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Discovery in Flint Ridge, 1954 - 1957

By PHILIP M. SMITH

PRESIDENT, The Cave Research Foundation, Inc.

photographs by WILLIAM T. AUSTIN

Flint Ridge is a term well known to many speleologists. The intense investigation of the cavern system that is in the ridge probably has no equal. The work in Flint Ridge is now a major effort of the Cave Research Foundation, an organization formed for the purpose of financing and directing scientific speleological investigations. Philip M. Smith, president of the Foundaton, has been with the Flint Ridge Project since it started. He was a member of the NSS expedition in 1954 and has been on many of the subsequent expeditions. Mr. Smith summarizes the highlights of exploration in the Flint Ridge system since 1954 in this paper.

INTRODUCTION

As members of the Floyd Collins' Crystal Cave Expedition returned through the tortuous labyrinth separating the Lost Passage from the well-developed commercial route, there was no doubt in the minds of many that explorers would soon return. The week-long assault on the Kentucky cave in the Spring of 1954 had revealed several new discoveries (Lawrence and Brucker, 1955) and as in many fields of exploration, the discoveries had raised the curtain on many possibilities for future work. These possibilities could be exploited only by further investigations within the cave.

Five areas were regarded as possessing major potential for further exploration. The Bogardus Waterfall region still had at least six unexplored leads on four levels in spite of intense exploration during the week's assault. A new discovery, The Lost Paradise, had been partially explored. Mud Avenue, possible clue to drainage within Flint Ridge, waited exploration by parties equipped with ropes, waterproof clothing, and rubber boats. Handley's Canyon, less promising because of extensive exploration out of the Expedition's Camp Two, contained a few unexplored crawlways. In the same general area the source of the C-3 Waterfall was yet to be investigated. And a fifth area, not even probed by Expedition personnel, was an unknown passage leading from the Scotchman's Trap; to the right of the Trap was the well-traveled supply route to Floyd's Lost Passage; to the left an unexplored passage headed for the heart of Flint Ridge.

Little did the weary cavers of February 20, 1954, realize that by May, 1957, more than 12,000 additional man hours would have been spent by a comparatively small, highly motivated group in pursuit of Flint Ridge discovery. This group unfolded the major extensions sought by members of the 1954 Expedition. In addition, their discoveries confirmed the hunch of many that Crystal Cave is an integral part of and gateway to a large cave complex beneath the ten square mile Flint Ridge, largest of three cavern filled, connected ridges in Mammoth Cave National Park.

Adventures in one part of the system were recorded by Brucker (1955). A few accounts have appeared in monthly speleological publications but the majority of the discoveries have not been reported. This discussion summarizes recent discovery in Flint Ridge, outlines the magnitude of the project, and attempts to convey some notion of the time expended in the exploration during the period June 1, 1954, to May 15, 1957. Since new discovery is underway as this is written, the narrative will be continued in a later report.

SUMMARY OF EXPLORATION

Review of exploration logs during the writing of *The Caves Beyond* made it evident that accounts of the Bogardus Waterfall area contained discrepancies. Further, they did not seem to correspond with the description of the Waterfall discovery trip by Jim Dyer, Bill Austin, and Bud Bogardus in 1949. Consequently, of all the areas demanding further exploration, first priority was given to the B-Trail – Bogardus Waterfall Trail network. In early June, 1954, a five man party made an 18 hour trip into the Waterfall area. Passages found on the original discovery trip were "re-discovered". Not all had been entered on the week-long expedition. Two exploring teams, working along crawlways that Dyer, Austin, and Bogardus had entered, simultaneously discovered that both crawlways opened into the top of a small pit. Because of its onyx decoration, it was named Black Onyx Pit.

What lay beyond remained a mystery until Thanksgiving, 1954. A combined exploration-survey team of eleven persons pushed beyond Black Onyx Pit. A complex series of dome-pits was discovered. The feature attraction of this network was one exceptionally large dome-pit, seen from a balcony mid-way between the top and bottom. Discovery from this vantage point led to the name Overlook Pit. From the balcony, Bill Austin and the author pushed on through a half mile long walking passage descriptively christened Storm Sewer, to an underground river, the Eyeless Fish Trail. This was followed upstream half a mile.

The Overlook area and Eyeless Fish Trail were not surveyed until February, 1955. In the same month a two man party discovered a short-cut to the Overlook Pit that bypassed a tedious crawlway. Further exploration and survey (Brucker op. cit.) revealed that the downstream end of Eyeless Fish Trail is close to Pike Spring, a resurgence long known as a focal point of Flint Ridge drainage.

Numerous potential leads were opened to exploration by the discovery of the Eyeless Fish Trail. Jack Lehrberger and Bill Austin systematically explored these in early 1955. Passages on a level with the water table were all that were found for sometime, but a climb through a series of domes culminated in the discovery of several extensive passages. One 2.6 mile long passage was named Turner Avenue in honor of Edmund Turner, explorer-geologist in the Kentucky cave area early in this century. Throughout its length Turner Avenue is typical of the large Kentucky cavern passages. High ceilings, floors occasionally covered with fill, sporadic limestone breakdown, and a variety of speleothems are all features of Turner Avenue. An upper level, Upper Turner Avenue, contains unusual gypsum displays (figs. 2, 3).

Still another passage reached via Eyeless Fish Trail is Pohl Avenue. It is also a major cave passage, an estimated 1½ miles in length. Discoveries off Pohl Avenue have led to new dome-pits such as the Pennsylvania Pits, found by members of the Nittany Chapter, and many yet-to-be explored crawlways (fig. 1). Several stream passages have been found in the Pohl Avenue exploration.

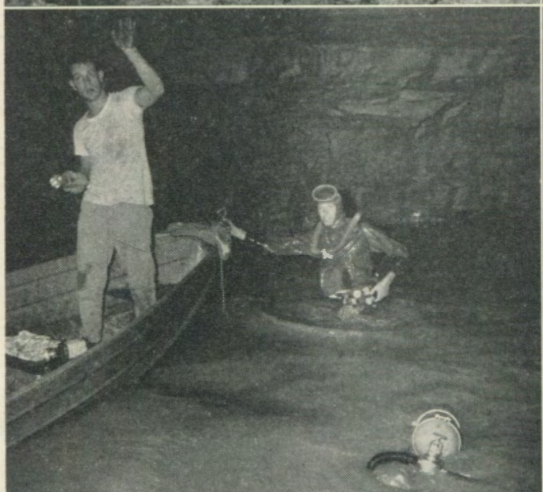
While Lehrberger and Austin were pushing the exploration of Turner Avenue, Central Ohio explorers directed attention to the left of Scotchman's Trap. An exploration reconnaissance there by Lehrberger and others showed that it continued well into Flint Ridge. Three remarkable trips led by Roger Brucker, Red Watson, and Roger McClure were made in June and July, 1955. Three persons participated in the first, six in the second, and eight in the third. The last two were rapid assault expeditions each running 24 hours in length. A seemingly never ending gypsum filled crawl and crouchway of 2 miles led to a canyon and a stream passage. These await exploration by hardy cavers capable of withstanding fatigue imposed by cave far more difficult than the well-known crawlway going the other direction from Scotchman's Trap.

Floyd's Cave, a small cave known to Floyd Collins and one rarely entered in recent times, was re-explored in January, 1956. Burnell Ehman, leader of the trip, and Louise Storts found passages that need further investigation before they can be properly evaluated. Brill Cave, a completely new small cave, was discovered by Donald and Frank Brill in June, 1956, as they were making their first trip with Central Ohio explorers.

The closeness of the downstream end of Eyeless Fish Trail to Pike Spring prompted further investigation in that area. Extensions were found, the chief of which was an angular shaped








Top left: Fig. 1, Typical dome-pit intersecting the 1½-mile-long Upper Turner Avenue. Top right: Fig. 2, Unusual speleothem in Upper Turner Avenue. Center left: Fig. 3, Unusual speleothems in Upper Turner Avenue. Center right. Fig. 4, The diving platform of the entrance to Pike Spring. Clearance visible above water is result of an extensive mining operation directed to opening another cave entrance. Work was carried under a cliff 60 feet. Bottom left: Fig. 5, Divers returning from exploration in newly discovered chamber beyond the end of the blasted passage. Tender in boat mans lines, relays signals to group on platform at entrance to Spring. Bottom right: Fig. 6, Intersection of a phreatic lateral passage and a dome-pit, one of three such intersections in this shaft.

chamber called the Golden Triangle Room. This discovery reduced the known distance between the cave and the surface considerably (fig. 7). A stream flowing through this room was found to contain remnants of a sleeping bag zipper, presumably from the sleeping bag inadvertently dropped into X Pit in 1954.

Two large extensions to Turner Avenue have expanded materially the known cave in Flint Ridge. Ellis Avenue, over a mile long, still contains potential leads even though it has been repeatedly entered. It was first explored in May 1956, by a party including James G. Ellis, member of the 1954 Expedition. A more recent find is Gravel Avenue discovered in early 1957 by Austin and Lehrberger. Sand and gravel fills in this passage are a laboratory for geological research. A new dome-pit complex and several waterfalls have been found. An estimated 2¼ miles has already been explored.

During the three years since the Society's Crystal Cave Expedition some further exploration has taken place in the areas examined at that time. A stream passage at the head of the C-3 Waterfall was penetrated to a siphon. Dome-pit complexes off Mud Avenue reveal still further vertical solution features. Digging in the sand fills of the Flat Room yielded no promise of continuing passage. Similar excavation at the south end of Floyd's Lost Passage indicates this major avenue may continue in proportions comparable to those already discovered.

The above paragraphs may make spectacular discovery seem almost routine. It is not. The extraordinary find continues to be interspersed among many less dramatic but equally important trips into the cave. In the past year, since the Spring of 1956, more than 40 trips have been made. Lehrberger and Austin alone have made 24, averaging twelve to fourteen hours in duration. Seventeen trips have been made by the Central Ohio Chapter. Many have yielded no important discovery except the fact that a suspected lead goes nowhere. Large and small, the discoveries of the past year have resulted in 7.8 miles of new cave.

UNDERWATER EXPLORATION

The exploration of Pike Spring became a logical endeavor as two nearby water courses had been located — Eyeless Fish Trail and the stream flowing from X-Pit to and through the Golden Triangle Room. Neither stream accounted for dyes put in Colossal and Great Salts Caves in 1925 which also had made their way to Pike Spring. It was felt that underwater exploration in the Spring could give entry to other cavern passages and stream systems.

Dr. H. B. Thomas had attempted an investigation a number of years ago. With far less knowledge than available through the recent surveys, he had blasted into the limestone cliff above Pike Spring. No air filled cave was discovered. Dr. Thomas' work did provide, however, a six foot high air filled chamber going back under the cliff sixty feet. Through this opening new efforts could be directed.

The Cincinnati Diving Club was interested in the problem by Flint Ridge explorers. Since August, 1956, the Diving Club has made two diving trips to Pike Spring and spent the winter preparing for further efforts. The project has been directed by Robert Cumming.

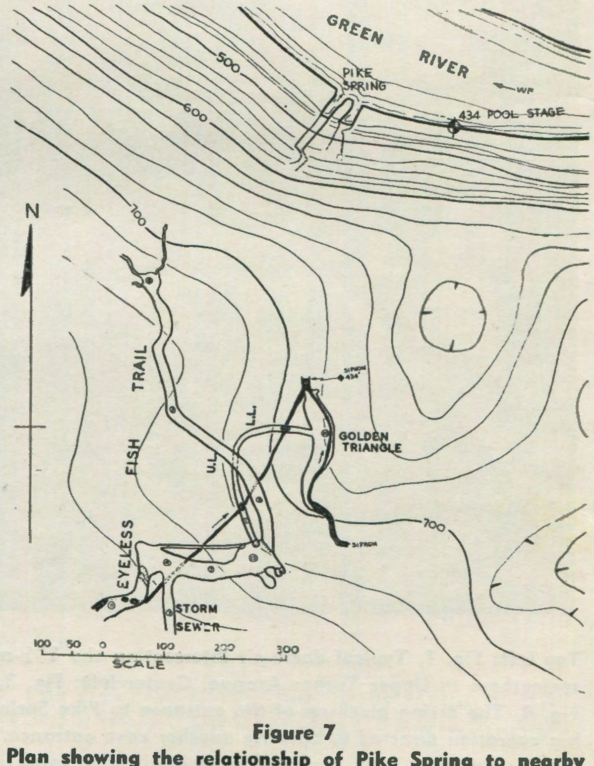


Figure 7
Plan showing the relationship of Pike Spring to nearby cave passages. Topography is superimposed; contour interval is 20 feet. Dotted portions of Pike Spring are underwater surveys.

A preliminary reconnaissance of Pike Spring was made on September 1-2, 1956. To exploit the beach head available through the blasted channel, the divers constructed a wooden raft at the base of the Flint Ridge bluff (fig. 4). The first dives by Bruce Lewis and Dave Roebuck produced no prospects of an accessible underwater passage. Visibility in the muddy water was zero. Repeated dives were made. Each time the groping efforts expanded the knowledge of the water course. Finally, a body-sized fissure through which passage was possible was located (fig. 5.) Exploration had to wait until another weekend.

A five man team, wiser and more experienced as a result of the first effort, returned to Pike Spring on September 29-30, 1956. A push through the small fissure brought the divers into a large water filled chamber, the full dimensions of which are still unknown. There are indications that there may be an air space above the water area.

A second and smaller resurgence of Pike Spring was also entered. It is unlike the main channel in that it shows little evidence of current flow. Guide lines were extended into the passage 90 feet.

New equipment has been under development during the Winter and Spring, 1956-57. A superior underwater compass has been developed, a depth gage constructed and calibrated, and color coded guide lines with concrete anchors prepared. A third assault on Pike Spring is planned in early June, 1957.

Besides being a means of exploring the physical dimensions of stream passages, the diving, as it is refined, will provide a new technique for Flint Ridge study. Underwater fill deposits may be analyzed through the collection of stream bottom samples. Phreatic and vadose solution features may be examined by mapping passage profiles. The silting problem at the base level of the caves in the Mammoth Cave area can be further investigated, perhaps solved, by the diving program.

GEOLOGICAL OBSERVATIONS

Exploration and survey have made possible observations on dome-pits, mechanics of cavern breakdown, cave origin, and the occurrence of unusual speleothems.

Dome-pits continue to be found frequently in the exploration of Flint Ridge. Of all theories advanced concerning the origin of this outstanding cavern feature, the one set forth by Pohl (1955) remains the most plausible. Pohl believes dome-pits are formed by solutional enlargement of vertical cross joints by seeping surface waters. The shafts have developed and are continuing to develop as an integral part of the process of headward and areal advance of surface valleys. In Kentucky, the dome-pits are found at the heads and edges of these valleys surrounding plateau-like ridges capped with the resistant Cypress sandstone.

Cavern surveys laid over surface topographic maps in several recently discovered areas show all pits and domes to be on the edges of the plateau. Size (age) can be correlated with the position of the dome pits relative to the limits of headward advances in encroaching valleys. No causative relationships between the vertical shafts and lateral passages have been noted. Frequent intersection of dome-pits and lateral passages between the tops and bottoms of the shafts are observed throughout the cave (fig. 6). Shaft drainage utilizes lateral passages only where the passages occur at the base level and beneath the actively forming pits.

Bretz (1956) recently re-emphasized another popular theory of vertical solution in which a coring mechanism is the responsible agent. Vadose water flowing through anastomosis patterns well above the water table slowly percolates through joints towards the water table. Channels cut by the flowing waters gradually loosen columnar cores of rock which fall into a cavern passage below. Remains of cores at the bottoms of pits are accepted as evidence in support of the theory. The coring mechanism idea also presupposes an existing lateral drainage somewhere beneath the forming dome-pit.

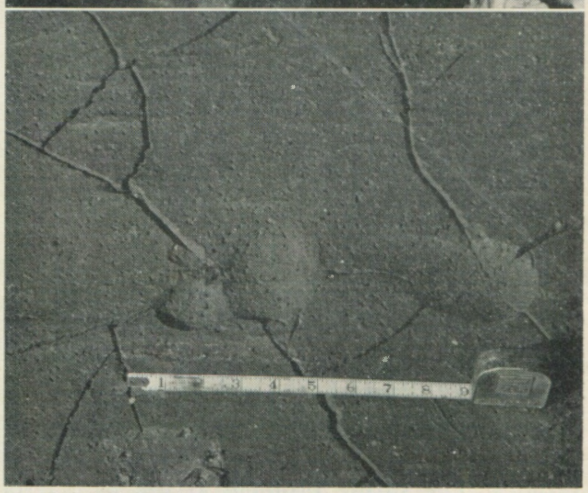
Examination of Flint Ridge dome-pits shows no evidence fitting either of the conditions necessary in the coring mechanism theory. No cores have been located in the 50 to 60 pits examined carefully. It is improbable that, had the cores existed, they would all have been dissolved away. Lateral passages or chambers very seldom occur near the bottoms of pits; the pits extend well below the intersecting lateral passages in most cases.

Breakdown occurs widely in Flint Ridge. Types and causative conditions outlined by Davies (1951) exist. Limestone-sandstone breakdown develops where passages lie close to the surface, especially at the intersection of lateral passages and hillsides. Limestone breakdown develops in low arched passages where a second passage lies close by. Breakdown is frequently found adjacent to the intersection or crossing of large passages.

Block type breakdown has been found, however, where none of the conditions outlined by Davies apply. Examination of the breakdown, cavern ceiling, and walls in such areas suggests an additional cause of limestone breakdown. It is the pressure from developing gypsum and other salts between the surfaces of bedrock joints. Pressure developed by gypsum in joints and along bedding planes is considerable. Ceilings where breakdown has occurred show evidences of this in further gypsum development between joint surfaces of limestone *in situ.* With continued mineral growth, breakdown results. In some cases block breakdown must be accepted as evidence with reservation because of subsequent mineral development on the breakdown. One breakdown, showing signs of comparatively recent geologic origin, supports the theory as the stage of gypsum development on the breakdown is identical to development along joints in blocks that remain attached to the ceiling. Further study of this phenomenon is underway.

The classic, two-cycle phreatic theory of cave origin does not adequately account for lateral solution in Flint Ridge. Likewise, the postulation of red clay fill processes near the end of the phreatic cycle, presumably under quiet phreatic conditions, does not solve problems of origin. An adequate theory of Kentucky cave origin can not be developed until extensive field work is done on the following: levels including controlled vertical surface and cavern surveys; fills as studied by core samplings and stratigraphic correlation; and the shapes of certain cavern passages and related solution features as determined by excavation in filled passages and underwater exploration.

Swinnerton (1932) and Pohl (1936) have made observations that remain pertinent, and, that have been overlooked in some of the more recent speculation about the Kentucky cave area. Swinnerton emphasized the importance of regional base level and the importance of lateral flow in the phreatic zone at or immediately below the water table. His arguments against



Top: Fig. 7, Flint Ridge explorer Jack Lehrberger examing glauberite formation. Bottom: Fig. 8, One of several footprints found on damp fill. Side lighting gives false appearance of raised print.

deep-seated phreatic solution appear valid. Pohl first brought attention to the diverse nature of the fill deposits and the possible relationship between fills and Pleistocene drainage. He also pointed out the possible influence of resistant beds on cavern development, their relationships to hydrostatic pressures, and their special significance in regions of gently dipping beds.

A new theory, a four stage theory of cavern development in the Potomac River drainage basin (Davies, 1957) bears study in its possible extension to the Flint Ridge system. Davies' observations were made in an area little influenced by Pleistocene glaciation. The effect of the Pleistocene epoch on Flint Ridge and the application of the Davies theory to it will have to be evaluated in the future.

The occurrence of unusual speleothems has been noted. Several new mineral occurrences have been located in Flint Ridge. One has been analyzed to date. It is sodium sulphate decahydrate, or glauberite (fig. 8). Study of others is underway and will be reported in a forthcoming *NSS Bulletin* article.

A speleothem complex, unlike any reported prior to its discovery, also has been found. On one column nine feet high and ten feet in diameter, are intermingled flowstone, stalactites and stalagmites, helictites, several forms of gypsum including flowers and hair gypsum, cave grape, and what is believed to be selenite. When the sequence of deposition of material in this speleothem is determined it may shed light on several problems connected with cavern origin in Flint Ridge.

ARCHAEOLOGICAL DISCOVERIES

At the time of the 1954 Expedition burnt reeds, parts of a torch used by Indians, were found in a crawlway near the Devil's Kitchen on the commercial route. Nine inches long, one half inch in diameter, these charred torches were the first archaeological find made in Floyd Collins' Crystal Cave.

