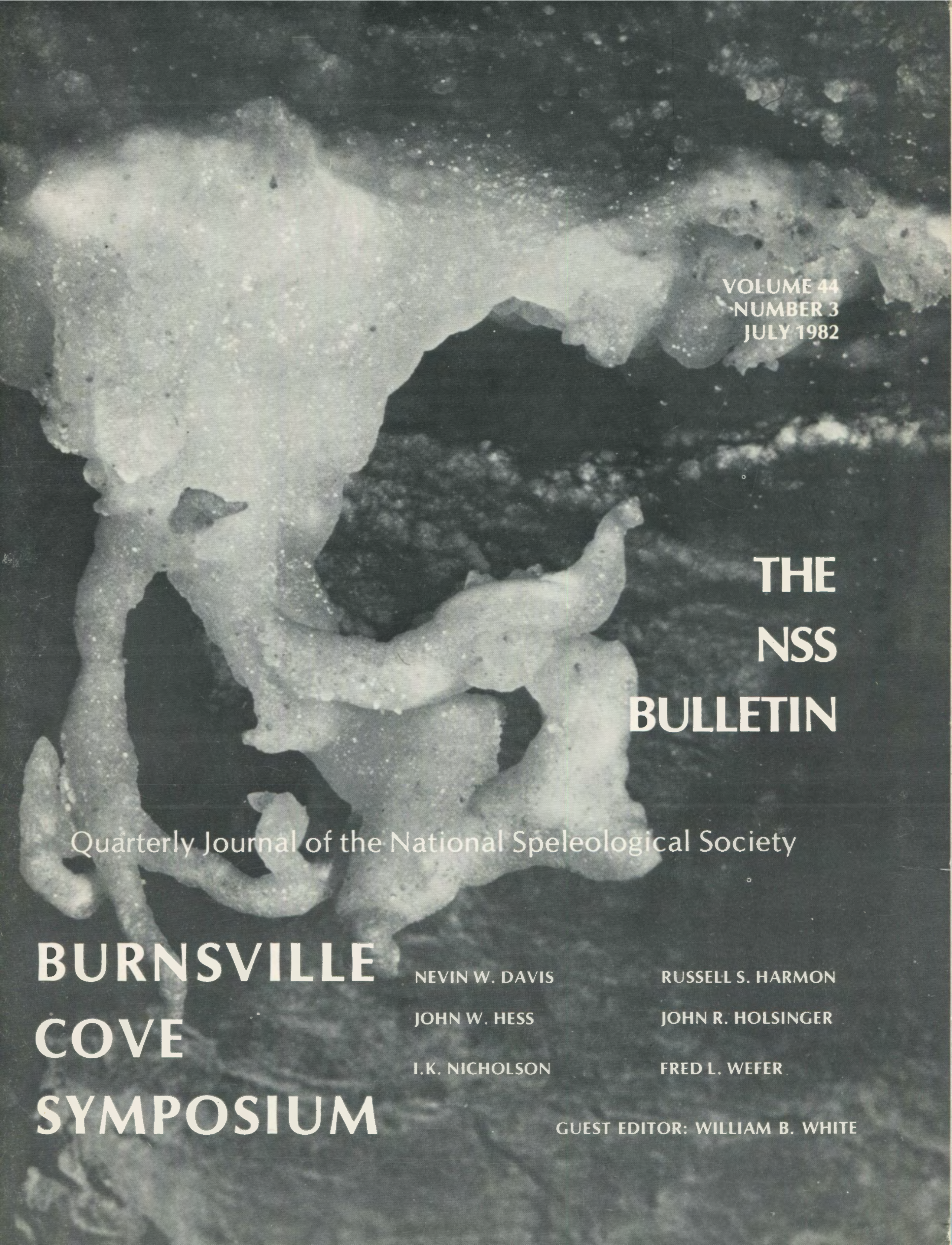

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THE NSS BULLETIN

Quarterly Journal of the National Speleological Society

BURNSVILLE COVE SYMPOSIUM

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of

BURNSVILLE COVE, VIRGINIA

BURNSVILLE COVE lies within the folded and faulted carbonate rocks of Bath and Highland counties, Virginia. The Sinking Creek Cave System in Burnsville Cove is an important integrated karst drainage system made up of five individual caves: Boundless, Butler, Breathing, Better Forgotten, and Aqua caves. The largest of these, the Butler Cave — Sinking Creek System, is owned and managed by the Butler Cave Conservation Society, Inc. (BCCS), a non-stock, non-profit organization incorporated in the Commonwealth of Virginia. The BCCS promotes the exploration and scientific study of caves.

Scientific research on the cave systems of Burnsville Cove date at least back to the early 1950's, when Nittany Grotto members mounted an intensive effort to produce a complete and detailed survey of Breathing Cave. This was followed in the late 1950's by the geologic investigation by George Deike for his M.S. thesis. Although Deike's thesis is dated 1960, most of the field work was completed before the discovery of Butler Cave in 1958 and as a result, only a brief discussion of the larger cave appears in the thesis. During the decade that followed, there was substantial scientific work on the cave systems and on the overall hydrology of the Burnsville Cove drainage system by those who appear as co-authors of this symposium. There appeared a number of abstracts and several short reports; however, the details of these investigations were never published.

On 11 February, 1971, a meeting of the Directors of the BCCS was held at which a proposal was discussed for a comprehensive study of the Burnsville cave area. The study was to be as complete as practicable and the results were to appear in *The NSS Bulletin.* Seven articles covering geology, geomorphology, hydrogeology, hydrochemistry, history, mineralogy, and biology were the result. These seven papers are intended to provide a comprehensive statement of our present knowledge of the Burnsville Cove karst.

A word of explanation may be necessary about the lead paper, which deals with the history of exploration and survey. Although it is certainly well known, it may not be widely appreciated that karst science, at least in the United States, rides on the backs of the cavers who contribute freely of their time and effort for exploration and survey. The historical article is an effort, perhaps for the first time, to set the record straight. Without the efforts described there, none of the papers that follow would have been possible.

William B. White
John W. Hess
coordinators

Wefer, F.L. and I.K. Nicholson (1982) — Exploration and Mapping of the Sinking Creek System: *NSS Bulletin* 44:48-63.

EXPLORATION and MAPPING of the SINKING CREEK SYSTEM

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SUMMARY

Breathing Cave was surveyed by the Nittany Grotto of the NSS during the period 1954 through 1958. New discoveries in the late 1960's led to some additional mapping. The current extent of the cave is approximately 5 miles.

Aqua Cave was discovered in July 1956 by Bevin Hewitt while diving Mill Run Spring. It is the final resurgence on the Bullpasture River of the Sinking Creek System. Diving the sumps at the back of the cave has not produced significant extensions.

Butler Cave was discovered in May 1958 by Kennedy Nicholson. The largest of the five caves, the current map of Butler Cave shows more than 16.75 miles of passages. Exploration is continuing at both the upstream and downstream ends of the cave.

Better Forgotten Cave was first entered in November 1959 by Lief Mollo and Jim Hixson. Explorations in the late 1960's led to many additional passages being discovered deep under Chestnut Ridge.

Boundless Cave was discovered in 1957, but was not explored until 1959, when its entrance crawl was dug open by Bill Plummer and Bill Buckingham.

These 5 caves have been shown to be parts of the Sinking Creek System by water tracing; however, no traversable connection has been found between any two of the caves. The total of the known passages in the 5 caves exceeds 21 miles. The Butler Cave Conservation Society, Inc. currently owns and controls access to Butler Cave, where most of the current effort in exploration and mapping is centered.

BURNSVILLE COVE (Fig. 1) is a relatively wide, synclinal valley located in Bath and Highland counties in west-central Virginia. The axis of the syncline runs from southwest to northeast. The valley is bounded on the northwest by Jack Mountain and on the southwest by Tower Hill Mountain and Bullpasture Mountain. The southwest boundary may be taken as Warm Springs Mountain, and we will discuss mainly the area southwest of the Bullpasture River. Chestnut Ridge is a prominent anticlinal ridge near the middle of Burnsville Cove[1]. The Sinking Creek System consists of a series of network side caves feeding down dip into a main trunk channel developed along the plunging axis of the Burnsville Cove syncline. Five caves are included in the integrated drainage system: Boundless, Breathing, Butler, Better Forgotten, and Aqua[2]. These caves have been shown to be parts of the Sinking Creek System by water tracing, although human passage between any two of these caves has not been achieved.

This paper is a first attempt at a history of the exploration and mapping of the caves of the Sinking Creek System as it occurred during the 20-year period between January 1954 and January 1974. The history of mapping and exploration in Breathing Cave prior to the Nittany Grotto activities is not covered, nor are several caves in Burnsville Cove which have not been shown to be connected with Aqua Cave. Another topic not covered is the "breathing phenomenon." While certainly a part of the history of Breathing Cave, it is part of the history of the exploration and mapping only in that it acted as a stimulus for some of the early surveying in the cave. Readers interested in this topic are referred to the bibliography by Plummer[3].

The account contained in the following pages has been gleaned from over 650 pages of field trip reports, scientific papers, letters, unpublished notes, survey books, and the personal recollections of the authors, one of whom was present and active throughout the period being considered. We are especially indebted to those cavers who took the time to write the hundreds of field trip reports. Direct references to many of these have been made in the text. But even with this seeming wealth of material, some of the history is obscure. This is particularly true of the activities in some areas of Butler by teams of cavers led by Mike Hamilton. Mike left stacks of survey notes and added tremendously to our knowledge of the cave beyond Penn State Lake and the Frothing Slosh, but apparently left no written narratives of his activities.

Because this is the first attempt at such a history, some omissions and even some errors have probably been made. Additional material was solicited by a letter writing campaign to cavers known to have been involved. We are thankful for the information gained in this manner, sparse though it be, and would welcome any additional information which readers may care to transmit.

INTRODUCTION

For the Nittany Grotto, it all started on a rainy day in January, 1954 when 9 cavers left State College, Pennsylvania on their first grotto trip to Virginia. As has been the practice since, a number of well-known caves were visited along the way, and Breathing Cave in Burnsville Cove was not even the major objective. Ironically, the first attempt to locate the entrance was unsuccessful, "foiled by darkness." Two days later, after a long stay in Clark's Cave, the group did find the entrance to Breathing Cave, spent six hours exploring and taking pictures, and stayed the night in the Camp Room. Their exploration was terminated at the Splattermite Climb[4]. The second trip to Breathing by Nittany cavers was made in December, 1954. No field trip report was published, but it is known that the two cavers negotiated the Splattermite Climb and explored beyond. By the time of the third trip, the activity was being referred to as "the annual Nittany Grotto pilgrimage"[5]. This time, 2½ days were spent camping in and exploring the cave. The 13 member team pushed past the Splattermite Climb and explored the Cathedral Passage, the Laundry Chute, and the Grand Canyon Passage. They were stopped by the Waterfall, which they thought could not be descended without a rope. In these first trips, a considerable portion of Breathing Cave was explored and hundreds of photographs were taken.

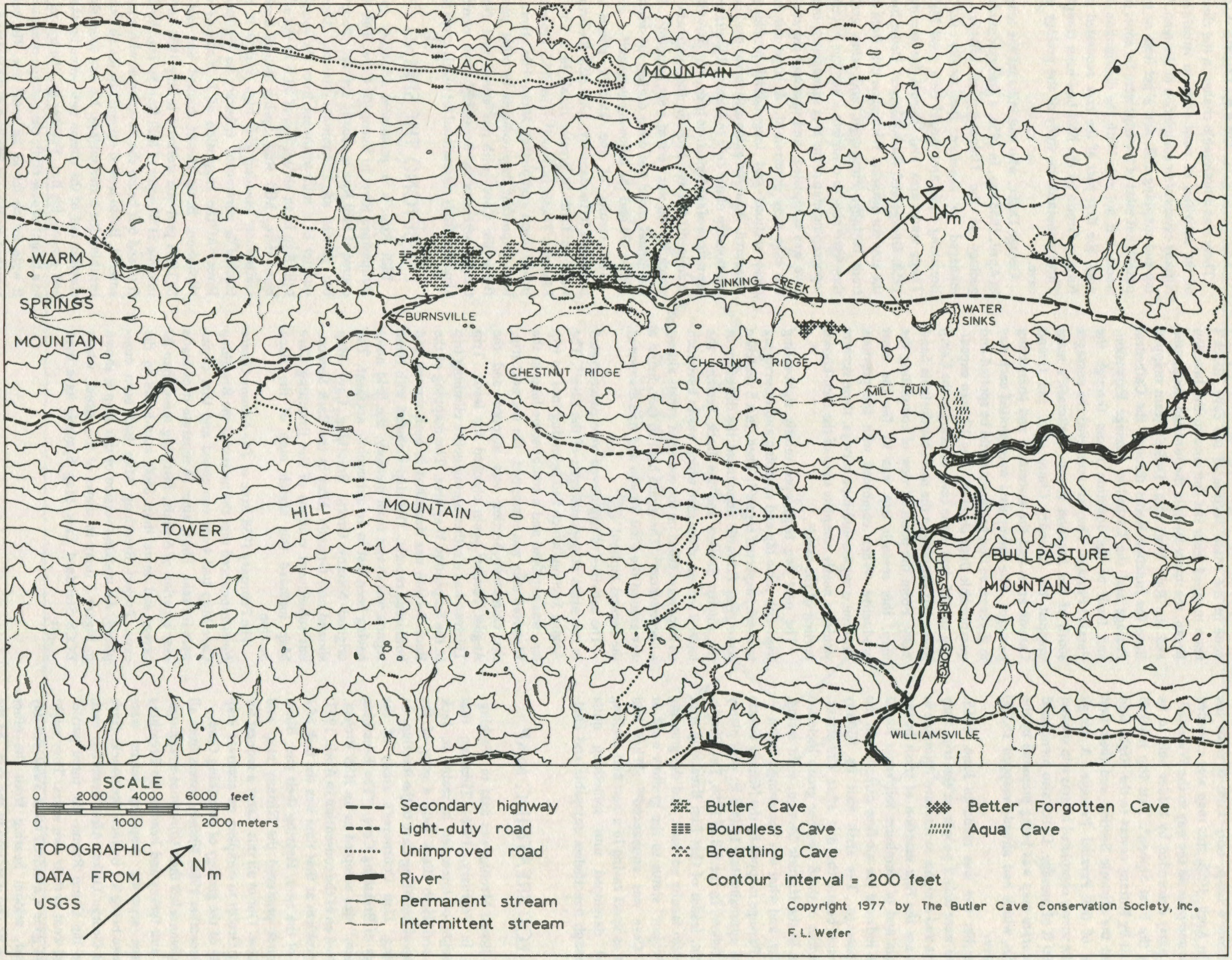


Figure 1. Location and surface relations of the caves of the Sinking Creek System, adapted from USGS 7½' series, Williamsville and Burnsville quadrangles.

