more remote sections of the cave. The development of the cave is joint controlled to a large extent. The cave is named for the immense amount of beautifully shaped calcite crystals found on the walls formed in several crystal types. Many other minerals are present as crystals and speleothems including aragonite frostwork, manganese, quartz fins, and the more usual types of speleothems. The cave is well known for its numerous and varied types of formations. The cave is being studied and surveyed by members of the National Speleological Society at the present time. The cave has strong winds, and like Wind Cave, forms an interesting meteorological problem, (Fig. 66).


Lilburn Cave Tulare County, California Giant Forest Quadrangle  
(19 on Plate 1) 36°36' N Lat., 118°55' W Long.

This is probably California's longest cave, with about 3 miles of cave passage known, (Fig. 67). Exploration is difficult because of the inaccessibility of the cave. At least 330 feet of relief occur within the cave. Lilburn is a marble cave, and the walls display many cross-sections through minor structure. Portions of the cave carry a flood-stage stream which washed out mudbanks in 195
Figure 65. Jewel Cave National Monument, topography from USGS Jewel Cave Quadrangle, 1:24,000.
Figure 66. Map of Jewel Cave, taken from Herb Conn.
Figure 67. Map of Lilburn Cave, modified from Caves of the Sequoia Region, California, Guidebook to the 1966 NSS Convention, p. 30.
exposing a series of maze like passages. The rooms contain large crystals and many speleothems. A fifty foot descent through breakdown then leads to the river passage with much labyrinthine development, pools, and waterfalls. This stream exits at nearby Big Spring, which is currently the focus of a hydrographic study being conducted by the Southern California Grotto of the N.S.S. The relationship between the erosion surface perched 2000 feet above the cave system and the cave itself is presently being studied. The cave is generally developed parallel to the strike of the near vertical beds, and shows a close relation to the joint system present in the bedrock. The cave is gated, and access to it is controlled.

Caves of the Sequoia Region, Guidebook to the 1966 N.S.S. Convention, p. 29.

Lost River Karst Area
Orange County, Indiana
Mitchell, Paoli, Georgia and
French Lick Quadrangles
T. 2 & 3 N., R. 1 E. & 1 W.

This area, a karst area rather than a cavern, is a classic example of karst and cavern development in the United States (Fig. 68). Numerous papers have been written concerning its unique development of subterranean drainage, and it has been used to illustrate the early stages of cavern development in many texts on the theory of the origin of caves.

The Lost River topographic drainage, the upper portions that feed the underground stream system, includes about 163 square miles of surface area, just south of the drainage area of Blue Spring Cave (# 27). One hundred square miles of the basin consists of normal surface drainage that discharges some of its waters into swallowholes along the beds of the streams. About 24 square miles is in two separate drainage basins, one which discharges its water into another stream, Lick Creek, and another which is a separate subterranean tributary system to Lost River. Most of the unique caverns, sinkholes, swallowholes, and springs are located within an area of about 40 square miles.

The area has been adequately described by C. A. Malott, but a few features are here worth particular mention. The area includes more than a dozen swallowholes, notable the Stein, Turner, and Tolliver Swallowholes, each along the dry-bed that serves as a flood water overflow route on the surface when the subterranean channels that drain each swallowhole become gorged with water. Tolliver Swallowhole is the farthest downstream of the major swallowholes and is basically a steeply descending channel that drops about 50 feet from the dry-bed into part of the cavern system of Lost River.

The water which enters Tolliver Swallowhole drains westward through limestones of the Blue River Group (Mississippian age) about one mile to Wesley Chapel Gulf, a collapsed sinkhole or uvala, that has formed by the falling in the network of passages of underground Lost River. The gulf is about 10 acres in size and has a maximum depth of 100 feet. Water which passes through the gulf in time of flood, or under and around the gulf in normal and flood flows, resurfaces at a series of mud-lined springs in a short channel about two miles to the west discharging the low flow drainage of 109 square miles, (Fig. 69).
Figure 68. Map of the Lost River area showing subterranean drainage routes (Murdock and Powell, 1968).
Figure 69. Topographic map of Wesley Chapel Gulf, with explored parts of underground Lost River.
The Orangeville Rise, about one mile north of the Rise of Lost River, is a more picturesque spring that drains a separate portion of the Lost River drainage basin and a karst valley to the north of Orangeville. Numerous large caves are known in the Lost River area.


Lost Soldier Cave
Tulare County, California
Kaweah Quadrangle

Lost Soldier Cave, (Fig. 70 ) is an extensive marble cave with more than 3000 feet of passages and a depth of 297 feet; its relation to the Tertiary erosion levels in the area is still not quite understood. The cave is a multitude of small passages on many levels connected by pits up to 60 feet deep. Several rooms contain speleothems and aragonite crystals. Most of the cave is dry except for the lowest level, the Lake Room. Possible connections with nearby caves are being explored. The name comes from a rescue in 1910 when Park rangers rescued a soldier from this previously nameless cave.


Caves of the Sequoia Region, California, Guidebook to the 1966 N.S.S. Convention, p. 33-35.

Mammoth Cave
Edmundson County, Kentucky
Mammoth Cave and Rhoda Quadrangles
Mammoth Cave National Park

Mammoth Cave, (Fig. 49 ), is perhaps the most famous cave in the United States. The only other caves that could compare with it are Carlsbad Caverns in New Mexico, and the Flint Ridge System located just northeast of Mammoth Cave.

Mammoth Cave has had more written about it and has perhaps been seen by more people than any other cave in the United States. The history of Mammoth Cave has been well documented since 1798. Guided tours of Mammoth Cave may have began as early as 1813, according to some researchers. Saltpeter mining operations during the War of 1812 have left a very good record of their history.

Perhaps the most significant discovery in the exploration of Mammoth Cave occurred in 1835 when a young negro guide named Stephen Bishop crossed the Bottomless Pit on a cedar pole. At that time, the Bottomless Pit marked the end of the cave, today it is the mere beginning. Stories of huge passages and underground rivers that were discovered in Mammoth Cave spread across the nation. Tales of "150 miles of passage" grew commonplace. A detailed account of the history of Mammoth Cave is given by Sloane in Celebrated American Caves, and Halliday in Depths of the Earth. A discussion of the early history of Mammoth Cave is given by Burton Faust, Saltpeter Mining in Mammoth Cave, Kentucky.
Figure 70. Plan and section of Lost Soldier Cave, modified from Caves of the Sequoia Region, California, Guidebook to the 1966 NSS Convention, p. 34.
Since the cave became a National Park, in 1941, its fame has spread worldwide. Although not near its celebrated length of 150 miles, the cave is the second largest cave in the United States with a mapped length of over 46 miles, (Fig. 49), although no single up-to-date map of the entire cave is available. Geologically, Mammoth Cave is very significant. Studies in Mammoth and nearby Flint Ridge are yielding much information on speleogenesis. Numerous papers concerning the geology and hydrology of Mammoth Cave have been published some of which are cited at the end of this description.

Ecological and biological surveys of Mammoth Cave show it to be rich with fauna. Barr, 1967, lists 200 species of animals that have been recorded in Mammoth Cave, 22% of which are troglobites, or true cave dwellers, 36% are troglophites and 22% are trogloxenes. Mammoth Cave has been, and still is an important center for research in speleobiology.

Mammoth Cave is noted for its large passages, and length, but it is almost devoid of formations. However, the mere size of its passageways make it scenic. One beautiful area, the "New Discovery" contains one of the best gypsum displays in the United States. The celebrated frozen Niagara section of Mammoth Caves, although impressive, is not one of the best cave formations localities in the nation. Whatever Mammoth lacks in beauty, however, it more than makes up for in scientific value, natural history, and anthropological significance. Few other caves contain such an excellent record of pre-Columbian Indian. Exploring Mammoth has been the site of extensive research in anthropology, and many fascinating discoveries concerning the cave and how it was used by pre-Columbian Indians made Mammoth Cave is truly one of the most significant caves in the United States.

Cave Research Foundation, 1960, Speleological Research in the Mammoth Cave Region, Ky.
National Park Concessions, Inc., 1951, Mammoth Cave National Park, Ky.
Faust, Burton, 1967, Saltpeter Mining in Mammoth Cave, Ky., Tilson Club, 90 pages.
Meloy, Harold, 1968, Mummies of Mammoth Cave, Historical Research Project on Mammoth Cave, 40 pages.
Mark Twain Cave and Cameron Cave are maze type caves, similar, though not as large, to Anvil Cave, (#1), in Alabama. The two caves are located on opposite sides of Cave Hollow, near Hannibal, Missouri, and are not connected, although they are very similar.

Mark Twain Cave (Fig. 71) is commercialized and is electrically lighted. The cave has a rich history dating from the days of Mark Twain, and is the cave that Mark Twain described in his novel Tom Sawyer. Most of the passages are of a high narrow walking nature, and over 2 miles of interlacing passages have been mapped.

Mark Twain Cave is interesting geologically in that it is a prime example of a maze cave. Maze caves are relatively rare especially in this area.

Cameron Cave (Fig. 72) lies 1,500 feet northwest of Mark Twain Cave and is believed to have once been a part of Mark Twain Cave, before being divided by Cave Hollow. Cameron Cave is an even more extensive maze than Mark Twain Cave, and over 4 miles of passage has been mapped in the cave. As in Mark Twain Cave the passages are generally of walking height. Cameron Cave is gated but has not been developed commercially.

McKittrick Hill Caves

McKittrick Hill forms the peak of Azotea Mesa and contains four caves within 1 mile of each other under the same hill. They are Endless Cave, Sand Cave, McKittrick Cave, and Dry Cave. There have been about 3 miles of passage mapped, 1/3 of it recently discovered. Although some of the beautiful formations had been vandalized, additional untouched areas were recently discovered. Geology and Biology groups have collected data for a future NSS Bulletin article. Endless Cave is a complex maze mapped passage 10,000 feet with "no end in sight." There is probably as much cave passage per unit of surface area in the McKittrick Hill area as in any other area in the United States. Dry Cave, also under this area is also a complex multi-level maze work of passage, with pits and domes and formations. A hypothesis on its origin is in Texas Caver, June 1965, p. 107-1.
Figure 71. Map of Mark Twain Cave, modified from Bretz, 1956, p. 151.
Figure 72. Map of Cameron Cave, taken from Bretz, 1956, p. 56.
Millrace/Crockett Caves

These two caves are part of what has been called the Malpain Cave System, referring to the Malpias lava flow, a basalt flow 44 miles long and 5 miles wide. The flow occurred 1500-2500 years ago, making it one of the most recent flows in the United States.

Six caves are known in this system, but only two have been surveyed. These are Millrace and Crockett Caves, each unique. Millrace is developed in a 50 foot bed of pure brown gypsum, with the eastern edge defining one side of a mile wide lava flow. The cave extends beneath this flow. This cave was thought to be the most extensive gypsum cave in the United States, until the formation in the area of the cave is 300 to 1000 feet thick. There are also solution pits and slots in the cave. The cave should never be entered in wet weather, for flash floods can completely fill the cave.

Crockett's is a contrast to Millrace. The entrance is a large sink a mile away from the lava. The cave itself is 3/4 miles long and is said to have one extremely large room. One wall is a bedding plane dipping 28° and the other wall is a joint. Part of the passage lies under an anticline. Speleothems appear both as calcite and gypsum. There are helictite-stalactites six feet long, as well as boxwork in gypsum and calcite. This boxwork is well developed and some of the best outside of the Black Hills. There is also gypsum in crystals resembling dogtooth spar.

Moore Cave System

The Moore Cave System, located about 3 miles northwest of Perryville, Missouri, is probably the longest cave system in Missouri. Carroll Cave, (#39) is probably just as extensive, but explorations in it have lagged in recent years. About 15 miles of passage have been mapped in the two separate caves that make up the Moore Cave System (Fig. 73). Berome Moore Cave, the largest of the two caves contains over 12 miles of surveyed passage, and shares the same stream with the smaller Tom Moore Cave, which lies to the south of its larger brother.

Tom Moore Cave first received interest in July of 1959. Subsequent mapping projects conducted in 1960 and 1961 revealed about 2 miles of cave passage and 4 entrances to the cave.

The extensive Berome Moore section was first entered in October 1961 through an excavation in the side of a sinkhole north of Tom Moore Cave. To this day, this artificial entrance is the only entrance to the Berome Moore section. Berome Moore was gated in March, 1965 as a measure to conserve the cave.
Figure 73. Map of the Moore Cave System, modified from the Brome Moore Research Project, 1969.

MOORE CAVE SYSTEM
Perry Co., Missouri
It was realized soon after the discovery of Berome Moore, that the cave presented an excellent opportunity for speleological research. Thus, an underground camp was constructed in the cave in April 1965 to provide scientists with an excellent laboratory in which to carry out research. The Berome Moore Research Project was thus born. Besides an accurate survey of the cave, projects are being conducted in paleontology, hydrology, and ecology. Foremost in the minds of the researchers is the conservation of the cave.

As with any large cave, the passages of the Moore System vary considerably in size and character. The cave contains many excellent formation displays, but is not particularly noted for its beauty. Of special interest is the "Cat Track Passage", a one-mile long dry upper level passage containing in its clay floor the tracks of a large Pleistocene cat. The survey and study of the cat tracks is only one of the many paleontological studies being conducted in the cave.

The Moore System and Mystery Cave (#46) to the south lie beneath one of the finest examples of a sinkhole plain in the United States. The Moore System is also an excellent cave system in which to study cavern development and karst hydrology. Studies in these fields are also being conducted at this time, as well as a comprehensive survey of the fauna found in the cave and a detailed study of its ecosystem. Berome Moore is one of the most scientifically significant caves in the United States. Besides its underground camp, Berome Moore is in an excellent state of preservation and is essentially in a wilderness state. Further inquiries about the Moore System should be directed to Gregory Yokum, director of the Berome Moore Research Project, Route 3, Desoto, Missouri.

Personal communication, Jerry D. Vineyard, Missouri Geological Survey; N.S.S. significant cave files, Moore Cave System, and the Proposed Perryville National Karst Area.

Berome Moore research project, 1968, 5 page brochure published by the Middle Mississippi Valley Chapter, N.S.S.

Mystery Cave Filmore County, Minnesota

(38 on Plate 1)

Mystery Cave is located 8 miles southeast of Spring Valley, Minnesota and the longest cave in the Upper Mississippi River Valley. Caves are rare in this area and when they are found are seldom very large. In this respect Mystery is unique, over 12 miles of passages have been surveyed in the cave, making it one of the longest caves west of the Mississippi River.