The most important archaeological discovery in the Kentucky cave area in two decades occurred as a result of recent exploration. Two sets of human footprints have been found on the damp, clay covered floor of a walking passage (fig. 9). From the alignment of the large toe, it is probable that they are tracks of Indians. Footprints indicate that the Indians traversed the passage in both directions. First reported by Phinizy (1956) they are far from any present entrance to the cave. Such finds demonstrate the speleological changes taking place in modern geologic time for the entrance likely used is now filled with breakdown.

SURVEYING AND TECHNIQUES

Methods of overlay in which the cavern passages are superimposed upon surface topography have continued to be employed in the mapping of the Flint Ridge system (Brucker in Lawrence et al, 1955). Developed shortly after the 1954 Expedition, these techniques provide a maximum amount of accurate information at a comparatively low cost. The overlay permits cavers to view the system three-dimensionally.

Several problems have been encountered. Dimensional instability of photographic reproductions of the surface and cavern surveys has caused some differential print shrinkage. Errors are slight, but must be corrected as the master maps are drawn up. Eventually the technique used will be replaced by a better but more costly process.

The foremost problem has been the rapidity with which the original series of topographic maps was antiquated by an ever expanding cavern network. Additions were made, but the maps became impossibly difficult to index. A new series, now in preparation, is expected to take care of anticipated project growth (fig. 10).

Vertical survey has yet to be made in large portions of the cave. Its absence has not hindered accuracy necessary for studies underway at present.

As stratigraphic correlation, geologic mapping, and detailed studies of individual cavern areas are undertaken, a completely new survey of portions of the cave is being made. Problems of such a survey and tentative solutions will be the subject of a forthcoming paper by William T. Austin.

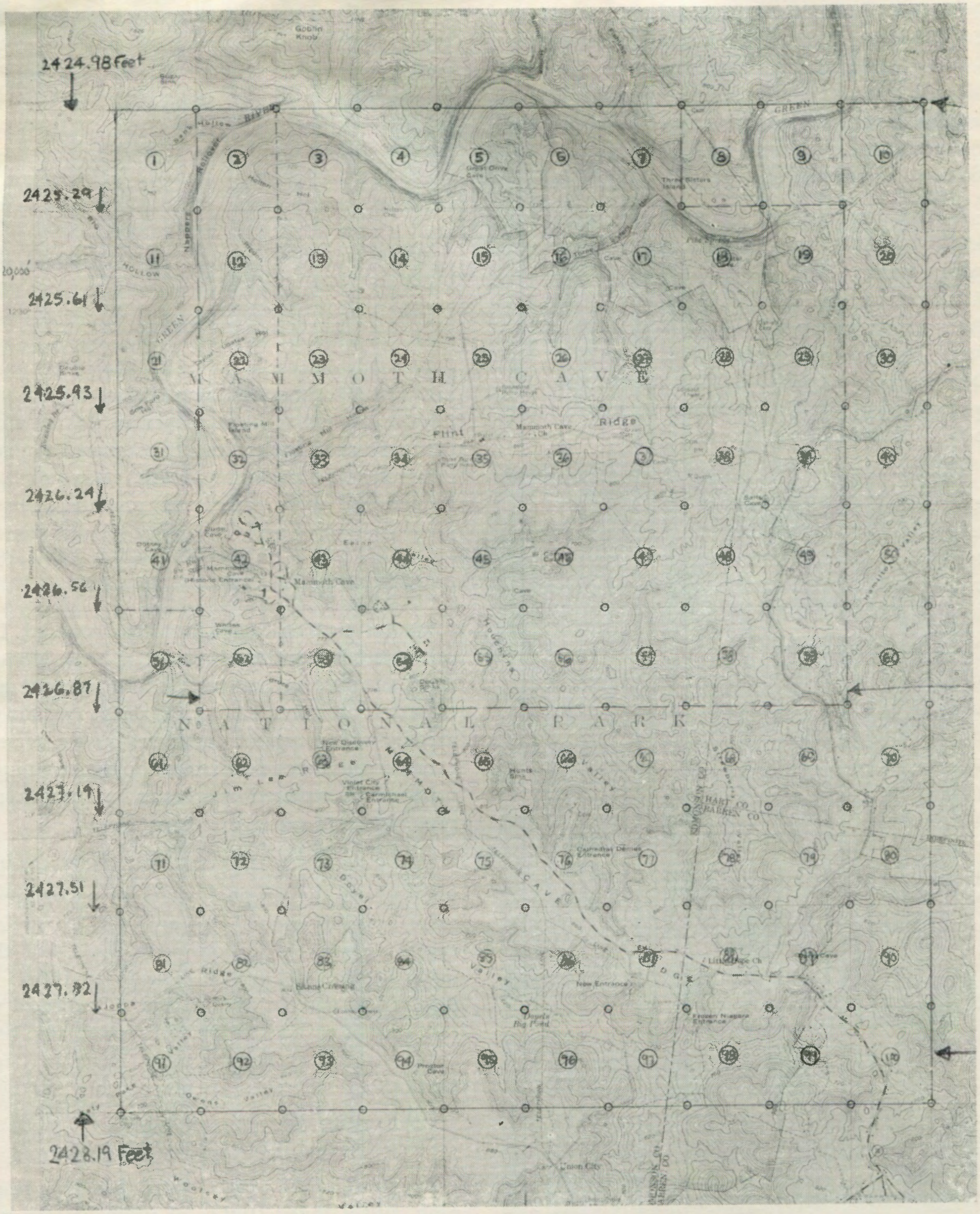


Figure 10. New indexed map series in preparation for the plotting of cavern and terrain features. Scale: 1 inch equals 4800 feet.

LOGISTICS

Rapid expansion of the known cave system has created problems of support far beyond those encountered in normal speleological work. Organization and supply of parties has undergone constant revision as changing needs within the cave have developed. Buildup of personnel and equipment underground, the method of support adopted for the 1954 Expedition, has been found unsuitable for present work. Once exploration was pushed beyond the Overlook area where Camp Pit, a supply depot, was established, the number of supplementary base camps required would have equaled the number of camps necessary for an assault on an 8000 meter peak.

The rapid assault technique and some items of new equipment used in Flint Ridge were described two years ago. (Smith in Lawrence et al, 1955) Techniques have not changed a great deal. Some points of penetration remain beyond the capabilities of rapid assault. The unexplored canyon and stream to the left of Scotchman's Trap is one of these. Rather than establish bases that would supply a two to four man team at the point of departure, it is preferable to train, through motivation and physical conditioning, an assault team capable of the job. It is a simpler method than the base camp approach; parties can be trained for 36-48 hour operation. In Flint Ridge there is no substitute for the excellent physical conditioning of regular caving trips.

Communication continues to be a vital factor in the success of all Flint Ridge work. Improved communication processes, coupled with new technical devices permit better intra-cave and cave-surface communication (Lawrence and Jones in Lawrence et al, 1955). New telephone systems are still under development. Radio tests have been made. The advances will be described by David Jones in a forthcoming *Bulletin* article. A log of all exploration adds a continuity to the project, permits the writing of summary articles such as this.

To avoid the fatiguing travel through five miles of cave before reaching the major unexplored passages, the management of Floyd Collins' Crystal Cave consented to and bore the expense of a new entrance (fig. 11). Digging and blasting took five months. The entrance was completed in June, 1956, and named the Austin Entrance in honor of its constructor. Entry through the Austin Entrance brings one into the spaciousness of Pohl Avenue, named after the cavern geologist and sponsor of the entrance project. From the entrance it is merely minutes to unexplored cave.

Figure 11

Construction activities during digging of the Austin Entrance. The project was a five-month operation consuming 3600 man hours, one ton of dynamite, and five years off Jacque Austin's life.

Housing of surface operations and personnel was facilitated by construction of a bunkhouse and operations center in September, 1956. This building is a permanent headquarters for the numerous trips.

Flint Ridge teams do not hold with the opinion, "The speleologist can usually avoid the difficulties and dangers without neglecting any important item in his study" (Bretz op. cit). The hindrances, dangers, and difficulties frequently require seemingly spectacular devices, rigging, and methods. The cave cannot be considered as studied without a careful examination of even the least accessible portions.

In Flint Ridge there is a dual responsibility of obtaining valid speleological data as well as logistical information on techniques that make possible speleological discoveries. A summary of organizational principles (Smith, 1956) is one such fulfillment of the responsibility. Forthcoming data on communication systems will be another.

FUTURE OUTLOOK

Only as the discoveries of the last three years have been made have the participants and others recognized the project longevity necessary if the investigation is to yield the data anticipated. Discovery to date represents a small yet significant beginning.

During the period described in this paper the Flint Ridge work has been carried out as an official project of the National Speleological Society. In keeping with a decision to expand the facilities, exploration, and scientific program in Flint Ridge, those active in the project have decided to reorganize the study as a non-profit corporation. The corporation, *The Cave Research Foundation*, will explore and scientifically study the cavern system, aid in preserving it as the unique wilderness feature it is, and assist in interpreting the cavern features to the public. The National Speleological Society's publications will be an outlet for the dissemination of much of the Foundation's data.

In the immediate future, the investigation of Pohl Avenue has first priority. Diving in Pike Spring will continue and diving inside the cave may be initiated. Preliminary surveys in geology, hydrology, meteorology, and archaeology will allow the Foundation directors to plan effective research programs in these fields. An increased publication program will make data available more frequently than in the past.

E. A. Martel (1905) speaking before the Eighth International Geographic Congress in Washington, noted the absence of reliable information and complete exploration of the great Kentucky caves. After citing examples of misinformation and absence of data, he outlined a belief that it represented the finest speleological study area available to man. Martel concluded by urging the Congress to recommend to American governmental agencies and geographical associations to include the cave systems within their studies as "objects of accurate and thorough investigation." For years little has been done to fulfill Martel's urgings. It is hoped that the investigations outlined here, and the newly formed foundation to further study Flint Ridge may fill a gap too long existing in American scientific study.

ACKNOWLEDGMENTS

Names of personnel have been employed in the discussion as an aid in clarifying the chronology of exploration; they do not represent all the major contributors to Flint Ridge investigation. The author hereby acknowledges the work of all participants, be they occasional or regular members of the exploration and surveying teams.

Thanks are due to David Huber who helped Roger Brucker with the map of the Pike Spring area, and to Dave Roebuck who reviewed the section on underwater exploration. The whole manuscript has been critically reviewed by Roger Brucker, Flint Ridge Project Leader, 1954-1957.

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Non-Carbonate Deposits of Carlsbad Caverns

By JOHN M. GOOD

Carlsbad Caverns is an attraction to both the tourist and the scientist. In addition to its size it contains numerous speleothems and earth fills that present intriguing problems to the scientist. John M. Good, a member of the National Park Service, was stationed at Carlsbad Caverns for several years before his assignment to Lake Mead and his present assignment at Dinosaur National Monument. During his stay at Carlsbad Mr. Good made detailed examination of the geology of the cavern and had the opportunity of discussing his observations with many visiting scientists. His observations on fills and related features are presented in this paper.

INTRODUCTION

Unlike most cavern systems, Carlsbad Caverns presents evidence of two phreatic cycles and two vadose cycles. During the first phreatic cycle the caverns were formed by solution along joints in the Capitan limestone. The chambers and passageways seen today were formed during this phreatic period which occurred before the Pecos lowland developed. As the lowland formed and the water table dropped in the adjoining Guadalupe Mountains, the first vadose cycle began. Small streams deposited sand and silt in the Big Room.

Later the Pliocene (?) Ogallala formation filled the Pecos lowland and the water table rose to re-establish phreatic conditions in Carlsbad Caverns. It was during this second phreatic cycle that the massive gypsum deposits were formed in the Big Room. When the Pecos drainage was established and the present valley developed, the second vadose cycle began. All the formations seen today are products of this second vadose period.

Although many papers have been written on the origin of limestone caverns, few authors have included much information about the deposits of sand, silt, clay, and gypsum in them. Carlsbad Caverns contains many deposits of this nature. Studies of these cave deposits may well prove to be valuable in reconstructing the physiographic history of the general areas in which caves are found, and will increase present knowledge of the vadose phase of cavern development.

CLASTIC DEPOSITS IN THE BIG ROOM

Most of the sands, silts, and clays occur in isolated deposits on the floor of the Big Room and each is widely separated from the others by masses of gypsum, collapse blocks, and flowstone. A common feature of many deposits is a layer of white sand as the youngest detrital sediment. In some deposits only the younger sand remains and no trace of the older sediments occurs. The thickness of this sand layer varies depending on the topography of the cave floor. Near the Bottomless Pit it is less than one foot thick, but east of the Rock of Ages, where the floor is very irregular, the sand is a few inches to more than four feet thick. In some places along the walls the sand occurs as great half cones whose maximum thickness at the wall may exceed ten feet.

Generally the upper part of the sand is quite pure and friable. The lower is often partially cemented by calcite, silica, or limonite, and may contain clay. Where clay is present in the basal sand, the gradation upward into pure sand is marked by no discernible break in deposition. The amount and mode of occurence of the clay is variable. It may be so concentrated that it forms a matrix through which the sand is evenly disseminated or it may be in the form of pure lumps or flakes. Where in the latter form, the clay has possibly been derived from deposits found elsewhere in the cave. Pure blue-green clay occurs in floor pockets east of the Rock of Ages and as pellets in nearby sands.

Under the binocular microscope the sand is seen to be composed largely of quartz. A very few particles of chert, satinspar gypsum, limonite, and perhaps pyrolusite or psilomelane make up the remainder. The quartz grains are frosted or clear, angular to well-rounded. Many of the clear grains have well developed crystal faces and some contain black inclusions. The well-rounded grains are usually frosted but the great majority of grains, frosted or clear, are quite angular. Some of the fragments are thin and tabular; these are clear. The degree of sorting varies from location to location but the differences are small and everywhere the deposit is a very fine-grained sand.

Perhaps the most striking deposit in the Big Room is the great amount of gypsum. This mineral occurs as large tabular bodies in the west end of the Big Room, and, east of the Rock of Ages, scattered corroded blocks indicate that at one time the deposit was much more extensive. The thickness of the gypsum is extremely variable. Near the Lunchroom are blocks about three feet thick; near the Shrine the deposit reaches a maximum thickness of eighteen feet, and north of the Jumping-Off Place the thickness is estimated to be thirty feet. The gypsum is honeycombed by vertical tubes whose diameters vary from an inch to a foot or more and whose walls are fluted. These tubes are formed by dripping water; their departures from the vertical indicates subsequent movement. Such departures are rare but do occur in blocks around the edges of the central mass. Usually the tubes flare abruptly at the floor and often a mound of flowstone is found therein.

In all exposures that have been examined the gypsum is quite pure. No silt or sand partings were found. Locally it may be brown instead of white but this seems to be a surface stain attributed to bat guano washed into it. Much time was spent trying to find collapse material that could be proved to have fallen during deposition of the gypsum. Only one such ceiling fragment was found. Locally the gypsum blocks are covered by flowstone and stalagmites. Bat guano, too, is found on the gypsum.

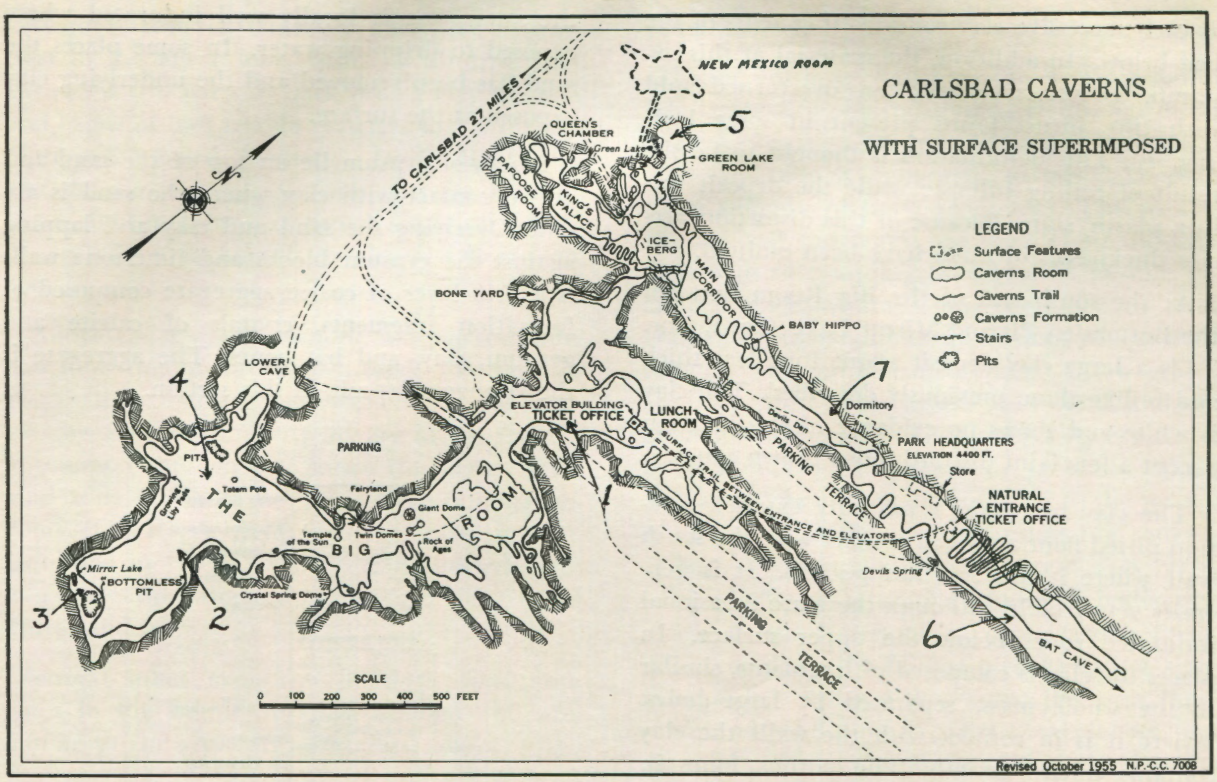
In many wall pockets and side passages of the Big Room gypsum is present as a rind or crust on the walls. This occurrence is also found in the Bottomless Pit. Such gypsum is a flowstone deposit and therefore probably had a different origin than the main mass in the Big Room.

In developing the cavern for public use the earliest trails in the Big Room and elsewhere were surfaced with clay and sand. These materials were obtained from deposits in the cave that generally lay some distance from the trails. It is in these pits that the best exposures of secondary deposits occur as elsewhere they are commonly covered by flowstone, gypsum, and collapse blocks.

One of these pits was formerly beside the trail southwest of the presently used entrance to the Lower Cave (fig. 1, Loc. 1). Recently it was filled with debris during construction of the new elevator shafts. Very little bedrock was exposed in the pit. Overlying the limestone was a white structureless clay of variable texture and thickness. It is composed of plastic fragments with waxy lustre and well indurated saccharoidal zones. These two extremes grade into each other. Where indurated the cement is calcite. It is probable that some of this clay is altered limestone as it can be traced into fresh bedrock at some contacts. In this clay are nodules that disintegrate to powder when touched. These are also found in overlying beds and are thought to be leached limestone pebbles. The white clay is one foot or less in thickness.

Above the white clay is a layer of dark brown and gray clay about six inches thick, which contains some bands of lighter brown clay. The upper thickness of this brown and gray clay is very irregular due to erosion prior to deposition of the overlying silts.

The overlying brick-red, gray, and yellow silts are two feet thick. A cursory examination indicates that these silts are even-textured; however, a sample of the brick-red silt examined under the binocular microscope was found to be composed of sand and silt in alternating layers less than one half inch thick. The silt layers contain a large amount of red clay; the sand layers contain very little clay, but the sandy texture is masked by a clay coating on the individual



Map courtesy National Park Service

Figure 1

Map of Carlsbad Caverns, showing the locations of the described deposits. Numbers refer to localities cited in text.

grains. The sand is composed predominately of quartz but contains minor amounts of gypsum and calcite. It is very fine-grained and most of the individual grains are subangular. A few quartz grains are found in the silt layers but the contacts between the silts and sands are quite sharp. The upper silts are well indurated by calcite and gypsum.

Above these silts are isolated blocks of gypsum. These are pierced by many vertical tubes formed when water falling from the ceiling dissolved and eroded the gypsum away. On sides of the blocks are closely spaced half tubes indicating that these blocks are remains of larger masses.

Another excellent exposure of sediments lies near the trail between the Shrine and the Bottomless Pit (fig. 1, Loc. 2) in a partially excavated clay bank. The oldest material is dark brown clay containing irregular masses of plastic white clay of waxy texture. The dark brown clay grades upward into a zone of predominately light brown clay that contains pink bands near the top. Brick-red silts and sands make up the rest of the exposure. The red sediments contain streaks of brown and maroon colored silts and sands. Here, too, the sands and silts were deposited in thin discrete layers although they seem to contain fair amounts of clay. In the red zone is a thin continuous bed of white friable clay that may have been derived by leaching of a former flowstone floor. The upper layers of the red zone are overlaid by a thin indurated white sand eight inches thick. Limestone and gypsum blocks are scattered on the surface above the fill.