Bath Co., VA
Highland Co., VA

see p 71

By 1955, much of the cave had been visited by others; however, the then generally available map ended at Lover's Leap, only 1100 ft from the entrance. In April, 1955, this map was extended by compass and pace all the way to the Waterfall, which the party descended by ladder only to be stopped by the First Siphon[6]. This trip marked the first visit by Nittany cavers to the Right End Section and the Historic Section and their first negotiation of the Parallel Passage. A rough sketch of the survey completed on this trip showed some 10,000 ft of passage. Deike also mentioned that an accurate map was being prepared by the D.C. Grotto, which had already mapped 15,000 ft of the cave.

Trip number five was made in June, 1955. While there were only 2 people on the trip, they spent 4 days and 5 nights in the cave[7]. Notable in the report are the first mention of trash in the Camp Room and of aluminum foil vanes found installed to indicate the air-flow direction in the entrance passage. The sixth visit by Nittany Grotto cavers began the day after Christmas, 1955. Activities of the 8 member group included exploration in the Historic Section, sight-seeing, photography, and what was becoming a habit — mapping[8]. Passage mapped by the Nittany Grotto now totaled approximately 15,000 ft, with plenty of leads to follow. In the fall of 1956, Dr. Charles P. Thornton, leader of that first Breathing trip, became grotto faculty advisor[9], and the granting of "NSS Project" status to the grotto's work at Breathing Cave was announced[10]. What had started out as sport caving in a new and exciting locale had developed into something quite serious, though nonetheless enjoyable and challenging.

PROJECT BREATHING MAP

An NSS Board Meeting was held in Washington, D.C. in February, 1956. Thinking that someone might be interested in seeing it, Jack Stellmack and Herb Black took a copy of the Nittany map of Breathing Cave to the meeting. At that meeting, Don Cournoyer's study of the meteorology of Breathing Cave, "The Breathing Phenomenon," was accepted as an NSS Project, to be reported on at the convention in April, 1957. A serious problem at that time was the lack of a good map of the cave. Hearing their cue, Black and Stellmack produced the Nittany map and stole the show. Out of all this, came a request for the Nittany Grotto to complete an accurate map and a study of the geology of Breathing Cave.

On 26 December 1956, Nittany cavers from all over Pennsylvania left their Christmas wrappings, fireplaces, and turkey and headed for Breathing Cave. Three separate mapping teams were formed, these being led by Jack Stellmack, Herb Black, and George Deike. After breakfast each morning in the Camp Room, the three parties split up and went to their own areas. They might as well have gone a hundred miles away. All day they worked, seldom hearing from the other groups, as if no one else were in the cave. At the end of the day, it must have been very warming to come into camp and see bright lanterns and friendly faces. All of the mapping on this trip was done in the Main Section of the cave. Black's team mapped from the entrance to the Junction Room, the upper levels in the Junction Room area and the Rain Well area. Deike's team mapped from the Junction Room through the Cathedral Passage and the Cathedral Passage Extension, and back to the Junction Room through the Parallel Passage. They also surveyed the passages south of the Junction Room. Stellmack's team mapped the Laundry Chute area, the Grand Canyon area, and the associated and connecting passages. The survey data were plotted each day in the cave, so that problems could be spotted and questionable data checked. The 12 man expedition spent 5 days in the cave, cooking in the Camp Room but sleeping in the more comfortable Sand Alley. From the point of view of completing the map, this seventh trip was by far the most productive. When combined with the previous Brunton compass-and-tape surveys, these surveys yielded a nearly complete map of the then-known portion of the cave[11].

The next two trips were mostly sight-seeing trips with some tag-end mapping and resurveying to check suspected errors[12]. Then, in a 5 sentence report, Jay Edwards announced the discovery of the August Section and the Back Section, the latter a section of the cave which was to have such an important effect on the course of events almost a decade later[13]. The group had, in fact, found a way around the First Siphon and had discovered the Second Siphon!

The activities of trip eleven were concentrated in two areas at opposite ends of the cave[14]. The August Section, which had been dug into on trip ten, was explored and a troublesome loop in the Waterfall area was remapped. On the next trip, the Gumband Section was mapped and the August Section again checked for leads. Trip Thirteen was a rather unproductive climbing trip in the Serpentine Way area. The mapping of the Back Section was described in both serious and humorous reports. The map included with these reports was drawn from memory, the field notes having been lost in an automobile accident. The original Nittany Grotto Breathing Cave Map showed only Gremlin Alley in the Back Section, but subsequent editions of the Breathing Cave Map included this sketch map of the Back Section.

The February 1958 issue of *The Nittany Grotto News* announced that the master of the Breathing Cave Map had been completed and that copies were for sale. Thus, after 14 separate trips made over a period of 6 years, involving more than 50 cavers and more than 3500 man-hours in the cave, Project Breathing Map had been completed. An updated version of this map is shown in Figure 2 (map in center of this issue), where BCCS Standard Cave Map Symbols have been used[15].

GEORGE DEIKE'S BREATHING CAVE

There was a noticeable change in the character of the activities of most trips to Breathing by Nittany cavers after completion of the map. Some tag-end mapping still, and a pet lead or two to push[16], but most of the trips were for sport caving (most, but not all). With the distribution of the map, the first part of the task requested of the Nittany Grotto by the NSS had been completed. There remained the study of the geology of the cave.

George Deike, who had initiated the mapping in April, 1955 was, in 1958, a graduate student in geology at the University of Missouri. He managed to convince the faculty that the Breathing Cave area would be a good Master's Thesis study area and, during the summer of 1958, George and Ruth (Ginger) Deike lived in the area for 6 weeks. With some help from cavers from Nittany, Pittsburgh, and other grottoes, they were able to complete a number of tasks. A topographic map of the area immediately over the cave was completed, and accurate elevations in the cave were determined. A large number of cross sections and longitudinal profiles were measured. A careful examination was made of the relationship of the cave to folds and faults and to the nature of the limestone beds. The cave fill was examined, and the beds on the mountain from which the fill was derived were sampled[17]. Some additional work was done during the winter of 1958-1959 and the following summer[18].

The results of the Deike's efforts were published in the January, 1960 *NSS Bulletin* and were set forth in greater detail in a 155 page Master's Thesis in June[19]. The NSS Project had finally been completed. Meanwhile, there had been important developments in other parts of Burnsville Cove, with the result that Nittany Grotto activities in Breathing Cave would be almost entirely recreational for nearly seven years.

BEYOND THE SPRING

Mill Run is a prominent tributary to the Bullpasture River in Burnsville Cove. The upper course of Mill Run is usually dry and overgrown, but carries an intermittent stream. About a quarter of a mile upstream from the mouth of Mill Run is an abrupt rise of 30 ft in the stream bed. Here, Mill Run Spring issued from an underwater opening 2 ft high and 9 ft wide, feeding a permanent tributary to Bullpasture River. At the suggestion of I. Kennedy (Ike) Nicholson, Bevin Hewitt donned wet suit and SCUBA gear one weekend in July 1956 and slid into the 51°F water of Mill Run Spring. About 35 ft in and 6 ft below the elevation at which he had entered, Bevin looked up and saw his air bubbles breaking the water surface. He was soon able to clamber out of the stream onto some breakdown and remove his fins. Further on, the ceiling rose to a height of over 60 ft; the passage continued 30 ft wide for as far as he could see. He quickly returned to the outside to tell the support party what he had found[20].

Two weeks later, a party of three spent 4 hours exploring the new "Lockridge's Aqua Cave," as Bevin had named it (Fig. 3). Big streams were found to run through most of the cave; one lake they discovered was over 40 ft wide and 15 ft deep. A new entrance was created later that summer which allowed entry without SCUBA gear. This was done by removing rocks from the spring outlet to lower the water level, and by a careful application of dynamite to a hole to the left of the outlet. In the early fall, Mike Nicholson made a 6 hour solo trip; the notes he made resulted in the first map of Aqua Cave. On Thanksgiving Day 1956, a six-member party carried one set of SCUBA gear to the Siphon Room at the end of the right hand, or B, Passage. Mike dived into the gently downward-sloping underwater passage. The slight current was sufficient to carry off the mud as soon as it was raised, thus visibility was quite good. At the end of his 80 ft safety line, the passage was a broad avenue, still sloping downward[21]. Because the Nicholsons had become involved in other activities in Burnsville Cove, the next attempt at diving in Aqua Cave would not be made until May 1960. This attempt to dive French Lake at the end of the left hand, or A, Passage was foiled by unusually high and turbid water[22]. The first mention of life in Aqua Cave appears in the report of a trip made that September[23].

In 1962, there were 3 more dives in Aqua by Hank Hoover and Dick Kutz. First to be attacked was the Siphon Room. The diving was ideal: 30 ft of visibility and enough current to carry away any mud. The underwater passage was 5 ft high, 10 ft wide, and curved toward French Lake; total length was 150 ft, at which point it ended in breakdown too small to crawl through. Next to be attempted were the sumps beyond French Lake. The First and Second Siphons were easily negotiated. The Third Siphon was 50 ft deep where the end of the 180 ft safety line was reached. The passage continued in very clear water with a cross section of 10 by 10 ft[24]. The third dive was again directed at Third Siphon, beyond French Lake, this time with a much longer safety line. The diver turned around 400 ft into the passage and 80 ft down; the 5 ft high by 12 ft wide passage was still going[25]. The return was not without incident, a knife, the safety line reel, and both fins being sacrificed in the process. During these two diving trips, a Brunton compass-and-tape survey of the cave was also completed.

THE CAVE THAT HAD TO BE

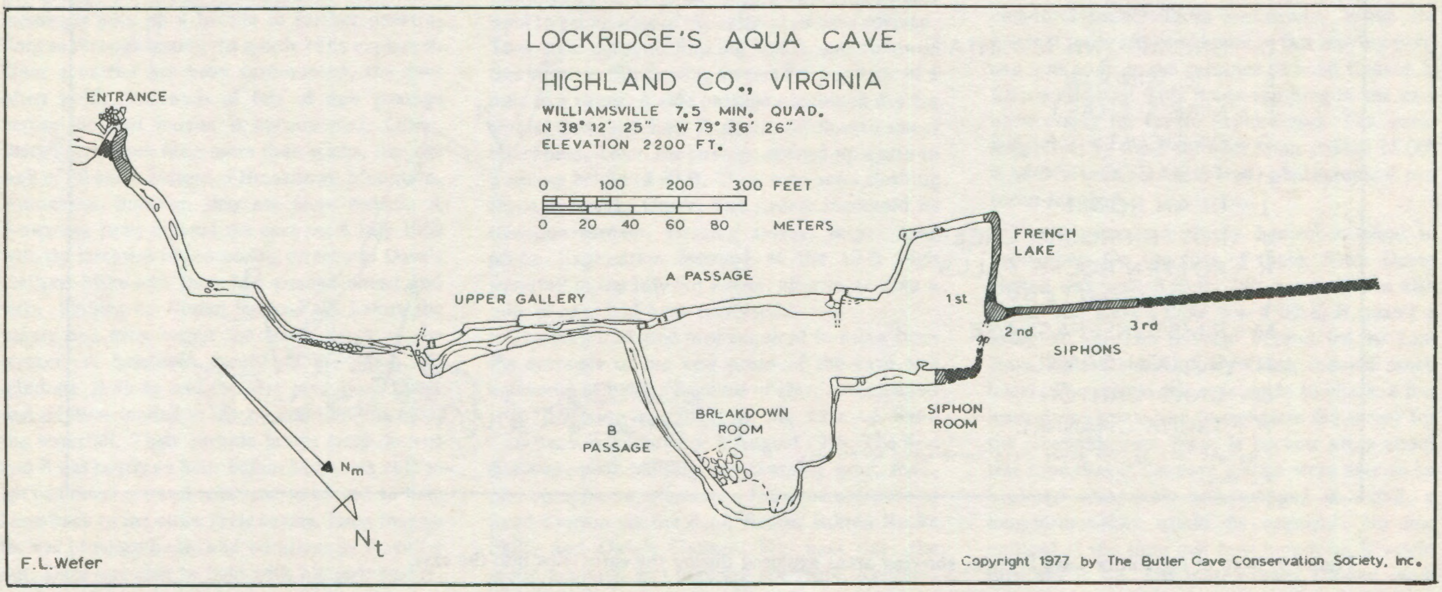
By 1957, the sumps had effectively stopped further penetration of Lockridge's Aqua Cave. In the hope of finding an entrance leading to passages beyond the sumps, the Nicholson family began a search of the surface above. Numerous sinkholes were found, and several small caves were located, but they lead nowhere. Expanding the search to a large portion of Burnsville Cove, they began checking sinkholes and following dry stream beds towards the mountains in an effort to locate an entrance, any entrance. During the winter of 1957-58, Dave Nicholson found a hole near the top of Chestnut Ridge. The hole led to a large room, which led to the top of a 14 ft drop into another fair-sized room. All of the side leads either pinched out or ended in breakdown, except one. This narrow corridor carried a strong draft of air and headed in the direction of Aqua Cave! After squeezing past a fallen rock slab which nearly blocked this passage, the explorers were able to walk for some distance. Then the passage got narrower and lower, and water seeping in from small cracks forced them to crawl in a stream to proceed. Eventually, this passage became just too tight. They named this miserable cave Rat Hole 1179, an exaggeration of the number of "rat holes" they had discovered and explored. The cave was referred to as "Chestnut Ridge Blowing Cave" in *Caves of Virginia*.

It was during this period that people realized that there are no permanent surface streams in Burnsville Cove. The Nicholsons eventually investigated Burnsville Sink, an extremely large sinkhole many acres in extent. In times of heavy rain, much water flowed into it, but there was no evidence of water backing up to any extent. There simply had to be a large cave system in Burnsville Cove to carry away the rainwater, and this water must supply the numerous springs along the Bullpasture River, including Mill Run. Two small caves were discovered in Burnsville Sink: now almost forgotten Burnsville Sink #1 ended in a veritable rabbit warren of tiny holes in the bottom of the small cave. Burnsville Sink #2 (now known as Boundless Cave) was so miserable that its complete exploration would be deferred for some time.

On 30 May 1958, another entrance was discovered in Burnsville Sink. Ike Nicholson pulled some loose rocks out of a small hole under a sandstone ledge about 100 ft above the bottom of the sink and crawled into a small room with a pit in its floor. At the bottom of the easily chimneyed 35-ft pit was a slot too small to penetrate, but the strong wind blowing out told Ike that this cave continued. Later that same day that slot, now called the Glop Slot, was enlarged enough for the smallest person in the party to get through. He didn't go very far, but far enough to see that this cave was getting bigger!

The first significant penetration of newly discovered Butler Cave (named after its owner, Carl Butler) was made on 14 June 1958 (Fig. 4). Seven cavers, including Ike and his sons Dave and Mike, went through the still more-enlarged Glop Slot and found their way to the First Big Room, a passage so large that their lights revealed only the downward-sloping flank of Breakdown Mountain. Exploration was concentrated in the area through the Window, including Mike's Shaft and

Figure 3. The Hoover-Kutz map of Aqua Cave.