Mystery Cave has two entrances, both of which are operated commercially. The second entrance was discovered in 1958. After explorers negotiated a series of crevices at the end of the commercial section of Mystery Cave, they found themselves in a very large series of passages. Later exploration in this area found the new entrance which was dug open after explorers heard the sound of an airplane. The new entrance, now called Minnesota Caverns, is located about 1 1/2 miles from the old entrance to Mystery. The Minnesota Caverns end of the system is by far the most beautiful. The cave is joint controlled, and has a few very impressive formations areas, mostly located at the Minnesota Caverns end of the system. Many multicolored flowstone deposits ranging from
The "5th Avenue" a long straight passage in Minnesota Caverns is also impressive. A "door to door" trip thru the system, although containing much of the commercial section is very difficult due to the crevice section in the middle of the system.


Mystery Cave
Perryville, Missouri
Perryville Quadrangle
NW1/4 NE1/4 Sec. 9, T. 34 N., R. 11 E.

Mystery Cave is located about 4 miles south southeast of Perryville, Missouri, and about 7 miles from the extensive Moore Cave System. The area around Perryville, Mystery Cave, and the Moore System is an area of excellent karst topography. There are numerous caves in this area, the most notable of which, besides the two already mentioned, are Krause Cave and the extensive Lost Cave System. Probably the largest and some of the most significant caves in Missouri are located in this area. About 25 miles of cave passage has already been mapped in the area. Underground drainage is extremely well developed and tremendous opportunities for speleological research exist.

Mystery Cave has a mapped length of about 11 miles, and is very large. The main stream passage of the cave ranges from 7 to 60 feet high and 5 to 40 feet wide. Many large rooms exist in both the stream passage and several upper level dry passages. Mystery Cave is extremely scenic having many beautiful formation areas. The cave abounds in fauna, as over 33 separate animal species inhabit the cave. The main passage in Mystery Cave contains a large stream which has many numerous tributaries. The drainage networks in the area is very complex, and of special interest to hydrologists. Some research has been done in Mystery Cave, but has not been as vigorous as that conducted in the Moore System. Mystery Cave is gated at the present time, and access to the cave is controlled in the interest of conservation by the Little Egypt Student Grotto of the National Speleological Society.

Personal Communication, Jerry D. Vineyard, Missouri Geological Survey;
N.S.S. significant cave files, Mystery Cave.

Neff Canyon Cave
Salt Lake County, Utah
Sugar Horse Quadrangle
Wasatch National Forest

Two thousand feet up the western slope of the Wasatch Mountains just outside of Salt Lake City, lies the well concealed mouth of the United States deepest cave, Neff Canyon (Fig. 74 ). The cave was discovered in 1949 by some high school hikers, three of which became trapped on an upper level when their rope proved to be too short. They were rescued without too much trouble, but the incident caused difficulty which ultimately led to the gating of the cave.
Figure 74. Map of Neff Canyon Cave, modified from Halliday, 1959, p. 62.
The actual entrance to Neff Canyon Cave is a vertical slit along the side of a fissure. It is only one foot wide and two feet long. There is a drop of eight feet to the horizontal passage. This passage continues for a few hundred feet with a small width and height. Along this passage are several pits, and much breakdown. On one side of the passage the shale and limestone contact differs by three feet where a vertical fault has occurred. Descent continues down a series of inclined slopes and pits through the Great Pit, the Devil's Slide, and the Big Room, itself a drop of 80 feet. The total length, it is 1,170 feet deep, 95 feet deeper than Carlsbad. This depth in a series of complex inclines and drops is made over shale and limestone. The cave extends downward to the very bottom of the limestone and cut into the weaker shale below. Rocks are easily dislodged and become dangerous to cavers. The Forest Service gated the entrance to the cave, which is on government land.

Wm. R. Halliday, 1959, Adventure is underground, Harper and Row Publishers, p. 60-84.

Newsome Sinks Karst Area
Morgan County, Alabama
Newsome Sinks Quadrangle
Sec. 35 & 36, T. 6 S., R. 1 W., & Sec. 1,2,11,12,13,14,24, T. 7 S., R. 1 W.

The Newsome Sinks Area, (Fig. 75 ), located west of Morgan City, in Morgan County, Alabama, is a prime example of karst development. Newsome Sinks is a landlocked north-south trending karst valley some 4 miles long, 1 mile wide, and some 400 feet deep. The sinks drain an area of roughly 14 square miles, and all drainage is subterranean. With no surface stream flowing along the length of the valley. Newsome Sinks resembles a normal stream valley except length of the valley. Newsome Sinks resembles a normal stream valley except that both ends of the valley are closed off and the floor of the Sinks is pitted the numerous sinkholes.

The floor of the Sinks is 100 feet above the level of the adjacent Cross Valley.

Initially, Newsome Sinks was occupied by a normal surface stream. As the stream cuts down through the Pennsylvanian Age cap rock, and into the underlying Mississippian limestone, it was captured by joints and bedding planes in the limestone. The stream was diverted underground and flowed down the dip of the beds to emerge possible at a resurgence near the present entrance to Skidmore Cave. This subterranean diversion of surface waters is responsible for the development of the numerous caves located in Newsome Sinks.

Later, a surface stream, cut into the subterranean channel, creating a resurgence at the present location of Hughes Cave. Further downcutting shifted the resurgence downstream to Hughes Spring, and created new lower levels to the existing caves. A much more detailed account of the geologic history of Newsome Sinks is given by Varnedoe, 1963.

All together, over 40 caves are known in Newsome Sinks, (Fig. 76). Most of the cave entrances are in sinks and over 50,000 feet of passages have been surveyed in Newsome Sinks. The two longest caves in the sinks are Turtle Cave and Wolf Cave. Most of the passages are now dry and carry water only during
Figure 75. Topographic map of the Newsom Sinks Karst Area showing cave patterns, topography from USGS Newsom Sinks Quadrangle, 1:24,000.
Figure 76. Caves of the Newsom Sinks Karst Area, modified from Veitch, 1967, Caves of Alabama, p. 44, 45, and 47.
periods of very heavy rains. Other caves located in Newsome Sinks are, Hughes Cave, Chapel-Coon-Root Cave, Log Cave, Log-Log Cave, Poodle Cave, Sawmill Cave, Manuley Cave, and Mike's Wolf Cave.

The Newsome Sinks area is almost totally undeveloped, and is essentially in its natural state. The Sinks are wooded and for the most part uninhabited. Newsome Sinks is very interesting geologically in that it is a classic example of the karst stream.


Powell Cave

Menard County, Texas

10 miles west of Menard, Texas

(79 on Plate 1)

Powell's Cave, Menard County, Texas, is Texas' longest cave. Project "72" of the Texas Speleological Association in 1961 resulted in mapping and exploring in the cave. Major projects were the mapping of the maze area of the cave, a large water passage found near the end of T.S.A.'s 1962 project, the difficult upper stream passage, three long crevices, Medlin's attic and the Serpentine Root Room Passage. Eight mapping teams spent a total of about 24 hours each in the cave; only one survey was finished. 10+ miles have been mapped in the cave with more to go.

Other aspects of the project included biological studies, and sediment analyses for fossil remains, etc. Invertebrate fossils, mostly from the clay and upper limestone units of the cave, have been collected for identification and study.

Texas Caver, Vol. 9, No. 9, publication of the Texas Speleological Association, p. 123-126.

Sinnit-Thorn Mountain Cave

Pendleton County, West Virginia

West Circleville Quadrangle

(94 on Plate 1)

Sinnit Entrance-38°31'08" N Lat., 79°22'08" W Long.

The entrance to Sinnit Cave lies only 800 feet east and 250 feet below the entrance to Thorn Mountain Cave. Sinnit was a Civil War saltpeter mine. There are a few large rooms in the cave. One, called the Big Room is 800 feet long, 75 feet wide, and 40 feet high, and is the principal attraction of the cave. There are many fossils embedded in the walls of this room. One side passage is filled with three to six inches wide pillars covered with black manganese dioxide crystals common in this cave. There are also calcite spikes, gypsum, and flowstone. The entrance to Thorn Mountain Cave is a 40 foot drop. There are also white crystal formations and fossils in this cave, as well as white soda straws. There are several crevice passages, pits, and rooms. The deepest pit is 135 feet. The total depth of the system is 350 feet. In Thorn Mountain globulites are found associated with dogtooth spar.
The opening of Bat Bone extension raised hopes that a connection might exist between the two caves. In 1962 a party entered Thorn Mountain Cave and proceeded to the end of the extension, where they broke through to a party on the other side, thus forming the Sinnit-Thorn Mountain Cave System.


Sloan's Valley Cave System

Sloan's Valley Cave System located southern Pulaski County, Kentucky, is a large and relatively unknown cave complex. Little in the way of published material has appeared concerning the system, and what is presented here is largely from personal sources. Exploration and survey of the cave are being conducted by members of the Blue Grass, and Cincinnati Grottos of the National Speleological Society.

The cave is a sprawling complex of passages situated under and in ridges adjacent to Sloan's Valley. 15 miles of passage have been reported surveyed in the system with much of the cave yet to be mapped. The cave contains one very large room for which it is noted, and has several entrances. Little detail concerning the nature of the cave is available.

Sloan's Valley (Fig. 77) itself is a rather scenic karst valley south of and immediately adjacent to the Cumberland River. The valley floor is perched about 80 feet above the normal level of Lake Cumberland, and drainage to the river is underground through the cave. Sloan's Valley, along with the Newsome Sinks of North Alabama (Map #5), are both large former surface stream courses, that have lost their waters to caverns developed beneath the valley.

Personal Communications.

Spirit Mountain Cave

Spirit Mountain Cave was formerly known as Frost Cave and later as Shoshone Cavern National Monument after President Taft visited it and recommended it as a National Monument. The cave entrance is shown on the Cody Quadrangle, and is located at an elevation of 6200 ft. It was never developed by the government but was leased to a private corporation and has presumably been developed as a tourist attraction. The cave is well known locally and appears to be a very long cave. Estimates of 8½ miles are said to be explored, lying under much of Spirit Mountain. The manager of the cavern allowed exploration in return for information on what was found. Many interesting things have been found, including gypsum plates, flowers, and angel hair. There are fluorescent minerals. A sample of purple flowstone was analyzed by x-ray diffraction and found to be pure florite, the first definite report of such an occurrence.
Figure 77. Topographic map showing locations of the major entrances to the Sloan's Valley Cave System, topography from USGS Burnside Quadrangle, 1:24,000.

- cave entrance

N 0 1 mile
The cave lies in the Madison limestone and it was originally thought that it extended downward 1,100 feet to the Shoshone River. The explored depth was not more than 250 feet however. An old map shows seven levels, which lie over each other. A maze is developed at the 250 foot level. The passages appear to be a deep crevice developed on a single joint. Calcite dripstone is found in several colors.


Swago Creek Karst Area
Pocahontas County, West Virginia
Marlington Quadrangle
2 miles west of Marlington

Swago Creek is an interesting cave area containing a system of several caves and pits, of which a few are of special note. The area is located in the upper third of the Marlington Quadrangle, Pocahontas County, West Virginia. It is bounded on the south, east, and west by the Greenbrier River, Swago Mountain, and Rodgers Mountain and on the north by the northern end of Stony Creek Mountain. The caves and pits are mostly developed in the Greenbrier limestones, and include the Carpenter-Swago Pit System, Cave Creek Cave, Overholt Dome Cave, Overholt Saltpeter Cave, Overholt Blowing Cave, Schoolberry Cave, Swago Roadside Pit, Tub Cave, and Barne's Pit (Fig. 78).

Swago Pit has a 51/2 foot drop with waterfall to a passage with a series of 5 pits and domes. Through these a second level 50 feet lower is reached, which consists of a slot passage with 2 waterfalls at its end. A passage at the bottom of the second waterfall connects with Carpenters Pit. Carpenters Pit is a 75 foot pit which, besides connecting with the system just described, has a passage leading to a dome complex on the opposite side of the ridge from the Carpenters entrance. 1 3/4 miles have been mapped in this system with an additional mile estimated to remain, (Fig. 80).

Cave Creek has a beautiful fern covered entrance 50 feet wide and 10 feet high, with a waterfall just inside. About 1,500 feet have been mapped in this cave.

Overholt Dome Cave is a small dome-pit complex directly above part of Tub Cave. Overholt Saltpeter Cave contains remains from saltpeter diggings such as troughs and a puddler.

Overholt Blowing Cave is a wet, arduous cave having 1 mile of mapped passage with 1 1/2 miles estimated to remain. This cave is hydrologically significant in that water derived from the cavern's drainage from the western part of Dry Creek Valley flows from the rear of the cave down a series of waterfall domes and on through horizontal passage out the entrance. The water and wet domes of Overholt made exploration and mapping both difficult and slow, (Fig. 79).
1. Barnes Pit.
2. Beveridge Cave.
4. Beveridge Hole.
5. Beveridge Pit.
6. Carpenters Pit.
7. Cave Creek Cave.
8. Cook Cave.
10. Dry Creek Indian Cave.
11. Friels Cave.
14. Hause No. 1 Cave.
15. Hause Pit.
16. Hause Waterfall Cave.
17. Kee No. 1 Cave
18. Kee No. 2 Cave.
19. McClintocks Grapevine Pit.
20. McClintocks No. 1 Pit.
21. McClintocks No. 2 Pit.
22. McClintocks Wormaway Cave.
23. McKeever's Chimney Pit.
24. McKeever's No. 1 Pit.
25. McKeever's No. 2 Pit.
27. Overholts Blowing Cave.
28. Overholts Dome Cave.
29. Overholts Salt peter Cave.
30. Rockhouse.
31. Ruckers Jug Cave.
32. Rush Run Grotto.
33. Rush Run Pit No. 1.
34. Rush Run Pit No. 2.
35. Schoolberry Cave.
36. Swago False Bottom Cave.
37. Swago Horse Cave.
38. Swago Pit.
39. Swago Roadside Pit.
40. Tub Cave.

Figure 78. Caves of the Swago Creek Karst Area, taken from Davies, 1958, p. 279.
Figure 79. Map of Overholt Blowing Cave, modified from 1970 NSS Convention Guidebook, op. p. 40.
Figure 80. Map of Swago Pit, taken from 1970 NSS Convention Guidebook, p. 36.
Schoolberry Cave
(Swago Creek Karst Area)
Pocahontas Co., West Virginia

Figure 81. Map of Schoolberry Cave, modified from 1970 NSS Convention Guidebook, op. p. 45.
Schoolberry Cave is a complex small cave on four levels containing 18 dome pits. The mapped length of the cave is 630 feet, (Fig. 81).

Swago Roadside Pit is a 60 foot entrance pit to a passage with a dome pit complex and numerous speleothems.

Tub Cave contains the largest room in any West Virginia cave. The room is 625 feet long, 200 feet wide, and 25-60 feet high, with a 50 foot high, 40 feet in diameter flowstone on breakdown in the south end.

Barne's Pit is a 20 foot pit with a waterfall. At the bottom are passages trending towards Carpenter's Pit and Cave Creek Cave. This pit cave has a mapped length of at least 1500 feet.