All the sediments in this exposure contain sand grains and leached limestone pebbles. The sand and silt percentages increase upward at the expense of the clay until the beds near the top of the brick-red zone contain very little clay and the white sand layers none at all. Depositional breaks appear to exist between some of the clays as each successive clay contains fragments of the bed below. In addition, the material at this exposure is deformed into an overturned fold with tiny thrust faults present in some beds (fig. 4). This deformation is thought to be the result of ceiling collapse while the deposit was in a plastic state. Because of this distortion precise thicknesses of zones have been omitted.

At the south end of the Big Room between the Bottomless Pit and Mirror Lake (fig. 1, Loc. 3) is a large clay deposit about four feet thick and unlike those previously described. The clay is white and shows no evidence of stratification except a few faint discontinuous brown zones.

The clay lies upon a partially exposed solution pitted floor and is in contact with the south wall where it fills solution pockets. It is generally very friable, although there are occasional indurated zones below the upper surface. In places the clay is composed of fragments, similar to the whole mass, separated by large holes. Where it is in contact with the walls the clay contains calcite crystals. The porous zones in the clay may be places where calcite crystals developed and were later dissolved, leaving molds behind. Irregular sandy zones occur in the clay and a large amount of chert is present in the lower part of the deposit where it occurs as irregular, poorly cemented, flattened lumps that are banded and gray to brown in color. The banding is generally concentric and suggests concretionary origin. The lumps are contained in a horizontal band of unknown extent. The upper surface of the clay is marked by a fairly continuous indurated zone whose top surface is flat but whose lower surface is very irregular. The cement in this zone is calcite and possibly some gypsum or silica.

Above the clay there is generally a layer of friable sand one inch to eight inches in thickness which contains indurated zones. The sand is composed of quartz grains ranging in size from 0.10mm. to an estimated 0.01mm. in diameter. The indurated zones produce some unusual and beautiful pseudomorphs of calcite with silica sand making up the bulk of the material in the crystals. The crystals cleave as do ordinary calcite crystals. These interesting crystals are best developed in indurated zones just above the underlying clay. The upper surface of the sand zone is locally well indurated where exposed to dripping water. In some places the sand has been removed and the underlying clay exposed at the surface.

Blocks of gypsum lie on top of the sand and are in contact with clay where the sand is absent. Overlying the sand and clay and lapping against the gypsum blocks and limestone walls is a thin layer of coarse aggregate composed of formation fragments, crystals of calcite and gypsum, clay, and bat bones. The aggregate is the youngest deposit in this section.

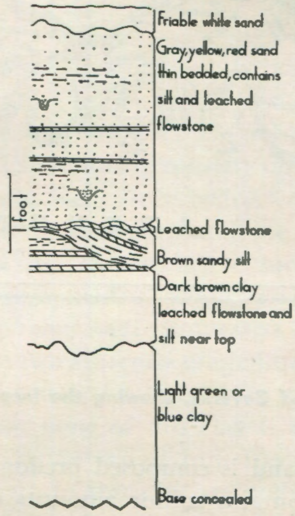


Figure 2

Diagrammatic section of clastic deposits found in the Big Room at Loc. 4.

In the center of the Big Room, midway between the Bottomless Pit and the Jumping-Off Place (fig. 1, Loc. 4), are found the best and largest exposures of clay, sand, and silt (fig. 5). Figure 2 is a diagrammatic profile of this section. The oldest sediment exposed is about two feet of light green or blue clay. This clay is structureless and very pure, containing no silt or sand as is usually found in clays elsewhere. The lower contact of this bed is not exposed; the upper is quite irregular and suggestive of erosion prior to deposition of overlying sediments.

Above the basal green and blue clay is a dark brown clay whose maximum thickness is eighteen inches. The upper part of this clay contains silty zones between bands of pure clay in contrast to the lower zone, which is silt-free. Between the two parts of dark brown clay are several bands of buff friable material that probably represents leached flowstone. Down dip to the east the alternating clays and silts are beveled by an eight inch layer of brown sandy silt which is covered by an undulatory leached flowstone floor.

Above the leached flowstone is a two and one half foot zone of thin-bedded sand. The sand is gray, yellow, and red, well bedded, and contains varying amounts of silt. Evidence of cut-and-fill is common through the entire thickness. This sand zone also contains remnants of flowstone floors. The upper eight inches of sand is well indurated by calcite. Above the indurated sand is a very thin discontinuous layer of friable white sand.

Several other exposures of clays, silts, and sands in the Big Room were studied and are similar to the sequences described above.

CLASTIC DEPOSITS IN THE NEW MEXICO ROOM

The New Mexico Room is difficult to enter. It is reached by climbing through several joint enlarged passageways north of the Green Lake Room (fig. 1, Loc. 5). In several places along the passages the ceiling is of great height and at intervals above the floor the walls meet to form natural bridges. The nature of the floor is generally concealed beneath flowstone and no clastics are seen until the room itself is reached.

The floor of the room is almost entirely covered by collapse blocks. Near the entrance a small part of typical solution floor is exposed. The floor pits and tubes contain a small quantity of sand. A few badly corroded gypsum blocks are present near the center of the room.

The most impressive deposit in the room is the vast quantity of sand along the northeast wall. The deposit does not extend far into the room but is probably a minimum of fifty feet thick along the walls. High upon the north wall are small solution passageways that extend away from the main room. These are commonly choked with sand that is covered in part by a rind of gypsum. No collapse blocks were found in the sand. The sand is generally friable and contains no clay or silt.

In the northeast wall near the floor are found tabular bodies of sandstone that dip north 65 degrees east at angles approximating 33 degrees. The sandstone is light gray to tan depending upon amounts of limonite present. The rock is banded and the bands are parallel to the contacts with surrounding limestone. A sample examined microscopically was composed of sand grains having maximum dimensions of less than 0.20mm. and more than 0.01mm. A few grains are finer. Most of the grains are frosted, and angular to sub-angular. They are poorly cemented by a non-carbonate material, probably silica. The sandstone here is quite similar to the youngest found in the Big Room but does not contain as large a percentage of small grain sizes. It is believed that these tabular sandstone bodies are as old as the limestone in contact with them. They could not be fillings of pre-existing solution pockets because the contact between limestone and sandstone is gradational. These gradational contacts also argue against the deposits being sandstone dikes. Possibly these sandstone bodies are outliers of a more extensive sandstone that was deposited behind the Capitan reef in which the cave was formed and may represent filled channels from which the finer sand fractions were carried by currents into the basin from behind the reef. The steep dip may be due to the slope upon which the sands were deposited or the original dip may have been steepened by diagenetic changes. Most of the sands in the New Mexico Room were probably formed by the weathering, in place, of the sandstones (Moran, 1955).

The southwest wall of the New Mexico Room is undercut and the floor slopes steeply to the southwest. Very little sand is found along this wall.

CLASTIC DEPOSITS OF THE LOWER CAVE

The major part of this section of the cave lies northwest of and 90 feet below the Big Room. Most of the passages are narrow, low, sinuous, and contain little of scenic value. In these passages are found the deposits of a vadose stream.

The vadose stream entered the Lower Cave in a section that underlies the Lunchroom. Originally several vertical passageways were used concurrently as several small corridors in this part of the Lower Cave contain much silt and fine sand in stream deposits. These deposits are not thought to be very thick as projections of the floor rise above the silt surface. The discharge of these small streams coalesced to form a large one flowing south. The stream deposits become progressively thicker downstream until they reach a thickness of more than 20 feet near the Jumping-Off Place. In this general vicinity are collapse blocks partially embedded in the silt and also irregular floor projections where the deposits are thin.

During later stages of stream action the silt and sand deposits were trenched and partially removed by a stream which deposited coarse gravel and cobbles throughout most of its course. These coarse deposits were seen only in one of the passages near the stream head and in none of the small passageways along its course. All the cobbles examined were composed of locally derived limestone and most were well rounded.

Near the head of the stream the passageway is filled almost to the ceiling by a mass of collapse blocks that apparently lies on cobbles and is partially covered by flowstone. Downstream the cobbles are completely covered by flowstone. North of the Jumping-Off Place the silt terraces are locally covered by flowstone which supports several massive columns over 15 feet high.

The original condition of the Lower Cave prior to the establishment of the stream is indicated by the walls and ceiling of the passage where well developed spongework exists. Some small passages above the stream level have floors composed of similar spongework. Many of the anastomosing tubes in the spongework contain dense dark green clay, pellets of which occur in the silts and sands (fig. 6). This clay has been found in widely separated parts of the Lower Cave.

CLASTIC DEPOSITS OF THE BAT CAVE AND MAIN CORRIDOR

Bat Cave is the eastward extension of the Main Corridor. At the extreme east end of the Bat Cave are found remnants of an extensive cave fill more than 23 feet in thickness, as is shown in figure 3.

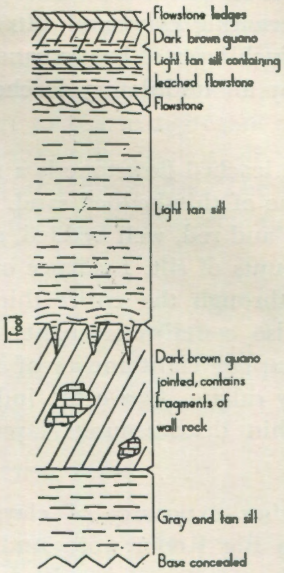
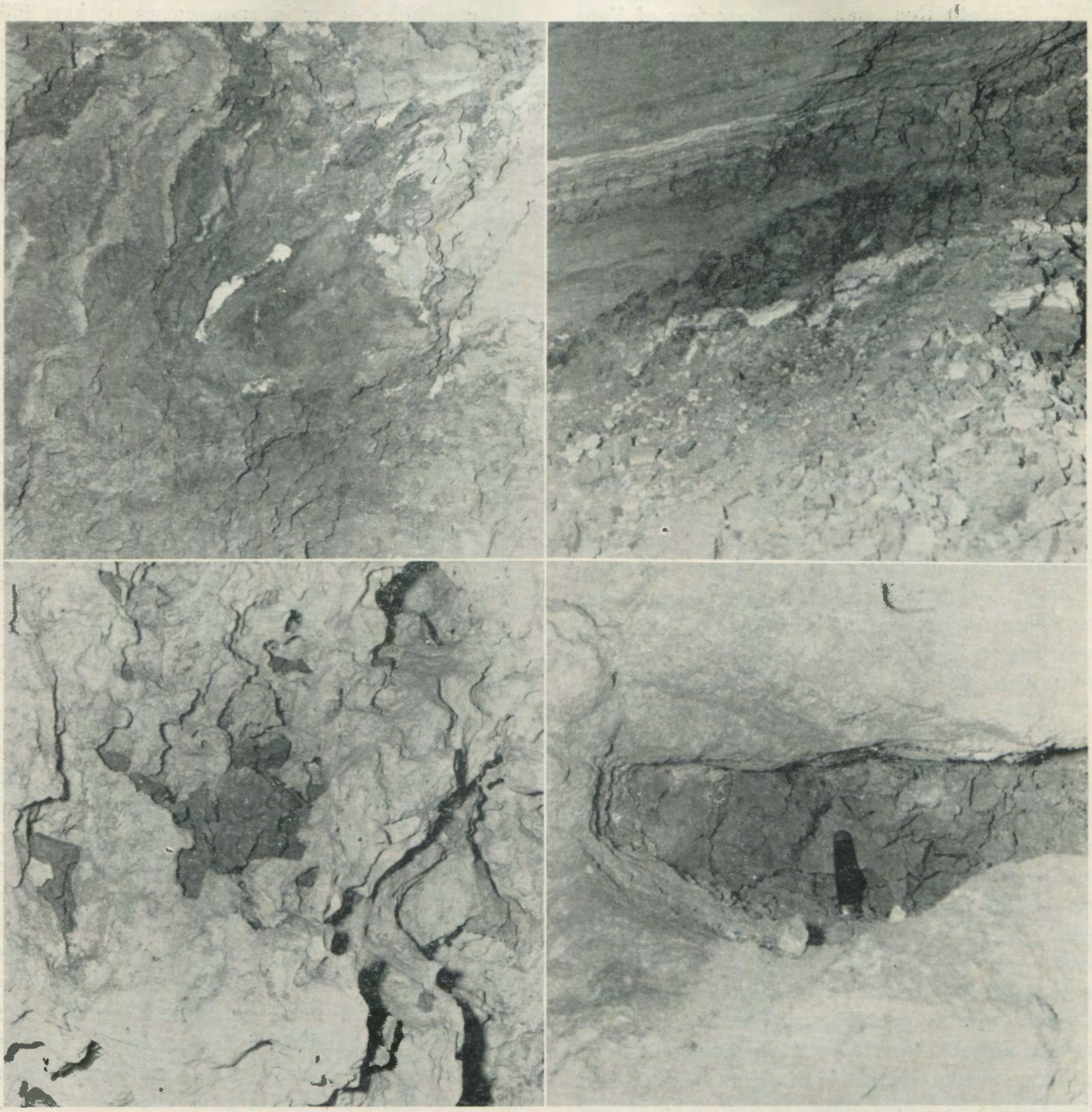


Figure 3

Diagrammatic section of clastic deposits found at extreme east end of Bat Cave.

Ledges of flowstone along the walls lie above the youngest parts of the fill and indicate that the fill was probably covered by a series of flowstone caps that were formerly the floors of the passage. The upper six to eight inches of the fill is composed of dark brown bat guano that contains light colored pellets of clay. The guano is compact and may have been deposited in water. Below the guano are 18 to 20 inches of light tan silt in beds of varied thickness that are separated by leached flowstone floors. The upper contact of the silt is gradational into the guano above. The silt lies upon a six inch leached flowstone floor that can be traced westward to where it is solid flowstone. Beneath the flowstone are nine feet of tan silts. The even bedded character in the upper part of the tan silt is absent in the lower part of the section. Below the silt is a layer of dark brown guano about six feet thick. The upper surface of the guano is jointed and where separation along the joints occurred younger silt filled the fissures. This



Top left: Fig. 4, Deformed silt beds in Big Room, showing intense deformation caused by the fall of ceiling fragments while the silt was still in a plastic state. Top right: Fig. 5, Undisturbed section of clastics in Big Room showing layers, from top to bottom, as follows: thin beds of gray, yellow, and red silty sands; sands; light, undulatory, leached flowstone layers; brown sandy silt that bevels underlying beds; dark brown clay containing silty zones near top and leached flowstone near base of exposed section. Bottom left: Fig. 6, Lower cave, dense, dark green clay in a typical spongework ceiling, thought to be a phreatic clay of the first cycle. Bottom right: Fig. 7, Papoose Room, wall pocket containing green clay of probable phreatic origin.

guano layer also contains large fragments of wall rock. Beneath this guano are four feet of light gray and tan silts. The lower part of the section contains many rounded clay pellets and some sand grains. Milky quartz and purple quartzite are found in the coarse sand fraction of a sample taken from this horizon. The base of this silt zone is not exposed so the total thickness of the clastics is not known.

The entire silt section becomes progressively more sandy to the west, in the direction of the main cavern. Near the east mine shaft the clastics are composed of sand cemented by clay. In the sand are leached limestone pebbles that exhibit a high degree of rounding. As the section becomes sandy it also thins. This thinning is due to the west dip of the topmost flowstone layer, remnants of which are still present. This flowstone, a remnant of a former floor, meets the present floor between the two guano shafts and seems to terminate at a large hole. It could not be definitely determined whether this thinning was due to erosion of the silts prior to deposition of the flowstone or to nondeposition.

No extensive deposits of silt or sand were found between this point and the natural entrance. Some silty clays are present on ledges along the south wall near the entrance but if large deposits are present they lie buried beneath the fallen material that partially fills Bat Cave between the west mine shaft and the entrance.

No rounded stream pebbles are found east of the natural entrance. They are present in a dark brown silt of undetermined thickness just west of the entrance in the Auditorium (fig. 1, Loc. 6). These silts also contain bat and rodent bones in great profusion. The silts can be traced west to the Devil's Den where they are covered by collapse material.

Near the Whale's Mouth the trail transects a flowstone covered deposit of clastics. These clastics are silts and sands with the latter predominating. They are buff, red, and white, and contain pebbles of limestone and sandstone. A small deposit of sandy unstratified clay, resembling those in the Big Room, occurs along the trail just above the Whale's Mouth.

Rust red silts containing well rounded limestone pebbles occur in spongework pockets 400 feet below the surface in the lower Devil's Den (fig. 1, Loc. 7). Some of the pebbles are leached badly but many seem as fresh and unaltered as those found on the surface. In this same location one can go east below trail level to where much collapse material is present. Large and small cobbles found here show sub-rounded surfaces. If this rounding was due to stream action all evidence of the stream has been destroyed save the cobbles themselves.

From the Devil's Den to the scenic rooms the floor at trail level is composed of collapse material, flowstone, and bat guano. No deposits of clay or silt were seen. Both are present, however, in the scenic rooms. Stratified silts form the floor of the King's Palace and are locally covered by flowstone and collapse blocks. The thickness of the silts is in excess of four feet and the upper four feet that is exposed contains no clay zones or flowstone. Green clay is found beneath the flowstone floor and in wall cavities of the Papoose Room (fig. 7). The clay is commonly pure but may contain varying amounts of sand.

Leaving the Lunchroom it is possible to go northeast up a former stream channel floored with pebbles and cobbles to where the channel is lost beneath a mass of collapse. On the far side of this collapse is a passage formed by the overhanging north wall of the Main Corridor and rubble to the south. This passage is parallel to and approximately 300 feet beneath the Devil's Den. A relic channel of a silt depositing stream is found in this passage. Although the passage is trenched there are no gravels present to indicate it is a part of the stream course which extends from the collapse to the Lunchroom. The articulated remains of a ground sloth, *Nothrotherium,* were recovered from the upper part of the silt deposit. These silts are similar to those elsewhere in the cavern. In the north wall, to the east of the silts but on the same level, are anastomosing tubes that have been partially or completely filled with fine grained limestone. This filling is gray-green and banded in places. When present the bands have the same general trend as the line of contact between the wall rock and the tube filling. The limestone in the tubes is softer than the wall rock but it in no way resembles altered flowstone. This type of tube filling has not been seen elsewhere in the cavern; its origin and age are unknown.

GYPSUM DEPOSITS

Bretz (1949, p. 461) recognized the problem of origin presented by the great amount of gypsum in the Big Room and elsewhere in the Cavern. He said that the familiar explanation of the escape of CO_2 does not apply. In fact it does not seem possible that the gypsum could have been deposited under vadose conditions at all. Under vadose conditions the gypsum-bearing waters would have had to be impounded and held for a tremendous length of time for evaporation to form this massive deposit. Even if such conditions prevailed it is probable that the deposition of gypsum would have been interrupted at some time during this long interval and some sand and silt deposited. Examination of many sections of gypsum did not reveal sand or silt. The conclusion then is that the gypsum is a phreatic deposit formed during a second cycle after the cave had been made in the first.

The other evidence for two phreatic cycles in the development of Carlsbad Caverns and others in the area is thoroughly discussed in two papers by Bretz and Horberg (Bretz, 1949, pp. 447-463; Bretz and Horberg, 1949, pp. 477-489).

The probable source of the gypsum was the evaporite beds deposited in the Delaware Basin during Ochoa time near the end of the Permian. Outcrops of gypsum can be seen today in the Pecos valley at an elevation above the floor of the Big Room.

DEPOSITION OF GYPSUM

The change from vadose conditions to the second phreatic cycle must have been caused by a general rise of the watertable that flooded the lower levels of Carlsbad Caverns. This change in the watertable was probably caused by deposition of conglomerate in the Pecos lowland east of the present escarpment. During this period of deposition it seems plausible that shallow saline lakes formed. Under climatic conditions similar to today's these lakes would be warm and therefore capable of holding great amounts of gypsum in solution. If these lakes or their discharge stream developed subsurface drainage, their gypsum-laden waters could have entered the cavern. As the waters cooled they would be forced to deposit some of the gypsum.

The highest level of the water table during this second phreatic cycle is not known, but the deposit of selenite in the Devil's Den indicates that the water level was at least 300 feet above the floor of the Big Room. No massive gypsum deposits have been found above this level.

This second phreatic cycle was terminated when erosion removed the valley fill from the Pecos lowland. The water table sank and the vadose environment was re-established.

In various sections in the cavern gypsum forms a rind on the walls. These deposits are not believed to be of phreatic origin but rather to have been formed by gypsum-bearing waters that evaporated on the walls during the present vadose cycle.