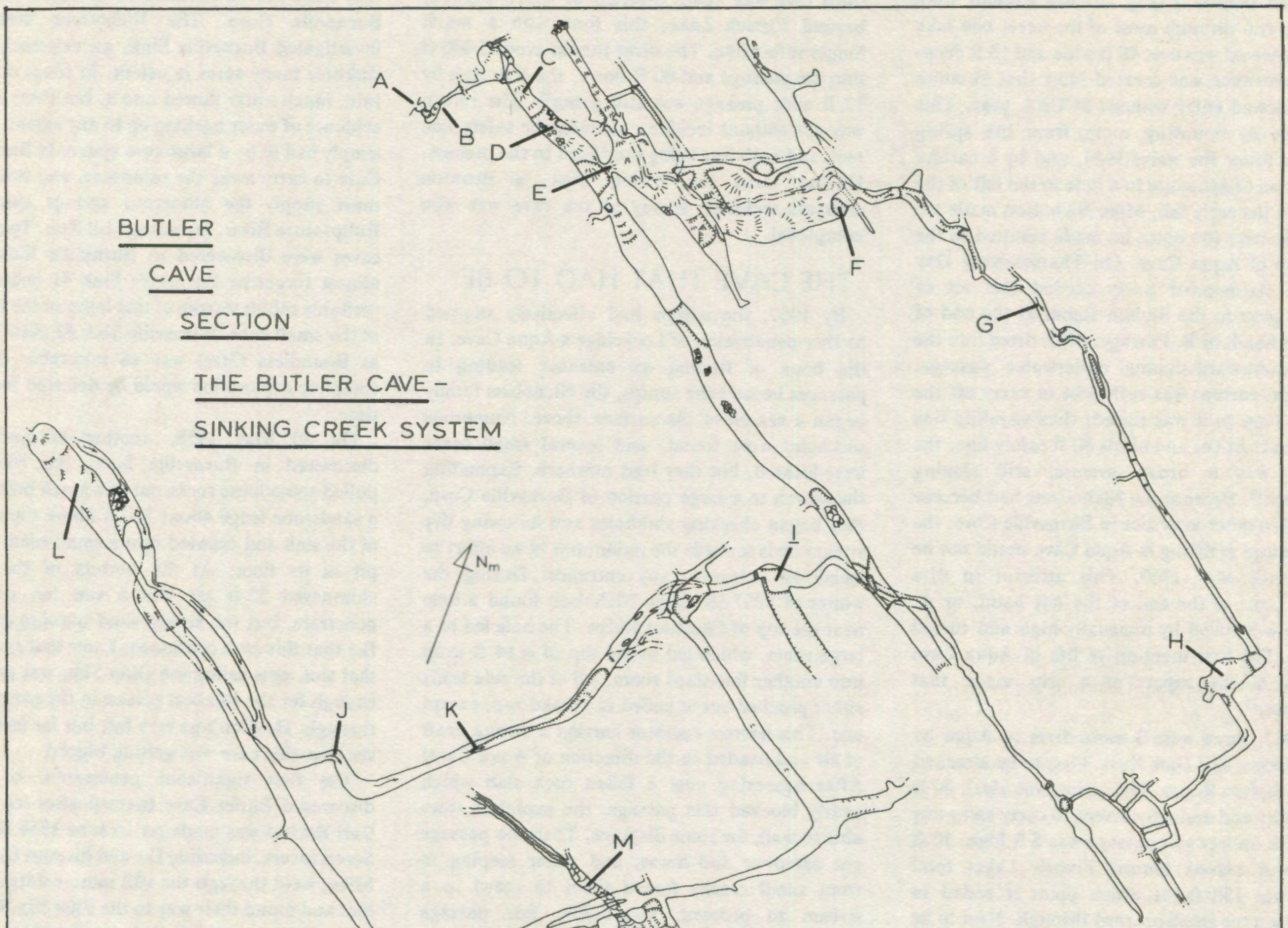


Figure 4. Map of the Butler Cave Section, showing areas explored during the early trips into the cave.

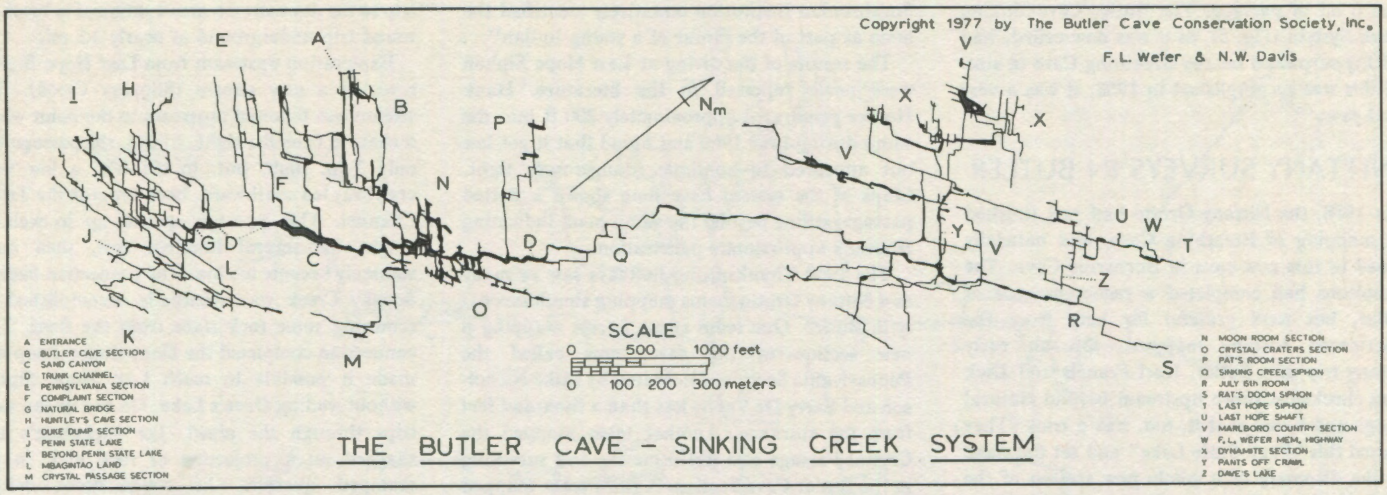


Figure 5. A map of the Butler Cave — Sinking Creek System, showing approximately 15 mi of passages.

Difficulty Creek, the downstream penetration of which stopped only at the third stream belly crawl.

More virgin cave was discovered on 21 June 1958. The First Big Room was blocked by a sheer, 30-ft high wall of cave fill at the bottom of Breakdown Mountain. A route to the top of this wall was found, and the passage beyond was explored. Two streams were encountered, one of which turned out to be the continuation of Difficulty Creek beyond the third crawl. The connection was established at the Tobacco Room. They also explored through the Bean Room, down the 70-ft climb to Rotten Rocks Creek, up Rotten Rocks Falls, and to Dave's Gallery. With almost 4000 ft of passage explored, Butler Cave was already a significant find. More importantly, the stage was set for an even bigger discovery.

Butler has always been a cave of thresholds, giving up its secrets reluctantly. The cave seemingly puts up a barrier to further penetration, as through testing the mettle of its explorers. Once a barrier has been surmounted, the cave often yields thousands of feet of new passage before the next barrier is encountered. Often, these barriers are little more than tricks, like the wall of fill at the bottom of Breakdown Mountain. Sometimes, however, they are more serious. A 5-member party entered the cave on 4 July 1958 with the intention of proceeding directly to Dave's Gallery. Mike and Dave had pushed ahead and were climbing up Rotten Rocks Falls before the others had even begun the climb down to the stream. A handhold came off as Mike was climbing. Both he and the rock landed on Dave, and all three landed in the pool at the bottom of the waterfall. Their carbide lamps were doused and it was nearly an hour before Mike was able to get one dried out and relit, and managed to help Dave back to the other three cavers. Even though he was bleeding badly and occasionally blacking out, Dave was able to help with his own rescue. Hours later a doctor removed rock fragments and closed the face wound with eight stitches.

IT GOES

Dave missed the trip on the next day, when a three-man team again headed for Dave's Gallery. They followed this to the intersection with the Rimstone Passage, then through 90-Ugh Crawl to the Trunk Channel at Sand Canyon. The big passages in Butler had been similar to the large passages in Breathing Cave, but this Trunk Channel was something else! Almost a hundred feet wide at Sand Canyon, it simply stretched off into darkness. They explored 500 ft upstream and more than 1000 ft downstream to Sinking Creek. Realizing that much more cave lay ahead, and that Dave would be disappointed to miss the initial push, they turned back.

After a few hour's rest and a hearty meal, the group, now including Dave, returned to Sand Canyon and explored downstream, pacing as they went to get an idea of the amount of cave covered. They soon came to Sinking Creek and followed this large, swiftly flowing stream for a quarter of a mile to a sump. A side passage continued dry for several thousand feet. A short, silt-floored crawl intervened. Then, the passage opened up again to a ceiling height of 50 ft. They were soon sloshing through Sneaky Creek. The stream increased its size downstream, forming several large, deep pools. Exploration stopped at the 10-ft high waterfall in the July 6th Room, after more than a mile of cave had been traversed.

The length of time now required to move from the entrance to the new areas of the cave was measured in hours. Because of this, an extended trip, involving camping in the cave at Sand Canyon, was initiated on 8 August 1958. The first day was spent hauling the camping gear, food, photographic supplies, etc., from the entrance to Sand Canyon via the Bean Room, Rotten Rocks Falls, and Dave's Gallery. The next day, the group explored and mapped upstream, discovering Huntley's Cave, the Natural Bridge, and a maze of passages to the west. Huntley's Cave, a section of Butler Cave, was so named because it was initially explored by Huntley Ingals on a solo trip that day.

The third day saw one group mapping in Huntley's Cave and a larger group exploring beyond the July 6th Room to Rat's Doom Siphon and a sump now called Dave's Lake. Several days were spent exploring side passages nearer to Sand Canyon, including the Moon Room Section, Crystal Craters, and the Crystal Passage. They also explored additional passages in the Butler Cave Section and mapped the first short cut route from the entrance to Sand Canyon. This route was pioneered by Cliff Forman, who entered the cave alone and followed the trail of footprints to the Bean Room. He lost the trail just beyond this point, sat down to have a cigarette, noticed his smoke going through a hole in the ceiling, followed it, and ended up at Sand Canyon. This short cut eliminated Rotten Rocks Falls and Dave's Gallery from the route. Further exploration in this area would lead to an even better short cut, now used almost exclusively. While the original route required hours, a fast moving party can now go from the entrance to Sand Canyon in fifteen minutes! This made camping in the cave unnecessary for future explorations. The week-long effort by the 7-member team yielded 15,000 ft of new cave — discovered, photographed and recon-mapped.

Two trips were made by 3-member teams in September. On the first of these, Rat's Doom Siphon was pushed to the bitter end. It was also found that Dave's Lake was a trick; it wasn't a sump at all. The passage beyond led to Last Hope Siphon and Slippery Creek (named much later). The second trip was made to check a few leads downstream and to complete the survey for the reconnaissance map. It became clear about this time that if the cave system were ever to be explored completely and mapped in detail, a long-term effort would be required. No one realized at the time just how long-term it would turn out to be. The map already showed more than 6 mi of passage. The Butler Cave-Sinking Creek System (Fig. 5), as it was now called, had quickly surpassed nearby Breathing Cave in size. All this was accomplished in 1958; it was a very good year.

NITTANY SURVEYS IN BUTLER

In 1958, the Nittany Grotto had just finished the mapping of Breathing Cave, and naturally turned to this new cave in Burnsville Cove. The Nicholsons had completed a reconnaissance of Butler, but were grateful for help from the experienced Nittany mappers. On an early Nittany trip into Butler, Karl Francis and Dick Kutz checked a sump upstream beyond Natural Bridge and found that it, too, was a trick. They crossed this "Penn State Lake" and set the stage for the discovery of a whole new section of the system[26]. Butler Cave was first mentioned in the Nittany Grotto Newsletter in a humorous report by Matthews[27], but the cave was not entered on that trip. Mapping of the Butler Cave-Sinking Creek System was voted an official grotto project in the fall of 1958, and the first Nittany Grotto mapping took place over the Thanksgiving weekend. The 10-member team was first given a tour of the cave by Mike Nicholson[28]. The following day, they began running a survey to connect the entrance to Sand Canyon by two separate routes, a task which took 2 days and showed Sand Canyon to be more than 300 ft below the entrance. A planned follow-up trip in December was foiled when the group forgot to obtain the key to the cave before leaving for Virginia[29].

The existence of the Butler Cave-Sinking Creek System was brought to the attention of the National Speleological Society at its 1959 annual convention, held that year in April in Springfield, Missouri[30]. The second Nittany mapping trip took place on 30 May, 1959. The group split into two teams: One mapped downstream from Sand Canyon, the other mapped upstream from the July 6th Room. The two teams met 6 hours later after each had set more than 50 stations, for a total of 6844 ft of passage. This survey, which formed the backbone of the traverse line map, showed the July 6th Room to be more than 420 ft below the entrance[31]. Over the Fourth of July weekend, 3 Nittany teams mapped simultaneously in Butler. One team mapped the Moon Room Section, one in Huntley's Cave, and one from the Natural Bridge towards Penn State Lake[32].

On 30 January 1960, diving equipment was carried to Dave's Lake in preparation for a dive at Last Hope Siphon[33]. The next day, a team began mapping from Last Hope Siphon towards the July 6th Room[34]. This survey was finished on 28 February[35]. An attempt to dive the sump over the 1960 Easter holiday was thwarted by a temporary sump at Dry Sumps[36]. On the same trip, a clear quartz crystal 2 in. in diameter was found beyond Penn State Lake. The party returned downstream a few days later, but the water was still too high. A fossilized bone and more quartz crystals were found beyond Penn State Lake. Experts at the Smithsonian Institution tentatively identified the bone as part of the femur of a young Indian[37].

The results of the diving at Last Hope Siphon were never reported in the literature. Hank Hoover penetrated approximately 200 ft into the sump during June 1960 and found that it got low but appeared to continue, dangerously tight. Maps of the system have long shown a dotted passage outline beyond the sump pool, indicating Hoover's approximate penetration.

The 1960 Thanksgiving holidays saw as many as 4 Nittany Grotto teams mapping simultaneously in Butler. One team spent 2 trips mapping a new section of the cave, now called the Pennsylvania Section, discovered by Mike Nicholson and Larry De Venny less than a thousand feet from the entrance! Another team mapped the Crystal Passage and did some tag-end surveying in the Butler Cave Section. A third team mapped through the Window and down Difficulty Creek. Team four ran a new traverse line from Sand Canyon to the Natural Bridge and tied it into a previous survey near Penn State Lake. They also added to the survey of Huntley's Cave[38]. Following this expedition, there was a 3-year lull in serious activity by the Nittany Grotto in the cave system. The total of the Nittany-surveyed passages came to only 5.3 mi.