Tumbling Rock Cave, located north of Scottsboro, Alabama, is the most famous cave in Alabama, and rates as one of the most visited non-commercial caves in the Southeast. Tumbling Rock is in some respect one of the most unusual caves in the United States. It is the only known natural cavern where asphalt oozes into the cave passage. The cave also contains a very impressive black flowstone deposit, once called the Asphalt Pool. This name later had to be changed when the real asphalt was discovered. The Pillar of Fire located 6,000 feet from the entrance is perhaps the most impressive mineral formation in the cave. This large blood-red stalagmite is well worth the 4-hour trip via two short but difficult crawls back to it.

Tumbling Rock has other claims to fame. Besides its varied colored speleothems, the cave contains vugs of celestite crystals and gypsum needles. The vandalaized outer sections of the cave boast mud casts from saltpeter vats dating back to Civil War time. No one has yet discovered the source of the caves radioactive air which is one of the many unexpected surprises that this cave has produced in recent years. The exploration of Tumbling Rock seems never to be complete. Exhaustive work has pushed the end of the cave to the northwest toward Round Cave, and major discoveries were also made near the entrance in 1960 and 1966.

Tumbling Rock can be characterized as a large solution passage modified extensively by breakdown (Fig. 82). In several places large rooms have been formed by collapse of the cave and large breakdown mountains have passage resulted. Tumbling Rock has been a spelunker’s cave. Tight crawls connect the spectacular back sections of the cave although the passage from the entrance to the Great Hall of Mysteries is hardly more than a walk. Tumbling Rock is a cave where any overturned rock could lead to a spectacular new discovery.

N.S.S. News, April, Vol. 16, No. 4, p. 30-32.

Wild Woman Cave, developed across a thrust fault having a vertical displacement of 2700 feet in the Arbuckle limestone. The explored passages as of 1958 were about three miles, with 13,000 feet mapped and a projected length of five miles (Fig. 83). The water table in the area is very close to the surface. There are at least three entrances, only one of which is now enterable. Prior to 1956 the known portion of the cave was in very small and the sinkhole entrance dropped 44 feet to the passage. A crevice in the floor leads to a lower level, which is the water passage. A new entrance, 1,464 feet from the original makes descent into the cave much easier, with no climbing gear needed. It also avoids the long low crawl in the water passage. The cave is a part of a huge drainage system, similar to the Laurel Creek System in West Virginia, but larger. Both levels of the cave fill completely after sufficient rainfall (about 6”). The cave temperature is 64°. There are some speleothems, cave crickets, spiders, bats, and crayfish.
Figure 82. Map of Tumbling Rock Cave, modified from Veitch, 1967, p. 37.
WILD WOMAN CAVE
Murray Co., Oklahoma

Figure 83. Map of Wild Woman Cave, taken from Oklahoma Geology Notes, vol. 19, no. 2, 1959, p. 28-29.
About 4½ miles of passage has been mapped in this cave, and probably several miles remain to be surveyed. The National Park Service has lighted 1½ miles, and used this as their commercial tour. Wind Cave contains the normal varieties of speleothems, but is primarily of interest, both geologically and scenically, because of the unusual mineral types and crystal forms found here. One of these, a product of differential solution called boxwork is especially noteworthy. The cave is developed within the upper 250 feet of the Pasasappa Limestone, although most of the cave is within the upper 125 feet. The surveyed length of Wind Cave is about 11 miles. The surface area of the park is a protected remnant of the great prairie (Fig. 84).

Wyandotte Cave is one of the oldest commercial caverns in the United States, as well as one of the caves which has been featured in numerous papers written about its size, dripstone deposits, Indian artifacts, and interesting passages.

Wyandotte, reportedly discovered in 1798, contains about 5.5 miles of passages, although many authors have claimed the cave was in excess of 21 miles long (Fig. 85). Many exaggerations concerning the size of the passages were promoted by the Rothrock family, which owned the cave for 146 years. The cave is now an Indiana State Recreation Area controlled by the Division of Forestry.

Material of historical interest in the cave ranges from archeological evidence that Indians mined white aragonite dripstone from deep within the cave (as well as flint from the cave walls) to the fact that either saltpeter or epsom salts were mined from the cave during the War of 1812.

The size of the cave has been greatly exaggerated to compete with Mammoth Cave, Kentucky, for tourist trade. Yet the passages are generally large, including two large rooms caused by collapse. Dripstone deposits are scarce, but include helictites, flowstone and the massive Pillar of the Constitution, a column 73 feet in circumference and 25 feet high.
Figure 85. Map and section of Wyandotte Cave, taken from Powell, 1968.
Wyandotte Cave has probably the greatest vertical relief of any cave in Indiana, developed in several levels, which corresponds to stages of erosion along adjacent Blue River. The levels are a result of development at base levels, partly controlled by local stratigraphy within the Blue River Group (Middle Mississippian age) which includes limestone, dolomite, and shale, all transected by the cave.

### Caves considered significant for Archaeological, Paleontological or Historical Aspects

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Big Bone Cave is one of the best known and most historic caves in Tennessee, and contains some of the best saltpeter relics in the country. The cave is located in Van Buren County, about 1 mile north of Laurel Creek Church. Over 3 3/4 miles of passage have been mapped in the cave, (Fig. 86).

Big Bone Cave was the center of a very extensive Saltpeter mining operation during the War of 1812. As many as 300 men worked in the cave at one time and an elaborate arrangement of leaching vats and overhead trainways were constructed by the miners. In one room alone there are 19 hoppers in an excellent state of preservation.

In 1811, miners working in the cave unearthed a skeleton of a *Megalonyx jeffersonii*, a giant ground sloth, which inhabited the cave during the Pleistocene Epoch. It is from these bones and others found later that Big Bone Cave takes its name. These bones are some of the earliest reported discoveries of fossils in a cave. The history of the bones was written up by Thomas C. Barr, in the 1957 Speleo Digest, p. 4-6.

In 1824, a farmer digging bat guano for fertilizer came across another set of remarkably preserved bones, again of the Giant Ground Sloth. These bones were sold to Vanderbilt University. Another set of bones were discovered in 1896 by Henry Mercer to the American and Prehistoric Archeology Department of the University of Pennsylvania. Mercer also unearthed scattered remains of small animals, and remains of a large herbivorous animal about the size of a bear. One of the skeletons of the Giant Sloth removed from Big Bone Cave was the only known specimen with a complete pelvis.

Except for the entrance, the cave is very dry and dusty. The cave consists of two major branches. Arch Cave Branch, and the Bone Cave Branch. The Arch Cave Branch, west branch, is a complex labyrinth consisting of about 2 miles of mapped passage. The most significant feature of the Arch Cave Branch is the Muster Ground, a long, dry, sandy floored passage, 30 to 50 feet wide, as much as 12 feet high, and 1,275 feet long. Well preserved niter vats are seen in this passage.

The Bone Cave Branch, east branch is very long and sinuous. This very dry, dusty passage averages about 15 feet high and 10 feet wide for the first half mile of its length. Remnants of the Saltpeter operations are numerous in this section of the cave, 25 niter hoppers, some quite large, occurring in the center of the passage at one point. A catwalk was built over the vats during the Civil War era.

In 1956, a major discovery was made near the back end of the Bone Cave Branch. A small crawl was opened up, which led explorers through ½ mile of cave that had not been entered in 94 years. In this section were found several interesting relics from exploration during the Civil War era, including fragments of an 1831 newspaper, and hand blown whisky bottles. Bone Cave, with its rich historic heritage is being considered by the Tennessee Department of Conservation as a State Park.
Figure 86. Map of Big Bone Cave, modified from Barr, 1961, fig. 121 and 123.
Cave-in-Rock Hardin County, Illinois
(26 on Plate 1) Location indicated on Cave-in-Rock Quadrangle

Cave-in-Rock Cave is a small, historic cave with a large impressive entrance near the Ohio River. The entrance is at the base of a 60 foot cliff and is about 18 feet high and 28 feet wide. The cave itself is only 150 feet long. From 1780-1830 the cave was the home of numerous counterfeiters, thieves, murderers, and pirates who used it as a headquarters and because of its convenient location for preying on the Ohio River boat traffic. Several times it was raided by militia in an attempt to clean it out, but the measures were ineffective until 1831, when the last remaining counterfeiter was scared out of the area by a posse of Regulators. Today Cave-in-Rock is the scene of an Illinois State Park.

References:


Cherokee Cave St. Louis County, Missouri
(41 on Plate 1)

Cherokee Cave is a relatively small cave located in the city of St. Louis, (3400 South Broadway). The only known natural entrance, to Cherokee Cave was located in the bottom of a small sinkhole and enlarged in 1850 by the Minnehaha Brewing Company. The brewery company excavated much fill from the cave and used it as a storage area for beer.

In 1946, a remarkable deposit of bones were found in Cherokee Cave. Excavation of bones was conducted by the noted paleontologist, G. G. Simpson. The bones were mostly those of peccanies, small pig-like animals, the relatives of which live today in the southeastern United States. Bones and skulls were so thoroughly mixed that it is believed that the animals drowned in some catastrophe flood, and were later washed into the cave. More than 1000 skeletons were excavated from the cave fill. Other bones, including those of armadillos, bears, beavers, porcupines, raccoons, wolves, and woodchucks were also excavated. The bones were definitely of Pleistocene Age Study of fills indicated four separate episodes of filling and partial excavation.
Some interesting problems in Pleistocene geology have developed from study of the bones of Cherokee, some of which are still unanswered.

Cherokee Cave is not very impressive, but is of great interest to paleontologists.

References:


Cumberland Bone Cave
Allegheny County, Maryland
Frostburg Quadrangle
(37 on Plate 1)

Cumberland Bone Cave is located in Allegheny County, Maryland. The cave entrance lies in a cut made by the Western Maryland Railroad at the base of an escarpment of Devonian limestone about seventy-five feet high. The limestone belongs to the Keyser member of the Helderberg formation and is a part of the steeply dipping west flank of the Wills Mountain anticline.

Considerable fossil material was destroyed by blasting and shoveling before the real significance of the find was known. The attention of the United States National Museum was directed to the site in 1912 and the first quarrying operations in the cave were conducted by Dr. J. W. Gidley from 1912 to 1915. Early results of Dr. Gidley's study were published in two reports which included a new species of wolf and a black bear.

Many of the species of fauna found in the cave are comparable to forms now living in the vicinity but others are distinctly northern or Boreal, and some are related to species of the southern region. Remains of animals larger than a black bear are rare in the collection, probably owing to the means of accumulation and to regional environment. The collection of fauna from this cave is one of the largest ever found in the eastern United States. The period in which most species lived was the Pleistocene. The cave's remains were found to contain forty-five species of mammals, twenty of which are extinct. A partial list of animals recovered includes bison, bear, grizzly, mastodon, peccary, puma, tapir, elk, and crocodile.

Many of the species were found after Gidley's work had ceased. In 1952 a work crew was assigned to the biggest cave excavation job ever undertaken in the eastern United States. The job was undertaken by the railway and used compressors, drill pipe, dynamite, and other equipment. Two thousand cubic feet of rock were removed. The bones unearthed since 1950 were mainly fragmented and intermingled with clay and breccia. These were cleaned and identified, resulting in a total of forty-five species found together in the cave.
Friesenhahn Cave

Bexar County, Texas

(75 on Plate 1)

Friesenhahn Cave is one of the most important paleontologic sites in the United States. The cave is very small, but excavation in the cave floor deposits have yielded an unusually large and varied collection of fossils, including many skeletons, partial skeletons, and 3700 isolated teeth and bones. More than 30 genera of mammals, reptiles, amphibians, and birds are represented. The fossils represent both the animals which used the cave as a den and their victims. Some of the bones found come from large animals like the elephant, camel, mastodon, horse, bison, tapir, and deer. Most of these animals were too big to enter the cave themselves, but their carcasses were probably dragged into the opening by carnivores. The carnivores found here include saber tooth cats, bear, wolf, and coyote. Bones of immature elephants are found closely associated with the saber tooth cat.

Also included in the fossil fauna were a large variety of rodents. Nine different genera of these were found. A few pieces of flaked flint which closely resemble flint scrapers were found. However, it is not known for sure if these were formed by man or natural processes. Other evidences of man occur and suggest his presence in the vicinity at this time. However, until more conclusive evidence is found, the presence of Pleistocene man in this cave must remain speculative. The cave itself is now entered by a six to ten foot diameter vertical opening which drops 30 feet to the cave's passage—which is 60 feet long and 30 feet wide. The bedrock floor is buried beneath much alluvial fill which leaves only two to six feet of open passage height. Several large stalagmites, one of which is 8 feet in diameter, are partly or wholly buried in the fill. There are several features in the floor deposits which seem to indicate the cave is part of a connected system.

The cave was most likely formed during Tertiary and early Pleistocene times. Zones 2 and 3 of the deposits are the most fossiliferous of any tested in the excavations. The occurrence of late Pleistocene genera indicated that these zones originated in the Wisconsin stage of the Late Pleistocene.

References:

Speleo Digest, 1962, published by Pittsburg Grotto, p. 2-24 to 2-31; map included.
Greenville Saltpeter Cave

Monroe County, West Virginia
Alderson Quadrangle
37°32'56" N. Lat., 80°40'14" W. Long.

Greenville Saltpeter Cave, Monroe County, West Virginia, is the third largest cave in the state. Over 13,000 feet of passages have been mapped, encompassing most of the known cave, and four entrances have been located (Fig. 87). Passages in this cave are quite large. One room in the cave is 500 feet long, 75 feet wide, and 50 feet high. Cave pearls and rimstone dams are found in Greenville Saltpeter. Near the Saltpeter entrance is a large flowstone dome named the Haystack.

Saltpeter miners probably used the western entrance to reach the area from which most of the peter dirt was taken. In the passage off this entrance are cart ruts, burro tracks, mattock marks and other relics of saltpeter mining.

Laurel Creek Cave, near Greenville Saltpeter, also has saltpeter workings and relatively large passage about six to fifteen feet high and twenty to thirty feet wide. About 5,000 feet have been mapped in the cave.

References:
-----1965, Caverns of West Virginia, West Virginia Geological Survey, p. 35.

Gypsum Cave

Clark County, Nevada
Henderson Quadrangle
16 miles east of Las Vegas

Gypsum Cave, Nevada is one of the most archeologically significant caves in the United States. It is a small cave, consisting of 5 interconnecting chambers, and being only 300 feet long. Ground Sloth remains have been found here with ancient human bones, some of the oldest known in North America. This cave provided the first good evidence that early North American man hunted and used ground sloths for food, hide, and other products. Indian relics and other remnants of early inhabitants have also been found.