PRE-PLEISTOCENE HISTORY OF THE CAVERNS

The age of Carlsbad Caverns is still not definitely known. Gardner (1935, pp. 1271-72) believed that a period of one million years was more than ample for the development of Carlsbad. King (1948) wrote that the caves of the Guadalupe Mountains were all of Pleistocene age. In contrast to these opinions, Bretz (1949, pp.447-463) concluded that Carlsbad and other caves of the Guadalupe block were formed at a much earlier date, probably before the Pliocene? Ogallala formation was deposited. The age assigned by Bretz seems to be the most logical one because it is not likely that the complex deposits in Carlsbad could have been formed during the present erosion cycle.

The study of deposits in Carlsbad Caverns has also led to some interesting conclusions concerning the origin of the caverns. They have developed along joints parallel to the reef escarpment and cross joints at right angles. The position of the joints suggests some relation to the Permian structural features rather than Cenozoic but the age of the joints is unknown (King, 1948, p. 119).

Phreatic conditions must have prevailed during most of the formative period. Most of the features described by Bretz (1949, p. 720) as being of phreatic origin — ceiling and wall pockets, spongework, continuous rock spans, and joint determined cavities — are found on all levels and in most sections of the cavern system. In addition to phreatic conditions the position of the water table was a very important factor during the formative period.

The Capitan formation is composed of calcitic and dolomitic limestones in beds ranging from fifteen to several hundred feet in thickness. According to King (1948, p. 62) dolomitic limestone is more abundant in the southern Guadalupe Mountains than in the northern part of the range. The bedding planes are indistinct. Caverns developing in such massive rocks could be expected to show little or no development upon separate levels if their formation were controlled primarily by solution activity deep within the phreatic zone. In Carlsbad Caverns this development at separate levels is quite pronounced and the changes in level are abrupt. The unimportance of bedding as a controlling factor in chamber development is seen in the west end of the Big Room. This entire section of the cave, from the Bottomless Pit to the Jumping-Off Place, has been formed in the steeply dipping foreset beds of the Capitan reef and yet there are no changes in floor levels or chamber configuration to mark this sudden change in bedding attitude.

Water table control seems to be the only factor that could account for the levels found in Carlsbad Caverns. The phreatic features of the cavern indicate that the top of the water table must have delineated the upper limit of the active zone. It seems probable that waters containing carbon dioxide gas and various soil acids would percolate down to the water table, there to form a zone of relatively great acidity that would be capable of dissolving limestone and dolomite much more rapidly than the less acidic waters deeper in the phreatic zone. The thickness of the highly acid zone would depend upon the influx of water from the surface but should always be present. Its lower limit would be difficult to determine because of its gradational character.

If the water table did exert the control suggested herein, then the development of levels in Carlsbad should have some correlation with the geomorphic history of the area prior to the present erosion cycle, since Bretz (1949) has shown the cavern system antedates the reef scarp.

There is little evidence in Carlsbad Caverns of a clay filling period before the vadose cycle. Clay deposits have been found but are generally interbedded with other sediments or stratified. Only in the Lower Cave, the Left Hand Tunnel, the Papoose Room, and the Boneyard has the writer seen clay he would consider phreatic in origin. The best exposures are seen in the walls and ceilings of the Lower Cave north of the presently used entrance (fig. 6). Here are found anastomosing tubes, several inches in diameter, that are partially or completely filled with dense, hard, green clay that is much darker than that exposed elsewhere in the caverns. This clay is found in many side passages of the Lower Cave and may well have been deposited in the spongework before the larger passages were developed. The composition of the clay is not known.

The structureless white and blue-green clays of waxy texture that are found in wall pockets and as basal members of clastic deposits in the Big Room may represent remnants of a more extensive cavern fill but this seems unlikely. Some of the white clay can be traced into unaltered limestone. Fragments of the light blue-green clay were examined by Miss Beth Madsen of the United States Geological Survey, who identified them as montmorillonite; this is a mineral not likely to occur in a phreatic cave clay. It seems likely that with the exception of the tube-filling green clay all deposits in the cave were formed during the vadose cycles. Bretz (1949, p. 454) reached the same conclusion on the basis of other data.

These basal clays may have been deposited in isolated pools at various times during the early vadose history of the cave. They may have been extensive at one time, but if so, subsequent stream action reduced them to present proportions.

The silts and sands that unconformably overlie the clays indicate a period of rapidly changing conditions in the Big Room. Varve-like zones of silt and sand succeed each other, each layer containing only minor amounts of the other size. In such a series may be found one or more thin friable layers that are thought to represent buried flowstone floors. Above these remnants of former floors the clastics commonly differ in texture and color from those below. Frequently the deposits become progressively more sandy toward the top. The upper layers are often composed of fine silt-free sand exhibiting cut-and-fill features.

It is the writer's opinion that these deposits record a period in the cavern's vadose history prior to the development of an integrated stream pattern within the cavern. Several small streams may have flowed through parts of the Big Room at different times, reaching the Lower Cave through the many holes in the floor of the Big Room. At intervals when stream action was at a minimum or absent, flowstone floors would form only to be covered by the next period of deposition by an active stream.

The streams in the Big Room may have been contemporaneous with the silt depositing streams in the Left-Hand Tunnel, the Lower Cave, and the section northeast of the Lunchroom, but this is unlikely as these streams were well integrated. Also, the deposits in the Big Room are covered by a blanket of very pure silica sand that is not found elsewhere in the cave.

The origin and mode of deposition of the silica sand is a major problem. It lies on bedrock and isolated deposits of clay and silt. In the latter case it contains fragments of the underlying clays and silts. The sand may be a few inches to several feet thick and along the walls it forms half cones. These half cones indicate that part of the sand filtered into the Big Room through ceiling fissures but how it became so widespread in the Big Room without being deposited elsewhere in the cavern is unknown. Possibly the deposits were not confined to the Big Room but later streams buried or removed them from adjacent rooms.

It is logical to suppose that this sand was derived from the weathering of sandstones found in the adjoining Tansill formation. Samples of the cavern sand are identical to those of the Tansill.

A profound change in the cavern's regimen followed the period of sand deposition and is evidenced by the great masses of gypsum that overlie the sand. The gypsum deposits probably formed under phreatic conditions caused by a rising watertable.

The ages of the clastics and gypsum are unknown and the problem involves many factors beyond the scope of this paper. The ages of the gravels on the Guadalupe Mountains and of those near the present Pecos River have an important bearing on the age of the gypsum deposits in the cave because the phreatic cycle during which they were deposited was initiated when the gravels filled the lowland and raised the watertable in the cave. Bretz and Horberg (1949) present evidence that these gravel deposits, though widely separated and at different elevations, are both part of the Ogallala formation. Philip T. Hayes (1956) has been doing geological mapping in the area for the U. S. Geological Survey and believes the gravels along the Pecos are much younger than those on the Guadalupe Mountains and were probably deposited during the Pleistocene. Thus, the gypsum may have been deposited in Pleistocene or Ogallala time depending upon the physiographic history of the fill in the Pecos lowland.

The writer believes a Pecos lowland existed prior to Ogallala time and that its floor, although probably higher than the valley floor today, was still below the elevation of the Big Room floor. During Ogallala time the lowland was filled and gypsum was deposited in the Big Room. In any event, whatever the age of the gypsum, the method of deposition would probably be the same.

PLEISTOCENE AND RECENT VADOSE HISTORY

Prior to the deposition of silt in the Left-Hand Tunnel, conditions favored the growth of stalagmites. These were later buried and are now exhumed in part where the silts have slumped into floor cavities.

After the period of stalagmite formation a system of silt-depositing streams developed in the passages beneath the Main Corridor and in the Left-Hand Tunnel. In the Lunchroom they seem to have joined and dropped into the Lower Cave 90 feet below. These streams were probably small. They must, however, have existed for a long period of time as the silt deposits are extensive and reach a thickness of more than 16 feet in the Lower Cave.

Later during the vadose cycle the small stream that flowed into the Lunchroom from the northeast received an enormous increase in flow, at least periodically. With increased competency this stream entrenched its silt deposits and deposited within the trench coarse gravel and cobbles of limestone. The entrance used by this cobble-depositing stream is unknown as it is only possible to trace it a short distance northeast of the Lunchroom before it is lost beneath a mass of rubble. Its exit also is uncertain. The writer has traced the stream approximately 2,400 feet in the Lower Cave to a tubular exit that leads downward at a steep angle. This tube can be followed a short distance but there are no cobbles in it. It has been suggested that the increased flow was due to an underground detour of a surface stream, possibly the one in Walnut Canyon, during flood stages (Bretz, 1949, p. 453). This vigorous stream was rather short lived as it did not modify the limestone floor or walls where it was in contact with them. Its termination was caused by blockade of the entrance or erosion of the canyon floor to such a degree that the entrance was above flood levels. After termination of the stream the floor of the cave stream channel was covered with flowstone that supports columns more than fifteen feet high.

It seems strange that although the Ogallala formation was deposited on the surface above the cavern none of the pebbles or cobbles in the cavern stream's bed are quartzite or chert but rather are limestone exclusively. This anomaly is emphasized if the supposition is true that Walnut Canyon predates Ogallala time and must therefore have been completely filled with gravels. This problem resolves itself when it is realized that most of the fragments in the Ogallala are local limestone. This would be the case in a short canyon, particularly when its base level was determined by a gradually filling Pecos lowland. As base level rose the canyon stream would aggrade and the source of pebbles and cobbles would be limestone in Walnut Canyon.

A very puzzling problem is presented by the deposits at the extreme east end of Bat Cave, a description of which has been given previously in this paper. The clastics here must be younger than the Ogallala formation because sand grains of purple quartzite and milky quartz found in the lowest exposed beds are not found in the local country rock and could only have come from the Ogallala. Quartzite pebbles are cemented to the floor and walls of Bat Cave Draw which parallels Bat Cave to the south but this draw terminates about a half mile west of the guano shafts and has a very small drainage basin. To assume the great volume of clastics in the Bat Cave was deposited by floodwaters in Bat Cave Draw would be incorrect unless it could be shown that the draw's drainage was once more extensive than at present. The clastics could have entered the cave from the draw through a rift in the roof of Bat Cave west of the guano shafts. This rift is only a few feet above the floor of the draw and about 75 feet north of it. The writer has been unable to determine whether or not the Bat Cave Draw drainage was instrumental in filling this section of the cavern. If it was not, then the clastics must have been introduced through the main entrance although no evidence remains to support such a thesis.

SUMMARY

Carlsbad Caverns has had a long and varied history of development. Prior to Ogallala time the first phreatic period of the cavern's development had been completed; the cavern configuration and volume were probably quite similar to those of the present day, and vadose streams were depositing sand and silt in the Big Room. As Ogallala deposits filled the Pecos lowland and lapped onto the Guadalupe Mountains, the caverns were inundated and phreatic conditions prevailed once more. During this second phreatic cycle it seems probable that the massive gypsum of the Big Room was deposited. It is believed that the deposition was caused by a decrease in temperature of gypsum-saturated ground water causing those waters to precipitate part of the gypsum in the cave.

When the Ogallala clastics were removed and the Pecos drainage established, the attendant lowering of the watertable was reflected in the cavern by a return to vadose conditions. During this recent vadose cycle part of the Walnut Canyon drainage was diverted into the cave to form the cobble-depositing stream whose course can be traced from the Lunchroom through the Lower Cave. The clastics of the Bat Cave and Main Corridor could have been deposited by runoff in Bat Cave Draw at roughly the same time. These deposits were probably introduced through the present entrance or a rift in the ceiling of Bat Cave. Evidence is lacking as to which entrance was used.

Finally the cavern streams, which at best may have only flowed intermittently, dried up entirely and cavern modification ceased except for the very slow growth of a few formations which continues today.

ACKNOWLEDGMENT

The writer wishes to thank Dr. J Harlen Bretz for the use of his field notes which proved very helpful during the course of this study. Mr. Bennett T. Gale and Mr. Richard G. Prasil of the National Park Service made several valuable suggestions as to content and method of presentation.

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Endellite and Hydromagnesite from Carlsbad Caverns*

By WILLIAM E. DAVIES and GEORGE W. MOORE

George W. Moore and William E. Davies are members of the U. S. Geological Survey. At present Mr. Moore is on leave to do graduate study at Yale University. The hydromagnesite and endellite in Carlsbad Caverns were observed during the study of cavern fills by the authors, a study which it is hoped will contribute to a better understanding of Pleistocene chronology.

During 1956 the writers on two separate occasions had the opportunity of investigating the geologic features of Carlsbad Caverns. Most of the material collected had been previously examined by John M. Good at the time he was stationed at Carlsbad Caverns and is described in his paper that appears elsewhere in this issue of the Bulletin of the National Speleological Society. In the New Mexico Room, however, there were two additional mineral occurrences noted in 1956 that had not been previously recorded: those of hydromagnesite and endellite.

The New Mexico Room is 300 feet north of the route traversed on the public tour and has not been developed for public use (fig. 1). Unlike most of the cave, this room contains considerable water. The speleothems are wet; several pools exist; and flowstone and rimstone are extensive along the north side of the room. The altitude of the New Mexico Room is approximately the same as that of the lower cave. The temperatures is 61°F and relative humidity ranges from 98 to 100%. Along the north side of the room is a mound of clay about 30 feet high which is covered by flowstone and rimstone on the west half and stalagmites and columns on the east half. In this area are several shallow pools of water as much as 10 feet on a side. The remainder of the room contains considerable breakdown and along most of the walls speleothems are common.

*Publication authorized by the Director, U. S. Geological Survey

ENDELLITE

The clay exposed in the bank on the north side of the New Mexico Room is orange red to brown and is damp and slippery in places. Within the bank are several beds of white clay 6 inches to a foot thick These beds are irregular, consisting of nodules of the clay mineral *endellite.* The mineral is similar to the clay mineral halloysite differing only in that endellite [$Al_2Si_2O_5(OH)_4 \cdot 2H_2O$] contains two parts more H_2O that halloysite (Alexander and others, 1943; Bates and others, 1950). The nodules of endellite are 4 to 6 inches in maximum dimension, and on their outer surface there is a layer of black angular quartz grains. These quartz grains are similar to those occurring in other non-carbonate deposits in the cave (Good, op. cit.) and are apparently derived from sand beds in the reef limestone in which the caverns are developed. Their concentration on the surface of the clay nodules is probably a result of percolating waters within the cave fill. Brown and red stains are common on the outer surface and in streaks within the nodules.

In Carlsbad Caverns the endellite looks like tallow. It is white to very light gray, dense, and has a waxy luster. When damp it is very soft. When dry it resembles chalcedony in that it is dull gray, dense, hard, and has a conchoidal fracture. The damp, soft endellite readily disperses in water forming a milky suspension that quickly settles. When immersed in water and rubbed on the hands, endellite feels very much like soap.

Endellite has been described as a secondary mineral occuring in residual soils (Alexander and others, 1943) and as an authigenic hydro-

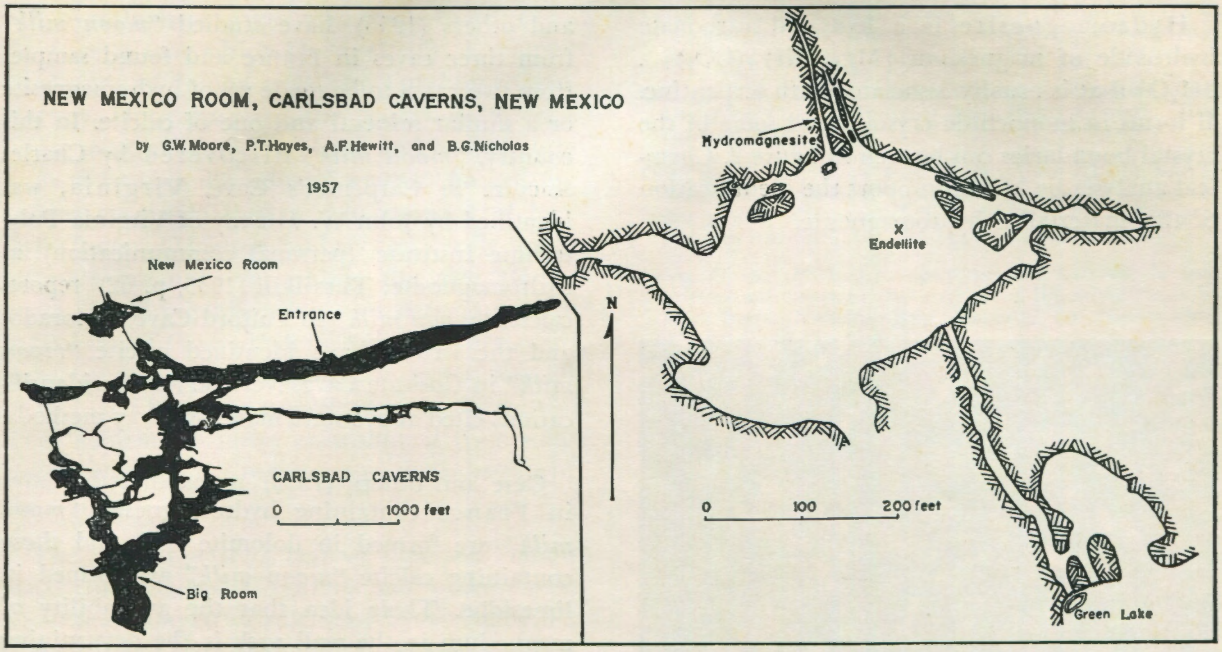

Figure 1

Map of New Mexico Room, Carlsbad Caverns, showing location of Endellite and Hydromagnesite deposits.

thermal mineral associated with other hydrothermal minerals in the Dragon Consolidated Mine near Eureka, Nevada (Schroter and Campbell, 1940). In Indiana endellite in buried soils in Lawrence County has been described by Callaghan (1948) who concluded it was a secondary mineral developed in an ancient residual soil.

In Carlsbad Caverns the mineral is probably secondary in origin but not from a residual soil. The clay in the New Mexico Room is too large in quantity to be ascribed to residual remnants left after the limestone was dissolved. As in most cave fills the clay was probably brought into the cave from surface residuum accumulated in the weathering of the limestone. Under such conditions the endellite was either present in the original residuum and selectively concentrated with respect to other clay minerals or it is a secondary mineral developed in the clay fill after it was deposited in the cave. The later genesis seems the most plausible and it is probable that the endellite is a result of further alteration in the cave of minerals derived from surface residuum.

HYDROMAGNESITE *("Moon Milk")*

Several fissure passages lead from the New Mexico Room. One of these passages, 2 to 4 feet wide, 30 feet high, and more than 100 feet long, extends north from the rimstone pool that lies near the center of the north wall. This passage is profusely decorated with coalesced stalactites along its west wall. On the lower part of the stalactites is a thick coating of damp *"moon milk"*, a white material that resembles cream cheese.

"Moon milk" is soft and plastic when wet but dries to a white powder. It is made up of grains less than 1/200th of an inch in diameter. Determinations by X-ray and optical methods by Charles Milton of the U. S. Geological Survey and Abraham Rosenzweig of the University of New Mexico have shown that the *"moon milk"* in Carlsbad Caverns is composed dominantly of the mineral hydromagnestite, but that traces of calcite are present.

Hydromagnesite is a hydrated carbonate hydroxide of magnesium $[Mg_4(OH)_2(CO_3)_3 \cdot 3H_2O]$ that is usually associated with serpentine. If forms in monoclinic crystals, and some of the crystal boundaries can be seen in figure 2. Chemical analyses by Milton support the identification of this material as hydromagnesite.

Photo by George W. Moore

Figure 2

"Moon milk" composed of the mineral hydromagnesite from Carlsbad Caverns magnified 100 times.

The use of the name *"moon milk"* for material in caves such as that described here originated through an error in translation. The original German term was *Montmilch* (=mountain milk), but it became confused with *Mondmilch* (=moon milk) which has almost the same pronunciation. The error was well established by the beginning of this century (Prinz, 1909) and because *"moon milk"* or *montmilch* is still used in current French and English literature, it is unlikely that the expression will be eliminated. Writers in German, however, now use the word *Bergmilch* (=mountain milk).

Until very recently, it was thought that all *"moon milk"* was composed of calcite ($CaCO_3$) or possibly of a form of calcite containing water known as hydrocalcite ($CaCO_3 \cdot 6H_2O$). Gèze and others (1956) have studied *"moon milk"* from three caves in France and found samples from two caves to be made up of hydromagnesite or a similar mineral and one of calcite. In this country, *"moon milk"* discovered by Charles Kacsure in Carpenter's Cave, Virginia, was identified by John W. Murray of Virginia Polytechnic Institute (personal communication) as hydromagnesite; Thrailkill (1955, p. 62) reports calcite *"moon milk"* in Fulford Cave, Colorado; and the writers have identified calcite *"moon milk"* in Goshute Cave, Nevada. All the identifications cited above were made by X-ray methods.