DOWNSTREAM DISCOVERIES

While Nittany Grotto activities suffered a lull, progress was being made by other groups. On 10 December 1960, three-quarters of a pound of fluorescein dye was released into Sinking Creek just upstream from its sump[39]. On the same day, charcoal filters were placed in the mouth of Aqua Cave and in Cathedral Spring, another spring on the Bullpasture River. The filters were negative on 17 December, so new ones were placed in these two most-likely candidates for the final resurgence of Sinking Creek. The new filters were tested on 27 December and the one from Aqua Cave found positive, indicating at least a water conection between the two caves[40]. A more complete hydrological survey of the several streams in the Sinking Creek System and in other caves in Burnsville Cove would wait a decade for completion.

During this period, the Nicholsons were concentrating their efforts in the area of the terminal sumps. They were hampered by the long distance from the entrance to the work area, and, as a result, a number of attempts were made to locate a downstream entrance to Butler[41]. Several caves were discovered and/or re-discovered, notably Better Forgotten Cave, but no passable entrance to the downstream area was located. Even a better entrance upstream would have cut some time off of the journey. An attempt to open a new entrance at the end of Dave's Gallery was made, in an effort to facilitate getting equipment downstream. The nearest point on the surface was located, and some digging was done. There was also some blasting from the inside, but the project turned out to involve more effort than it would have saved and was abandoned. Thus, each work trip to the downstream area continued to involve a round trip underground of nearly 3.5 mi.

Exploration upstream from Last Hope Siphon revealed a new stream (Slippery Creek). The stream was followed upstream to the point where it came in from the right. Ahead, the passage was only 3 in. high, but, to the left, a low wide crawlway led southward, back towards the Trunk Channel. This passage opened up to walking height for several hundred feet, then quite suddenly became too low. The connection back to Sneaky Creek was eventually accomplished by removing some rock slabs from the floor. This connection completed the Downstream Loop and made it possible to reach Last Hope Siphon without wading Dave's Lake. On one of the early trips through the crawl, Ike Nicholson's belt snagged on a projection of rock and, in the cramped quarters, he could move neither forwards nor backwards. His "rescue" was effected only after his companions unceremoniously relieved him of his trousers, hence the place became known as Pants Off Crawl. A hammer and chisel were later used to chip off the edges of the rocks one must pass between, but overweight cavers still experience some difficulty there.

Slippery Creek was followed to the right, upstream, to a point where it emerged from a hole too small for human entry. Attention then focused on the Sneaky Creek side of the Downstream Loop. Working their way upstream from Rat's Doom Siphon, they came eventually to a stream feeding into Sneaky Creek from the south. The stream itself came out of a low, water-filled passage, but, to the right, a crawlway led southwest, upwards to Evasor Gallery. Beyond, the ceiling again drops, but one can crawl to a small stream which disappears down a hole.

In June 1963, Mike Nicholson and Joe Faint followed that stream 700 ft down a crawlway now called Crisco Way, because of the slipperyness of its mud coating. At the end was a 40-ft pit, a passage leading to another stream, and a whole new section of the cave. Mike and Dave Nicholson and Dave Head made the second trip down Crisco Way to the section Mike had named Marlboro Country. They used a wooden piton, which expanded tightly into its crack as it soaked up water, to rig a ladder at the pit and explored several thousand feet of new cave consisting mostly of large galleries. On the third trip, Mike and Ike Nicholson, Bill Glosser, Dick Kutz, and Neil Wilding explored several thousand feet more. Three distinct streams were discovered in this lower level of the cave, one of which they felt must be Sinking Creek beyond its siphon (Fig. 6).

A strong current of air was found to flow down from Evasor Gallery and through Marlboro Country, where it disappeared in breakdown in the Candle Room near the point where a small stream enters. It was hoped that by tracing this air current to the surface, an easier route into Marlboro Country might be found. In late September, 1963, Mike Nicholson and Joe Faint broke a vial of ethyl mercaptan in the crawlway leading to Evasor Gallery. The skunk-like smell

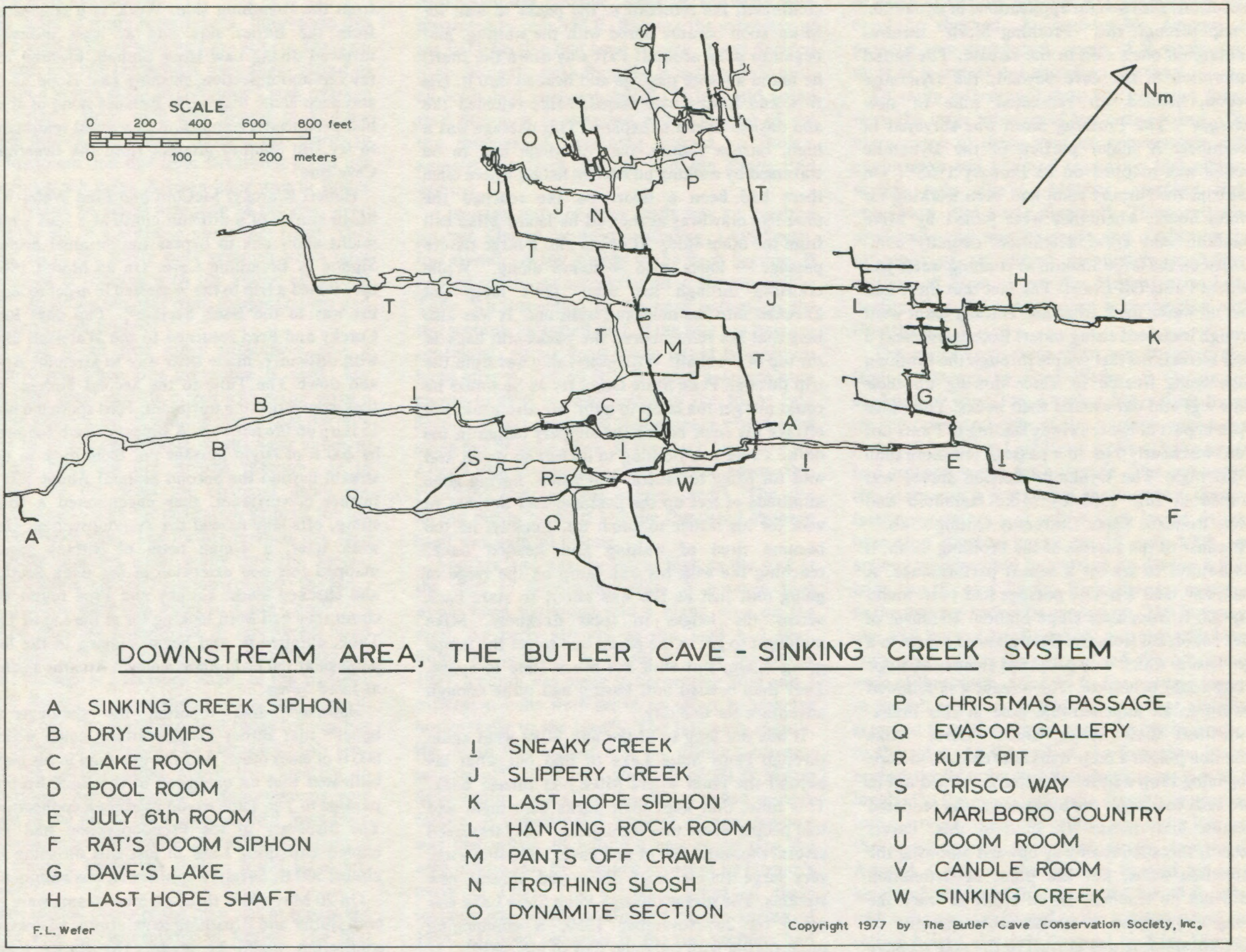


Figure 6. The downstream area of the Butler Cave — Sinking Creek System, showing the Downstream Loop Section, the Dynamite Section, and Marlboro Country.

appeared approximately 3 hours later at a hole in a streambed over the area. Several weekends were spent trying to open the boulder-choked pit, but by Thanksgiving the project looked hopeless. The pit was so filled with precariously perched breakdown blocks, cobblestones, and wet slippery mud that collapse was a very real danger. In order to determine just how deep a dig would be necessary, a survey had to be made. Mike Nicholson led the crew which mapped through Marlboro Country. The stretch from the Pool Room in Sneaky Creek through Evasor Gallery to the start of Crisco Way was mapped by a Nittany Grotto crew[42]. The result showed that the shaft would have to have been more than 300 ft deep, and the project was abandoned.

On 1 August 1964, reconnaissance trips were made to Huntley's Cave and Penn State Lake in preparation for a mapping effort 2 weeks later[43]. A joint expedition involving members of the Pittsburgh, Reading, York, and Nittany grottoes was held on 15 August 1964[44]. John Haas led the trip to Marlboro Country, the purpose of which was to explore the Candle Room area. No new passages were found; however, some details of the geology were worked out.

George Deike[45] had earlier noted that Breathing Cave is confined to about 80 ft of Keyser limestone sandwiched between two sandstone layers. Except for the entrance area, the upstream part of Butler Cave is below the lower sandstone. Haas noticed that the Trunk Channel went up through the lower sandstone at Dry Sumps. Thus, the Downstream Loop is also between the two sandstones. In crawling down Crisco Way, they were crawling on the lower sandstone, which was penetrated at the 40 ft pit. Marlboro Country is below the lower sandstone at the same stratigraphic horizon as most of the upstream areas. The expedition also deployed mapping teams in Huntley's Cave, the Natural Bridge area, the Crystal Craters Section, and the downstream Trunk Channel. The Trunk Channel group discovered what came to be known as the Pat's Room Section. Several thousand feet of passage were added to the map.

On 5 September 1964, the stretch of passage from the Pool Room through Pants Off Crawl to the Hanging Rock Room was surveyed by a crew led by Mike Hamilton. The next day, they mapped a side passage off of Evasor Gallery[46]. The next major mapping effort occurred during the 1964 Thanksgiving weekend, with participation by Baltimore, Reading, Richmond, V.P.I., and Nittany grottoes[47]. Five different mapping teams were in the cave on one of the days. Total passage surveyed came to approximately 5000 ft. There were mapping trips to Marlboro Country, Huntley's Cave, Crystal Craters and the Rat's Doom Siphon area.

There have been relatively few trips to Marlboro Country since these early efforts. An extended exploration and mapping trip by members of the V.P.I. Grotto in November 1966 involved camping in Marlboro Country[48], but little new passage was mapped. In March, 1969, a team checked out some leads and waited for fluorescein dye to come through from Sinking Creek. They found many high leads which are unchecked still, today[49].

In the fall of 1964, attention turned to that hole from which issues Slippery Creek. Dick Kutz was able to enlarge this stream passage to human dimensions with several applications of dynamite. A trip through this "Frothing Slosh" involves crawling on one's side in the stream. The initial exploration of the cave beyond, the Dynamite Section, yielded an estimated mile of new passages[50]. The Frothing Slosh was surveyed in December. A major portion of the Dynamite Section was mapped on 23 January 1965[51]. On that trip, the Nittany team had been working for several hours, when they were joined by Mike Hamilton and crew. Hamilton casually commented on the large amount of running water just north of Pants Off Crawl. The fact that there had been no water there when the Nittany team went through indicated rising water! Both teams beat a hasty retreat, the last people through the Frothing Slosh being treated to water flowing up their pants legs and out around their necks. The water depth in part of the crawlway leading to Pants Off Crawl was nearly 6 in. in a passage not more than 15 in. high. The Dynamite Section survey was finished in July 1965 by Mike Hamilton and cavers from the Duke University Outing Club.

Because of the success at the Frothing Slosh, it was natural to try for a repeat performance. A short, low, and wet side passage had been found only 500 ft from Last Hope Siphon. Removal of some cobble fill from the floor allowed access to a tight fissure which only people as slender as Hope Warig could penetrate. The stream was followed upward to an impenetrable hole in this breakdown-filled Last Hope Shaft. Here, Mike Hamilton placed a large dynamite charge, in hope of opening it up a little. The charge turned out to have been too large; the breakdown was rendered unstable and unsafe. In spite of this, cavers carefully threaded their way upward following the detonation wires, but the point of detonation could not be reached. In an effort to trace the strong air current, a considerable quantity of white phosphorus was burned in the side passage leading to the shaft. The air current carried a tremendous amount of white smoke up the shaft, but cavers scouting the surface above did not spot it. The shaft has been probed sporadically since, but no way through the breakdown has been found[52]. What's more, the place seems to change from visit to visit.

BEYOND PENN STATE LAKE

In the early months of 1959, the upstream end of the Trunk Channel began to attract some attention. Nittany Grotto cavers had pushed across Penn State Lake the previous fall, but all passages beyond had appeared to be blocked. When Dave Head discovered an upper level, Ike and Mike Nicholson decided to take a look beyond the lake. It was very nearly their last! As Mike was attempting to push through the blocked stream passage, Ike happened to look up and discovered a twisting, shaft-like fissure which they were both soon climbing. Above, they found a cross passage which Mike explored in one direction, Ike in the other. Both men left their cave packs at the top of the fissure. Ike's lead soon ended in a difficult climb, while Mike's continued. Ike returned to the packs to wait for Mike, soon became bored with the waiting, and began to poke around. Part way down the shaft, he found another passage and headed into it. His first lead having also ended, Mike rejoined Ike and dashed ahead to explore. This passage was a high, narrow fissure, part of which had to be traversed by walking on narrow ledges where once there had been a floor. As Ike reached the tube-like crawlway at the end he heard Mike call from the other side, "It opens into a large fissure passage — looks good — follow along." While crawling through the tube, Ike's lamp got knocked into the mud and went out. It was also here that Ike remembered the packs still back at the top of the shaft! With everything wet from the trip through Penn State Lake, try as he would he could not get the lamp to light. He also could not retrace his steps across the slippery ledges in the dark. There was nothing to do but sit down and wait for Mike to return. But Mike, having gone hundreds of feet up the passage, had decided to wait for his father to catch up. Luckily, he too became tired of waiting and headed back, reaching Ike with his own lamp on the verge of going out, just as Ike was about to start back across the ledges in total darkness. Mike managed to get to the packs and to get the lamps going again, but with not much time to spare. They then headed out, having had quite enough adventure for one day.

It was not long until Ike and Mike went again through Penn State Lake to find out what lay beyond the point where Mike had turned back. This time, they kept their packs with them and told people where they were going. They traversed several thousand feet of new cave, including some very large rooms, and discovered several new streams. The survey through Penn State Lake was made on 26 November 1959, a challenging undertaking with only one foot of airspace[53].

In the summer of 1964, a young aborigine from New Guinea, the subject of an anthropological study by Dr. Carlton Gajdusek of the National Institutes of Health, was allowed to lead the exploration of a passage which Mike had found beyond Penn State Lake. Observations were made of Mbagintao's ("bog-in-taw") reactions to this, his first caving experience, and of his sense of direction underground (quite good!). The passages explored on that trip were collectively named Mbagintao Land. Mbagintao Land was mapped by Mike Hamilton and crew on 25 July and 20 August 1964[54]. Some additional passages beyond Penn State Lake were surveyed on 30 December 1967[55].