Interesting variations in the content of various layers of sediments have been observed in Gypsum Cave. M. R. Harrington found, in several layers, evidence of Paiute Indians, then a layer of dirt with no artifacts of any kind, and finally evidences of early Pueblo Indians. Further excavation produced signs of earlier inhabitants, culminating in the exposure of a layer of ground sloth dung about 10,000 years old. In the same layer were found Folsom points. Anthropologists feel that this cave represents one of the earliest habitation sites in North America.

References:
Speleo Digest, 1956, p. 2-16.
Figure 87. Map of Greenville Saltpeter Cave, taken from Davies, 1958, p. 176.
Haynes Cave
Monroe County, West Virginia
Ronceytere Quadrangle
(93 on Plate 1)

37°41'13" N. Lat., 80°29'00" W. Long.

Haynes Cave is a saltpeter cave of slight length. The main importance of the cave are the relics of Civil War saltpeter mining which are preserved. Bridges over shallow pits, troughs, and a winch made from sapplings are among the many articles left by the miners, many of which are in an excellent state of preservation. Coarse gypsum crystals up to three inches thick and coarse gypsum flowers cover most of the walls. At the back end of the cave is a guest's register dating back to 1915. Haynes has a mapped length of 1000 feet. It is developed on two levels within the Patton Limestone. (Fig. 88).

References:

Personal Communication.

The Leatherman Caves
Western Connecticut and Westchester County, New York
(22 on Plate 1)

The Leatherman was an itinerant who regularly traveled a 365 mile circuit in Western Connecticut and Westchester County, New York. On this route he kept an exact time schedule, appearing again 34 days after he was last seen at a particular place, to receive a meal from a proud housewife, and then spend the night in a nearby cave or rock shelter. Some of these caves have come to have historical significance. The caves he stayed at, about 20 in number, were scattered along his route. All were small. Three of the better known Leatherman Caves are Simsbury Caverns, Watertown Black Rock Cave, and Tories Den.

Of these, Torie's Den is probably the most significant. It was used by Tories as a hideout and refuge during the Revolutionary War, in addition to the Leatherman's later occupancy.

References:

Figure 88. Map of Haynes Cave, taken from Davies, 1958, p. 178.
New Paris Sinks
Bedford County, Pennsylvania
Bedford Quadrangle
1.5 miles northeast of New Paris

(63 on Plate l)

The New Paris Sinks are located near New Paris, about 20 miles from Bedford, Pennsylvania. These deep sinkholes served in the past geologic times as traps into which animals fell. An excellent record of the life that inhabited Pennsylvania thousands of years ago was thus created. As the sinks were gradually filled up with animals and plant remains, they recorded both the life and indirectly the climatic conditions that have existed during the past 12,000 years. By excavating debris from the sinks and noting the types of fossils found at a given depth, paleontologists have been able to reconstruct the picture of climatic changes since the end of the Ice Age.

A group of amateur paleontologists from Pittsburg first noted the significance of the sinks in 1946. It was not until 1958, however, that serious excavation of the sinks began. "Sinkhole No. 4", Lloyd's Rockhole, as it was called, proved to be the most promising. In 5 years, 125 tons of fill was removed from this sink and an amazingly complete reconstruction of the prehistoric climate and animal life of Pennsylvania was obtained. 2,769 reptiles, birds, amphibians, and mammals as well as readily identifiable plant pollen proved to be a major paleontological find.

The most common remains found at New Paris were the skulls of the yellow-checked vole, a small burrowing rodent that lives today in the subarctic regions from Hudson Bay to Alaska. The presence of these and other subarctic species indicated a much colder climate at the close of the Ice Age. Carbon-14-dating of charcoal in the sink indicated the vales inhabited the area about 11,300 years ago. Pollen enabled paleontologists to reconstruct the plant community existing at that time, and this an almost complete biological reconstruction was obtained. John Guilday, curator of the Carnegie Museum gathered all the data from the excavations, and was able to reconstruct a picture of the changing ecological communities in Pennsylvania during the past 12,000 years.

The fascinating Sinks at New Paris are one of the few places that has been found where both animal communities and plant communities could be correlated together, and a definite date placed on them. Most fossil bearing fills in caves have been so deranged by flood waters, that it is impossible to correlate or date them. Thus, the discovery at New Paris has been a major contribution to a better understanding of the past Ice Age climatic environment of Pennsylvania.

References:

Russell Cave

(6 on Plate 1)

Russell Cave is one of the most significant archeological sites in the southeastern United States. The cave was first investigated by amateur archeologists in 1953, who found numerous bone tools, stone points, potsherds, and Indian ornaments. The Smithsonian Institution's Bureau of Ethnology and the National Geographic Society then began a systematic dig in the cave. As the dig progressed, the archeologists found almost perfect layers of bones and other remains of long occupation. The oldest evidence of habitation found were 23 feet below the dirt floor. The lumps of charcoal found there were carbon dated at about 9000 years old. Russell Cave was given to the National Park Service. It is now the site of a National Monument. Several articles concerning Russell Cave have appeared in National Geographic Magazine and are cited below.

References:


Samwel Cave

(21 on Plate 1)

Samwel Cave is a short cave located along the McCloud River Canyon at the northern end of Shasta Lake. It is considered significant because of the many fossil discoveries which have been made there. In its 900 feet of passage, many fossil remains of extinct animals including the Pleistocene timber wolf and coyote, have been found buried in the floor and partly calcified or surrounded by flowstone and other speleothem deposits. At the bottom of a 68 foot pit in the cave a calcified mountain lion was found, along with animal skulls with wide, curving, ox-like horns. Large deposits of bones from a wide variety of ancient animals, along with the skeletons of an Indian girl who, according to legend had fallen while in search of a pool of water reputed to have magical qualities have also been recovered from the cave.

References:


Sand Cave, Kentucky is the historic cave where Floyd Collins was trapped by a small rock on January 30, 1925. He was the discoverer and primary explorer of Crystal Cave, a part of the large Flint Ridge System (#32). Early in 1925 he signed a contract with some local landowners to explore Sand Cave and a few others in the hope of finding a cave suitable for commercializing. After working in Sand Cave for about three weeks, he was on his way out, possibly to tell his employers of a new find, when a 27 pound rock slipped, pinning his ankle. Rescue attempts were ineffective especially because of the huge disorganized mass of people that collected about the cave entrance. A shaft dug from the surface reached him too late. The shaft was temporarily closed, then reopened to recover Floyd's body. His body now rests in a bronze casket in (Floyd Collins') Crystal Cave. The Floyd Collins story is one of the classic adventures concerning American Caves.

References:


Sandia Cave is located at an elevation of 7,275 feet above sea level in Las Huertas Canyon of the Sandia Mountains, New Mexico. The cave extends 600 feet back into a cliff and averages 12-13 feet in diameter. The significance of the cave began to grow after the initial finding of a few archeological artifacts by a New Mexico College student. The first few objects were interesting enough to warrant further investigation by archeologists. The initial discovery of importance was finding a claw of a giant sloth which inhabited the area 10,000-20,000 years ago. Gradually, the findings began to fit together into a remarkable picture of the earliest known man in North America-Sandia Man. At first it was thought that the artifacts and an ancient camel bone beside a hearth in the cave were associated with Folsom man, then the oldest known American hunter. Further evidence showed that this assemblage belonged to a group of early men who hunted the green hills of New Mexico long before Folsom man. There were the contemporaries of the mammoth, mastodon, camel, and savage carnivores.

The fill deposits of Sandia Cave are well stratified, with a heavy deposit of guano, dust, and rocks on the top. At the very front of the cave fragments of pottery, buckets, and yucca sandals of the Pueblo era were found. Directly below the top layer is a crust of calcium carbonate, deposited as a sheet when the cave was in a wet stage. This sheet is important because it prevented more recent deposits from contaminating the older protected deposits below. All material below the crust is Pleistocene. A layer of bone fragments and projectile points below the crust belonged to Folsom man. Beneath this
layer lies a deposit of yellow ockre, laid down by water in another wet period. Below this are the most important deposits, accumulated in a dry period. Traces of bone fragments, campfires, and flint implements were found. The implements were entirely different from those of Folsom man and resembled the flint points of the Paleolithic age in Europe. Dr. H. R. Crane of the University of Michigan has dated fragments of a mammoth tusk found in the Sandia layer by Carbon 14 analysis and fixed the age at over 20,000 years. Other evidences of Sandia man have been found in an old beach layer of what was a large lake during the ice age. Old fragments and campfires may show the movement of Sandia man from this large lake which is east of the Sandia Mountains and is now dry, to the foothills of the Sandia Cave area.

References:


Sauta Cave

(S on Plate 1)

Jackson County, Alabama
Searington Quadrangle
SE1/4 SE1/4 Sec. 7, T. 5 S., R. 5 E.

Sauta Cave is a large cave, located south of Lim Rock in Jackson Co., Alabama (Fig. 89). The cave's major noteworthy feature is its rich historical heritage. The cave was mined for saltpeter during both the War of 1812 and the Civil War. Many remnants of the saltpeter operations can be seen in the cave today. The relics include a very large kettle used to leach the niter, and an old wooden railway. Unique to Sauta Cave are the "Catacombs," an intricate system of tunnels excavated in the cave filled for the purpose of mining saltpeter. The Catacombs date from the Civil War, and are so extensive that a new area containing tools left there from the Civil War was found as late as 1965.

Sauta Cave is recorded in literature as early as 1812, and figures in one of the oldest lawsuits in northern Alabama. In 1819, Sauta Cave became the county seat of the nearby organized Jackson County. During the early 1950's, Sauta was equipped by the National Guard as a fallout shelter, a project which was soon abandoned.

Besides its rich history, Sauta is also noted for its several scenic sections. Among these are the Mountain Room, a mound of breakdown 100 foot high, with a group of stalagmites on the top, and the Formation Room, with its five rimstone dams. The cave also contains a lower stream level, which leads to another lower entrance, and a very scenic section known as the Grand Canyon.

References:

SAUTA CAVE
Jackson Co., Alabama

Figure 89. Map of Sauta Cave, modified from Veitch, 1967, p. 39.
Sloth Cave, also known as Rampart Cave, lies at the east end of Lake Mead in the sheer face of a cliff wall of the Colorado River canyon. Although the cave does not have any scenic formations of interest, it is a considerable paleontological interest. The primary value of the cave, which is perched above the Colorado River, is that it contains remains of the ground sloth which inhabited the area thousands of years ago. After its significance for scientific study of prehistoric animals became known, it was sealed shut with a steel gate by the National Park Service.

References:

Arizona Highways, September 1966, p. 29.
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Bat Cave
Greer County, Oklahoma
(58 on Plate 1)

One of the classic examples of the proliferation of living organisms associated with organic excreta of cave bats is found in Bat Cave, on the west edge of the Wichita Mountains. The cave is noted as an illustration of the ecological interdependence of many species of cave inhabitants. This cave is the largest bat colony cave in Oklahoma, with an estimated 1 to 3 million bats. Guano is mined from the cave and there are at least five other caves in Oklahoma containing deposits of guano. Where bat colonies provide organic material in caves, life may exist in abundance. White blind flatworms are very numerous in the cave, and isopods in fairly large numbers have been observed. Inside the cave is a deep guano bog with a stream flowing over it. Its depth is unknown. Nearer the wall, directly under the bat colony, the deposit rose fifteen feet from the bog level. Several large concentrations of white planaria exist along the bog, with a very large colony overall. The planaria are concentrated on dead insects and pieces of rotting wood. Their size ranged from a few millimeters to nearly one half inch. They swim at the surface or move along the bottom. Some of the isopods were observed by Mohr to be feeding on a submerged bat.

References:


Donaldson Cave System
Lawrence County, Indiana
(28 on Plate 1)

The Donaldson Cave System is a part of the cave system of Spring Mill State Park. The cave entrance is a very beautiful one, often described in the literature. More than 9,000 feet of passage are mapped in this system, which includes Bronson and Twin Caves which are connected by the main passage (Fig. 90). The passages diverge from the main entrance. The ones to the right and left soon terminate, but the center passage, a narrow gorge with water emerging from it continues the entire length of the system.

Several biology studies have been done on the cave fish Amblyopsis spelaeae and the ecological relationships between the troglobitic crayfish Orconectes pellucidus and the troglophilic Cambarus bartoni. The cave and its inhabitants are protected by the Indiana Division of State Parks.

References:

Mohr, C. E., T. L. Poulson, 1966, Life of the Cave, pp.92-95, pp.119-123.
Powell, R. L., 1961, Caves of Indiana, pp. 60-61, 63-65, 73.
Figure 90. Map of the Donaldson Cave System, modified from Scott, 1909, p. 404-406.
Ezell Cave
San Marcos, Texas
(74 on Plate 1)

Ezell Cave is a small fault-formed cavern having no great significance except for its fauna. In this respect it excels. Nature Conservancy, an organization which protects types of wildlife on the verge of extinction, recently purchased the cave for $16,000.

Regarding the unique biology of the cave, it contains the rare and fascinating Texas Blind Salamander (Typhlomolge rathbundi), one of the two known truly troglobitic salamander species in America. It is found only in this cave. Also occurring here only is the transparent shrimp. In all, thirty six species are known to exist in Ezell Cave, of these, ten are aquatic, including six of which are known to occur only here. This is indeed a unique biological phenomenon which is deserving of the protection it is now getting.

References:

Texas Caver, published by the Texas Speleological Association, April 1968, p. 50-51.

Shelta Cave
Madison County, Alabama
Meridianville Quadrangle
SE ¼ NE ¼ Sec. 27, T. 3 S., R. 1 W.

Shelta Cave is located inside the city of Huntsville, Alabama. The cave is currently owned by the Nature Conservancy, and is being purchased by the National Speleological Society as a nature preserve. The cave is located in northwest Huntsville on Cave Street and was about to be swallowed up by urbanization until purchased by Nature Conservancy in 1967.

Shelta is not a very spectacular cave. It contains one very large room, a broad underground lake, and some massive rimstone dams, but other than this it is not impressively scenic (Fig. 91). The cave has two entrances very near each other, each being a drop of about 20 feet. The cave consists primarily of two large chambers which are called the East Hall, and the "Big Room" respectively. The large underground lake fluctuates in level according to the seasons, and at low water numerous small side passages can be entered. Shelta Cave has an interesting and well documented history. Being very near an urban development it has suffered heavy vandalism. Fortunately the water in the cave is not polluted. However, the cave contains much trash, some of which has recently been removed in a vigorous cleanup effort.
Figure 91. Map of Shelta Cave, modified from Veitch, 1967, p. 19.
Shelta is noted mainly for the small creatures that inhabit its waters, and move about its walls and floors. From a biological point of view, Shelta is one of the outstanding caves of North America. The cave is located in a region noted for its great diversity of cave life. Add to this Shelta's food-rich aquatic and terrestrial habitats and the result is one of the most unusual underground ecosystems in North America. Shelta Cave is the type locality for nine species of troglobitic cave animals. "Its large underground lake provides an unequalled opportunity for ecological investigations of the ground-water fauna of a major karst region," says Thomas C. Barr, Associate Professor of Zoology at the University of Kentucky.