Gèze and others (1956) noted that the caves in France containing hydromagnesite *"moon milk"* are formed in dolomite rock and those containing calcite *"moon milk"* are formed in limestone. Their idea that the availability of magnesium in the wall rock is the determining factor for hydromagnesite or calcite *"moon milk"* is supported by the present investigation Although the greater part of Carlsbad Caverns are formed in the highly calcitic part of the Capitan limestone, the New Mexico Room is in part of the Capitan that is gradational into the dolomite of the Yates and Seven Rivers formations (P. T. Hayes, personal communication).

Because the grains of calcite *"moon milk"* are elongated along a rhombohedral edge rather than parallel to the crystal axes, the grains have inclined extinction in polarized light rather than parallel extinction which is normal for calcite. This apparent optical anomaly and the fact that moon milk is saturated with water has led some to believe that the material is not actually calcite but hydrocalcite. The observations by Mackenzie (1923) that hydrocalcite began to decompose at 41°F has led Trombe (1943) to propose that *"moon milk"* forms as hydrocalcite at temperature near freezing, and is later converted to a mixture of calcite grains and water as the temperature rises. This method of formation seems unlikely, however, in Goshute Cave, Nevada, where calcite *"moon milk"* is apparently being deposited today at a temperature of approximately 55°F.

A hypothesis of origin that seems to better fit the facts is that which Hoeg (1946) developed after study of *"moon milk"* in Tukthuset Cave, Norway. Hoeg dissolved the *"moon milk"* in a dilute mixture of hydrochloric and hydrofluoric acids to remove the mineral matter. An organic residue then remained which consisted of bacteria, fungus filaments, and an apparently heterotrophic organism resembling the alga *Gloeocapsa.* These organisms live as a natural culture in Tukthuset Cave which provides darkness, constant temperature, and abundant moisture — all factors that favor the growth of microorganisms. They evidentally derive nourishment from solution or through the reduction of the minerals of the wall rock.

The present writers believe that the *"moon milk"* in Carlsbad Caverns and other caves, whether composed of calcite or hydromagnesite, is created as a part of the life processes of microorganisms living in the caves.

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Addenda to the Caverns of West Virginia

Editors Note—Almost a decade has passed since the West Virginia Geological Survey published its report on the caves of that state (Davies, William E. The Caverns of West Virginia: W.Va. Geol. Surv., vol. 19, 1949). During this period a great amount of effort has been expended in exploring West Virginia's caves. From this work has come much new and important data. Davies' statement in the introduction to the West Virginia Geological Survey volume to the effect—"The author is well aware that additional caves will be found; that new passages and chambers will be discovered by those who explore the many side passages and small crawlways leading off those already explored and described; and that pits now blocking further penetration will be conquered and exploration extended further into the unknown."—has been borne out. This is gratifying for at the time the report was published there was widespread feeling among many members of the National Speleological Society that systematic regional surveys would take the zest out of caving as there would be little left for the speleologist to report on. Time has shown that this is not the case. In West Virginia, Pennsylvania, Maryland and other regions where systematic surveys have been published the studies are the foundation for a vast field of additional investigation rather that an end of such work.

The data presented below have been supplied by many speleologists. In some cases the information was gleaned from casual conservations; in other cases it has come from lengthy reports prepared by the those who have visited many West Virginia caves. In the latter group are Earl Thierry, and Benjamin N. Nelson who supplied most of the information. Source for information has been cited at the end of the description of each cave. Where no source is cited credit for the information should go to Earl Thierry and members of the Charleston Grotto, National Speleological Society.

The addenda to the Caverns of West Virginia includes descriptions of new caves (indicated by an asterisk), additions to descriptions that appear in the original report, and corrections to major errors in former descriptions. The caves are located by latitude and longitude scaled from topographic maps; elevations of the entrances are in feet. In addition the name of the U. S. Geological Survey topographic map (quadrangle) is cited for each cave.

BERKELEY COUNTY

Hundred Holes — 39° 30' 55" N, 77-51-55 W, El. 380 — Williamsport Quad.

Along Opequon Creek; 200 yds. S of Isaac Walton Club in small wooded sink; vertical pit, 20 ft. to ledge then 15 ft. steep slope in narrow twisting passage; small twisting crawl 30 ft. to room 15 ft. high. (D. C. Speleograph, Sept. 1952)

GRANT COUNTY

***Kesner Cave** — 38-51-13 N, 79-07-20 W, El. 2325 — Petersburg Quad.

1 mi. N of Deep Spring School in saddle of mountain; ½ mi. NE of a triangular shaped sinkhole. 75 ft. pit, small room at base with passage 200 ft. long, mainly crawlways with dome pits. (Netherworld News, Nov. 1956)

GREENBRIER COUNTY

***Bethel School Cave** — 37-56-19 N, 80-29-09 W, El. 2200 — White Sulphur Springs Quad.

3/8 mi. NE of Bethel School.

Bone Cave — 37-59-45 N, 80-20-08 W, El. 2000 — White Sulphur Springs Quad.

Cave has 3 entrances all in the same quarry. Large numbers of beautiful speleothems.

*Buckeye Creek Cave	37-58-33 N 80-24-03 W El. 1970	White Sulphur Springs Quad.

1/4 mi. W of Old Rapp School, 5 mi. E of Williamsburg. Explored for about 4900 ft.; not completely explored. Main lead follows a live stream, very wet and very dangerous in flood season.

Burnholt Cave	37-47-15 N 80-27-48 W El. 2050	White Sulphur Springs Quad.

Corrected lat. and long. 2000 ft. explored upstream crawling in stream; possible passages on upper level.

*Coffmans Well Cave	37-55-00 N 80-24-50 W El. 2180	White Sulphur Springs Quad.

1.8 mi. W of Frankford across road from Coffman Cave.

*Culverson Creek Cave	37-56-28 N 80-27-10 W El. 2050	White Sulphur Springs Quad.

1/2 mi. W of Unus, 3 mi. SE of Williamsburg. Cave entrance is in a rock bluff 50 ft. high which blocks Culverson Creek Valley on the east. The entrance, 50 ft. wide and 20 ft. high, is blocked almost completely by an enormous interlocked mound of logs and debris. A hole next to the roof lets one drop down behind the debris barrier to a lake about 10 ft. deep, 60 ft. long and 50 ft. wide. Main portion of cave follows the stream draining this lake. 10,800 ft. of passage explored; passages 12-35 ft. wide, 4 ft. or more high; 450 ft. from entrance large mud-floored room to SW; not completely explored. Extremely dangerous at flood season; poles 30 ft. long are lodged high up in the ceiling deep in the cave.

*Erwins Cave	37-42-42 N 80-27-28 W El. 2250	Ronceverte Quad.

1 mi. W of Organ Cave P.O.; connected to Lipps No. 2 Cave.

*Fort Spring Cave No. 1	37-44-17 N 80-32-03 W El. 1925	Alderson Quad.

0.6 mi. SE of Fort Spring above the western tunnel of the C&O RR; brush covered entrance in sinkhole; not explored.

*Fort Spring Cave No. 2	37-43-23 N 80-31-44 W El. 1800	Alderson Quad.

Small cave above Windy Mouth on the south bank of the Greenbrier River, 3/8 mi. E of Windy Mouth.

*Fort Spring Cave No. 3	37-43-24 N 80-31-37 W El. 1800	Alderson Quad.

On south bank of the Greenbrier River, 1/2 mi. E of Windy Mouth Cave.

*Fort Spring Cave No. 4	———	Alderson Quad.

Small entrance near Windy Mouth, 2 mi. S of Fort Spring, 1 mi. E of Perry School; not explored.

*Frog Hollow Cave	———	Clintonville Quad.

On farm of Allen Judy, Raider Valley between Asbury and Alta; stoop entrance to passage 5 ft. wide, 8 ft. high, sloping down at 5% grade; several hundred feet long ending in a pool.

*Fuells Drop Cave	37-58-11 N 80-24-27 W El. 2200	White Sulphur Springs Quad.

4.6 mi. E of Williamsburg, south of Buckeye Creek; 30 ft. drop with a few small crawl leads; completely explored.

*Fuells Fruit Cave	37-56-59 N 80-24-30 W El. 2050	White Sulphur Springs Quad.

4.6 mi. E of Williamsburg and 3/4 mi. W of Old Rapp School. About 1000 ft. of passage going up small stream; completely explored; entrance room is used as a storeroom for canned fruit.

Fuller (Thorny Hollow) Cave	37-56-00 N 80-25-38 W El. 2150	White Sulphur Springs Quad.

Additional 2 mi. of fissure passage, 1-10 ft. wide, 1-100 ft. high explored northwards from north entrance; 3 waterfalls, first 25 ft. high, second 10 ft., third 40 ft. about 1 mi. in; passage beyond falls muddy; 1/2 mi. beyond falls passage blocked by fill and breakdown. (Up Rope, vol. 10, no. 6, July 16, 1953).

*Harrah Cave	37-54-04 N 80-32-34 W El. 2125	Clintonville Quad.

At Hughart, 1/8 mi. SE of the school.

Higginbotham Cave No. 3	37-55-49 N 80-24-36 W El. 2220	White Sulphur Springs Quad.

Corrected lat. and long.; located 1.2 mi. W of Frankford, 0.4 mi. S of road from Unus to Frankford.

*Jarrets Water Cave	37-53-52 N 80-30-46 W El. 2100	Clintonville Quad.

1-1/2 mi. east of Hughart. Explored down a live stream to a pool of water and a possible siphon. 630 ft. of passage, more likely in drought season.

*Johnson Cave	37-42-54 N 80-30-30 W El. 2100	Clintonville Quad.

2.3 mi. SE of Hughart, 0.8 mi. north of U.S. 60 intersection. A small rathole on the east side of the county road; completely explored.

Lewis (Crookshank) Hole	38-04-30 N 80-18-56 W El. 2500	Lobelia Quad.

90 ft. entrance shaft; stream flows in. Recent removal of gravel by stream flushing forms stoopway for 500 ft. to main passage 25 ft. high, 10 ft. wide trending E, 2600 ft. long; logs in passage 30 ft. above floor; several dome pits near entrance. 1100 ft. from entrance side passage trending N 300 ft.; stream flows along this passage to lake at end. Cave extends close to Snedegars Cave (D. C. Speleograph, May 1955)

*Limestone Cliff Cave — 37-52-09 N, 80-24-04 W, El. 2200 — White Sulphur Springs Quad.

1/2 mi. E of Maxwelton at west end of a large sink.

Ludington Cave — 37-53-28 N, 80-23-22 W, El. 2150 — White Sulphur Springs Quad.

Entrance 7 ft. high and 10 ft. wide; steam passage 620 ft. to top of 40 ft. waterfall; explored 2500 ft.; not completely explored.

McClung Cave — 37-52-52 N, 80-23-24 W, El. 2260 — White Sulphur Springs Quad.

Keyhole passage with steeply sloping clay banks extends for 1900 ft. to breakdown beyond which is a passage 20 ft. wide, 25 ft. high for 300 yds.; narrow sewer 1 ft. high, 90 ft. long opens to a large long passage to breakdown; beyond breakdown is a dusty crawl 240 ft. long after which passage enlarges and divides; left branch circles to left to join main cave at end of first breakdown; right branch continues as long silt floored passage ending in a small room; passages progressively lower in ceiling height towards rear. (David Spitler and Netherworld News, Aug. 1957)

*Millers Caves — 37-58-55 N, 80-27-12 W, El. 2250 — White Sulphur Spring Quad.

2.3 mi. SE of Sunlight; two small caves; partly explored.

Organ Cave — 37-43-02 N, 80-26-14 W, El. 2200 — Ronceverte Quad.

450 ft. passage opens from near Rock Organ to surface in a sinkhole; gravel block 150 ft. from exit, bypassed by small fissure. (NSS News, March 1951)

Poor Farm (Greenbrier) Cave No. 2 — 37-57-45 N, 80-27-55 W, El. 2200 — White Sulphur Springs Quad.

1-1/2 mi. SW of Williamsburg, 0.2 mi. S of Poor Farm (Greenbrier) Cave.

*Powells Lid Cave — ——— — White Sulphur Spring Quad.

Near Yorks Cave; 18 ft. drop to sloping floor; bottom filled with debris. (Netherworld News, Nov. 1955)

Spencer Cave — 37-59-04 N, 80-23-18 W, El. 2000 — White Sulphur Springs Quad.

Correct location is on south bank of Spring Creek, 2 mi. W of Renick; entrance 30 ft. wide, 50 ft. high, rectangular in shape; to west of entrance is a passage to west for 100 ft.; ends as crawl over rimstone pools; to east of entrance is small sinuous crawlway high above level of entrance. (Howard Watkins)

*Spur Cave — 37-58-11 N, 80-22-41 W, El. 1900 — White Sulphur Spring Quad.

3 mi. N of Frankford between RR and Spring Creek; in creek bank, very wet, 2 entrances.

Taylors Falls Cave — 37-49-32 N, 80-28-15 W, El. 2000 — White Sulphur Springs Quad.

Corrected lat. and long. Cave is in NW end of sinkhole.

*Wilsons Cave — 37-49-04 N, 80-29-31 W, El. 1950 — White Sulphur Spring Quad.

2.5 mi. W of Lewisburg, 1/8 mi. W of Milligan Creek. Dammed for a hydraulic ram.

*Wilsons No. 2 Cave — 37-48-57 N, 80-29-34 W, El. 1900 — White Sulphur Springs Quad.

2.5 mi. W of Lewisburg, 1/8 mi. W of Milligan Creek. Stream dammed to supply water to a hydraulic ram.

Wind (Windy Mouth) Cave — 37-43-24 N, 80-32-00 W, El. 1750 — Alderson Quad.

Crawl entrance leading toward SW to at least several miles of passage; believed to be second to Organ-Hedricks in length; not completely explored.

*Windmill Cave — 38-00-06 N, 80-27-50 W, El. 2200 — Lobelia Quad.

1.1 mi. south of Trout P.O.

* (No Name) — 37-56-45 N, 80-28-43 W, El. 2250 — White Sulphur Springs Quad.

1.8 mi. south of Williamsburg; partly explored.

*(No Name) — 37-47-27 N, 80-27-40 W, El. 2050 — White Sulphur Spring Quad.

Location: 1 mi. SW of Lewisburg; pit 20 ft. deep; completely explored.

* (No Name) — 37-49-30 N, 80-27-20-W, El. 2000 — White Sulphur Spring Quad.

1.6 mi. N of Lewisburg in E edge of sink; low entrance 3 ft. high, 8 ft. wide, sloping down; not explored.

*(No Name) — 37-49-25 N, 80-28-28 W, El. 2050 — White Sulphur Springs Quad.

2 mi. NW of Lewisburg, 1/4 mi. E of U.S. 60; low stream entrance; not completely explored.

* (No Name) — 37-49-02 N, 80-27-10 W, El. 2200 — White Sulphur Spring Quad.

1 mi. N of Lewisburg; narrow vertical fissure; not explored.

* (No Name) — 37-59-23 N, 80-27-35 W, El. 2100 — White Sulphur Springs Quad.

1/4 mi. N of Sunlight, 2.2 mi. NE of Williamsburg; reported saltpeter cave; not explored.

HARDY COUNTY

Joshua Cave — 38-52-16 N, 79-03-24 W, El. 2100 — Petersburg Quad.

Small cave; numerous muddy crawls. (D. C. Speleograph, Nov. 1951)

JEFFERSON COUNTY

* (No Name) ——— Shepherdstown Quad.

1 mi. SE of Moler Crossroads in quarry; passage 40 ft. long; stream crosses passage. (Bernard Smeltzer)

* (No Name) ——— Keedysville Quad.

1000 ft. NW of cave described above; 2 large sinks; shaft 40 ft. deep in smaller sink; stream at base; crawlway 20 ft. down shaft. (Bernard Smeltzer)

* (No Name) ——— Charlestown Quad.

1-1/2 mi. SE of Moler Crossroads in quarry; passage 35 ft. long; probably a remnant of larger cave; numerous speleothems. (Bernard Smeltzer)

MERCER COUNTY

* (No Name) ——— Bramwell Quad.

Pit near Nemours Cave

MONONGALIA COUNTY

*Maiden Run Caves 39-35-57 N 79-51-34 W El. 1500 Morgantown Quad.

Maiden Run 1200 ft. NE of W. Va. 7; high fissure passage with steeply sloping entrance; passage wet; dripping spring over entrance. Small cave opening in quarry where W. Va. 7 crosses Maiden Run. (Ted Ruhoff)

MONROE COUNTY

*Bear Hole 37-36-27 N 80-32-34 W El. 2050 Alderson Quad.

1 mi. N of Union, 1/2 mi. W of W. Va. 3; sinkhole 45 ft. deep with one small muddy crawl lead at the bottom; completely explored.

*Chambers Cave 37-32-04 N 80-25-00 W El. 2350 Ronceverte Quad.

Entrance at base of cliff on N side of low rise, west end of large sink 1.8 mi. SSW of Gap Mills; entrance 10 ft. wide, 5 ft. high, ceiling lowers to a stoop short way in; after 50 ft. passage opens up & divides; low ceilings and crawls SW to large room 450 ft. from entrance; breakdown, pools, scattered speleothems in room; cave continues upstream to SW for 2000 ft. to breakdown; several large rooms 200 ft. long, 40-50 ft. wide and up to 70 ft. high along passage; a few large speleothems. 400 ft. from entrance is passage to east, 100 ft. long, twisting, crawlway, muddy; room 200 ft. long, 30 ft. wide, 60 ft. high; far end blocked by massive flowstone; small crawl passage in stream for another 250 ft. (Ken Nicholson)

*Cold Hole 37-40-53 N 80-33-32 W El. 2050 Alderson Quad.

1/2 mi. NW of Sinks Grove; small shattered cave; completely explored.

*Deales Hole ——— Alderson Quad.

Possible cave 1/4 mi. S of Crowder's Cave.

*Destitute Cave 37-41-25 N 80-26-20 W El. 2050 Ronceverte Quad.

1/8 mi. S of U. S. 219 and Greenbrier Co. line.

*Dicksons Cave 37-40-38 N 80-27-38 W El. 2050 Ronceverte Quad.

1/2 mi. E of U. S. 219, 1 mi. N of Second Creek Community; 400 ft. of passage; completely explored.

Haynes Cave 37-41-13 N 84-29-00 W El. 2120 Ronceverte Quad.

Corrected location: cave on E side of county road.

Indian Draft Cave 37-34-58 N 80-33-32 W El. 1875 Alderson Quad.

Corrected location: located 0.4 mi. S of Indian Draft School; an upper level leading off the south passage is small, difficult to traverse but is well decorated; ends in small chamber 4 ft. square; south passage ends after a difficult crawl at a crystal lined pool 25 ft. long, 10 ft. wide, 30 ft. high.

Irons Cave 37-37-19 N 80-39-00 W El. 1850 Alderson Quad.

Corrected location: located 1 mi. NW of Johnsons Crossroads.

Laurel Creek Cave 37-33-32 N 80-39-56 W El. 1680 Alderson Quad.

Passage 2000 ft. or more long extends north from upper level 100 ft. west of Theater Room; numerous speleothems, several side passages.

*Maddys Cave 37-33-07 N 80-40-24 W El. 1700 Alderson Quad.

0.7 mi. NE of Greenville; not explored.

*Mitchells Cave 37-34-27 N 80-33-17 W El. 1950 Alderson Quad.

1.2 mi. S of Union on W side of U. S. 219; small cave. (Netherworld News, Nov. 1955)

Mott Hole 37-40-04 N 80-34-50 W El. 2530 Alderson Quad.

Corrected location: 2-1/4 mi. W of Sinks Grove, 1/2 mi. NW of W. Va. 3; vertical entrance shaft 20 ft. in diameter; total depth is 203 ft. with the deepest single vertical drop being the entrance drop of 39 ft.; horizontal stream passage at bottom about 500 ft. long; completely explored.

Pattons Cave 37-32-36 N 80-23-56 W El. 2400 Ronceverte Quad.

Last 1000 ft. of cave is area of extensive breakdown (fig. 1). (W. E. Davies, Ted Schad)

*Steeles Pit ——— Alderson Quad.

Pit in ridge across Burnside Creek from Steeles Cave; now covered up with no entry possible.