BACK TO BREATHING

It was early realized that Breathing Cave must be a side cave of the Sinking Creek System[56]. Jim Hixson led probably the first trip to Breathing with the aim of finding a connection to Butler[57]. His party checked a lead in the Right End Section and found some new passages, but no connection. Because entry to Butler was severely restricted, an unknown but probably considerable number of attempts were made over the years at a connection from the Breathing side. Work at a connection from the Butler side had at least indirectly involved diving Last Hope Siphon, blasting into the Dynamite Section, pushing Last Hope Shaft, and even some digging[58]. Because none of these had produced a connection, it seemed reasonable to try still another attempt from the Breathing Cave side.

Robert (Corcky) McCord and Fred Wefer had heard stories of a difficult climb at a lead which might allow one to bypass the terminal Second Siphon in Breathing Cave. On 25 March 1967, they joined a trip to the Waterfall in order to learn the way to the Back Section[59]. Two days later Corcky and Fred returned to the Waterfall and, with difficulty, made their way to Gremlin Alley and down The Tube to the Second Siphon. As they were returning upstream, Fred spotted a hole 15 ft up on the left wall. A slippery climb followed by 200 ft of virgin passage put them back in the stream beyond the Second Siphon! About 500 ft farther downstream, they encountered a third sump, officially named the Pseudopsyphon. One week later, a 4-man team of Nittany cavers mapped this new extension of the Back Section and checked leads. Corcky and Fred found the climb they had been looking for at the top of The Tube, climbed it, and began digging in the low passage at the end, a place which became known as Lead Seven.

Halliday[60] had reported the then-current belief[61] that Butler and Breathing came within 800 ft of each other, and the line map in his book indicated that an extension of the Back Section parallel to The Tube would produce a connection. The discovery of the Pseudopsyphon had extended Breathing Cave in just this direction by almost 500 ft. Surely, a connection was imminent.

On 20 May 1967, three-member teams were in both Butler and Breathing to determine where the connection would be made. The Butler team placed two activated charcoal filters ("Dunn bugs") at each of 4 points where water enters the Slippery Creek passage. They also operated a low-frequency radio transmitter, designed and built by Nevin W. Davis, at three of these sites[62]. The Breathing team placed fluorescein dye in the stream at the Pseudopsyphon and listened with the radio receiver[63]. The dye was expected to enter Butler at Last Hope Shaft, and the directional receiving antenna was expected to give the distance between the 2 caves; however, the transmissions were not heard in Breathing. The radio equipment took such a beating in transit that its range was only 90 ft when later tested on the surface. The dye was not visually detected in Butler, and later testing of the bugs removed that day, one from each of the 4 stations, yielded a negative result. The digging done at Lead Seven was the only positive accomplishment of the long day of work. The other set of Dunn bugs was picked up on 21 June[64]; all were positive when placed in a solution of 5% potassium hydroxide in ethyl alcohol[65] and viewed under ultraviolet light. This was initially interpreted as indicating the presence of a local water table between the 2 caves[66], a situation which would have ruled out a traversable connection.

In order to verify these results, fluorescein dye was placed in the Breathing Cave stream again on 30 June, and two Dunn bugs were again placed at each of 4 points along the Slippery Creek passage in Butler[67]. Bugs were also placed in Sinking Creek Siphon and Evasor Gallery, two places so far upstream that dye from Breathing could not possibly reach them. A seven-hour wait in Butler still yielded no visual detection of the dye, even with the aid of a portable ultraviolet lamp. This time, all of the filters were greenish when later examined in solution with the aid of ultraviolet light, including the ones from Evasor Gallery and Sinking Creek Siphon!

It was found that other substances give a positive test when this procedure is used. For example, spent carbide mixed with water gives a strong positive test. It was concluded that the only ways to obtain dependable results were either to visually sight the dye coming through, or to release the dye from the charcoal using the solution and check the coloration without the aid of ultraviolet light. The former method was used to prove that the water going into the Second Siphon flows into the Pseudopsyphon[68]; the latter was used to trace this water to Aqua Cave[69].

The question paramount in everyone's mind was, what had gone wrong? Why had the dye not come through at Last Hope Shaft, or the Hanging Rock Room, or somewhere? As a first step in finding out, the newly repaired radio transmitter was carried to the top of The Tube on 15 July 1967 and the surface point above this location in Breathing Cave was found[70]. Measurements were made of the dip of the magnetic field lines from the loop transmitting antenna so that the depth of the antenna below the surface could be determined[71].

The second phase of the plan was to repeat the above with the transmitter in Butler. The first attempt, on 30 December, was foiled, again by equipment problems[72]; however, the second attempt, on 27 January 1968, was successful[73]. The surface points and depths were found for the entrance to the Frothing Slosh Passage and Last Hope Siphon.

Phase three involved connecting the 3 surface points for the caves to the USGS bench mark at the beginning of the road to Breathing Cave. The survey which accomplished this was done partly with a unipod-mounted Brunton compass[74] and partly with a hand-held Brunton[75]. The horizontal error-of-closure of the almost 7000 ft loop was only 13 ft. The relationship of the Back Section of Breathing to the surface was discussed by Wefer[76]. The relationship of the two caves to each other and to the surface is shown in Figure 7 (The dashed passage beyond Last Hope Siphon is a very recent discovery, which is discussed below). Since the Burnsville Cove synclinal axis was known to plunge to the northeast, the reason that no dye was detected became obvious!

A CONTINUED PUSH

The fact that the relationship between the 2 caves was not as expected did not mean that no connection was possible. After all, the caves were separated by only 950 ft. Because the extension of the Back Section had been so easy, it was decided to continue the push from the Breathing side until all leads had been exhausted. This would entail very thorough exploration and mapping of the two sections of Breathing nearest to Butler, namely: the Back Section and the Right End Section.

Checking some of these leads was an involved process. One of the most intriguing, Lead Seven, had stimulated the interest in the Back Section. It headed southwest across the pit at the top of The Tube. An inspection of the joint pattern in the two sections indicated that, if the very low passage continued, strong cross joints would be encountered after 40 and 60 ft[77]. Because passages were known to exist in these joints in the Right End Section, it was predicted that passage would exist along one of these joints in the Back Section also. After 5 trips involving digging at Lead Seven, this Predicted Passage was encountered[78]. The dig turned out to be 60 ft but the Predicted Passage itself was only 60 ft long.

Another lead was discovered high on the wall at the start of Serpentine Way. A passage here would head southwest into a blank area on the map. An early attempt at this lead had been foiled by inability to locate it[79]. In November 1967, a climb was made in Serpentine Way and 3 expansion bolts were set in an effort to traverse horizontally to the lead[80]. The following month, the climb was redone and the difficult traverse completed[81]. This lead went all of 20 ft before dead-ending. Not all of the efforts ended in such failure. A considerable amount of new passage was discovered, including a new route into the area of unstable breakdown explored by Hixson's party in 1960. The extended effort in these sections was finally completed in the spring of 1974. Mapped passages in the two sections had increased by almost a factor of two. The Back Section and the Right End Section are now the most thoroughly explored and mapped in Breathing Cave, yet no connection has been found.

FROM THE BUTLER SIDE

All reasonable possibilities of a connection from the Breathing Cave side were exhausted quite early. As work progressed on the unreasonable ones, attention was also focused on the nearest sections in Butler. The effort from the Butler side eventually resolved itself into three activities: exploration, examination, and excavation. The exploration, or rather the re-exploration, began on 30 December 1967, after failure of the radio equipment. The Slippery Creek passage from the Frothing Slosh to the Dave's Lake turnoff was very carefully checked for leads[82]. The passage from there to Last Hope Siphon was checked on 27 January[83]. Various other parts of the Downstream Loop were checked during 1968 and 1969[84]. The northeastern end of the Dynamite Section, with its joint pattern so reminiscent of Breathing was also checked[85]. During these explorations, every nook and cranny of every accessible passage was illuminated and carefully checked. A considerable amount of passage was discovered, some of it virgin, but most of it simply not shown on the map.

Of more importance than the passages found were the large number of leads discovered. The examinaton of these went on concurrently with exploration and involved expansion bolt climbs, scaling pole climbs, blasting, pushing tight crawlways, and some digging[86]. These activities produced some new passages and confirmed the existence of an almost completely mud-filled section of cave above the Downstream Loop Section, but did not produce a connection with Breathing.

The major excavation effort was centered at a lead discovered by Fred Wefer on the second exploration trip. Two blowing holes were found on the northwest side of the passage only a few hundred feet from Last Hope Siphon, holes which had escaped notice for a decade. The one nearer the sump was a few inches in diameter; the one farther upstream was only a little larger. It was here that digging began on 13 July 1968, an activity which would be carried on during 8 field trips over the next 2 years. First, the very entrance to the passage had to be opened up. The floor and one wall were of hard-packed, wet clay with large embedded rocks; the ceiling and the other wall were of limestone. After 15 ft, the passage jogged to the left and became wide enough that material removed from the center could simply be pushed to the sides. At the end of the first trip, it was optimistically estimated that the passage was 50 ft long[87]. On the second trip, the digging progressed into a stretch where the ceiling was quite low but the loose gravel floor was easily excavated. Around a corner, the passage opened up to a height of one foot. This continued for 40 ft, after which the passage turned to the northwest and the ceiling height abruptly dropped to 3 in. Digging at this point involved lying in wet, gorpy mud, in a tight crawlway, in a strong, cold wind. Further digging was postponed until those involved had wet suits.

Digging resumed 6 months later, the interval between having been spent checking more hospitable leads in the Downstream Loop Section. Progress now was very slow, indeed. Water flowed in as the floor of the passage was lowered, creating a wallow which had to be occupied while digging[88]. The passage became known as the Fred L. Wefer Memorial Highway, after the caver who had found the lead, had started the dig, and had been on every digging trip. He had also been threatened with premature interment there if the lead did not go! The Highway was surveyed on 19 April 1969 to find out if a short auxiliary dig would allow easier access to the wallow. The survey showed that it would not!

On the 13 September trip, it was clear that the ceiling height increased considerably just a few feet ahead, and that the wallow was about to end[89]. On 21 February, the wallow was found full of water, and digging was impossible. A channel was made to drain away some of the water, and an

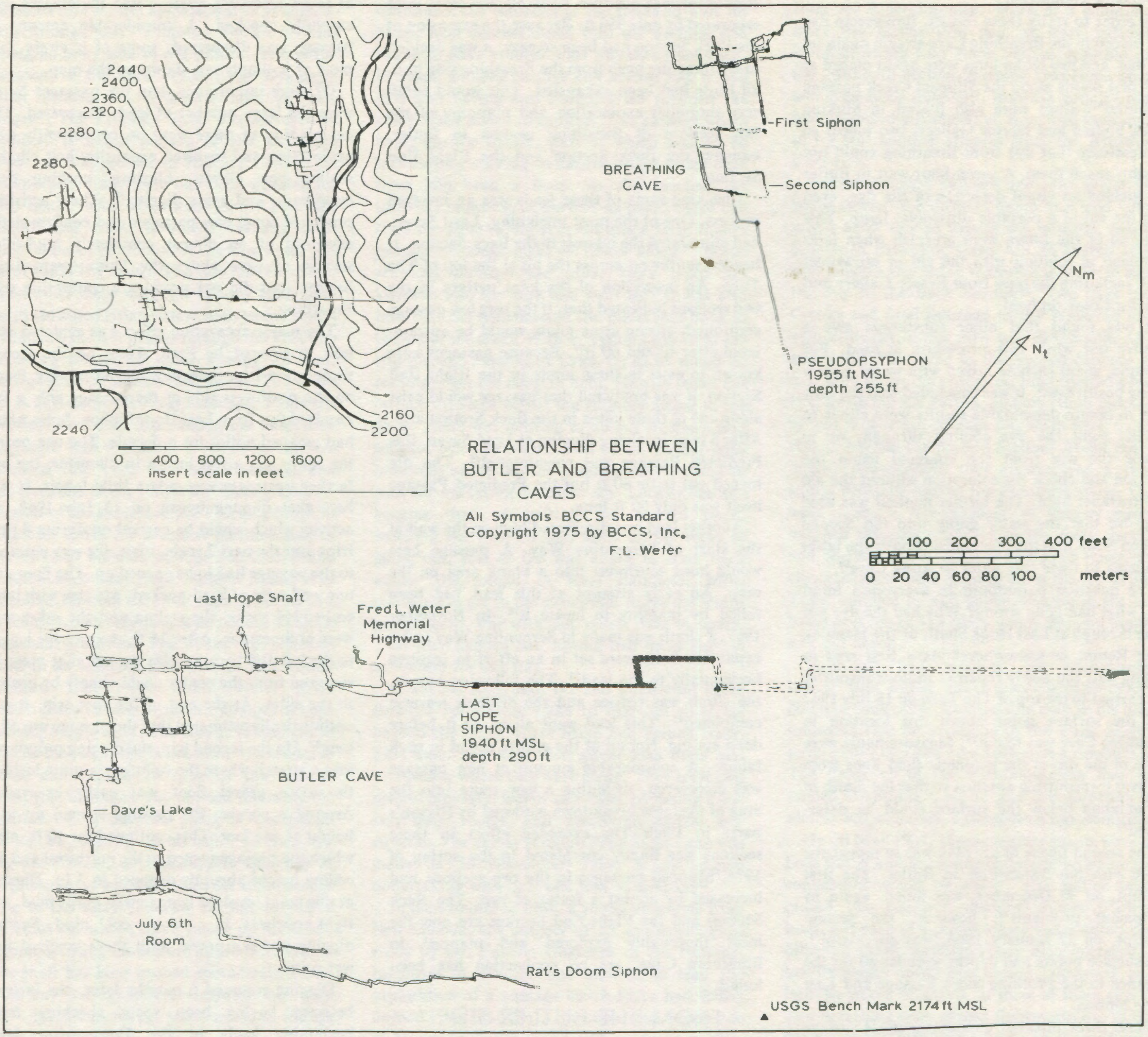


Figure 7. The relationship between Breathing Cave and Butler Cave; insert shows the surface relations.

attempt was made to blast out a rock which had been making crawling around the tight corner into the wallow quite difficult[90]. The blast was found to have been successful on 4 April, and digging continued[91].

The wallow was finally penetrated on 30 May 1970 when, after finding that he was stuck in the passage and could not back out, Fred extruded himself into the small room beyond. The passage continued on the other side, 2 ft wide but, again, 3 in. high, with a wind literally whistling through. After making careful notes about the room and what would be required to continue the dig, he opened up the crawlway a bit so he could get out, then left. No one has been there since.

On 26 August 1970, a 100 gram vial of ethyl mercaptan was broken in the Highway, the air flowing into the passage carrying the skunk-like scent with it[92]. This technique, which had been successful in Marlboro Country, was a miserable failure. The smell did not reappear in the Dynamite Section of Butler, nor in Breathing Cave, nor at any of the blowing holes at the land surface above. The large draft of air, which flows into the dig during the summer and out during the winter, drying the walls on the outsides of the bends of nearby passages, has still not been traced.