Studies of the life in Shelta are progressing at this time, and Shelta may become one of the most important natural underground laboratories in the world. Stewart B. Peck, Museum of Comparative Zoology at Harvard University has stated, "The terrestrial invertebrate fauna at Shelta Cave may be almost as rich as that of Mammoth Cave," and the aquatic fauna is believed to be richer.

John Holsinger, Assistant Professor of Biology, University of Tennessee, has stated, "Shelta Cave with its large lake; abundance of food, and diversity of fauna is one of the most interesting and biologically significant caves in the United States. In addition to containing blind, unpigmented fish, crayfish, and amphipods, the water in this cave contains the only known population of the troglobitic shrimp Palaemonias alabamae."

Shelta is one of the only two underground ecosystems known to be inhabited by three distinct species of troglobitic crayfish. One of these species is known only to exist in Shelta Cave. Shelta also contains a unique population of gilled cave salamanders, about which very little is known.

Shelta has one of the most complete and simplified ecosystems in the world. At the present time the cave is gated and is being protected pending purchase by the National Speleological Society.

References:

N.S.S. News, Published by the National Speleological Society, February 1968, p. 28-31.

Texas Bat Caves

Frio (Bat) Cave
Uvalde County, Concan Quad.
29°26'04" N. Lat., 99°41'04" W. Long.

Bracken (Bat) Cave
Comal County, Bat Cave Quad.
29°41'12" N. Lat., 98°21'08" W. Long.

Ney (Bat) Cave
Medina County, Bandera Quad.
29°36'13" N. Lat., 99°07'26" W. Long.

These three caves are the homes of millions of bats in the southwestern United States. The caves lie on the Edwards Plateau in central Texas, and were the sites of rich guano mining operations (Fig. 106).

One of the biggest guano mining operations was at Frio Cave in Uvalde County. At least a thousand tons of Cave earth were leached here, and operations continued into the twentieth century. The cave is one of the four greatest bat caves in the United States. Among its many huge chambers is one 1000 feet long, 600 feet wide, and 40-100 feet high. Several studies on bats and rabies have been done at Frio. The cave also supports a large population of troglobitic insects.

Bracken Bat Cave and Ney Cave contain the two highest concentrations of bats of any United States cave. Ney is first, followed by Bracken. Dr. L. S. Adams, who led a team which visited 1,000 caves and 3,000 mines in search of great concentrations of bats, judged the number of bats in New Cave at over 20 million, followed closely by Bracken cave located in Comal County, Texas. Carlsbad had previously been considered the country's greatest bat cave.

Ney Cave located in northern Medina County, was little known during the Civil War but became famous a century later. A flat opening in the side of a low hill permits a climb down into the entrance chamber. The walls and ceiling are completely blanketed with bats during the summer. To facilitate the removal of guano from an upper level, a thirty six foot shaft was bored to the surface. The guano may be knee deep in the summer. Beetles, parasites and other insects can be found in hordes, consuming the flesh of dead bats. There is a constant run of guano and parasites. Birds of prey are attracted to the cave area waiting for the flights of bats. They dive upon the descending bats and usually emerge with their prey.

The survey of bat caves by Dr. Adams was a preliminary step in a wartime project of WWII known as operation X-Ray. In October 1943 screened enclosures were erected at the entrances of Ney and Bracken so that the bats could be trapped as they attempted to emerge at dusk. Up to 1 million bats could be caught in one night. The bats were then shipped to the headquarters for testing, in New Mexico. Each bat was fitted with a small incendiary device weighing about an ounce and would burn eight minutes. It was planned to have the bats and their packages released over areas in Japan. The bats would seek refuge in buildings, plants, etc. and consequently discharge the incendiary bomb which would ignite the buildings or ammo factories and destroy them. In 1944 the project, which had cost $2,000,000, was abandoned due to secret progress on the atomic bomb.
References:

Speleo Digest, 1962, Frio Cave, p. 136-139.
### Caves considered significant for scenic reasons

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Carlsbad Caverns East
Carlsbad Caverns National Park

Carlsbad Caverns is well suited to be a tourist cave. Its huge rooms, beautiful and large formations attract over half a million visitors every year. The cave was first known to Indians similar to the Basket Makers and later to bands of nomadic Apaches. A boy was lowered to the cavern floor in 1883, but did not explore beyond the twilight zone. Jim White, a local cowboy, entered the cave in 1901 and was immediately interested in the size and magnificence of what he saw. Though few believed his stories of the huge columns and vast chambers, he built rude trails and guided those who were interested.

In 1903 a mineral claim was filed on Carlsbad with the intention of mining the large quantity of bat guano accumulated through thousands of years from the millions of bats living in the cave. Guano was mined until 1923 by at least six companies, who removed an estimated 100,000 tons. No great profit was made, however, and mining activity slacked off after this period. People visiting Carlsbad at this time were lowered to the floor of the Cave in the ore buckets used for lifting the guano to the surface.

The government became interested in Carlsbad in 1923 after pictures and a report on the cave impressed them with its potential. In 1930 it was established as one of our national parks (Fig. 92). Soon after government employees began to build adequate trails, photograph the galleries and map the cave. Bat banding and other biological studies were also begun.

Tourists now entering Carlsbad descend a total of 730 feet through Bat Cave and the Devil's Den to reach the level of the Green Lake Room and King's Palace (Fig. 93). The main corridor is a mile long, 40 to 200 feet wide, with a 250 foot high ceiling. The Big Room is another huge chamber 3,000 feet long with a ceiling height of from 30 to 285 feet. The room has more than 12 acres of floor space. Stalactites of all shapes and sizes, massive draperies, helictites and other formations occur in great quantities in many pastel colors, from creamy tans to peach to red. Some of the largest most massive, stalagmites known are in the Hall of Giants. Giant Dome, the largest of these, is 62 feet high and at least 20 feet in diameter. Carlsbad is the second deepest cave in the United States with a total depth of 1076 feet. Despite this great depth no running water has yet been found in the cavern.

New Cave, which is also in Carlsbad Caverns National Park, has even larger stalagmites and pillars than Carlsbad. The Christmas Tree, a massive what stalagmite, is one of the most interesting of these formations. A large colony of bats, whose bones have been found imbedded throughout flowstone in the cave.

References:

Figure 92. Topographic map and line drawing of Carlsbad Caverns, topography from USGS Carlsbad Caverns East Quadrangle, 1:24,000.
Figure 93. Map of Carlsbad Caverns, taken from P. G. Sanches, 1964, Roswell Geol. Soc. Guidebook, p. 48.
Caverns of Sonora

Sutton County, Texas

(72 on Plate 1)

8 miles west of Sonora

The Caverns of Sonora, previously known as Mayfield Cave, is one of Texas' more recent commercialized caves. It is one of the most beautiful caves in the world and contains a profuse array of magnificent formations of delicacy and great variety. While the passages aren't the longest in Texas, they are completely filled with helictites, soda straws and many other beautiful formations (Fig. 94).

Until 1955 no cavers considered Mayfield Cave worth a second visit. The cave was thought to have been completely explored by local people and amounted to a rather ugly collection of barren tunnels leading into a large room. This was considered the end of the cave and the only leads were high on the other wall and seemed unpromising. There was a narrow risky ledge near the ceiling which sloped to a sixty foot sheer drop. On Labor Day weekend 1955 members of the Dallas Speleological Society explored the old portion of the cave and one member scaled the dangerous ledge and inched his way across it. He successfully skirted the pit and entered an unexplored region of the cave. The rest of the group followed and explored with astonishment in the discovery.

The helictites of the cave are abundant and well developed. The entire wall on one side of the Helictite Room is completely covered with masses of clear helictites up to twelve inches long and averaging a quarter inch in diameter. Giant heligmites protrude from the floor and measure up to two feet high. Large areas on the ceilings and walls are covered with beautiful coralloids that reveal a crystal structure. The colors of these speleothems range from pure white to rust red. These sub-aqueous formations join to form "Christmas trees" up to four feet high and have been formed by coralloid deposition on stalagmites. Of interest also are stalactites that are wider at the bottom end than at the ceiling base. The coralloids and stalactites in the cave are outstanding. In the back and most remote part of the cave are some of the most dazzling and intricate formations. In what was once a rimstone pool are giant rhombohedral crystals of calcite. These orange crystals are stunning and measure up to three inches on a side. At one place these crystals have joined to form a horseshoe formation of both aerogenic and subaqueous origin. The soda straws stalactites in the cave average two feet long, but some are over six feet long and vibrate when they are breathed upon. Single speleothems have been named for objects they resemble: there is a unique six inch butterfly helictite, an eight inch tomahawk helictite, a fishtail, and the snake dance, a weird and beautiful heligmite.
Figure 94. Plan and sections of the Caverns of Sonora, modified from NSS Bulletin, vol. 24, p. 32.
The Hall of the White Giants is stunning with its coralloids and stalactites, and the Helictite Room as previously mentioned is a literal forest of gorgeous intricate helictites.

Recent biological investigations have turned up several interesting insects, one unique, and several rare. Bats, raccoons, cave crickets, and beetles, and millipeds inhabit the cave.

The Caverns of Sonora have been officially registered by the National Park Service as a United States Natural Landmark.

References:

National Geographic, Vol. 125, No. 6, June 1964, pp. 818-819.
Texas Caver, Vol. X, No. 12, cover.

Conley Hole Grundy County, Tennessee
Viola Quadrangle
(68 on Plate 1)

Conley Hole, located in Grundy Co., Tennessee, is one of the most spectacular pits in the United States. The pit opens directly onto the surface, and it is a free drop of 175 feet to the floor. The surface opening is about 15 feet by 25 feet and is located on the side of a mountain at an elevation of 1560 feet. A person descending the pit finds himself against a wall for the first few feet. The pit then bells out and one finds himself in the very center of a huge chamber 250 feet in diameter. The landing point of a descent is 100 feet from the nearest pit wall. Looking up from the bottom, the pit resembles a huge cathedral. The pit is particularly spectacular when light from the surface opening pours in and illuminates the bottom. Several beautiful draperies and flowstone formations adorn the walls of the pit making it one of the most impressive pits in the country.

Conley was once a very popular social gathering point for residents of the surrounding counties, and a winch and platform were constructed at the entrance to facilitate Sunday afternoon descents of the pit. These artifacts have long since fallen into decay.

References:

Cottonwood Cave is located in the Lincoln National Forest, about 3/4 mile from the Oak Canyon Fire Lookout. The exact location of Cottonwood is shown on the U.S.G.S. Carlsbad West Quadrangle. Access to the cave is controlled by the Forest Service Office in Carlsbad. Cottonwood is one of the better known and most beautiful caves of the Guadalupe Mountains. The entrance to Cottonwood is very long and impressive. The cave entrance is at an elevation of about 6,520 feet. The lowest pit in the cave, at the bottom of the Great Sand Slope, is 250 feet below the entrance.

Cottonwood is known basically for its huge formations, the large size of its passage, and its spectacular gypsum flowers. The cave essentially consists of two parallel passages running N 15° W (Fig. 95). These two passages the Entrance Hall and the Gypsum Hall, are about 100 feet apart and are considerably different in character.

The Entrance Hall is the larger of the two main passages, and extends from the entrance 750 feet back into the cave. The passage is roughly 50 to 100 feet wide and in plains is nearly 100 feet high. 350 feet from the entrance is a group of very impressive stalagmites up to 40 feet high and 15 feet in diameter. Another splendid display of stalagmites is located just inside the entrance of the cave. The Entrance Hall is well decorated with all types of dripstone deposits. The Entrance Hall ends at a 30 foot high flowstone bank. Beyond a pit the Great Sand Slope drops down 120 feet in a horizontal distance of about 200 feet. At the bottom of the slope, the ceiling is 150 feet overhead. Two pits on either side of the passage at the bottom of the slope lead to a lower passage which crosses beneath the lower end of the Great Sand Slope. Following the passage to the left brings one to a series of breakdown rooms. Entry into the Gypsum Hall is made by climbing up through this breakdown. The Gypsum Hall is very dry and somewhat smaller than the Entrance Hall. The floor of this passage is covered with loose slope breakdown as are some parts of the Entrance Hall. The passage trends in the same direction as the Entrance Hall and can be followed about 600 feet to the north where it ends in a 30 foot drop into the Terminal Room. The Gypsum Hall is primarily noted for its spectacular displays of gypsum and epsomite. This passage contains many gypsum and epsomite ouphololites, and epsomite stalactites are found near the Terminal Room. The passage is well known for it's spectacular 6 foot gypsum flowers.

In the Terminal Room are found the unusual "Active Tables." These formations have a flat layer of travertine extending out from the surface of a stalagmite. These "Tables" are 3 to 4 feet high and represent the surface of a pool which once filled part of the room. The vineyard effect is emphasized by botryoid formations below the level of the tables.

References:

COTTONWOOD CAVE
Eddy Co., New Mexico

Figure 95. Map of Cottonwood Cave, modified from Speleo Digest, 1961, p. (1-191).
Devil's Sinkhole  
Edwards County, Texas

(73 on Plate 1)  
9 miles northeast of Rocksprings

The Devil's Sinkhole, is a deep, bell-shaped, pit entrance to a large room. Early in its history a rancher descended Devil's Sinkhole and extended a water pipe from a pool at the bottom to the surface. The entrance is 75 feet across, but hard to see. One could easily drive or ride a horse into it if he were careless.

After dropping 200 feet to the top of a large breakdown mountain, the hole is undercut greatly. The breakdown may be climbed downward to the base of the mountain, about 300 feet below the entrance, where several lake rooms and numerous speleothems including helictites, canopies, bacon rind, and commoner types of speleothems are found. Devil's Sinkhole houses a large colony of bats, and is one of the most famous and well known caves of Texas.

References:


Fitton (Beauty) Cave  
Newton County, Arkansas

(14 on Plate 1)  
Northern portion of Co., exact location not available

Fitton Cave, also known as Beauty Cave, is well known to many spelunkers throughout the United States. It is the longest cave in the state, with 38,940 feet mapped by 1966, by the Arkansas Speleological Survey. The cave includes some very large rooms, canyons, funnel pits, and crawlways. The stream exit for the cave was found to be Bat Cave, already known as a cave. There are several waterfalls in the cave, ranging from 2 to 47 feet high. The entrance room itself is 700 feet long and averages 100 feet wide. Even this is smaller than some rooms up to 500 feet long, 150 feet wide, and 75 feet high. There is also much gypsum in the cave, occurring as angel's hair, needles as long as in Cumberland, Tennessee, flowers, rosetts, and fascinating helictite like curls. The fauna of the cave includes blind salamanders.