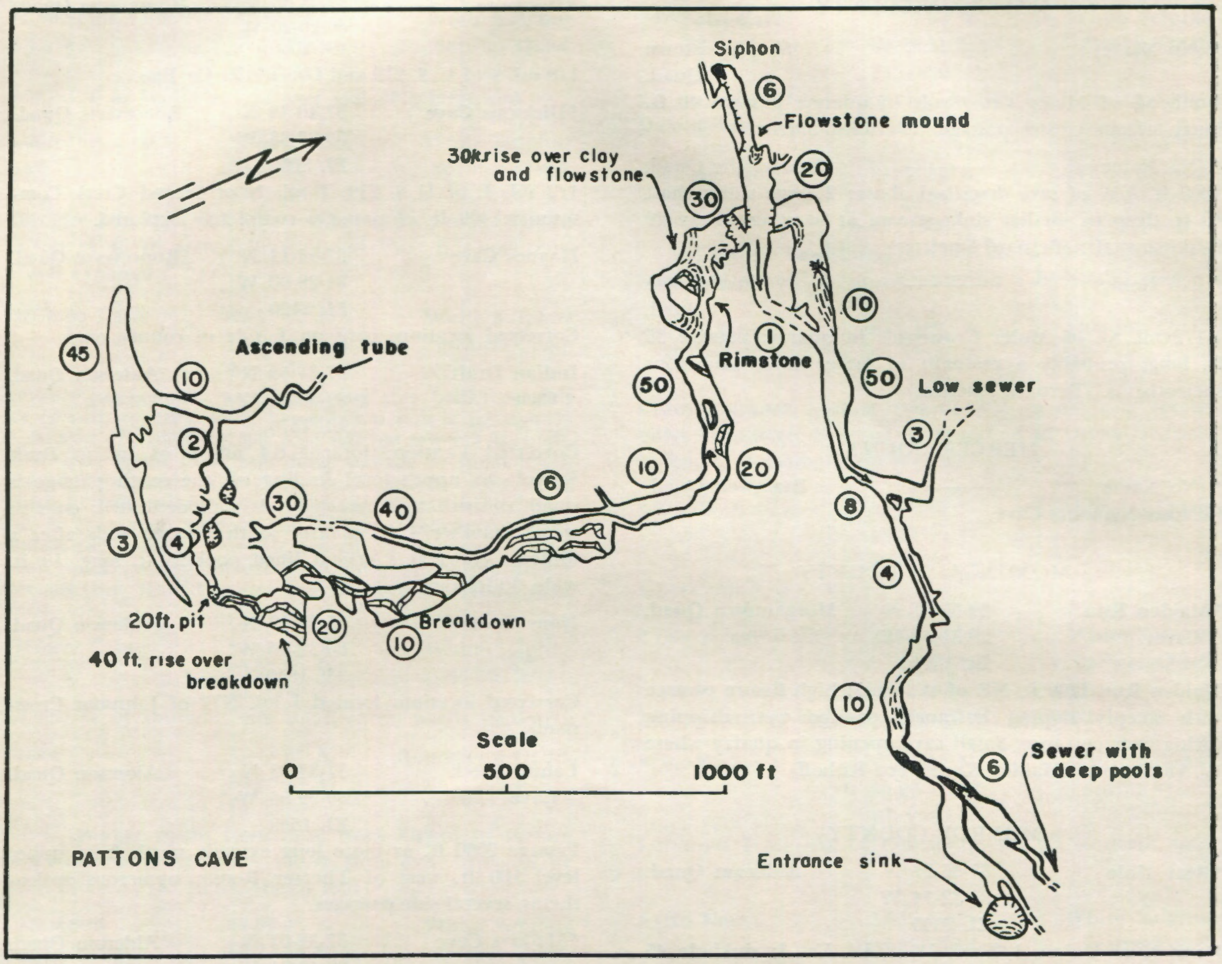

Figure 1

Map of Pattons Cave, from surveys by Ted Schad and William E. Davies, 1951. Encircled figures are ceiling heights.

*Sugar Tree School Cave	37-39-58 N 80-33-55 W El. 2100	Alderson Quad.

1.4 mi. W of Sinks Grove in sinkhole just north of the road; crawlway in mud; completely explored.

*Union Church Cave	———	Alderson Quad.

Small cave about 100 ft. long near Union Presbyterian Church. (Netherworld News, Nov. 1955)

NICHOLAS COUNTY

*Brocks Bridge Caves	38-16-20 N 80-49-08 W El. 1630	Summersville Quad.

W end of Brocks Bridge carrying W. Va. 39 over Gauley River; crawlway, 15 ft. long in limy sandstone; second cave 100 ft. N of E end of bridge; several small rooms and pits. (W. E. Davies)

PENDLETON COUNTY

*Allen Pitzenbargers Cave	38-43-17 N 79-12-34 W El. 2510	Fort Seybert Quad.

1.2 mi. E of Deer Run Community, 0.8 mi. SW of Egypt School; fenced drop entrance in a ring of trees; 60 ft. drop to the middle level then a talus slope 50 ft. W. to edge of a deep pool 5 ft. wide and 18 ft. long; lead on far side of pool, 25 ft. above water; muddy vertical slit down from middle level to stagnant water; completely explored.

*Bobs Mountain Cave	38-35-08 N 79-26-31 W El. 3200	Circleville Quad.

Summit of Bob Mountain, 3/4 mi. S of Mullinax Cave; cave in shape of inverted Y 3 ft. diameter with 10 ft. stem and 12 ft. forks, ending in narrow fissures. (D. C. Speleograph, June 1957)

*Bruce Rectors Drop Cave — 38-35-20 N, 79-20-53 W, El. 2150 — Circleville Quad.

4 mi. SW of Franklin on the W side of Neds Mt.; entrance 3 ft. x 4 ft. in a thick woods on a steep mountainside; pit 30 ft. deep with narrow fissure about 70 ft. deep at base; completely explored.

*Butcher Cave — 38-50-33 N, 79-23-25 W, El. 1800 — Onego Quad.

1/2 mi. N of U. S. 33, 1 mi. W of Mouth of Seneca; entrance 8 ft. above stream, 2 ft. hole opening to shaft 10 ft. diameter, 30 ft. deep; stream passage 12 ft. long at base; SE corner of pit is a passage 3 ft. wide dropping 5 ft. to room 10 ft. long, 5 ft. wide, 20 ft. high. (D. C. Speleograph, Aug.-Sept. 1951)

Cave Mountain Bat Cave — 38-49-35 N, 79-17-02 W, El. 2500 — Onego Quad.

Second cave 200 yds. south and 50 ft. above Cave Mountain Cave; small entry opening into walkway about 1500 ft. in length with several rooms and side passages. (Netherworld News, Nov. 1956)

*Cave Mountain Rat Cave — ——— — Onego Quad.

Near Cave Mountain Cave; single room entered through a very small tubular passage. (Netherworld News, Nov. 1956)

*Coverts Crevice — ——— — Circleville Quad.

3/4 mile from Propst Drop; 15 ft. pit, 2 leads at base; one 115 ft. long; second 20 ft. long to a fissure 90 ft. deep; 25 ft. passage at base of fissure. (D. C. Speleograph, July 1955)

*Deer Lick Pits — 38-35-36 N, 79-20-48 W, El. 2150 — Circleville Quad.

S of Deer Lick Draw, Thorn Run; small entrance to 35 ft. pit; 2nd. pit within 150 ft. of first reported to be a hole 4 ft. in diameter, 250 ft. deep. (W. J. Stephenson)

*Don Down Cave — ——— — Circleville Quad.

In vicinity of Propst Drop; 40 ft. pit, 2 leads at base too small to traverse. (D. C. Speleograph, July 1955)

*Eye Pit — ——— — Circleville Quad.

Sharps Ridge, E side of road, 1 mi. S Dahmer; 65 ft. pit to a broad ledge of rock and breakdown beyond which is a pit more than 30 ft. deep. (D. C. Speleograph, Dec. 1951)

*Flute Cave — 38-34-36 N, 79-21-39 W, El. 2200 — Circleville Quad.

Entrance at lower end of escarpment in which Hoffman School Cave is located, 50 ft. above road; 2 openings, south one a narrow fissure 1-2 ft. wide, 15 high, 100 ft. long, leading west to cave; north one peters out. Cave is a series of pits and domes 20 to 40 ft. deep connected by crawlways and stoopways; total length about 600 feet; cave trends south with several side passages and offsets to east. (H. H. Douglas)

Friends Run Cave — 38-39-06 N, 79-22-15 W, El. 2050 — Circleville Quad.

Located in cliff 75 ft. high; cave 25 ft. above stream; entrance a crawl 50 ft. long to a lead trending east to a pit; west lead contains a flowstone terrace beyond which are several passages and pits. (D. C. Speleograph, April 1951)

George Eye Cave — 38-32-26 N, 79-19-58 W, El. 2700 — Circleville Quad.

Entrance in middle of large field; pit covered with logs; entrance shaft 30 ft. deep; room to SW 100 ft. long, 6-8 ft. high, 10 ft. wide; numerous speleothems; 2 rooms to NE of entrance; first 20 ft. square; second 80 ft. long, 20 ft. wide, 5-25 ft. high, slopes to NE; some speleothems along walls and at end of room. (W. E. Davies)

*Hoffman Cliff Cave — 38-34-38 N, 79-21-49 W, El. 2235 — Circleville Quad.

In limestone cliff about 60 ft. above and 100 ft. east of Hoffman School Cave; vertical slit entrance several ft. wide and 12 ft. high; total length about 75 ft. of narrow vertical fissure passage several ft. wide with jagged walls.

*Hoffman Pit — 38-34-37 N, 79-21-50 W, El. 2295 — Circleville Quad.

150 ft. W and 120 ft. higher on escarpment from Hoffman School Cave; small circular opening 2 ft. diameter, 40 ft. deep; small passage at base which grades into a narrow fissure. (D. C. Speleograph, April 1951)

*Hourglass Cave — 38-45-37 N, 79-23-32 W, El. 2250 — Onego Quad.

3 mi. NE of Riverton; near small cemetery; 20 ft. well drilled and dug into small cavern room; numerous speleothems, some of aragonite. (Netherworld News, Aug. 1957)

*Keys Cave — 38-39-18 N, 79-20-38 W, El. 1850 — Circleville Quad.

On U. S. 33, 1 mi. W of U. S. 220. Entrance is a crawlway 6 ft. long, 8 ft. above creek, goes under road; small maze passages on 3 levels; levels 8-45 ft. apart; passages 2-10 ft. wide; some walkways; a few speleothems in rear part; chert lenses projecting from walls common. 75 ft. pit nearby; Friends Run Cave nearby. (William McCavit)

*Kindergarten Cave — 38-47-07 N, 79-22-43 W, El. 2160 — Onego Quad.

3.5 mi. S of Seneca Rock, 1/4 mi. W of Cave School; 30 ft. shaft; completely explored.

*Marshall Propst Pit — ——— — Circleville Quad.

Near George Eye Cave; steeply sloping pit, 100 ft. deep. (W. J. Stephenson)

Minor Rexrode Cave — 38-33-52 N, 79-21-38 W, El. 2200 — Circleville Quad.

Cave beyond sloping clay covered crevices (chutes) is on a higher level 18 ft. above main cave; upper level is 250 ft. long; first 80 ft. fissure 20 ft. high, 10 ft. wide sloping 45° SW; beyond is a narrow fissure with surface debris extending 100 ft. above floor of adjacent passage; fissure 2-5 ft. wide; several domes on SW side of fissure. (W. E. Davies)

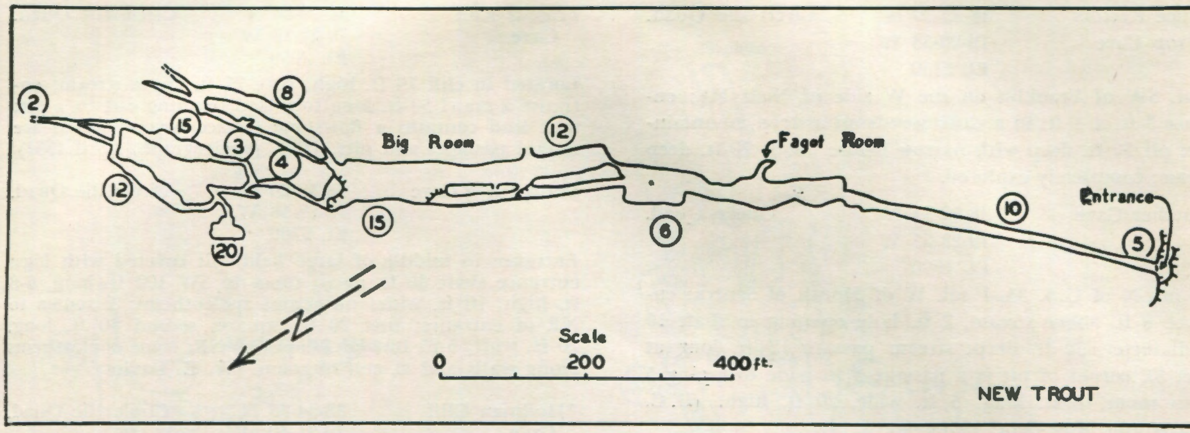

Figure 2

Map of New Trout Cave, from surveys by William J. Stephenson, 1952.

*Mullinax Cave — 38-34-55 N, 79-27-34 W, El. 2950 — Circleville Quad.

5 mi. NW of Cave P.O.; entrance passage 45° chute, 15 ft. long; cave 100 ft. long; 6-25 ft. wide, 10 ft. high; speleothems vandalized by lumbermen. (H. H. Douglas)

*New Trout Cave — 38-36-09 N, 79-22-08 W, El. 1870 — Circleville Quad.

In low escarpment, 300 ft. E of Trout Cave; 60 ft. above U. S. 220. Cave trends N40E; first 600 ft. a straight passage 4 to 15 ft. wide; 5 to 20 ft. high; ceiling along bedding planes dipping 35° to E; 2 rooms 150 ft. long, 50 ft. wide, 15 ft. high and 300 ft. long, 50 ft. wide, 10-25 ft. high 600 and 800 ft. in; few speleothems; walls and ceiling sooty; beyond rooms are two parallel passages 225 ft. long; 4-25 ft. wide; 3-15 ft. high; passages join near end of cave. Saltpeter mined in cave during Civil War; numerous mining implements recovered from cave. Cave developed along 2 joint systems (N4OE vertical to bedding; N4OW vertical) in Coeymans — New Scotland Limestone (fig. 2). (W. E. Davies)

*Propst Drop — ——— — Circleville Quad.

30 ft. pit on property of Oliver Propst above Thorn Creek Valley. (D. C. Speleograph, July 1955)

*Rexrode Drop Cave — 38-35-03 N, 79-23-48 W, El. 2850 — Circleville Quad.

On N side of Sandy Ridge 5-1/2 mi. SW of Franklin. 25 ft. entrance drop to floor slanting 30 degrees down to another 15 ft. drop (dead) and another 20 ft. drop; at bottom of 20 ft. drop a crawlway opens into a drop fissure too narrow for traverse; completely explored.

*Russell Lawrence Cave — ——— — Circleville Quad.

25 ft. pit with three passages; near Riverton School. (D. C. Speleograph, Aug. 1950)

*Simpsons Crawl Cave — 38-37-36 N, 79-15-59 W, El. 2860 — Circleville Quad.

On the E side of Dickinson Mt. 3 mi. S of U. S. 33 and 1/4 mi NE of Simpsons Drop Cave; 40 ft. crawl cave with entrance at the foot of a 10 ft. rock cliff; completely explored.

*Simpsons Drop Cave — 38-37-30 N, 79-16-09 W, El. 2950 — Circleville Quad.

On the E side of Dickinson Mt. 3 mi. S of U. S. 33; 25 ft. drop to a 30 degree slope for about 40 ft. total length; completely explored.

*Sinkhole Hollow Cave — 38-38-40 N, 79-15-05 W, El. 2200 — Circleville Quad.

1 mi. NW of Brandywine on the SE side of Dickinson Mt. and West of Heaverner Run. Entrance a 10 ft. diameter sinkhole with a 31 ft. drop to the top of a pile of debris; 15 ft. slope extends to a large boulder floor; several short 25 ft. crawls and climbs in jumbled boulders in the main entrance sink.

*Siple Caves — 38-44-11 N, 79-12-09 W, El. 2620 — Fort Seybert Quad.

1.8 mi. NE of Deer Run Community, 0.4 mi. N of Egypt School.

Cave No. 1 N10W from Guy Mallow House; drop hole 25 ft. deep.

Cave No. 2 under tree root 80 ft. up hill from Cave No. 1; crawl hole 20 ft. long.

Sites Cave — 38-36-00 N, 79-19-30 W, El. 2250 — Circleville Quad.

1/4 mi. E of Dry Run, 2 mi. N of Dahmer; 298 ft. entrance shaft; lower 90 ft. inclined to west; 300 ft. passage at base to SW and 300 ft. to NE, 5-15 ft. high; 10-40 ft. wide; room at SW end 35 ft. long, 45 ft. high; several high dome pits parallel to entrance shaft; numerous speleothems. (D. C. Speleograph, June 1953)

*Thorn Mountain Pit — 38-31-08 N, 79-22-17 W, El. 2400 — Circleville Quad.

In middle of pasture halfway uphill to Thorn Mountain Cave; entrance 2 ft. diameter, 4-5 ft. drop to steep slope 20 ft. down to dome shaped room 6 ft. high, 12 ft. diameter, 2 passages 40-50 ft. long lead off base of pit. (D. C. Speleograph, April 1952)

*Warren Harper Drop Caves — 38-47-34 N, 79-22-02 W, El. 2200 — Circleville Quad.

North side of the entrance drive to the farm of Warren Harper, 3 mi. S of Seneca Rock and 1 mi. NE of Schoolhouse Cave.

No. 1 143 ft. drop, no passage at bottom; entrance 5 ft. x 8 ft. surounded by rail fence.

No. 2 166 ft. drop, 20 ft. diameter well, no passage at bottom; entrance 2 ft. x 2 ft.

No. 3 25 ft. drop with narrow slit at base; entrance among cedar trees under a log.

No. 4 14 ft. drop, no passage at base.

No. 5 25 ft. drop with horizontal passage south into a dome pit; entrance 1-1/2 ft. x 3 ft. All these caves are completely explored. (D. C. Speleograph, Sept. 1950)

* (No Name) — 38-47-44 N, 79-22-34 W, El. 2050 — Onego Quad.

150 ft. NW of Cowhole Well; shaft 165 ft. straight drop, passage 15 ft. long at base. 100 ft. north of this is another pit, narrow, over 100 ft. deep. (D. C. Speleograph, June 1957)

POCAHONTAS COUNTY

*Allen Cave — ——— — Mingo Quad.

7 miles up Clover Creek from Clover Lick. (W. E. Davies)

*Barnes Pit — 38-12-43 N, 80-09-10 W, El. 2500 — Marlinton Quad.

2 mi. NW of Buckeye on ridge between Overholt Run and Swago Creek; 20 ft. pit with waterfall; dry passage at base trending towards Swago Pit; main passage crawl downstream towards Overholt Blowing Cave. (Netherworld News, June 1957)

*Beveridge Cave — 38-14-13 N, 80-07-51 W, El. 3000 — Marlinton Quad.

W side Dry Creek 2-1/2 mi. N of U. S. 219; 40 ft. passage with 2 rooms. (Ben Nelson)

*Beveridge Dome Pit — 38-14-35 N, 80-07-51 W, El. 3000 — Marlinton Quad.

Fork in Dry Creek, 3 mi. N of U. S. 219; crevice opening to dome 25 ft. high, 25 ft. diameter; dome is fluted. (Ben Nelson)

*Beveridge Hole — 38-14-35 N, 80-07-53 W, El. 3000 — Marlinton Quad.

200 yds. WNW of Beveridge Dome Pit; entrance 30 ft. from road in a shallow sink; 20 ft. passage to small room 7 ft. high; small stream in back part of cave. (Ben Nelson)

*Beveridge Pit — 38-14-10 N, 80-07-53 W, El. 3000 — Marlinton Quad.

700 ft. SSW of Beveridge Cave; 50 ft. pit with waterfall; several passages less than 50 ft. long at base. (Ben Nelson)

*Carpenters Pit — 38-13-01 N, 80-09-10 W, El. 2750 — Marlinton Quad.

2.5 mi. NW of Buckeye; 70 ft. W of Swago Creek Road; 3 level cave, 5,650 ft. long; 250 ft. vertical extent; trends N60E; entrance 90 ft. pit with waterfall; second drop of 30 ft.; stream on lower levels, upper level dry; lowest level 1600 ft. long; second level directly beneath upper level connected by pits; upper level trends S45E for 300 ft.; and S60W for 400 ft.; also N for 250 ft., then N60E for 800 ft.; passage 5-25 ft. wide; connects upstream with Swago Pit. (Ben Nelson)

Cass (Sheet) Cave — 38-23-59 N, 79-56-49 W, El. 2975 — Cass Quad.

1000 ft. W Cold Run School; stoopway trending N for 700 ft. to Big Room 180 ft. high, 900 ft. long, 20-40 ft. wide; dome at end; waterfall 130 ft. high at entrance to room; walkways and crawlways 2500 to east; reverses on lower stream passage trending west for 2500 ft.; Left Hand Passage leaves entrance passage just west of waterfall, trends NNE for 2000 ft. (Huntley Ingalls)

*Cassell Cave — 38-27-24 N, 79-53-48 W, El. 3060 — Cass Quad.