POTPOURRI

When the going downstream gets just too discouraging to bear, what do you do in Butler? You go upstream, instead. On 19 March 1970, during a tourist trip to the Pennsylvania Section, Nevin W. Davis heard running water in a low passage previously thought to be dry. Removing some rocks and crawling ahead, he was soon able to climb down ledges to a virgin section complete with a 50 ft waterfall and stream passage. Farther along, the stream disappeared into a small hole at the bottom of a 20 ft pit, but the passage continued across the pit, getting narrower and lower until finally it was blocked by fill bridges. Removing these and crawling forward, he was soon in a passage so huge that his lamp failed to adequately illuminate it! He was, in fact, in the Trunk Channel, 150 ft upstream from Sand Canyon[93]. This new section of the cave was mapped during one fourteen-hour trip on 24 June 1970[94]. Two members of the 4-man mapping team were quite unhappy, mainly with the duration of the trip, hence the name, "Complaint Section." It contains a half mile of new cave within a quarter of a mile of the entrance.

During the years 1968 through 1970, Nittany Grotto cavers were not the only ones working in the system. A group of cavers from the Duke University Outing Club had become interested in working in Butler also. On 13 September 1965, a new passage was dug open and surveyed near Penn State Lake, a passage which ran westward for more than a thousand feet towards nearby Boundless Cave. The team left a number of unchecked leads which were described as "awful tight"[95]. To avoid any possible friction with Nittany cavers working downstream, Ike Nicholson asked the Duke cavers to work upstream exploring these leads. They pushed these "awful tight" crawlways and found a virgin section of cave containing some sizeable walking passages. Their final map showed 2920 ft of new cave. In addition, they located a place where a large passage came very close to intersecting the main upstream passage near Penn State Lake and dug a connection called Cathy's Crawl providing easy access to the new section.

Because of the rivalry between the two groups, and because the Duke map lacked details such as ceiling heights and cross sections, some Nittany cavers doubted the very existence of the new section. On 25 July 1970, three Nittany cavers found their way through the tight crawlway called The Rectum and into the new section beyond[96]. The Duke map was found to be correct as far as it went, but a number of passages had obviously been omitted. It was decided to remap the Duke Dump Section in detail and to name it after the carbide dumps left by its discoverers. A large number of trips were led here by Nittany cavers in the following years, with the result that a very detailed map was completed[97]. Several of the Duke cavers joined the work parties and aided in the remapping effort. The total of mapped passages in the Duke Dump Section and the newly discovered connecting passages to the Huntley's Cave Section is now 7480 ft[98].

A large number of streams had been found in Butler, perhaps too many. It was early suspected that some of the streams which appear and then sump might reappear elsewhere in the cave. Beginning in March 1969, an effort was made to trace some of these streams. Fluorescein dye placed in Sinking Creek Siphon reappeared and disappeared several times before finally vanishing near Dry Sumps. Eight hours later, dye was found in what had been called Marlboro Stream #1[99]. Difficulty Creek was found to resurge in the Moon Room Section and join Sinking Creek. The source of Sinking Creek was later traced to a stream near Penn State Lake[100]. The previously unnamed stream which flowed out of the Dynamite Section, through the Frothing Slosh, and sank at the Hanging Rock Room was found to reappear near Dave's Lake, sink about 200 ft farther down the passage, reappear just downstream from the Fred L. Wefer Memorial Highway, and finally flow into and form Last Hope Siphon. Because of this curious pattern, it was named Slippery Creek[101]. Slippery Creek and Sinking Creek have both been traced to Aqua Cave[102].

There are several additional streams in Butler: Rotten Rocks Creek, Marlboro Stream #2, Marlboro Stream #3, and unnamed streams in the Complaint Section, Huntley's Cave Section, the Moon Room Section, plus at least two beyond Penn State Lake and many small but distinct tributaries to each of the above. The summer flood of 1969 provided a unique opportunity to study the possibility of being trapped downstream by high water[103]. Several potential trouble spots were identified; however, it was found that most of the downstream area would have been accessible. The Dynamite Section and Marlboro Country were considered dangerous exceptions.

In recent years, the efforts in Butler have been quite varied, both in location in the cave and in activities involved. A considerable amount of new passage has been discovered beyond Penn State lake, and mapping continues[104]. Attempts have been made to lower this lake by motorized pumping in order to provide easier access. Further attempts have been made to penetrate Last Hope Siphon and the resurgences and sinks of Sinking Creek. Studies have been made of the hydrology, water chemistry, geology and mineralogy,and biology of the cave[105]. Sections of the cave which appear to have been mapped with insufficient detail, or for which the notes are needed but missing, are being remapped[106]. A striking example is the recent complete resurvey of the Moon Room Section, with the discovery of virgin passage and a possibly traversable connection with Difficulty Creek[107].

A CAVE BETTER REMEMBERED

On 27 November 1959, Nittany Cavers entered a new cave on the northwestern side of Chestnut Ridge[108]. Leif Mollo and Jim Hixson penetrated 500 ft, to the top of a deep pit. Mike and Dave Nicholson and Hope Warig checked out the Hundred-Foot Pit the next day and reported that it was dead bottom[109]. They said that it was the worst pit they had ever done, and that they were so exhausted they let 400 ft of rope drop rather than pull it out. They dubbed this miserable hole "Better Forgotten Cave." The second Virginia Region Project had as its objective a search for new caves on and around Chestnut Ridge[110]. One party worked in the immediate area of Better Forgotten Cave, but, except for a few sinkholes and rock crevices, they located nothing new. Later in the day, they entered Better Forgotten, but did not go to The Hundred-Foot Pit[111].

Because it lies on a straight line between Butler Cave and Aqua Cave, Better Forgotten would not be forgotten. During the summer of 1967, the entrance was relocated. On a rainy weekend in September, Nittany cavers again entered the cave, but could not find The Hundred-Foot Pit[112]. They did report a high lead near the entrance, and that the cave was much bigger and muddier than indicated by Douglas[113]. They concluded that, all in all, the cave *was* better forgotten. And again it was forgotten, until the fall of 1969, when, under the gentle prodding of Ike Nicholson, the Nittany Grotto returned. The tight constriction just before The Hundred-Foot Pit had stopped the trip two years earlier. According, svelte Christine Davis accompanied her brother Nevin W. Davis and Jack Hess. Christine made it through the constriction labelled the Hundred-Pound Man's Misery on Hixson's sketch map, but Nevin and Jack had to enlarge it with a hammer and chisel in order to get through.

A week later they descended the Hundred-Foot Pit and followed the stream which pours down the pit to a small hole in a mud slide. Rocks dropped through this hole rattled on down out of hearing. Digging revealed a drop which required a rope for a safe first descent[114]. On 25 October 1969, Nevin and Jack returned with two 120-ft lengths of rope and rigged and descended the drop for the first time. All but the very bottom of the pitch was open enough to chimney. The bottom was very tight and awkward, giving the pitch its name, the Vertical Crawl. At the bottom of this was a large, mud-coated room, followed by a passage full of muddy breakdown blocks. This led to the 20-ft "Flowstone Drop," where the second rope was required, then to a huge stream passage! Upstream, the passage terminated in breakdown. Downstream, they encountered a stretch with only 6 in. of air space. A climb to a higher level allowed this "First Siphon" to be bypassed, but they were soon stopped by a deep pool of water with no obvious passage continuation.

In November, a 3-man team explored a side passage and pit in the upper part of the cave. The trip following that had as its major objective the finding of a route bypassing the deep pool blocking progress downstream. Nevin, Jack, and Fred Wefer succeeded in finding a climb up and over the deep pool, but they could not get down the other side for want of a rope. The pool was waded to a point where a passage could be seen leading off to the left, but because of the duration and severity of the trip out, it was deemed unwise to swim the pool to the passage. On 20 November 1969, they were once again at the pool, this time wearing wet suits. Beyond the neck-deep pool, they walked through nearly a thousand feet of virgin trunk channel, with passage widths up to 30 ft and ceiling heights of as much as 60 ft. This passage ended in a "Second Siphon," around which no route could be found[115].

The total drop in elevation from the entrance to the stream passage was estimated to be 360 ft; horizontally, the distance was only 700 ft. Rigging the various pitches had required a 50-ft and a 25-ft cable ladder, a 60-ft rope, and four 120-ft ropes, all of which were very wet and muddy. An indication of the difficulty of the cave is given by the fact that their trip out, derigging as they went, required 5½ hours[116].

Fluorescein dye placed in the Better Forgotten stream came out at Aqua Cave, but which stream from Butler was this? The first 3 pitches in Better Forgotten were rigged on 23 October 1970, as a first step in finding out. The same day, different types of stream tracers were released in Sinking Creek, Sneaky Creek, and Slippery Creek in

Butler. The next day, Ron Schrumpf and Nevin W. Davis spent 8 hours in Better Forgotten Cave. In spite of the low level of the water, the downstream sump was still impassable. The upstream breakdown was explored for 100 ft to an impassable plug. None of the three stream tracers were detected during this trip, and the origin of this stream remains undetermined[117].

Today, Better Forgotten Cave (Fig. 8) has an estimated depth of 420 ft and an estimated 4100 ft of passage[118]. All but 500 ft were discovered ten years after the initial exploration of the cave. While it has not been accurately surveyed, Better Forgotten Cave has not again been forgotten, at least not by the handful of people who have seen its trunk channel. The manila rope that the Nicholsons let drop in the Hundred-Foot Pit in 1959 is still there, marking the point where the going gets tough.

BOUNDLESS CRAWLWAYS

In 1957, when the Nicholsons were searching Burnsville Cove for new cave entrances, several openings were found in Burnsville Sink. One of these led to a wide but very low crawlway with a solid rock roof and a floor of cobbles and stream debris. This crawlway was so miserable and difficult to traverse that they decided to put off its exploration until some future time. Beginning the following spring, the Nicholsons were heavily occupied in Butler and, not surprisingly, never got back to this hole. Access to Butler was severely restricted almost from the start, a policy to which some members of the Baltimore Grotto were opposed. Perhaps partly because of this, there was interest in finding another entrance to Butler. As this hole was in the same sinkhole as the Butler entrance, it was a prime candidate.

That miserable crawlway was penetrated on 25 March 1959 by Bill Plummer and Bill Buckingham, but they were stopped several hundred feet from the entrance by a sand bank[119]. They returned the next day, armed with a short-handled hoe. Digging their way through, they explored the cave beyond to a point where they were stopped by a very tight fissure. Mapping their way out, they found they had explored about 1100 ft of cave. An interesting pattern was noticed in the air motion in the cave. During the day, the wind blew out of the cave, but at night, when the temperature was lower outside the cave than inside, the wind blew into the cave. This pattern suggested a second, higher entrance. Because the Butler entrance was approximately 260 ft higher and the 2 caves came within a few hundred feet of each other, Bill Plummer[120] theorized that a connection existed between Boundless and Butler. Later that summer, Bill had a look at the upstream end of Butler and commented that the appearance of some passages in that part of the system suggested an excellent chance for a connection with Boundless Cave[121].

During the second Virginia Region Project in July 1961, a team dug open the partially debris-plugged entrance and crawled to the Grand Canyon; however, because of the threat of thunderstorms they returned to the entrance without checking any of the leads shown on Plummer's map[122]. A good description of the cave can be found in a humorous field trip report by John Cooper[123], whose party explored and poked into some leads, but failed to extend the cave very much. In pushing a passage at the back of the cave, John Holsinger discovered that he had dug through a low, dry, sand crawl which had been dug out by Bill Plummer in 1959. Because the passage was quite dry with a strong current of air passing through, Holsinger[124] postulated that the passage had been filled by sand transported by wind.

A trip during April of the following year was foiled by water flowing into and flooding the entrance of what Lew Bicking thought was Boundless Cave, but was actually Burnsville Sink No. 1 Cave[125]. In March 1963, Lew also had a look at the upstream end of Butler, with an eye towards a connection[126]. A year later, he tried again to enter Boundless, found the hole he had looked at in 1962 again flooded, then found the actual Boundless entrance, but it too was flooded[127]. His efforts finally came to fruition on 26 November 1964 when, accompanied by Bruce Bennett and Don Miller, Lew Bicking finally made it into Boundless Cave. They had to dig their way through part of the entrance crawl, then used their shovel to dig at a lead shown on Plummer's map. They followed the new, eastward-trending passage through belly crawls and stoopways for 700 ft[128]. This new discovery brought the length of Boundless to about 1800 ft. Bicking's composite map of the cave, with some ceiling heights and place names added from the description by Cooper[129], is shown in Figure 8. Water flowing into the entrance has been traced to Aqua Cave, thus establishing Boundless as part of the Sinking Creek System[130].

Although passages in the two caves are known to come within a few hundred feet of each other, a traversable connection between Boundless and Butler has not been established, nor has it been sought by those currently involved in the exploration and mapping of the Sinking Creek System. It is felt that the problems involved in establishing control of a second entrance, an entrance which would not facilitate work in the System, far outweigh the importance of having an additional 1800 ft of passage in Butler Cave. Would-be visitors to the Boundless crawlways are cautioned that drainage from a considerable area enters the Sinking Creek System through the entrance crawl, making Boundless Cave subject to severe and dangerous flooding.

ACCESS TO THE SYSTEM: THE BCCS

The general caving public has been primarily interested in visiting only two caves of the Sinking Creek System: Butler and Breathing. Aqua, Boundless, and Better Forgotten have always been open, but except perhaps for Aqua, little interest has been shown in visiting them.

The situation with Breathing Cave has sometimes been a little touchy. Following a fatal accident in 1967[131], the owners requested that everyone entering the cave sign a release. Many cavers cooperated with this request; many did not. The procedure at least revealed the incredible amount of traffic in the cave (hundreds per month in some seasons). No wonder Breathing Cave is so thoroughly vandalized! Other problems arose when the land between Virginia State Route 609 and the properties containing Butler and Breathing entrances was purchased by a farmer opposed to cavers crossing his land. Cavers have at times been warned at gunpoint against trespassing. Local cavers should be consulted to determine the current procedure for gaining entry to Breathing Cave.

The discovery of Butler Cave in May 1958 was kept something of a secret from the start. Only people directly involved were to know about it, but Cliff Forman's impromptu appearance at Sand Canyon during the camping trip one month later indicated that the word was rapidly spreading. The almost inevitable problems of vandalism and injury were discussed with the owner, who decided that entry should be restricted. He did not want to be bothered by cavers seeking permission to enter, so gave the responsibility of control to Ike Nicholson. A few weeks after the camping trip, the entrance room was made safer by prying from the ceiling a very large and loose block. Early visitors to the cave will remember crawling over it to get to the entrance pit. The entrance was made secure and small enough by an application of steel reinforcing rods and concrete, that a chain stretched tightly across it would bar entry. The chain was fastened to the rods at either side of the hole by padlocks. During the early days, there were three keys, these being held by Ike and Mike Nicholson and by Jack Stellmack for the Nittany Grotto. Keys were not loaned or mailed, and only work parties were allowed to enter.