References:

Arkansas Speleologist, publication of the Razorback Speleological Society, Spring 1961.
Grand Caverns  Augusta County, Virginia
Harrisonburg Quadrangle
(84 on Plate 1)  38°15'37" N Lat., 78°50'10" W Long.

Grand Caverns is probably the oldest commercial cave in the United States, tours having been run as early as 1809. Its discovery is credited to Mr. Bernard Weyer, who is said to have dug into the cave while attempting to retrieve an animal trap. Soon after, the cave was opened to the public. Among those to visit Grand Caverns were Thomas Jefferson, and Stonewall Jackson. Civil War troops were quartered there in the 1860s. There are many beautiful formations in the cave, including large "shields" or palettes in addition to the more common types of formations. One of the most beautiful of these palettes is the Bridal Veil Shield, which is eight feet in diameter and 15 feet tall, with draperies and curtains hanging from it. Two of the highlights of the tour are Cathedral Hall and Jackson's Hall. Cathedral Hall is a large, high passage with many formations. Jackson's Hall is a room with a 90 foot high ceiling. The cave has two entrances, and is noted primarily for its rare shield formations.

References:

Grapevine Cave  Greenbrier County, West Virginia
White Sulphur Springs Quadrangle
(92 on Plate 1)  37°49'50" N. Lat., 80°27'00" W. Long.

Grapevine Cave (Fig. 96) is a well known and much visited West Virginia Cave. The cave has both vertical and horizontal passages. The entrance is a 115 foot pit. The extent of horizontal passage at the bottom of the pit is one-half mile. Inside is a variety of formations which include 20 foot columns, deep rimstone pools, and draperies. Numerous dome pits are also located in the cave. Bones of an animal were found in one place in the cave. Fauna observed in Grapevine includes mole salamanders, newts, and ravine salamanders. The cave has been commercialized as the Lost World, with a tunnel cut through solid rock to bypass the 115 foot pit entrance. Visitors are able to walk into the cave directly. The beauty of the cave is to be protected from straying visitors by photoelectric cells along certain areas.

References:
Figure 96. Map of Grapevine Cave, modified from Speleo Digest, 1966, p. (1-153).
James Cave, also known as Thousand Rooms, is a large complex cave with many formations, canyons, and pits. It is located on property owned by the Quality Courts Resort Hotel just south of the Mammoth Cave National Park. Passages are still being found in this expanding cave, with 5.75 miles of passage presently surveyed. It is noted for 40 Fathom Pit, a pit in two drops totaling 240 feet. When this pit was found, a passage was noted on the far side, but could not be reached. An expedition extended a pipe across the pit in an attempt to reach the other side. That particular trip failed to cross the pit, but later efforts were successful.

Attempts are being made to commercialize the route to 40 Fathom Pit and the upper sections of the cave. Exploration is continuing in the lower levels. Additional routes have been found to 40 Fathom Pit, from which passages extending to Cuddington Canyon, Thunder Pit, and Lower Bowel, Rodemaker Canyon, Kleenex Pit, and other new sections of James. Mapping trips to the cave are frequent and each one seems to produce new leads to be checked. Many cavers believe that James Cave connects with nearby Coach Cave. One possible location of this connection is a passage in Dyer Dome, which no one has yet entered. The dome has been climbed, but the hole was approached on the wrong side, so that the lead could not be entered. The cave is primarily a "cavers cave", but efforts are being made to open it to the public.

References:


Kickapoo Cave, Kinney County, Texas

(77 on Plate 1) exact location not available

Kickapoo Cave is located 20 miles north of Brackettville, Texas on Route 674. The cave is not long, only 1300 feet, but is renowned for the size of its passage and the huge columns it contains (Fig. 97). Entrance to the cave is made through a low opening near the top of a knoll. The cave is essentially a single large corridor up to 100 feet high, 120 feet wide and 800 feet long. The floor of the chamber is covered with very massive breakdown and the cave is dry throughout its length. 400 feet from the entrance 6 huge columns dominate the passage. These massive formations are 30 to 60 feet in diameter, and are very spectacular. A small but beautiful side passage to the left at this point contains a splendid display of gypsum formations. Past this point the floor drops some 35 feet and formations begin to appear on both sides of the passage. 800 feet from the passage is nearly filled by another huge column. This formation is 60 feet high and 150 feet in circumference, making it one of the largest dripstone-flowstone deposits in the country. Behind this column, the passage branches into two tunnels both about 10 feet wide and 10 feet high. The left hand branch contains many beautiful helictites.
Figure 97. Map of Kickapoo Cave, modified from NSS News, vol. 15, no. 3, March 1957, p. 34.
Visiting American Caves describes Lehman Cave as being highly decorated and having nearly all phases of cave development. It is noted for its unusual shield formations and twisting helictites, which cover the walls and ceilings. It is a superb stalactite cave. After rainy seasons there are several shallow lakes inside. The discovery of the cave was made by Absalom Lehman who was hunting for stray cattle in the Snake Range of eastern Nevada in the 1870's. His horse fell out from under him and stumbled into the natural opening of the cave, which is today a National Monument.

The Salt Lake City Grotto, in a technical report on the cave in October 1958, described the present state of the cave. They say that unfortunately, all areas of the cave known to visitors before it was made a National Monument have been subjected to breakage of formations and name writing. Some of the larger speleothems have been vandalized. The Gypsum annex of the cave is the only known section to escape vandalism, mostly due to its inaccessibility. There is a 20 foot pit into this section. There are few stalactites, but an impressive gypsum inerustation appears. Rare to the west, many gypsum flowers can be seen.

The lowest main level of the cave is at 6800 feet elevation. A secondary upper level may be present. Near the entrance the cave has been eroded away by a small gully where the Monument's buildings are located. The meteorological and hydrological conditions in the cave are highly variable, depending on the season of the year. The lakes formed in wet season are quite impressive. The commercialization of the cave has apparently reduced the cave life to a fraction of its former population. Algae and plants are present around most of the lights in the visitor's section (Fig. 98).

References:

Helmer, W., March 1957, N.S.S. News, p. 33-34.

Lehman Cave
White Pine County, Nevada

Lehman Cave National Monument

(51 on Plate 1)

References:

Speleo Digest, 1958, Published by Pittsburgh Grotto, N.S.S., pp. 1-323 to 1-325.
Speleo Digest, 1957, Published by Pittsburgh Grotto, N.S.S., p. 1-157
Halliday, W. R., 1959, Adventure is Underground, p. 189.
LEHMAN CAVES, NEVADA

Map by D. J. Green
Profile by G. W. Moore

1960

Figure 98. Map of Lehman Caves, taken from the California Caver, vol. 3, no. 4, p. 30.
Luray Caverns was discovered in 1878. It is highly decorated, and contains all of the common types of speleothems. Soon after its discovery it was opened to the public and is still one of the most highly decorated commercial caves in the United States. A main attraction of the cave is the Great Stalacpipe Organ, which produces musical tones by electronically controlled keys which strike stalactites making them ring. The total cave length is less than two miles (Figs. 99 and 100).

References:


Marvel Cave is a large commercial cave in Stone County, Missouri. The cave is very long, and when completely explored may be the longest cave in southwestern Missouri. The cave is also quite deep, cutting through several rock formations for a total depth of over 400 feet.

This great cave was partially explored as early as 1869. Marvel Cave is very prominent in the history of the area, and is mentioned in Howard Bell Wright's, Shepherd of the Hills. The cave was considered by early visitors to be "the gates of Hell." Today the cave is the center of nine large recreational developments known as "Silver Dollar City."

The entrance to Marvel Cave is very spectacular. Descending through its gaping entrance sink one finds himself at the top of a very impressive dome, at the bottom of which is the "Liberty Bell" a very massive stalagmite. The entrance to Marvel Cave is one of the most impressive cave entrances in the United States.

Marvel is very scenic and contains some very impressive dome-pits which are exceedingly well displayed on the commercial tour. The effect of stratigraphy on cavern development is very well illustrated in Marvel Cave. Some of the dome pits, the entrance room, and some very impressive formations are shown on the commercial tour. In 1958, the management of the cave sunk an inclined railway into the top of the "terminal domepit" to facilitate an easier tour. The cave is developed to a high degree but is indeed a beautiful and large cave.

References:

Figure 100. Section views of Luray Caverns, modified from Hack and Durloo, 1962, Geology of Luray Caverns, Va.

Natural Well

Madison County, Alabama
Huntsville Quadrangle
NW_\text{\frac{1}{4}} SE_\text{\frac{1}{4}} Sec. 33, T. 3 S., R. 1 E.

Natural Well is located on the west slope of McKay Hollow, on Monte Sano Mountain, just east of Huntsville, Alabama. Natural Well is an impressive 200 foot vertical shaft (Fig.101). It is readily accessible, and is a classic example of a domepit. The pit opens directly on the surface and is about 20 feet indiameter at the top. The pit bells out slightly and remains about 30 feet in diameter to the bottom. The walls of the shaft are smooth and dry, and the entire pit is rather impressive viewed from the top or bottom.

Natural Well is a historic pit first entered about 75 years ago, by a young negro who was lowered to the bottom in a bucket. During the depression, the C.C.C. constructed an elevator in the shaft with intentions of commercializing the cave. The venture failed and few remnants of the project can now be found. Later exploration of Natural Well revealed 3 large domes and about 2000 feet of horizontal cave passage at the bottom of the entrance shaft. Natural Well is only one of the many pit caves in the Cumberland Plateau of northeastern Alabama and although far from being the deepest perhaps is one of the most well known and impressive pits of the area.

References:


Neversink Pit

Jackson County, Alabama
Mud Creek Quadrangle
NW_\text{\frac{1}{4}} SW_\text{\frac{1}{4}} Sec. 4, T. 3 S., R. 6 E.

The Neversink is one of the many vertical shafts that are located in the Jackson County Mountains of northeastern Alabama. Although not the deepest pit in the area, the Neversink is one of the most scenic; for this reason it is included in this report. The pit is located on the side of a mountain north of Scottsboro, Alabama, and opens directly onto the surface. The surface opening is about 50 x 70 feet but soon bells out and maintains an average diameter of about 100 feet for its free drop depth of 180 feet. The walls of the pit are quite regular and cylindrical. The bottom of the pit is flat and strewn with debris that has fallen in from the surface. There are no passages leading off from the bottom of the pit, but the view
Section of Monte Sano showing position of the Natural Well. Ct, Tuscumbia limestone; Cgs, Ste. Genevieve limestone; Cg, Gasper formation; Chs, Hartselle sandstone; Cb, Bangor limestone; Cpv, Pottsville formation.

Figure 101. Plan and profile view of Natural Well, modified from Speleo Digest, 1960, p. (1-135).
looking back up to the surface is quite spectacular, and accounts for the
fame of the Neversink: the walls of the pit are sheer and lead upward to
the surface opening which is fringed in green, and a waterfall pours over
the lip of the pit, making the shaft very photogenic from the bottom.

References:


Onondaga Cave

Crawford County, Missouri
Sullivan Quadrangle
(47 on Plate 1)

Onondaga is a highly commercialized but beautiful cave, located in
Crawford County, Missouri. The cave is about one mile long, and is one
of the most scenic caves in Missouri (Fig. 102).

Onondaga was commercialized in the 1920's and until the late 1930's
was operated as two separate caves. The northern end of the cave was
operated as Missouri Caverns, and the southern end as Onondaga Cave. There
are many interesting tales about the rivalry between the two parts of the
now reunited cave.

Onondaga has been developed to a very high degree. The cave is
electrically lighted and contains easy walking trails. Onondaga is noted
primarily for its speleothems. Unfortunately, part of the cave will be
flooded by the proposed Meramec River Reservoir, and much of the beauty
of the cave will be lost.

References:

Bretz, J H., 1956, Caves of Missouri; Missouri Geol. Survey and
Water Resources; vol. 39, second series, p. 197-211.

Oregon Cavern

Jackson County, Oregon
(60 on Plate 1)

Known since 1875, this cave has about 2700 feet of passage way developed
commercial tours. Although there aren't many speleothems present, those
that are grouped together in a few small areas. The cave has several large
chambers, and is developed with a vertical relief of nearly 125 feet. The
relatively high moisture and cold temperature of the cave combined with the
large chambers yield somewhat of an austere impression. This is one of the
few limestone caves in the area. This cave is protected by the National
Park Service as a National Monument, and was established as such in 1909.

References:

Mohr, C. E., and H. N. Sloane, 1955, Celebrated American Caves,
Rutgers Univ. Press, p. 167.
publishers, p. 190.
Figure 102. Map of Onondaga Cave, taken from Bretz, 1956, p. 197.
Significant Limestone Springs of the United States

Springs issuing from limestone, so far as included in this report, are karst features directly associated with limestone caverns. They are simply the outlets for subterranean streams which flow through caverns. Springs, however, are significantly different from their associated caverns, in that they are visible at the earth's surface; therefore, they are of much greater scenic value to that segment of the public which will never enter or enjoy a limestone cavern. Limestone springs, in general, have had a far greater historical and economic significance than caverns, for many towns and cities were founded at springs capable of serving as a town water supply, some industries have established at springs, and thousands of farmsteads are at spring sites. Unfortunately, many of those springs which have been of greatest historical significance are no longer in a natural setting owing to the human modification of their surroundings. Much of the scenic value of natural springs is derived from the natural vegetation at the spring, which commonly is slightly different from adjacent areas that are dryer.

Numerous classifications have been devised to segregate springs, commonly on the basis of geologic or hydrologic types, size or rank based on discharge, chemical analysis of the water, and temperature. Springs discussed in this report are restricted to those which occur in limestones, commonly called karst springs, and are all of somewhat similar chemical character and temperature. The spring waters are generally high in dissolved carbonates and the water temperatures are within a range equal to the climatic temperatures of the area in which they are located, although usually the spring waters fall within a shallow range that approximates the average annual temperature of their area.

Karst springs, that is springs issuing from solution channels or caverns in carbonate rocks such as limestone, may be geologically and hydrologically sub-divided into several types, but most commonly they are simply either cave springs discharging water by gravity flow or are artesian springs discharging water which wells up from deeper lying conduits owing to hydrostatic pressure. Cave streams which discharge through an open cavern entrance are cave springs, although when the cave is named and enterable by man it is commonly referred to as a spring cave. Many cave springs are not enterable owing to obstruction of the outlet by collapsed material, but the cave stream flows through the break-down or talus. Large cave springs are associated with all of the major cave regions of the United States, but notably: The Pennyroyal Plateau of central Kentucky; the Ridge and Valley Province of Alabama, Tennessee, Virginia, West Virginia and Pennsylvania; the Highland Rim area of Alabama, Tennessee and Kentucky; and the cave region of Missouri and Arkansas.