S fork of Trout Run 1000 ft. W of road along flank of Back Allegheny Mtn.; entrance 96 ft. drop; 2 parallel fissure passages at base 1100 ft. long; 3 rooms each about 200 ft. long, 30 ft. wide, 70 ft. high; 60 and 80 ft. pits along passage; small stream in cave; cave trends S65W. (Charleston Grotto)

Cave Creek Cave — 38-12-12 N, 80-08-40 W, El. 2300 — Marlinton Quad.

Breakdown now blocks stream passage 300 ft. from entrance. (Willy White)

*Crossed Fingers Well — 38-12-54 N, 80-09-20 W, El. 2800 — Marlinton Quad.

250 ft. NNE of sink of Tub Cave; small entrance to 15 ft. pit, 2-1/2 ft. diameter, small offset to 4 ft. pit. (Ben Nelson)

*Dry Creek Indian Cave — ——— — Marlinton Quad.

100 yds. N of Beveridge Dome Pit; 37 ft. drop to a steeply sloping passage 60 ft. long. (Ben Nelson)

*Friels Cave — 38-12-28 N, 80-08-10 W, El. 2500 — Marlinton Quad.

Entrance in small sink 1.2 mi. W Dry Creek School, S side Overholt Run Road; sewer passage for 30 ft.; opens to room and 3 passages; main stream passage keyhole shape, with 15 ft. canyon; crawlways and rooms for 150 ft. to room 35 ft. high with waterfall. (Ben Nelson)

*Gay Cave	38-12-40 N 80-07-40 W El. 2550	Marlinton Quad.

Buck Run 3/4 mi. NE of Dry Creek School; upstream passage 15 ft. long; downstream passage to west 120 ft. long. (Ben Nelson)

*Gay Pit	38-12-38 N 80-07-15 W El. 2550	Marlinton Quad.

1800 ft. east of Gay Cave; 40 ft. pit; another 40 ft. pit nearby. (Ben Nelson)

Grimes Cave	38-27-32 N 79-54-01 W El. 2975	Cass Quad.

2000 ft. W of road on flank of Back Allegheny Mtn., on middle fork Trout Run; entrance 40 ft. above stream in cliff 20 ft. high; main passage extends to SW for 800 ft., 4-10 ft. high, 2 to 8 ft. wide; stream; room 160 ft. long, 20 ft. wide; 30-40 ft. high; 2 waterfalls 30 ft. high; cave continues as a water passage beyond waterfalls. Cave developed along joints at N25E and due east. (W. E. Davies)

*Hause No. 1 Cave	38-13-40 N 80-08-06 W El. 2750	Marlinton Quad.

W side Dry Creek 2 mi. N of U. S. 219; 15 ft. drop; 70 ft. passage 15 ft. wide, 25 ft. high with 14 ft. drop along it; 50 ft. side passage near end. (Ben Nelson)

*Hause Pit	38-13-40 N 80-08-10 W El. 3000	Marlinton Quad.

500 ft. N of Hause No. 1 Cave; 85 ft. pit with three interconnected dome pits; no lead at base. (Ben Nelson)

*Hause Waterfall Cave	38-13-37 N 80-08-18 El. 2750	Marlinton Quad.

W fork Dry Creek 2 mi. N of U. S. 219; narrow fissure walkway passages 30 ft. long. (Ben Nelson)

Ice Cave	38-05-35 N 80-17-10 W El. 3200	Lobelia Quad.

Corrected lat. and long. (Haskell McGriff)

*McClintocks Pits	38-11-25 N 80-10-10 W El. 3000	Marlinton Quad.

N fork McClintock Run 2.2 mi. WNW of Buckeye, 3 pits 30-40 ft. deep; one double domed. (Ben Nelson)

*McClintock Wormsway Cave	38-12-12 N 80-09-12 W El. 2300	Marlinton Quad.

0.9 mi. W Dry Creek School; 0.3 mi. N of McClintock Run: pit to fissure passage and crawls 65 ft. long. (Ben Nelson)

*McKeevers Chimney Pit	38-12-54 N 80-08-40 W El. 3000	Marlinton Quad.

SE end of Spruce Flats; fissure cave; no passage at base. (Ben Nelson)

*McKeevers No. 1 Pit	38-13-00 N 80-08-45 W El. 3000	Marlinton Quad.

SE end of Spruce Flats; 90 ft. dome-shaped pit. (Ben Nelson

*McKeevers No. 2 Pit	38-12-58 N 80-08-42 W El. 3000	Marlinton Quad.

SE end of Spruce Flats; 40 ft. dome-shaped pit. (Ben Nelson)

*McKeevers Waterfall Cave	38-13-18 N 80-09-26 W El. 2700	Marlinton Quad.

N fork Swago Creek 1.8 mi. WNW of Dry Creek School; pit with waterfall. (Ben Nelson)

Marthas Cave	38-07-39 N 80-14-45 W El. 2250	Marlinton Quad.

Entrance a low stoopway for 50 ft. to room with breakdown; main passage 20-30 ft. wide and high, trends S60W for 3200 ft. to stream filled passage; small stream through cave; floor bare rock, some silt; several areas of breakdown; several side passages; cave flooded to ceiling at times; logs wedged in ceiling; long passage on upper level. (W. E. Davies)

Overholts Blowing Cave	38-12-22 N 80-08-37 W El. 2400	Marlinton Quad.

Beyond stream crawlway cave trends N as a series of crawlways and large galleries; stream throughout main passage; several side passages; total length in excess of 7500 ft. (Netherworld News, June 1957)

*Overholt Dome Cave	38-12-56 N 80-09-20 W El. 2800	Marlinton Quad.

450 ft. NNE of sink of Tub Cave; 15 ft. dome pit to 45° talus slope 12 ft. long; connects with two interconnected dome pits 30 ft. high; small fissure leads to two other interconnected dome pits. Cave is directly above Tub Cave. (Ben Nelson)

*Ramp Hole	———	Cass Quad.

A fissure cave on center fork of Trout Run, 1/4 mi. W of Grimes Cave.

*Ruckers Jug Pit	38-13-38 N 80-08-12 W El. 2750	Marlinton Quad.

Across stream to east of Hause Waterfall Cave; 35 ft. drop to an 8 ft. dead bottom fissure. (Ben Nelson)

*Rush Run Grotto	38-11-25 N 80-08-35 W El. 2300	Marlinton Quad.

Near Rock House Cave; 25 ft. walkway to a small room. (Ben Nelson)

*Rush Run Pits	38-11-20 N 80-08-40 W El. 2750	Lobelia Quad.

4 pits 8-60 ft. deep in vicinity of Rush Run 2-1/2 mi. S of Lobelia. (Netherworld News, June 1957)

*Schoolberry Cave	38-12-58 N 80-08-24 W El. 2750	Marlinton Quad.

W side Dry Creek 1.2 mi. N Dry Creek School; 20 ft. walkway passage to 20 ft. pit; another 20 ft. pit offset from this; beyond pits on entrance level is fissure passage 35 ft. to 51 ft. dome pit; second pit adjacent; 165 ft. crawlway to a complex of pits and domes; 4 levels in cave; 18 dome pits; total length 630 ft.; cave trends SW; small stream in parts of cave. (Ben Nelson)

Sharps Cave 38-25-02 N Mingo Quad.
80-05-08 W
El. 2900

Main passage continues for 3600 ft.; large amount of breakdown; a few rooms 100 ft. long; 30 ft. high; last 200 - 300 ft. of passage a crawl in breakdown. (D. C. Speleograph, July 1952)

***Swago False Bottom Cave** 38-12-54 N Marlinton Quad.
80-08-38 W
El. 3000

SE end Spruce Flats; pit 58 ft. deep; stream at base drops down narrow fissure. (Ben Nelson)

Swago Horse Cave 38-12-56 N Marlinton Quad.
80-08-26 W
El. 2750

200 ft. S of Schoolberry Cave; 40 ft. walkway. (Ben Nelson)

***Swago Pit** 38-13-02 N Marlinton Quad.
80-08-51 W
El. 2900

2.4 mi. NW of Buckeye on E branch, Swago Creek; 1/2 mi. NE tub Cave; 60 ft. pit with waterfall; 2nd. waterfall drop of 34 ft.; 700 ft. stream passage with several domes and side leads to waterfall; dry passage leads off from top of 3rd. waterfall through 500 ft. of breakdown; passage continues 2000 ft. to gypsum area; ends in breakdown. Connection to Carpenters Pit via passage at base of third waterfall; 2 waterfalls enroute. (Ben Nelson)

***Swago Roadside Pit** 38-13-57 N Marlinton Quad.
80-09-03 W
El. 2800

2 mi. NE Buckeye; entrance small opening in ditch along side Swago Creek Road; 60 ft. entrance drop in shaft 5 x 20 ft.; first 20 ft. narrow fissure; passage at base 5-40 ft. high, 10-20 ft. wide, 500 ft. long trends N65E; 300 ft. from entrance is dome pit complex; room on N side of passage 300 ft. from entrance 120 ft. long, 40 ft. wide, 15 ft. high; speleothems numerous in room and along main passage. (Ben Nelson)

Tub Cave 38-12-50 N Marlinton Quad.
80-09-20 W
El. 2700

Corrected location: cave in sinkhole on saddle between Overholt Run and Swago Creek.

***Tyler Hole** 38-15-10 N Mingo Quad.
80-08-26 W
El. 3000

S end of hollow, 3/4 mi. S West Union School, 4 mi. NW of Marlinton; entrance shaft 15 ft. wide; 15 ft. drop to 45° mud slope; second drop of 25 ft. to talus slope in chamber 25 ft. long, 10 ft. wide, 40 ft. high; small well drops 10 ft. to mud fill. (Netherworld News, Aug. 1957)

Wanless Cave 38-26-22 N Cass Quad.
79-54-49 W
El. 3250

Entrance in sink 40 ft. deep, 100 ft. long, 35 ft. wide, 2050 ft. W of Wanless Church; passage trends S35W for 500 ft.; triangular shaped room 20 x 20 ft. near entrance dome pit 40 ft. high on west; main passage 3-6 ft. high, 2-5 ft. wide. 150 ft. dome at end with rimstone pool at base; considerable breakdown throughout cave. (W. E. Davies)

***Wanless Cave No. 2** 38-26-23 N Cass Quad.
79-54-34 W
El. 3150

1000 ft. ENE of Wanless Cave; 30 ft. pit, crescent-shaped fissure; 2 or 3 passages, one a sinuous stream passage 3 x 3 ft. trending west; second passage has pits and chimneys with stream, 500 ft. long to pinchdown. (Haskell McGriff)

*** (No Name)** 38-27-25 N Cass Quad.
79-54-06 W
El. 3125

4.3 mi. N of Cass on S branch of Trout Run (3/8 mi. W of Cassell Cave) .

PRESTON COUNTY

***Aurora Cave** 39-19-42 N Kingwood Quad.
79-34-10 W
El. 2560

1/2 mi. NW of Aurora; sink collapse opens to steep slope of breakdown in fissure; at base 2 holes 20 ft. diameter 35 ft. deep to 20 ft. diameter room; drop at end of room 30 - 40 ft. to water; loose rock in cave. (NSS News, Nov. 1956)

RANDOLPH COUNTY

Big Run Cave ——— Pickens Quad.

Near head of Big Run, 3-1/2 mi. SE of Valley Head; main passage curving in plan; walkway with stream; passage decreases in size gradually upstream; ends in breakdown. (NSS News, Nov. 1951)

***Massconny Cave** ——— ———

Near Star, SW Randolph Co.; 19 ft. drop to T shaped passage. (NSS News, Oct. 1954)

***Jordan's Drop Cave** 38-58-17 N Onego Quad.
79-26-19 W
El. 2525

2.3 mi. NE of Bonner Mt. School, 1 mi. W of Laneyville. A vertical well 15 ft. in diameter and 60 ft. deep; no horizontal leads; completely explored.

Nelson Cave 38-48-17 N Horton Quad.
79-33-16 W
El. 3155

1030 ft. up farm lane to Little Low Place W of Whitmer; main passage trends S25W, 30 ft. high, 4-10 ft. wide; small room on west of passage 50 ft. in; passage 500 ft. long; stream flows through cave and out entrance. (W. E. Davies)

*** (No Name)** ——— Horton Quad.

Deep vertical shaft due east of and directly across valley from Hazelwood Cave.

TUCKER COUNTY

Big Springs Cave 39-02-42 N 79-40-02 W El. 2450 Parsons Quad.

40 ft. beyond entrance breakdown; 200 ft. in passage divides; left lead stream passage; right lead walkway 1000 ft. to long crawlway and squeeze; open passage for 1000 ft. to room; 5 leads above stream passage; one opens to 45 ft. crawl and 1000 ft. walkway doubling back towards entrance. (D. C. Speleograph, Aug., Dec. 1954)

*Bonner Cave 39-01-26 N 79-34-24 W El. 2380 Parsons Quad.

2 mi. SE of Moore on W side of W. Va. 72; 8x10 ft. sink entrance; 45° slope for 50 ft.; 8 ft. drop down narrow fissure to passage several hundred feet long; breakdown; crawls; side passage crawlway 20 ft. long leads to rimstone pool; 2nd. cave reported nearby. (D. C. Speleograph, Oct. 1953)

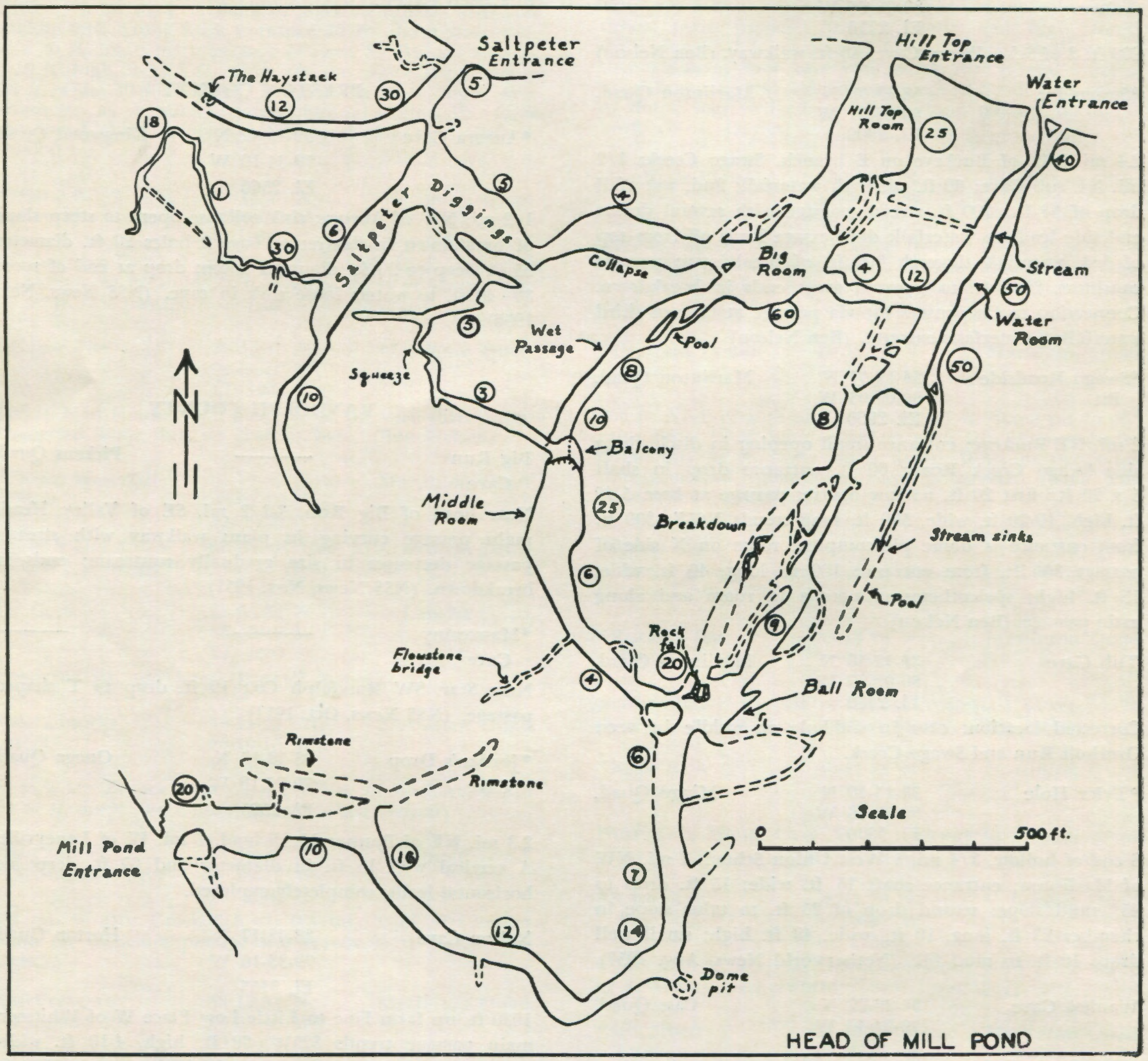

Figure 3

Map of Head of Mill Pond Cave, Greenville, Monroe County, from surveys by the Charleston Grotto, NSS 1948. Cave is described in original edition of Caverns of West Virginia.

Cave Hollow Cave — 39-00-50 N, 79-34-43 W, El. 2400 — Parsons Quad.

S side of hollow, opposite Richford; entrance 12 ft. wide, 8 ft. high; walkway stream passage trending SW; 20 ft. wide, 40 ft. high for 300 ft.; smooth walls, rock floor; wet crawl for 30 ft.; large passage 200 ft. to 20 ft. crawl; large passage extends 2000 ft. to dome pit 75 ft. high, 15 ft. diameter; NE side of dome pit is crawl 10 ft. long opening into passage trending SW; passage divides after 50 ft.; one passage heads SSE for 4000 ft. to Arbegast Cave; 2nd. passage squeeze over breakdown trending S 500 ft. to large room 50 ft. wide, 8 ft. high, 200 ft. long; from S side of room large passage SE for 1000 ft.; east side of room a passage 200 ft. long connects with Arbegast Cave; stream in Arbegast Cave flows N along east passage and then through Cave Hollow Cave. 1600 ft. from entrance to Cave Hollow Cave is small crawlway to NE; opens up after 150 ft. to large passage trending N 1700 ft. to breakdown; small stream along passage; several large passages also open off the east side of the main passage. (NSS News, Jan. 1952)

*Fanchler Cave — ——— — Parsons Quad.

SW end of Backbone Mountain, 1000 ft. above stream, N of Hendricks on Fanchler place; vertical shaft, passage at base. (Felix Robinson)

*Groundhog Cave — ——— — Parsons Quad.

12 mi. SW of Davis; entrance 3 x 4 ft. sloping 8 ft. to room 13 x 20 ft.; short crawlways from room; numerous speleothems. (D. C. Speleograph, Aug. 1954)

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IN PRESS FOR FORTHCOMING ISSUES

Rane L. Curl Statistical theory of cave entrances

William E. Davies Conservation of surface features in karst areas

William R. Halliday An initial survey of caves on the Hawaiian Islands

Huntley Ingalls Cass Cave

David B. Jones Telephone circuits used in Flint Ridge exploration

Raymond G. Knox The land of burnt out fires (Lava Beds National Monument)

Cord H. Link, Jr. Big Room Cave of Payne Cove, Tennessee

Arnold A. Meyers Caves of Yucatan and Guatamala

John W. Murray A peculiar type of cave gypsum

Brian J. O'Brien Caves of Australia

Robert E. Schworm The caves of Kwangsi, a picture story

Frantisek Skrivanek Status of cavern studies in Czechoslovakia

Rillenstein in Northwest Greenland*

By WILLIAM E. DAVIES

Most papers on caverns and related solution phenomena deal with features that are of large size. A discussion of rillenstein, however, focuses on the minute. In itself this "micro-karst" form is of little significance but when integrated with other aspects of solution it is the basis from which the large forms are derived. William E. Davies has spent two field seasons in northern Greenland as part of his work with the U. S. Geological Survey. His observations on rillenstein are a byproduct of these geological explorations.

In geological literature description of the gross features of the terrain predominates to such a point that the detailed features are ignored or only briefly noted. This is true of rillenstein. Only a dozen or so papers (Laudermilk and Woodford, 1932) have been published on the feature even though it is common on many limestone terrains and is particularly notable in semi-arid and arid regions.

The term rillenstein has been used for the small rills, scallops, grooves, and related features that are developed on the surface of exposed limestone (Laudermilk and Woodford, 1932). These features might also be termed "micro-karst". They have been reported to exist on limestones in North Africa, Spitsbergen, Switzerland, Egypt and the southwestern United States. Although most of the reported occurrances are either in hot desert or cold arid areas it should not be concluded that rillenstein is confined to such areas. The author has noted its development on limestone in temperate, humid climates, especially in the Appalachians of the Eastern United States.