During the middle 1960's, the work restriction was relaxed somewhat and people were allowed entry for purely sport caving. This was tried because of the large number of requests and the frequent breaking of the locks. Groups were sometimes loaned a key, so that the key-holder would not have to go to the entrance to unlock the cave. Instantly there arose the problem of key copying, necessitating still more new locks. In addition, it had been discovered that exceptionally small cavers could squeeze under the chain. Parties which had legally entered the cave often left the key in the entrance room so as not to risk losing it farther in the cave. Whole groups were found to have gained entry when a small caver went under the chain, found the key, and opened the cave from within. Even though these groups almost always took both the key and the lock with them, the potential for disaster existed, since legal entrants sometimes carried new locks with different keys!

In an effort to curb the practice of going under the chain, a 2-in. diameter pipe was placed over it, preventing the chain from being bent upwards.

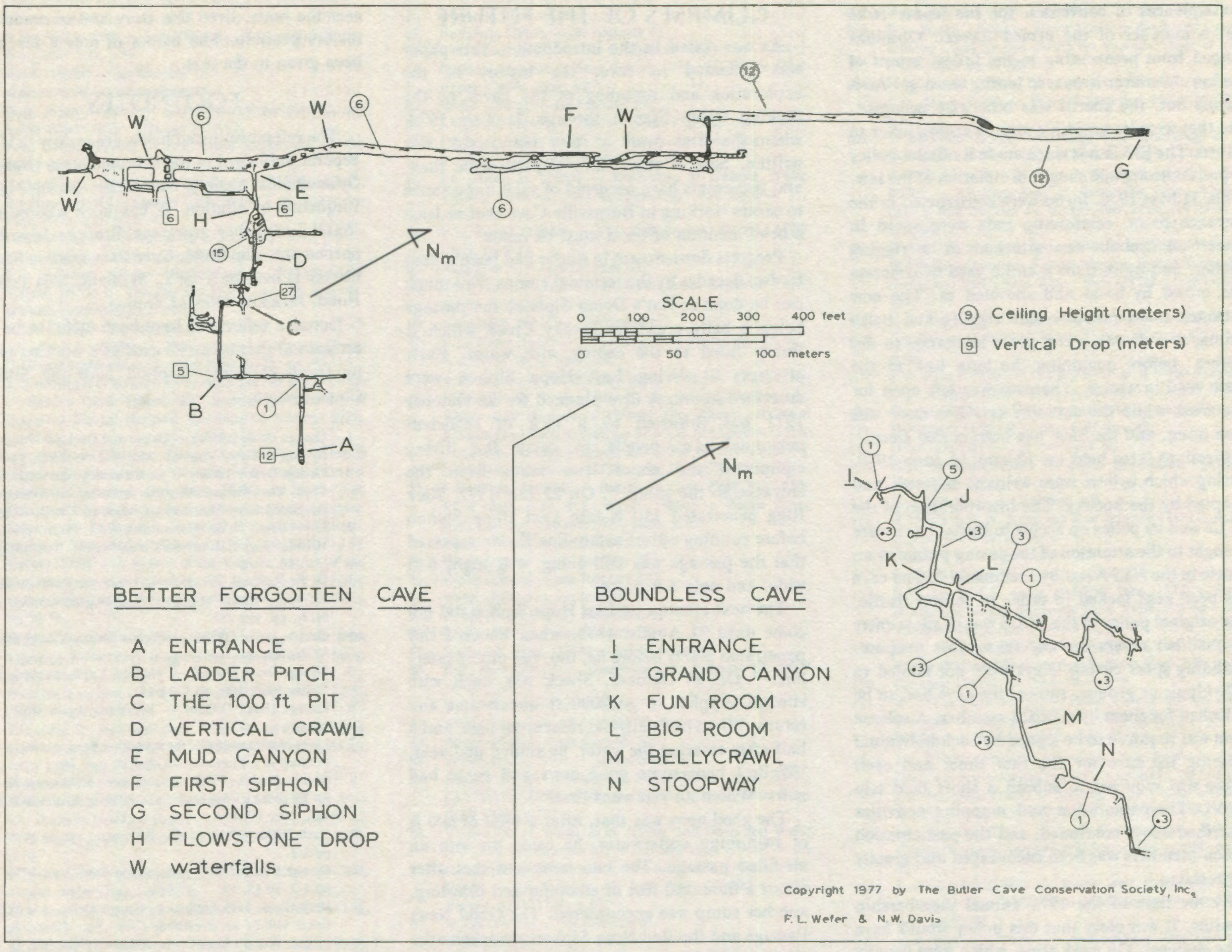


Figure 8. Sketch map of Better Forgotten Cave[109] and the composite map of Boundless Cave[128].

After an unauthorized party, including a nine year old boy and his parents, was discovered in the Moon Room, three large spikes were welded to the pipe so that not even a baby could have gotten under. The response to this was a return to the more direct method of breaking off the locks. The problem actually reached the point that it became necessary for every authorized party to carry a replacement padlock. There was naturally considerable apprehension on the part of the person responsible for controlling access, lest some unauthorized entrant be injured or locked in.

The idea of a society of concerned cavers to tackle these problems, rather than one private individual, was formulated in July 1968 by Nevin C. and Thelma Davis and Ike and Connie Nicholson. The idea was enthusiastically supported by a number of cavers approached as prospective members. On 2 November 1968, a group met in Nevin C.'s cabin on the Bullpasture River in Burnsville Cove, to form what became the Butler Cave Conservation Society, Inc. (BCCS). The first order of business was to secure a lease on the property containing the single entrance to Butler Cave. Along with this went legal access to the property, which was posted against trespassing. News of the formation of the Society was released to the caving public in the November 1968 issue of the *NSS News.* Plans were quickly made to replace the padlock system of entrance control and to incorporate the BCCS. By the second meeting, on 25 October 1969, the new gate was more than half completed. On 15 April 1970, the BCCS was incorporated under the laws of Virginia[132]. In May 1970, BCCS members presented a slide show and talk to the people of the Burnsville Cove area, the aims being to make the Society known to them and to establish better relations with the land owners.

Installation of the new cave gate was begun on 29 May 1970. Upon reaching the entrance, it was discovered that the lock had once again been removed. Work was nevertheless begun to enlarge the entrance hole. The entrance room breakdown block had previously been blasted, and the resulting smaller blocks were now removed. During this operation, a rope was discovered rigged in the pit. Someone was illegally in the cave! Later a very large pair of bolt cutters was found hidden in the entrance room.

Many hours of hard work by a dozen or more people resulted in the entrance room being cleared of rock and clay right down to solid limestone and the entrance hole being made large enough to accommodate the new gate. The steel frame was then welded and cemented into place. Because the gate is actually a solid steel door, a secondary entrance, much too small for people, was constructed for the bats.

The three people who had broken into the cave eventually appeared at the entrance pit, were ushered to the surface, and were detained while the sheriff was being summoned. It was discovered that the leader of the group was a "friend" of one of the BCCS members, knew that he would have been allowed entry if he asked BCCS members whom he knew to be in the area, but found it more "convenient" to cut off the lock. The question of what to do in such a situation had never been raised or discussed by the Society. No one knew exactly what the law was — whether its violation was a misdemeanor or a felony, what the possible penalty was, or the consequences of conviction for the leader (who was a member of the armed forces). Opinions ranged from prosecuting to the fullest extent of the law, whatever it was, to letting them go. As it turned out, the sheriff was otherwise occupied, and they were let go with a stern warning never to return. The BCCS has since made it official policy to prosecute anyone caught in violation of the law.

On 31 May 1970, forms were constructed in the entrance room, reinforcing rods were wired in place, an eyebolt was attached as a rigging anchor, and more than a cubic yard of concrete was mixed by hand and shoveled in. The new entrance room provides safe rigging and belay points, as well as a warm place to change to dry clothes before beginning the long trek to the main road in winter. The cave was left open for one week while the concrete set. The door was then hung, and the cave has been closed since.

Meetings were held on 13 and 14 June 1970, during which bylaws were written, debated, and adopted by the Society. The incorporation of the BCCS and its policy on access to Butler Cave were brought to the attention of the caving public in an article in the *NSS News* by Stellmack[133]. The cave has been kept locked in order to control traffic. The original policy of the BCCS was to allow entry to qualified cavers for any reasonable purpose, including sport caving. Keys were not mailed to individuals or groups, rather, the cave had to be unlocked for them by a BCCS member. A release form was required to be signed by each individual entering the cave for the first time, and each group was required to submit a short field trip report. The exploration and mapping activities described above continued, and the participation of non-members was both encouraged and greatly appreciated.

By the time of the 1971 annual membership meeting, it was clear that this policy would have to be changed. On work trips, which were usually led by BCCS members, vandalism was both avoided and actively discouraged. Areas visited mainly by sport cavers, on the other hand, had begun in only one year to suffer trash, carbide dumps, and trail markers. Regretably, the liberal policy of entry had to be changed. The BCCS now designates three or four weekends each year during which Butler Cave is open to responsible and capable persons who may enter unaccompanied to work toward Society objectives. These range from exploration, mapping, lead pushing, and digging to orientation and photography. At other times of the year, all cave trips, no matter what the objectives, must include a BCCS member.

On 11 February 1971, a meeting of the directors of the BCCS was held, at which a proposal for a comprehensive study of the Burnsville Cove area was discussed. The study was to be as complete in depth as practicable, and the results were to appear in *The NSS Bulletin*. A tentative list of papers and contributors was drawn up, and October 1972 was set as the target date for completion. This symposium, late though it be, is the direct result of that study.

GLIMPSES OF THE FUTURE

As was stated in the introduction, this paper was intended to cover the history of the exploration and mapping of the caves of the Sinking Creek System through January 1974, when the first draft of this manuscript was written. Several years have elapsed since then, and two events have occurred of such importance to cavers working in Burnsville Cove that at least a brief mention of them must be made.

Progress downstream in Butler had been halted for two decades by the terminal sumps. Not much can be done at Rat's Doom Siphon, the passage being a belly crawl in Sneaky Creek which is finally filled to the ceiling with water. Early attempts at diving Last Hope Siphon were described above. A dive planned for 23 October 1971 was thwarted by a lack of sufficient personnel, *i.e.* people to carry the diving equipment the almost two miles from the entrance to the sump[134]. On 22 July 1972, Rick Rigg penetrated 110 ft into Last Hope Siphon before running out of safety line[135]. He reported that the passage was still going, 4 ft high, 6 ft wide, and only 8 ft down.

The next attempt on Last Hope Siphon did not come until 31 August 1975, when Sheck Exley penetrated 500 ft before he, too, ran out of safety line.[136] On 24 October, Sheck was back with enough supplies to go 2000 ft underwater and return. When he finally did return, an hour and a half after entering the water, he smiled and said, "Well, I have some good news and some bad news. Which do you want first?"

The good news was that, after a total of 600 ft of swimming underwater, he came up into an air-filled passage. The bad news was that after about a thousand feet of stooping and crawling, another sump was encountered. The Good News Passage and the Bad News Siphon are schematically shown in Figure 7. A permanent guide line has been installed through Last Hope Siphon and more dives are planned

The second event of considerable importance was the purchase, in January 1976, by the BCCS, Inc. of the 65 acre farm on which is located the single known entrance to Butler Cave. Thus, the 25 members of the BCCS have taken it upon themselves to pay for a piece of property costing an amount comparable to the purchase price of Alabama's Shelta Cave and the NSS Office. And purely for conservation motives, since property owned by the BCCS, Inc. cannot be used for the monetary gain of the individual Society members. Only time can tell whether or not we few can do what it took almost 4000 NSS members to do!

ACKNOWLEDGEMENTS

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FOOTNOTES

The references listed below are mainly field trip reports published in the *Nittany Grotto* (National Speleological Society) *Newsletter*. Because of the frequency of citation, it has been abbreviated, *'NGN.'* All other grotto publications have been spelled out. The Butler Cave Conservation Society library is held by Toni L. Williams, 504 Delmar Road, Jackson, North Carolina.

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Wefer, F.L. (1982) — Surveying the Butler Cave — Sinking Creek System: *NSS Bulletin* 44:64-66.

SURVEYING THE BUTLER CAVE — SINKING CREEK SYSTEM

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SUMMARY

The Butler Cave Conservation Society inherited a map of the Butler Cave — Sinking Creek System which had been compiled from the work of numerous surveyors. Some of the survey notes have been lost, others are unintelligible. These have made the addition of maps of newly discovered passages difficult and have necessitated the resurveying of many sections of the cave. Current surveys are done with Brunton compasses and measuring tapes, are computer processed, and are stored in an orderly manner. Loops are adjusted to achieve closure by the Compass Rule. Radio location techniques were used in determining the relationship between Butler Cave and nearby Breathing Cave. Old survey data are being converted to machine-readable form; about two-thirds of the 100,000 ft of passages so far surveyed are machine readable.

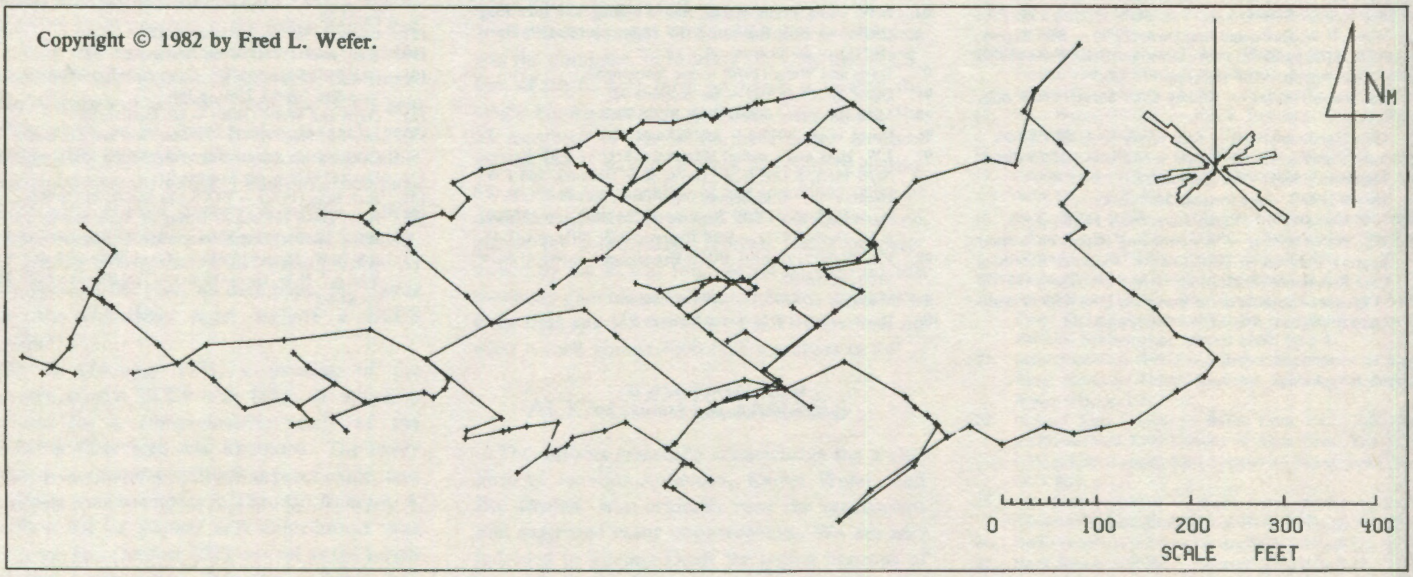
THE CURRENT MAPPING EFFORT in the Butler Cave — Sinking Creek System has evolved from earlier efforts described by Wefer and Nicholson in the preceding paper. The Butler Cave Conservation Society inherited a map drafted by a large number of people from the in-cave work of an even larger group. While some passages have been found to have been misplaced on the map, apparently during final drafting, experience has shown the map to be accurate in that no passage was shown which has not been located. There are, however, passages and leads in the cave system which are not indicated on the map. The tasks of tracing the history of these and, perhaps more importantly, tying their surveys into the existing traverse line are greatly facilitated when the old survey notes are available. The experience gained by Nittany Grotto cavers in mapping Breathing Cave led to a more-or-less standard system for taking the survey data in the cave, as described by Edwards (1958). This knowledge was handed down to succeeding generations of Nittany cavers, and some improvements were made. The result is that, for many of the early Nittany surveys in Butler Cave, the survey notes are both available and quite useful. Many areas of the cave were, however, surveyed by other groups. The survey notes of some of these are completely unintelligible, in so far as the in-cave sketches are concerned. These groups must have drawn nearly final versions of their maps quite soon after the survey trips and must have relied heavily on memory. No serious degradation in the quality of the final maps appears to have resulted, and the work of these groups is greatly appreciated; however, the lack of good quality in-cave sketches has caused some problems. For example, the addition of new passages to the map is difficult because the station locations often cannot be recovered. This, plus the loss over the years of some of the survey books and the discovery of much new passage, has resulted in many sections of the cave having to be resurveyed.