Many karst springs are artesian in nature, that is, the waters discharged at the spring ascend from cavernous openings at some depth below the surface outlet. Most artesian karst springs in the interior areas of the United States, such as the Ridge and Valley, Highland Rim, and Ozark areas, are alluviated cave springs that have been formed by the burying of cave springs by sedimentation within the surface valley to which the springs are tributary. The accumulation of sediments in the major surface streams essentially buries the cave springs, but the cave stream continues to discharge from the spring owing to the hydrostatic pressure within the impounded cave passages which is sufficient to ascend through the sediments and keep a rise pit open within the accumulating sediments (Powell, 1963). Most of the sedimentation in streams in the interior of the United States was during glacial stages of Pleistocene time.
A rise in sea level in the Floridian area of the southeastern United States has raised the water table level considerably above the level at which the caverns, now water filled, were originally formed, resulting in artesian flow and discharge of the runoff which enters the caverns. Some of the springs discharge as submarine springs into the seas, but many on land are discharging through former sinkholes.

Some artesian karst springs are caused by upwellings of water along joints and fault planes from cavernous zones at depth, such as those associated with the Balcones Fault Zone in the Black Prairie Region of central Texas.

Springs may also be ranked according to their amounts of water discharge, regardless of their geologic or hydrologic type. The discharge is commonly measured in cubic feet per second of flow, usually by methods applied to the calculation of flow of surface streams. Complications arise in ranking springs by size, however, for some springs consist of a grouping of discharge points within a limited area requiring several measurements, compounded by the situational where the stream from the spring may discharge directly into a surface stream or with too short a channel to provide a place of measurement. An additional problem is that of obtaining sufficient flow data over a time span to include seasonal variations such as low flows (droughty periods) and high flows (high precipitation periods) and enable calculation of an accurate average flow rate. The rank of a spring is best determined by the scale established by O.E. Meinzer (1923, p. 53), as follows:

<table>
<thead>
<tr>
<th>Magnitude</th>
<th>Average discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>100 second feet or more</td>
</tr>
<tr>
<td>Second</td>
<td>10 to 100 second feet</td>
</tr>
<tr>
<td>Third</td>
<td>1 to 10 second feet</td>
</tr>
<tr>
<td>Fourth</td>
<td>100 gallons a minute to 1 second foot</td>
</tr>
<tr>
<td>Fifth</td>
<td>10 to 100 gallons per minute</td>
</tr>
<tr>
<td>Sixth</td>
<td>1 to 10 gallons per minute</td>
</tr>
<tr>
<td>Seventh</td>
<td>1 pint to 1 gallon per minute</td>
</tr>
<tr>
<td>Eighth</td>
<td>less than 1 pint per minute</td>
</tr>
</tbody>
</table>

Note: One second foot equals 448 gallons per minute.

Although Meinzer's classification is based on average discharge, meaningful ranking may be done on a basis of minimum flow. The maximum discharge of some springs is significant or impressive, particularly that of most karst springs which characteristically have extreme fluctuations in comparison to other geologic types of springs. Fluctuations of maximum discharge above minimum discharge are usually ten times greater, and maximum discharges hundreds of times greater than minimum flow are not rare. Lack of fluctuations of karst springs is very rare.
The limestone springs of Florida are numerous and generally considered to include many of the larger springs of the United States. The springs commonly discharge directly into major streams and are found therefore within the valley areas of several physiographic units of local extent that have been delimited by R. M. Harper (1914 & 1921) and H. S. Puri and R. O. Vernon (1964, p. 7-15)(Figure 103.). The subterranean conduits which feed the springs have formed within limestones of Tertiary age, but the outcrop of these limestones, and therefore the headwaters of the subterranean systems, are mantled with thick deposits of Tertiary and Pleistocene age clays and sands, notably the cover of sand of the Hawthorn Formation.

References:


Ichatucknee Springs Columbia County, Florida
29°59' N. Lat., 82°46' W. Long.

Ichatucknee Springs, located 1 mile east of Hildreth, in Columbia Co., Florida, on the Suwanee County line, form one of the largest spring groups in Florida, and are the headwaters of the Ichatucknee River. Flow from the spring group comes dominately from seven separate pools located along the river. Measured discharges of the spring group vary from 250 to 470 c.f.s. with an average flow of about 320 c.f.s.

A large part of the flow of the Ichatucknee River originating at Ichatucknee Springs is believed to come from 2 surface streams, the Alligator Lake outlet, and Rose Creek. Both the Alligator Lake outlet, and Rose Creek, flow into swallow holes and disappear several miles to the northeast of Ichatucknee Springs.

The main headspring at Ichatucknee Springs forms a circular pool about 100 feet in diameter. The flow from this pool issues a submerged cavern outlet whose floor is about 14 feet below the normal pool level. The cavern mouth measures about 35 feet wide by 60 feet long. The measured flow of the headspring is about 45 c.f.s. Another similar sized pool is located .3 mile down the spring run from the headspring. This pool is unusual however, in that it resembles a huge jug that is about 35 feet deep. This jug-shaped spring generally has a much greater flow than the headspring.
Five other pools and spring groups are located within one mile downstream from the headspring on both sides of the river bank. Away from the headspring, the river broadens considerably, up to 200 feet, and becomes quite shallow. The shallow reaches of the river promote a luxuriant display of many varieties of aquatic vegetation. Ichatucknee Springs are located in a thickly wooded, scenic, and largely undeveloped area.

References:


Ponce de Leon Springs
Volusia County, Florida
29°08' N. Lat., 81°22' W. Long.

Ponce de Leon Springs are located about 8.5 miles north of De Land, in Volusia County, Florida. The springs form a semi-circular pool that is enclosed by a concrete wall about 170 feet in diameter. The springs have been developed as a tourist attraction, and many improvements have been made at the spring site.

Ponce de Leon Springs are principally noted for their rich history with the Spanish and Indians. Rumors exist that a Spanish treasure was buried in the spring in 1817. The Springs were discovered in 1562 by Don Juan Ponce de Leon, in his well known quest for the Fountain of Youth. Since then the springs have been the center of numerous stories and myths. A small Spanish colony was established near the Springs in 1570, and a sugar mill was later operated by the Spanish at the spring site. Spanish-Indian and Indian-American battles centered at and around the spring in later years.

The flow of Ponce de Leon Springs varies from about 20 to 40 c.f.s. and is used to run an undershot wheel driving a water pump. The springs are well developed for swimming, boating, picnicking, and fishing.

References:


Rainbow Springs (Blue Spring)
Marion County, Florida
Dunnellon Quadrangle
NE 4, SE 4, Sec. 12, T. 16 S., R. 18 E.

Rainbow Springs, (Blue Spring) located 4 miles northeast of Dunnellon, in Marion Co., Florida, is perhaps the largest single outlet spring in the United States. The headpool of the spring is roughly semicircular and is about 400 feet in diameter. The spring forms the headwaters of the Blue River (Rainbow River) and emerges in a very scenic tropical area. From the spring basin, Blue River (Rainbow River) winds its way approximately 5 miles
to a point where it joins the Withlacoochee River. The aquatic vegetation is reported to be very luxuriant at both the spring basin and along the spring run.

Four known underwater cavities discharge into the largest pool at Rainbow Springs. Another, much smaller pool 1 mile east of the main pool also contains 4 underwater cavities. Discharge from these two main pools form the scenic Rainbow River. Numerous smaller springs and sand boils are located along the Rainbow River.

As with most of Florida's springs, the water surface elevation of the main pool varies seasonally with the amount of rainfall. The maximum recorded pool elevation from 1930-1947 was 33.09 feet above mean sea level. The annual mean flow of Rainbow Springs from 1932 to 1946 was 699 c.f.s. The flow of Blue River (Rainbow River), and the Silver Spring Run generally compare very closely and display remarkably similar fluctuations.

Rainbow Springs remain essentially in an undeveloped state, although some tourist improvements have been made around the main pool.

References:


Silver Springs - Florida
Marion County, Florida
Ocala East Quadrangle
Cen. W 1/2, Sec. 6, T. 6 S., R. 15 E.

Silver Springs is located about 5 miles northeast of Ocala, Marion Co., Florida. Water discharged thru Silver Springs boils up in one very large pool, and thru numerous smaller spring outlets located along the spring run immediately downstream from the main pool. The main pool is nearly circular and is approximately 250 feet in diameter. Discharge along the spring run varies from about 600 to 1,100 c.f.s. with about half of this discharged thru the main pool. Although the total flow of the several spring outlets at Silver Springs makes it the largest spring group in the United States, records indicate that both Big Spring in Missouri, and Rainbow Springs in Florida have greater single outlet flows.

Beckman and Hinchy (1944), state:

"The available records indicate that the average flow of Big Spring in Missouri is about equal to that from the upper pool of Silver Springs in Florida and that these two share the distribution of being the largest single-outlet springs in the United States, although the total flow of the Silver Spring group is considerably larger than that of Big Spring."
Recent data indicates that the flow from the largest outlet at Rainbow Springs is probably greater than either Big Spring or Silver Springs. Nevertheless Silver Springs ranks as one of the largest and most impressive spring groups in the United States.

Several underwater cavern channels discharge into the main pool at Silver Springs, and are readily apparent from the surface. The largest of these cavities lies 36 feet below the surface of the pool and is about 65 feet wide and 12 feet high. Water discharged from this tube forms a gentle boil on the surface.

The springs lie on the western edge of an extensive cypress swamp, and are in a scenic locality, although extensive improvements have been made to accommodate tourists. The spring run winds through the cypress swamp for 5 miles until it joins the Oklawaha River. The depth of the spring run varies from 6 to 30 feet. A more detailed account of the geology and a detailed description of Silver Springs may be found in Springs of Florida, (1947).

The springs are extensively developed commercially and are one of the major tourist attractions of central Florida.

References:


Wakulla Spring

Wakulla County, Florida
14 miles south of Tallahassee

The spring is part of a wildlife sanctuary managed by the National Audubon Society. Wakulla Spring is a large resurgence, opening on the surface as a natural pool, as do many of Florida's large springs. The spring basin, nearly 80 feet deep opens into Wakulla Cave which has been explored back by divers some 1,100 feet (fig. 104). The cave passage is completely water filled, and is often 100 feet high. The passage width varies from 70 to 150 feet.
Figure 104. Profile map of Wakulla Spring, modified from Mohr and Poulson, 1966, p. 158.
In the early 1930's divers became interested in the large objects resting on the bottom of the spring basin. Several of the objects were brought to the surface and were identified as mastodon bones.

In November 1955, divers from Florida State University dove into the basin and entered the submerged cave for a distance of 250 feet. A mastodon femur was discovered at this point, 200 feet below the surface. In the months that followed, repeated dives were made in this area and several other bones were excavated from the sandy floor of the cave. These included remains of giant sloths, armadillos, deer and other animals as well as mastodonts. Another very interesting find was the discovery of 600 spear points along with the bones. A large amount of paleontological work has been done at Wakulla Spring, and a lot has been learned about the life that inhabited Florida many thousands of years ago. Several basic questions remained unanswered about this ancient graveyard, and divers at this time are trying to answer them.

References:


Weekiwackee River

Hernando County, Florida
Weekiwackee Springs Quadrangle
S 1/2, NE 1, Sec. 2, T. 23 S., R. 17 E.

Weekiwackee (road atlas shows Weeki Wachee Springs) Spring is the head of the Weekiwackee River on the gulf coast of Florida. The Weekiwackee River emerges full-blown from a spring or group of springs, and flows directly to the coast. The spring is located about 12 miles southwest of Brooksville, in Hernando County.

The spring headpool, the source of the river, is about 150 feet in diameter, and about 30 feet above mean sea level. Water leaves the spring basin through a channel about 100 feet in width, and flows directly toward the Gulf of Mexico some 12 miles to the west.

The present condition of the spring is not known, but Weekiwackee Spring and river have long been a popular recreational area for hunting, fishing, swimming, and boating.

References:

Wekiva Springs
Levy County, Florida
Bronson SW Quadrangle
NW \( \frac{1}{4} \), SW \( \frac{1}{4} \), Sec. 7, T. 14 S., R. 17 E.

The Wekiva Springs are located 4.5 miles northeast of Gulf Hammock in Levy Co., Florida. They are situated at the head of Wekiva River and have a measured discharge ranging from 55 to 100 c.f.s. Although not large the springs present an interesting geologic picture.

The main headpool is about 20 feet in diameter, and is surrounded of a dense growth of vegetation. The spring run flows a short distance, and disappears back into the rock, only to emerge a few feet further, forming a small natural bridge. The spring run continues another 50 feet, past several boils coming up through crevices in the limestone, and again sinks into the rock. It emerges 5 feet away, forming a second natural bridge. The run then enters a circular pool about 20 feet in diameter, from which the largest flow issues. This basin is about 21 feet deep.

Wekiva Springs are believed to be in their natural state, and are used only for swimming by local residents. The springs are here considered significant because of the repeated sinking and rising of the spring run.

References:

The Ozark region of southern Missouri and northern Arkansas contains many springs with discharge over 100 c.f.s. These springs drain large areas of a relatively flat upland, the Salem Plateau, and discharge into rivers that have cut deeply into the plateau surface. Large springs are found as tributaries to the St. Francis, Black, North Fork, Eleven Point, and Current Rivers on the south slope of the Ozark dome. Parts of the Current and Eleven Point Rivers containing several large springs in scenic surroundings are included in the Ozark National Scenic Riverways (fig. 105).

Most of the larger springs are located on the south slope of the Ozark Dome, but numerous smaller springs are on the north slope along numerous rivers draining into the Missouri, such as the Niangua and Gasconade Rivers. None of these smaller springs are here described in detail, but special note should be made of Bennett and Big Blue Springs in Dallas County, Missouri. Big Blue Spring has been sounded to a depth of 150 feet. These springs, as well as smaller springs in Camden and Dallas Counties are described in detail by Shepard (1904).

Some of Missouri's large springs are the principal attractions of state parks. These include Bennett Spring in Dallas County, Alley Spring and Round Spring in Shannon, County, Roaring River Spring in Barry County, and Big Spring in Carter County. Many others are popular camp grounds and picnic areas.

Most of the springs of the Ozark region, including the 15 largest in the Salem Plateau, discharge from Cambro-Ordovician dolomites and cherty dolomites of the Potosi, Eminence, Van Buren, Gasconade, Roubidoux and Jefferson City Formations. The springs receive their water from sinks and sinking streams in the upland areas. During dry months a large portion of the flow of the rivers of this region is derived from springs that discharge into them. Detailed accounts of the geology and hydrology of the spring areas may be found in Bretz, 1953, Shepard, 1904, and Beckman and Hinchey, 1944.

The following descriptions of springs in the Ozark region were deemed to be representative of the largest, most scenic and historic of the area. Several large springs are located along the Current River, in the Ozark National Scenic Riverways, which are not discussed here. These include Blue Spring and Welch Spring in Shannon County, as well as the Cave Spring System described elsewhere in this report.