During the summer of 1953 the author investigated an extensive area of limestones and dolomites in the vicinity of North Star Bay (formerly Thule) in Northwest Greenland (fig. 1). The dolomites and limestones are a part of a thick sequence of upper Precambrian sedimentary rocks known as the Thule Group. Table 1 is a summary of the stratigraphy of the Thule Group.

*Publication authorized by Director, U. S. Geological Survey.

The Thule Group is exposed from Narssarssuk (12 miles south of North Star Bay) to Inglefield Gulf. The sedimentary rocks occupy a series of broad synclines that are separated by block faults which bring the basement complex to the surface. The Narssarssuk formation is confined to the area between North Star Bay and Narssarssuk, where it underlies a highly dissected plateau. The upland is covered by glacial deposits but outcrops of the formation are numerous in steep walls of the valleys that are cut into the plateau (fig. 2). The sedimentary rocks weather to frost-split slabs and blocks that accumulate as talus on steep slopes or as a veneer a foot or more thick over bedrock on flat surfaces.

The climate of the North Star Bay area is that of the high arctic desert (Fristrup, 1953). Precipitation is low and averages about 2.5 inches a year. Most of it is in the form of snow although a small but significant amount is a result of summer rainfall. Winds are high with speeds of 20 mph common about 10% of the time. Temperatures commonly range from –41° to 40°F; the average is 25° to 35° in the summer months (June to September). Vegetation is sparse and is confined to areas of silty soils that are damp or are covered by standing water. Lichens are common on the basement rocks of the area and often mark much of the exposed rock. On the sedimentary rocks, however, they are relatively scarce and occur in isolated clumps.

Rillenstein is developed on limestone fragments in several other areas of Greenland. On the plateau west of Centrum Sö, Northeast

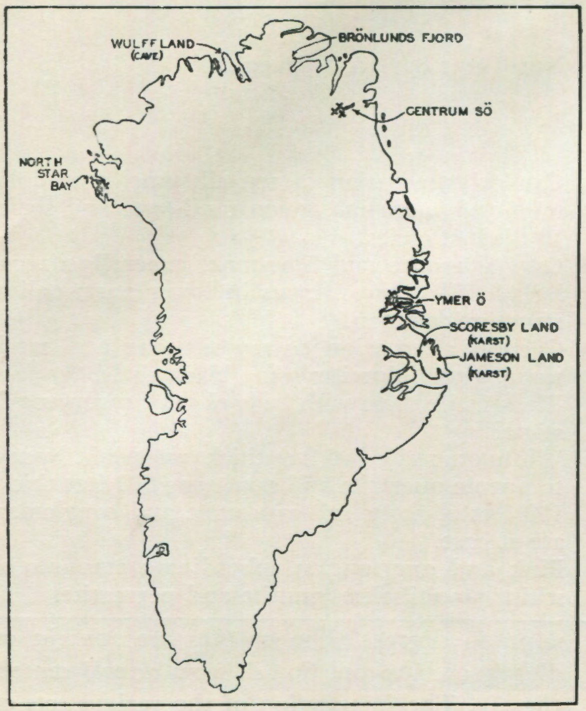


Figure 1

Map of Greenland, showing solution features. Areas of rillenstein shown by X.

Greenland, rillenstein was observed in 1956 to be common on fragments of residual rock debris derived from Silurian limestones. In this area wind erosion is at a minimum on the plateau upland. Rillenstein similar to that around North Star Bay has been pictured and described from the vicinity of Ymer Ö, East Greenland by Bretz (1935, pp. 224-226, 259) and by Flint (1948, pp. 193, 195, 196).

In the area around Brönlunds Fjord limestone and dolomite of the Thule group are present (Troelsen, 1949). In 1956 these rocks were examined by the author for evidence of rillenstein but only a few examples were found. The area is one of intense wind action and in most places wind polish on the rocks obliterated other features.

In the North Star Bay area rillenstein is most extensively developed on the dolomites and limestones of the Arferfik member of the Narssarssuk formation (fig. 2). It is also found on the dolomites in the Upper and Lower Red members of the formation. The dolomite has no subterranean features such as caves, tubes, or other cavities, probably because there has been little or no solution as permafrost in this area extends to a depth of more than a thousand feet.* The active zone above permafrost is less than two feet thick except on valley floors, where it may extend to a depth of several feet in the fine-grained sediments mixed with rock debris. In addition to the areas of bedrock, the cobbles and pebbles of limestone or dolomite that form a significant part of raised beach deposits also show extensive development of rillenstein and solution faceting (Nichols, 1953).

Rillenstein developed on the Arferfik member of the Narssarssuk formation is of two general types, depending on the lithology of the rock. The gypsiferous zones in the lower part of the member have a type of rillenstein that is etched into practically the entire rock surface. The other type, developed on the more massive, purer dolomites and limestones of the middle and upper part of the member, is more uniform and generally follows lines of weakness in the rock leaving some of the original rock surface intact.

In the gypsiferous zone the most common form of rillenstein is one in which the rock is pitted and fretted on all sides to such an extent that is has a rough, cinder-like appearance (fig. 3). This form is developed on slabs and irregular fragments of weathered rock that measure as much as 6 inches on a side. The pits are 1/8 to 1/4 inch in diameter and 1/4 to 1/2 inch deep. The rock that bounds the pits is generally about 1/8 to 1/4 inch wide, is extremely rough, and has jagged edges. On some specimens minute pinnacles, as much as 1/8 inch high, are developed where several pits abut. On many specimens the pitting has developed a series of anas-

*Karst features are seldom encountered in polar areas. A sinkhole terrain has been reported by Stauber (1940) to exist on a narrow, terrace-like lowland along the west side of Schuchert Flod (River) near its mouth in the southeastern part of Scoresby Land, East Greenland. The karst is in Permian reef limestone. Subterranean drainage occurs in Triassic marls or gypsum along the east side of a large valley a few miles south of the head of Carlsberg Fjord in Jameson Land, East Greenland. In 1956 the author observed a cave several hundred feet long with an entrance about 50 feet in diameter in limestone in the central part of Wulff Land, Northwest Greenland.

Table 1

Stratigraphic column, Thule Group, North Star Bay area, Greenland

Stratigraphic units	*Thickness*	*Character*
Top		
Narssarssuk formation		
Upper Red member	1500 feet	Cyclical alternation of red siltstone, gray dolomite and limestone, green sandstone and shale. 10 distinct cycles.
Arferfik member	400	Gray dolomite and limestone, generally irregularly bedded; gypsiferous in lower part; oolitic structure common.
Lower Red member	1500	Cyclical alternation of red siltstone and sandstone, gray dolomite; some black shale.
Dundas formation	2600	Black fissile shale with beds of gray, sugary sandstone.
Wolstenholme formation	1600	White quartzite 700 feet thick, underlain by red to purple quartzite and sandstone 800 feet thick. 100 feet of shale, soft sandstone and conglomerate at base.
Basement complex		Pink and gray gneiss; subordinate amounts of schist, amphibolite, granite and pegmatite.

tomosing grooves and ridges that resemble solution-morel sculpturing (Scott, 1947). This form occurs only in the gypsiferous dolomite and its extreme development is a result of the removal of the gypsum in addition to the surface solution of the carbonate. Much of the gypsum removed in solution is deposited as a white, crystalline efflorescence on the surface of the rocks or in the voids between slabs of rock.

In the purer dolomites the rillenstein is simple in form and generally follows geometrical patterns that reflect fractures, joints, or other internal structures of the rock. The simplest form of rillenstein is two or more sets of nearly parallel, intersecting straight grooves (fig. 4). The grooves are developed on blocks an inch or two in thickness and as much as a foot in length or width. The grooves are 1/32 to 1/4 inch deep and 1/64 to 1/16 inch wide on the upper surface (bedding plane) of the rock. The grooves are spaced from a half inch to an inch apart. They continue on the sides of the rock but here they are generally very shallow and narrow. The highs between the grooves have a few, small isolated pits but are otherwise smooth. The underside of the rock is pitted and has a thick deposit of calcite resembling caliche.

Another closely related form consists of V-shaped grooves 1/16 to 1/18 inch deep and 1/32 inch wide; sides of the grooves are smooth and slope 45 degrees. The grooves are straight or slightly arcuate and branch from several centers (fig. 5). The intersection of the various sets of lines forms a complex pattern of geometric figures. Towards the edge of the rock solution has eaten deeply along the rill lines, producing an extremely coarse serrated edge with indentations a half inch in width and length (fig. 7b). Rills are also developed on the sides of the rock. Grooving on the underside is similar but not as deep as on the top. The high areas between the rills are generally smooth, minutely pitted surfaces (fig. 6).

Arcuate rills are developed in dolomite blocks that are somewhat gypsiferous (fig. 7a). The rills are U-shaped in cross section and are 1/8 to 1/4 inch deep; highs between the rills have sharp, jagged pinnacles. Rills continue on the sides of the rock but are generally lacking on the underside. However, small pits and primitive groove tracings on the underside are probably incipient rill systems.

The extreme lineal development of rillenstein is in the form of broad, open grooves. The grooves are 1/16 to 3/8 inch wide, as much as 3/4 inch deep, and seldom more that a few inches in length. They are straight or slightly arcuate and generally parallel, although a few cross the others. On some rocks they are closely spaced but on others they are widely spaced. In cross section the grooves are U-shaped, rectangu-

Figure 2

Hills of limestone and dolomite in the Arferfik member of the Narssarssuk formation, Arferfik Valley, Northwest Greenland. Rillenstein is developed on the rubble of the valley floor, bedrock, and talus. Note dark areas on valley floor, indicating dampness.

lar (the depth slightly greater that the width), or V-shaped with steep convex slopes. The surface between the grooves is not etched except that where the dolomite is gypsiferous the highs between the rills are sharp pinnacles. Grooves generally continue a short distance down the sides and are developed to a limited extent on the underside. Many of the rocks that contain broad, open grooves are also deeply pitted. The pits are 1/8 to 1/4 inch in diameter and depth. Often they intersect or terminate a groove. In a few places the sides and bottoms of the pits are minutely terraced and reflect the laminae in the bedding of the rock.

A simple form of rillenstein consists of a series of pits developed on smooth surfaces. The pits are 1/16 to 3/8 inch in diameter, relatively deep, and most of them have thin lips that hang slightly over the pits. The pits are generally separated by broad, unetched rock surfaces. The pits also occur on the sides of the rock (fig. 8). On one specimen the pits are elongated and interspersed with short rod-like openings, 1/8 inch long and 1/32 inch wide. The rock has the apearance of cuneiform writing (fig. 9).

Rillenstein also exists in the form of fluting or scallops. The flutings are oblong to round, 1/4 to 1 3/4 inches across, and 1/8 to 1/2 inch deep. On most specimens the flutings grade into each other and are separated by narrow, sharp, irregular ridges. Where more than two flutings intersect, a sharp peak is formed along the ridge. On rocks with large flutings the highs separating the flutings are broad and show minor indistinct scalloping. The lips in the ridges of scallops often overhang the fluted depressions. On rock fragments imbedded in soil in a tilted position the overhang is on the upper side only. The sides of the rock are indistinctly fluted.

On some specimens the flutings are compound with small shallow scallops 1/8 to 1/4 inch in diameter superimposed upon scallops 1 1/2 inches in diameter. The larger scallops seem to be much older than the smaller, and often reflect some feature present in the bedding.

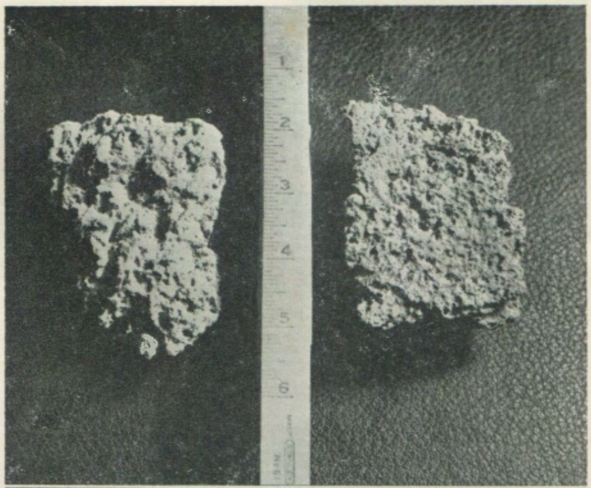
Flutings are often elongated and form long, groove-like scallops (fig. 10), separated by narrow irregular ridges. The scallops are 1/8 to 1/4 inch wide and 1/16 inch deep. Flutings of this type are developed on rocks that are imbedded in soil at relatively steep angles. The flutings extend only to the point of burial, below which the rock is unsculptured.

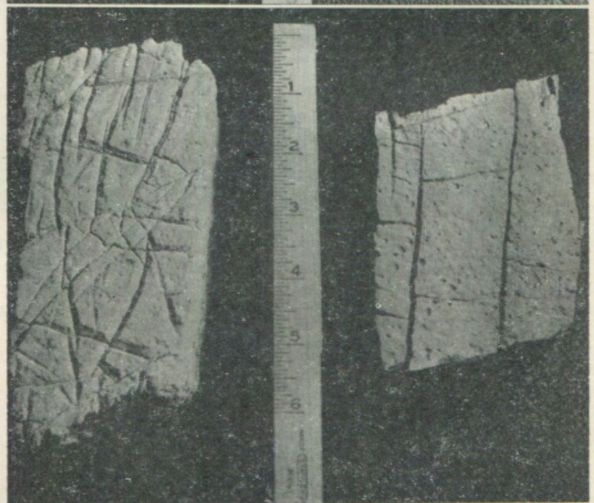
Rillenstein development is also reflected in differential solution of bedding on the edges of rock fragments. In this form the edge is minutely sculptured into a series of ridges and furrows that reflect the difference in the bedding (fig.11)

Another form of rillenstein observed in Northwest Greenland consisted of broad, irregular, ridge-like swellings 1/4 to 1/2 inch wide and 1/4 inch high. Grooves 1/32 inch wide and deep, are developed transverse to the swellings. The surface between the swellings is very rough and consists of "coral"-like knobs, pinnacles and other protuberances.

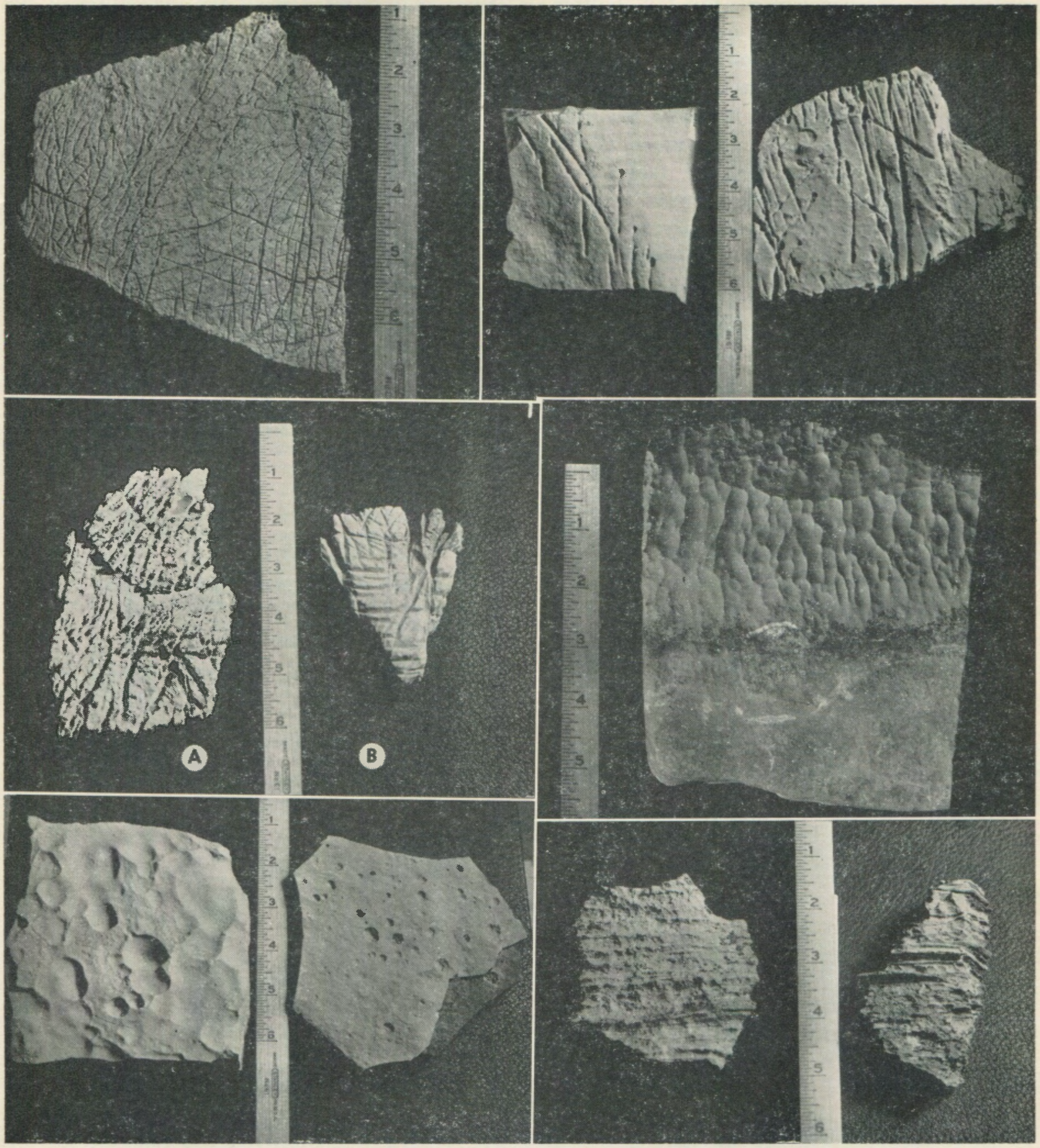
The origin of rillenstein has been ascribed to both solution and wind action. Rillenstein on dolomites and limestones of Northwest Greenland is probably a direct result of solution. In spite of the aridity of the region there is a considerable quantity of water on rock surfaces during the thaw period from June to September. The melting snow, both that which covers the rocks and that contained within the spaces between the rocks, supplies water through much of this period. Practically all meltwater is removed by surface flowage, because permafrost, which is generally less than two feet below the surface in talus slopes and residual rock debris over bedrock, prevents the water from infiltrating. In addition to meltwater there is an appreciable quantity of water deposited on the rock surfaces by summer rainfall. The dolomites and limestones, therefore, receive sufficient water during the melt season to account for a significant amount of solution. The role of anaerobic bacteria should also be considered as a possible important factor in the solution of limestone and the development of rillenstein. Studies along this line at present have not progressed far enough, however, to permit definite conclusions.

Three characteristics of the rillenstein are indicative of solution rather than wind erosion. The paper-thin grooves, as much as 3/4-inch deep, that are a common form of the rillenstein could be produced only by solution. Wind-driven particles could in no way penetrate the rock to such depths along the thin openings. The





Top: Fig. 3, Rillenstein developed on gypsiferous dolomite, resulting in a cinder-like surface. Center: Fig. 4, Simple rill pattern following joints or fractures. Bottom: Fig. 5, Rills developed as complex grooves branching from several centers.



Top left: Fig. 6, Branching rills with minutely pitted surfaces between the rills. Center left: Fig. 7, a Arcuate rills on gypsiferous dolomite; b. Deep rills on dolomite. Bottom left: Fig. 8, Rillenstein developed as shallow pits. Top right: Fig. 9, Pitted rills consisting of shallow pits connected by open rills. Center right: Fig. 10, Fluted surfaces developed on a tilted, partially buried rock. Flutings are on the part of the rock exposed to the air. Bottom right: Fig. 11, Ridges and furrows developed on bedding planes of thin-bedded dolomite.

development of rillenstein on the top, bottom and sides of the rocks would not be possible by wind erosion. At best, wind could only erode the tops and sides and the bottom resting on or buried in the ground would be protected. The pitted highs between grooves on much of the rillenstein are sharp, angular, and ragged and more typical of solution than of wind erosion. In addition, in areas where wind action is common, there has been little development of rillenstein.

The pattern of rillenstein is directly controlled by rock structures. Those forms of rillenstein that are essentially sets of straight, parallel lines follow joint patterns. Those that are arcuate or a complex of straight and arcuate lines follow fractures. The fractures are probably induced by severe frost action. Pits are generally developed in rocks that originally contained small vugs. Such rocks are very common in the Arferfik member of the Narssarssuk formation in Northwest Greenland. The vugs are about 1/32 to 1/16 inch in diameter and are enlarged to about 1/8 inch diameter in the development of rillenstein.

The extremely complex arrangement of pits and pinnacles developed on gypsiferous dolomite is unique. It is developed along numerous fractures that resulted from the deposition of the original gypsum as well as from voids left when the gypsum was removed.

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