References:


Big Spring - Missouri

Carter County, Missouri

Van Buren Quadrangle
NW ¼, NE ¼, sec. 6, T. 26 N., R. 1 E.

Big Spring, in Big Spring State Park, 4 miles south of Van Buren, Carter County, Missouri, is the largest spring in the Missouri Ozarks and is one of the largest single outlet springs in the United States. The spring is only 1000 feet from the Current River and discharges its average flow of 250 million gallons/day into that river.
Figure 105. Map of Missouri showing locations of springs described in the report "Physiographic Boundaries" taken from C. F. Marbut, 1896, and W. D. Thomsen, 1967, Regional Geomorphology.
Big Spring has been described as the most spectacular of the many large Ozark springs. It sets at the base of a large dolomite cliff about 100 feet high, and is located in very scenic surroundings. Water issuing from the base of the cliff roils upward in spectacular turbulent boils and upwellings that are equaled by few large springs in the United States.

The enormous volumes of water discharged from the spring flow toward Current River in a wide, shallow, and fast spring run. The average measured flow of the spring is about 430 c.f.s., and is unusual because of its relatively constant discharge. Big Spring appears to fluctuate much less than most other large limestone springs.

Numerous articles have appeared concerning the geology of Big Spring, and many unusual instances concerning the flow of the spring have been described. The spring is the principal attraction of the Big Spring State Park.

References:


Bretz, J. H., 1953, *Genetic Relations of Caves to Peneplains and Big Springs in the Ozarks*, p. 16.

---------, 1956, *Caves of Missouri*, p. 41-43.


Greer Spring

Oregon County, Missouri

Birch Tree Quadrangle

SW¹ Sec. 36, T. 25 N., R. 4 W.

Greer Spring is located in Oregon Co., Missouri, one mile north of the small town of Greer. The spring is very scenic, and has two outlets located in a very deep narrow gorge which is essentially in its natural state.

The two spring outlets are about 300 feet apart horizontally and 8 feet vertically. Flow from the higher of the two emerges from a low-roofed cavern entrance. The lower and larger of the two resurgences is a circular pool from which water boils up with great force. The basin is located near the stream flowing from the upper spring outlet. The stream containing the combined discharge of both springs then flows northeast approximately 1½ miles and falls about 62 feet through a very narrow rocky gorge, which is very scenic, to discharge into the Eleven Point River.

The discharge of Greer Spring ranges from a low of about 200 c.f.s. to a high of over 800 c.f.s. The average flow is about 300 c.f.s., making it the third largest spring in the Ozarks. During long dry periods, most of the flow of the spring comes from the lower outlet, the upper outlet sometimes going dry. Records seem to indicate that a lag of about 1 day exists between periods of heavy rains and maximum discharge from the spring.
The present state of Greer Spring is not known, but it is believed that the spring is still in its natural state and that it is one of Missouri's most scenic springs.

References:


Mammoth Spring

Fulton County, Arkansas
Mammoth Spring Quadrangle
Sec. 5 & 8, T. 21 N., R. 5 W.

Mammoth Spring is located on the northeast of the town of Mammoth Spring in Fulton County, Arkansas. It is one of the largest single outlet springs in the Ozarks, and is adjacent to a National Fish Hatchery.

Mammoth Spring is the resurgence of a very large subterranean stream that issues at the base of a limestone bluff. Discharge of the spring ranges from a measured low of 150 c.f.s. to well over 300 c.f.s. Subterranean water discharges into the spring basin through a large cavern opening 64 feet below the surface of the pool.

A large uvala 8 miles northwest of the spring is associated with the spring. This large collapse sink structure, known as the Grand Gulf, is 3/4 mile long and is believed to mark the course of the conduit supplying water to Mammoth Spring.

Water from the spring is currently used to operate a hydroelectric plant, but the scenic values of the spring have not been disturbed.

References:


Meramec Spring, located 6 miles southeast of St. James in Phelps Co., Missouri, has been described as one of the state's most scenic springs. Water issuing through Meramec Spring boils up in a circular basin, about 100 feet in diameter, situated at the foot of a prominent overhanging dolomite bluff. Discharge from the pool flows over a rustic dam, and then one-half mile along a scenic spring run to the Meramec River.

The spring was a source of water power from 1826 to 1877 for the Meramec iron works which operated at the spring site. The ruins of this small plant may still be seen. Today, water flowing down the spring branch is used as a source of hydroelectric power for the local area.

Meramec Spring, although usually calm and clear, becomes quite turbid and muddy after heavy rains in the area. It is very responsive to local climatic conditions as is evidenced by its extreme ranges in flow from 56 to 650 c.f.s. The measured average flow of the spring is 149 c.f.s. The spring is approximately the seventh largest spring in the state, although one of the most scenic. Meramec Spring remains in an essentially undeveloped state, and is a popular local part and picnic area.

References:


Rymer Spring, also known as Ebb and Flow Spring, is located at the base of a high hill in the Gasconade dolomite, about 10 feet from Jack's Fork of Current River in Shannon Co., Missouri. The spring discharges water into a small basin, about 2 feet above the level of Jack's Fork.

Rymer Spring is not large or considered extremely scenic. It's average flow is only about 5 c.f.s., and the spring has suffered some improvements, in that it is used as water supply for a fishing club and for Rymer's Ranch, a pleasure resort. What makes Rymer Spring unusual is its strange periodic or "ebb and flow" action. The flow of the spring undergoes abrupt fluctuations in flow at more or less regular intervals. These fluctuations are often as great as 20 c.f.s. Beckman and Hinchey (1944) list 24 such springs known in the United States, of which Rymer Spring is one of the largest.
Bridge, (1924), described the factors believed to be the cause of ebb and flow springs and he gives a comprehensive discussion concerning the flow of Rymer Spring, and lists the following data:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average number of crests per day</td>
<td>2.4</td>
</tr>
<tr>
<td>Highest rise in water level</td>
<td>1.0 ft.</td>
</tr>
<tr>
<td>Average rise</td>
<td>.53 ft.</td>
</tr>
<tr>
<td>Number of rises above .5 foot</td>
<td>1.1 per day</td>
</tr>
<tr>
<td>Shortest interval between crests</td>
<td>1 hour</td>
</tr>
<tr>
<td>Longest interval between crests</td>
<td>45 hours</td>
</tr>
<tr>
<td>Average</td>
<td>10 hours 10 min.</td>
</tr>
</tbody>
</table>

Most writers have considered ebb and flow springs to be the result of syphon arrangements that are periodically drained and refilled (Keller, 1947).

Water emerges from Rymer Spring in a small crevice 15 inches wide and 4 feet deep. A small run flows the short distance to Jack's Fork through two artificial collecting basins. The flow of the spring at low stage is relatively constant at 5 c.f.s. During high stages of Jack's Fork, water from the river floods the spring, but the flow from the spring is strong enough to keep the muddy river water away.

The present state of the spring is not known. Although small and not spectacular, its' ebb and flow discharge makes it significant. It is one of the largest of its kind.

References:


Bridge, Josiah, 1924, "Ebb and Flow Springs of the Ozarks".

Springs of the Balcones Fault Zone, Texas

Several large artesian flow springs are located in the Balcones fault zone of south-central Texas. The springs rise primarily from the Cretaceous Edwards Limestone along major faults located south of the Balcones escarpment, in Val Verde, Kinney, Uvalde, Bexar, Comal, Hays, and Travis Counties. The early settlement of many of the larger towns and cities in the area was based on the locations of these springs; San Antonio is a good example. Many of the large artesian flow springs of the area receive their water from highlands in the Edwards Plateau, north and northwest of the Balcones escarpment, and provide a perennial source of water. The detailed geology of the area may be found in the Water Supply Papers cited below, (Fig. 106).

Barton Springs located in Austin, Travis Co., has been regarded as a simple gravity flow spring, and is one of the smaller springs that will be discussed here, having an average measured discharge of 43 c.f.s. Although the spring is comparatively small it does exhibit a perennial flow into the Colorado River.

San Marcos Springs located in the northern part of San Marcos, Hays Co., is a much larger artesian spring having a recorded average flow of 144 c.f.s. Numerous flowing wells are also located in the San Marcos area. The artesian well at the U. S. Fish Hatchery in San Marcos is of significant interest. When drilled in 1895, its water carried up several hundred specimens of the rare Texas blind salamander, Typhlomolge, as well as numerous specimens of a rare species of fresh water shrimp, Palaemonetes antorum. These unique organisms have been reported only from caves of the Purgatory Creek System on the Edwards Plateau and this artesian well. An interesting account concerning Purgatory Creek and the artesian well is given in The Caves of Texas, 1948.

Comal Springs in New Braunfels, Comal Co., is one of the largest springs in the group with a reported average discharge of 315 c.f.s. The spring has a minimum flow of about 75% of its average flow. The spring is located at the base of a 100 foot escarpment, and issues from the Edwards Limestone. Although it is the second largest spring in the area, it has been regarded as a simple gravity flow spring. A smaller, somewhat less spectacular, but geologically similar spring, Hueco Spring, is located 3 miles north of Comal Springs. The discharge from Hueco Springs varies from 0 to 93 c.f.s. Both of these springs are located along faults.

Within the city of San Antonio, Bexar Co., lie two large artesian springs. San Antonio Springs, at the head of the San Antonio River, and nearby San Pedro Springs both represent the only large artesian groundwater outlets in Bexar County. Water discharged by both springs rises along fault planes from great depths in the Edwards Limestone.

No large artesian springs are known in Medina County, but numerous artesian wells are recorded that flow from the Edwards Limestone. The same is true of Uvalde County, although one fairly large spring, Leona River Spring, south of Uvalde flows under artesian head.

Las Moras Spring in Brackettville, Kinney Co., is another of the deep artesian circulation springs, and is the largest of several artesian springs which rise in Kinney County. The discharge of Las Moras Spring ranges from 10-30 c.f.s.
Figure 106. Map of the Balcones Fault Zone, Texas, showing locations of springs and caves described in the report.
Two very large artesian springs are located in Val Verde Co. One, San Felipe Spring, located in the town of Del Rio, has an average flow of 76 c.f.s. The other, Devil's River Spring, located on Devil's River, has an average discharge of 418 c.f.s., and is the largest spring of the Balcones Fault Zone area. It is believed that this spring may now be flooded by the Amistad Reservoir.

It should be noted that spring data for this report was taken from U.S.G.S. Water Supply Papers, and that considerable changes in flow could have occurred since the report was published. It should also be pointed out that the present condition of these springs in most cases is not known, and that some of the springs may have been altered in such ways as to destroy their scenic value.

References:


George, Wm. O., et. al., 1952, Geology and ground-water resources of Comal County, Texas: U.S.G.S. Water-Supply Paper 1138.


Other Limestone Springs considered of possible National Landmark Status

The following springs were also considered as possible National Landmark sites, but for various reasons were not considered to be as significant as those already described. Each, in some respect, is unusual. Compared to the springs previously described in detail, these springs are smaller, more commercially utilized, or less scenic springs that may have historical connotations or some degree of local or state wide reknown. The basic reasons why the individual spring was considered significant are listed, as well as references to more detailed information, where available.

Bellevonte Big Spring - Centre Co., Pennsylvania, largest of a group of springs along Spring Creek, historic significance, in central Pennsylvania.

Big Spring - Howard Co., Texas - Geologic significance.


Harrison Spring - Harrison Co., Indiana - historic significance and type locality of the alluviated cave spring.


Huntsville Spring - Madison Co., Alabama - Historic significance to the city of Huntsville. Similar in many respects to Tuscumbia Spring at Tuscumbia in Colbert Co., Alabama.


Troy Spring - Lafayette Co., Florida - scenic spring, popular to divers, historic significance.

Long Caves of the United States

The following list of long caves of the United States was prepared by W. B. White for the Commission on Long Caves of the International Congress of Speleology, and are correct to January, 1970. The list was published in the NSS News, vol. 28, no. 6, June 1970, and included the source for each cave. The sources are not included here. The distances listed may be taken as the accurate surveyed length of each cave. The list includes all reported caves in each state with a surveyed length of over 2km., or approximately 1.2 miles.

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**WEST VIRGINIA**

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STATE PARKS CONTAINING CAVES

ALABAMA:

Monte Sano State Park - one commercial cave, several others.

ARKANSAS:

Buffalo River State Park - Bat Cave, Indian Rock House Cave.
Devil's Den State Park - several caves.
Petit Jean State Park - several small sandstone caves.

CALIFORNIA:

Mitchell Caverns State Park - Tecopa Cave, Mitchell Cave.

FLORIDA:

Florida Caverns State Park - Florida Caverns.

GEORGIA:

Cloudland Canyon State Park - Case Caverns, Setton Cave.

ILLINOIS:

Cave-In-Rock State Park - Cave-In-Rock.
Ferne Clyffe State Park - Two sandstone caves.
Giant City State Park - several caves.
Mattiessen State Park - several caves.
Mississippi Palisades State Park - Bob Upton Cave, Bat Cave, others.
Starved Rock State Park - several sandstone caves.

INDIANA:

Clyfty Falls State Park - Bat Cave.
McCormick's Creek State Park - Wolfe Cave.
Spring Mill State Park - Donaldson Cave, Twin Caves, Bronson Cave, several others.
Wyandotte State Recreation Area - Wyandotte Cave, Little Wyandotte Cave, Saltpeter Cave, several others.

IOWA:

Backbone State Park - several caves.
Maquoketa State Park - thirteen caves.
Pikes Peak State Park - Sand Cave.
Wapsipinicon State Park - several caves.
KENTUCKY:

Carter Caves State Park - Cascades Cave, Saltpeter Cave, several others.

MISSOURI:

Meramec State Park - Fisher Cave, twenty others.
Cuivre State Park - several others.
Rockbridge State Park - Devil's Ice Box, others.

MONTANA:

Lewis and Clark Caverns State Park - Lewis and Clark Caverns.
Medicine Rock State Park - several small wind-carved caves.

NEW YORK:

John Boyd Thatcher State Park - Haile's Cavern.

OHIO:

Hocking Hill State Park - several sandstone caves.
Nelson Ledge-Kennedy State Park - small cave-like tunnels in glacial material.

OKLAHOMA:

Boiling Springs State Park - several caves.
Alabaster Caverns State Park - Alabaster Caverns.
Robber's Cave State Park - Robber's Cave-Sandstone.

OREGON:

Lava River Caves State Park - Lava River Caves.

TENNESSEE:

Cedars of Lebanon State Park - several others.
Pickett State Park -

TEXAS:

Longhorn Caverns State Park
Palo Duro State Park - several small caves in colluvium.

WISCONSIN:

Cave Point State Park - several shelter caves.
Capitalized cave names and major headings in this report, those cave names in capitals and lower case are alternate cave names or other caves that are merely mentioned. Primary page references are listed first, underlined page numbers refer to cave maps.

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