CURRENT MAPPING

The current mapping effort consists of three activities: surveying newly discovered passages, resurveying areas which were originally mapped with insufficient detail or for which the notes are needed but are not available, and the conversion of the survey data to machine-readable form. All current surveys are done with Brunton compasses and steel or fiberglass measuring tapes. In-cave surveys are done with hand-held Bruntons, both azimuth and inclination normally being recorded to the nearest one-half degree. Surveys of special importance are done with tripod- or unipod-mounted Bruntons. Distances are recorded to the nearest one-half foot. Some cavers habitually record distances to the nearest inch (or tenth of a foot). Although this "precision" is more than is necessary, old habits are hard to break and the practice is not objected to.

The holding of expeditions during which cavers from all over the eastern United States participate in work trips in the cave system has necessitated that the BCCS do some training in survey techniques. Note-takers are issued plastic clip boards containing survey note forms similar to

Figure 1. Plan view of the traverse line of the Duke Dump Section of the Butler Cave — Sinking Creek System, after tne loops were adjusted by the Compass Rule. This is one of the more complicated sections of the cave system.



those presented in the discussions of cave surveying techniques by Edwards (1958), Davidson (1967), Bridgemon (1970), and Freeman (1975). After computer processing, passage detail is transferred from the notes to a Calcomp plot of the traverse line. Occasionally, when the sketches are found to be intelligible only to their artist, he is required to make this transfer.

Experience with the data from the older surveys has shown that, to maximize their usefulness in the future, they must be processed and stored in an organized manner. Toward this end, each survey is labeled with the year in which it was made and with a letter to distinguish it from other surveys made during that year, e.g.: (73-A). The letters are not necessarily assigned in alphabetical order. The information about each survey is kept in a folder labeled with the survey name and the area, section, and cave in which it was made. A survey is considered complete when its folder contains the following: the original survey notes or a good xerox copy of them, a listing of the computer input containing the azimuth, inclination, and distance data as used in the processing, the printed output from the computer, a listing of the Cartesian coordinates of the stations, and one or more Calcomp plots of the traverse line (usually at a scale of 1:1200).

The techniques of processing cave survey data by computer have been extensively discussed by Wefer (1971). Reference should also be made to the report of Rutherford and Amundson (1974). Simple loops are closed by adjusting the data according to the Compass Rule. The closure errors normally are less than one percent of the perimeter of the loop. Multiple loops are handled by first closing the largest or outer loop in the area, its survey having been done with particular attention to accuracy. The interior loops are then adjusted, again by the Compass Rule, with the assumption that the coordinates of the end points are known without error. This procedure was discussed by Wefer (1971). It is used instead of a more sophisticated procedure, such as the least squares technique presented by Schmidt and Schelleng (1970), because of the desirability of processing the data as they become available and of not reprocessing the data as more interior loops are surveyed. The Calcomp plot of the traverse line of the Duke Dump Section of the Butler Cave — Sinking Creek System (Fig. 1) illustrates the complexity of multiple loops encountered. The plot shows data from five survey trips made over a two-year period by more than a dozen cavers. The effects of the adjustment of a loop survey by the Compass Rule have been presented in detailed mathematical analyses by Wefer (1974a, 1974b).

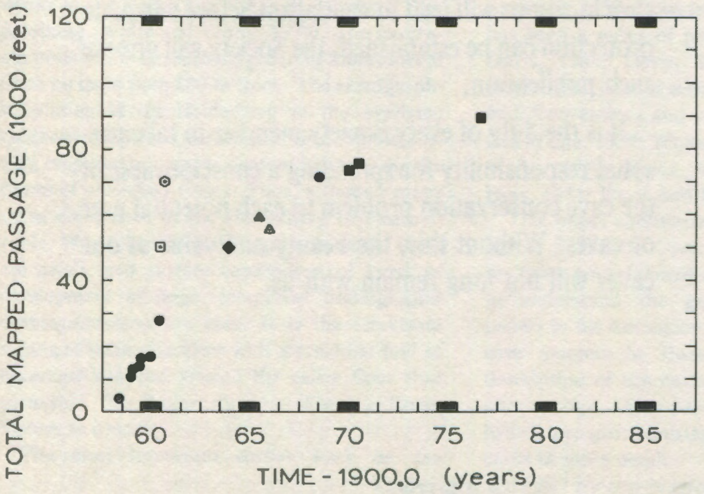
The work of determining the relationship between Butler Cave and Breathing Cave was complicated by the fact that the areas of nearest approach are far from the entrances. To eliminate a possible accumulation of errors in the underground surveys, the surface points over selected stations were determined by radio location techniques. These surface points were then connected by surveys. Radio location techniques have been discussed by Mixon and Blenz (1964), Plummer (1964), Mixon (1966), Charlton (1966), and references contained therein. Additional references and technical discussions have been given by Davis (1970a), who designed and built the units used in our work.

The master map of Butler Cave, showing the passage outline and some gross features of passage detail, is plotted at a scale of 1:1200. This single-sheet map provides a good over-view of the cave, but is physically too large (approximately 3 by 8 ft) and of too small a scale for many uses. Additional maps of the various sections of the cave are being drawn to a scale of 1:600 and will show all of the passage detail recorded by the survey team.

The Butler Cave — Sinking Creek System includes all presently traversable passages connected to the Butler entrance. Figure 2 shows total mapped passage length as a function of time. The early mapping efforts are represented by the steeply sloping line from 1958 through about 1961; progress was rapid during this period because the Nittany Grotto was mapping previously discovered passages. From 1962 through the present, the going has been slower, mapping having had to be preceded by pushing leads, digging, blasting, etc.

The author has undertaken to convert all survey data to computer-processed Cartesian coordinates, so that the complete traverse line of the cave can be plotted by computer. Progress on this project has recently been slow because of the lack of some of the old survey notes and difficulty in understanding others. As of 1 January 1980, the computer-plottable traverse line totaled 67,870 ft, or about 70% of the 100,000 ft of known passages.

Figure 2. Total mapped passage in the Butler Cave — Sinking Creek System as a function of time, from: White (1960, 1970) ●, Nicholson (1964) ◆, Hamilton (1965) ▲, and Davis (1970b, 1971, 1977) ■. The open symbols present data from authors not directly involved in the mapping: Cooper (1960) ⊡, Holsinger (1961) ⊙, and Halliday (1966) ▲.



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NSS POLICY FOR CAVE CONSERVATION

The National Speleological Society believes: That caves have unique scientific, recreational, and scenic values; That these values are endangered by both carelessness and intentional vandalism; That these values, once gone, cannot be recovered; and That the responsibility for protecting caves must be assumed by those who study and enjoy them.

Accordingly, the intention of the Society is to work for the preservation of caves with a realistic policy supported by effective programs for the encouragement of self-discipline among cavers; education and research concerning the causes and prevention of cave damage; and special projects, including coöperation with other groups similarly dedicated to the conservation of natural areas. Specifically:

All contents of a cave—formations, life, and loose deposits—are significant for its enjoyment and interpretation. Therefore, caving parties should leave a cave as they find it. They should provide means for the removal of waste; limit marking to a few, small and removable signs as are needed for surveys; and, especially, exercise extreme care not to accidentally break or soil formations, disturb life forms, or unnecessarily increase the number of disfiguring paths through an area.

Scientific collection is professional, selective, and minimal. The collecting of mineral or biological material for display purposes, including previously broken or dead specimens, is never justified, as it encourages others to collect and destroys the interest of the cave.

The Society encourages projects such as establishing cave preserves, placing entrance gates where appropriate, opposing the sale of speleothems, supporting effective protective measures, cleaning and restoring over-used caves, coöperating with private cave owners by providing knowledge about their caves and assisting them in protecting their caves and property from damage during cave visits, and encouraging commercial cave owners to make use of their opportunity to aid the public in understanding caves and the importance of their conservation.

Where there is reason to believe that publication of cave locations will lead to vandalism before adequate protection can be established, the Society will oppose such publication.

It is the duty of every Society member to take personal responsibility for spreading a consciousness of the cave conservation problem to each potential user of caves. Without this, the beauty and value of our caves will not long remain with us.

White, W.B. and J.W. Hess (1982) — Geomorphology of Burnsville Cove and the Geology of the Butler Cave — Sinking Creek System: *NSS Bulletin* 44:67-77

Geomorphology of BURNSVILLE COVE and the Geology of the BUTLER CAVE — SINKING CREEK SYSTEM

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SUMMARY

Burnsville Cove is a synclinal valley in Bath and Highland counties, Virginia. A doline karst, an elaborate underground drainage system, and the Butler Cave — Sinking Creek System are developed in the Silurian-Devonian Helderberg limestones. Large dolines occur in the upland portions of the cove. The cove is an underdrained valley terminating downstream at a large closed depression. Fitting the valley profile to exponential functions permits correlation of valley levels with terrace levels in the Bullpasture River.

The Butler Cave — Sinking creek System is composed of a central trunk channel along the synclinal axis with dip-oriented side caves. The overall pattern is a network maze with orientations controlled by the local joint pattern. The lower Clifton Forge sandstone exerts a prominent lithologic control, resulting in two interconnected tiers of caves and a locally perched drainage system at the downstream end. The cave contains a complex boulder and cobble fill that seems to represent a rapid infilling event of pre-Wisconsinan age.

Burnsville Cove is located in the Valley and Ridge Province of the Appalachian Highlands about 50 km west of Staunton, Virginia in Highland and Bath counties. The villages of Burnsville and Williamsville are situated near the southern and northern limits of the cove respectively. The northern boundary of the area discussed here is the Bullpasture River, a tributary of the James River, which is part of the Atlantic slope drainage. Burnsville Cove is a synclinal valley underlain by the Helderberg group of Silurian — Devonian limestones. Within the cove is the 23 km-long Butler Cave — Sinking Creek System, the longest cave in Virginia and one of the longest in the United States.

The Burnsville Cove karst is an interesting, perhaps unique example of a major cave and underground drainage system developed in the Helderberg group of limestones. The main developments of karst in the Appalachian Highlands are of two types: karst in the nearly flat-lying Mississippian limestones of the Allegheny and Cumberland Pleateaus and karst in the folded and faulted Cambro-Ordovician limestones in the Valley and Ridge and Great Valley provinces (White and White, 1979). The cavernous zone of the Helderberg group of limestones is often no more than 100 m thick. The stratigraphic relation of the Helderberg to the overlying Oriskany sandstone determines that the Helderberg crops out as narrow, sinuous bands along the flanks of secondary ridges. Thus, although many caves are known in the Helderberg in Pennsylvania, West Virginia and Virginia, many of them are small, and surface expressions of karst or development of large, integrated underground drainage systems are rare. It is the structural setting of Burnsville Cove with a synclinal fold of limestone wrapped around the valley floor that permitted the Butler Cave — Sinking Creek System to develop.

The most important earlier work on the Burnsville Cove area is that of Deike (1960a, 1960b), who made an intensive study of Breathing Cave. Descriptions of most of the caves have appeared in abbreviated form in the two surveys of Virginia's caves (Douglas, 1964; Holsinger, 1975).

Work on the geology of the Burnsville Cove caves has been underway intermittently since the discovery of the Butler Cave — Sinking Creek System in 1958. However, the only written output has been a series of progress reports (Hess and Davis, 1969; Davis, 1971; Hess, Davis, and Wefer, 1971) and a series of oral presentations at NSS Conventions and other meetings (Nicholson and White, 1959; White, 1965; Hess, Davis, and Wefer, 1970; Davis, Wefer, and Hess, 1970; Hess, 1971; Davis and Hess, 1974).

This paper summarizes the background geology of Burnsville Cove. Physical descriptions of the caves are presented only to the extent needed to understand the geology. Wefer (previous paper) in his discussion of the exploration of the cave systems in Burnsville Cove develops a description of the caves and their geographical relationships. Other papers which follow treat the hydrology, geochemistry and mineralogy of the caves in more detail.

THE GEOLOGIC FRAMEWORK

Physiographic Setting

The dominant landforms of the Valley and Ridge Province of the folded Appalachians are long, roughly parallel mountain ridges with intermediate strike-oriented valleys. Figure 1 shows the arrangement of ridges in the Burnsville Cove Area. Ridgetop elevations are in excess of 900 m, valley floors are at 450 to 550 m.

The principal surface stream in the region is the south-flowing Cowpasture River. One of its tributaries is the Bullpasture River, which flows southwest from McDowell along the axis of a shale-floored valley until it abruptly turns east, cuts a deep, narrow gorge through Tower Hill and Bullpasture mountains, and joins the Cowpasture River near Williamsville. The gradient of the Bullpasture is to the south while the gradient of Burnsville Cove is to the north. The Bullpasture maintains a well-developed flood plain through most of its length. The flood plain is at an elevation of approximately 550 m at the point where the river leaves the valley to enter the gorge. The Bullpasture deepens its channel very rapidly and is a steep-gradient, rough-run stream on a boulder/cobble bed through the gorge until it emerges at grade with the Cowpasture River at an elevation of about 500 m. The Cowpasture River also has a well-developed flood plain at this elevation. Figure 2 shows the flood plain elevations of the two principal rivers, the summit lines of the mountains and intermediate ridges, and the approximate gradients of the Burnsville Cove drainage.

Burnsville Cove is bounded on the west by Jack Mountain, which forms a continuous wall with no breaches of its Clinch sandstone cap. Streams rising on the eastern flanks of Jack Mountain flow

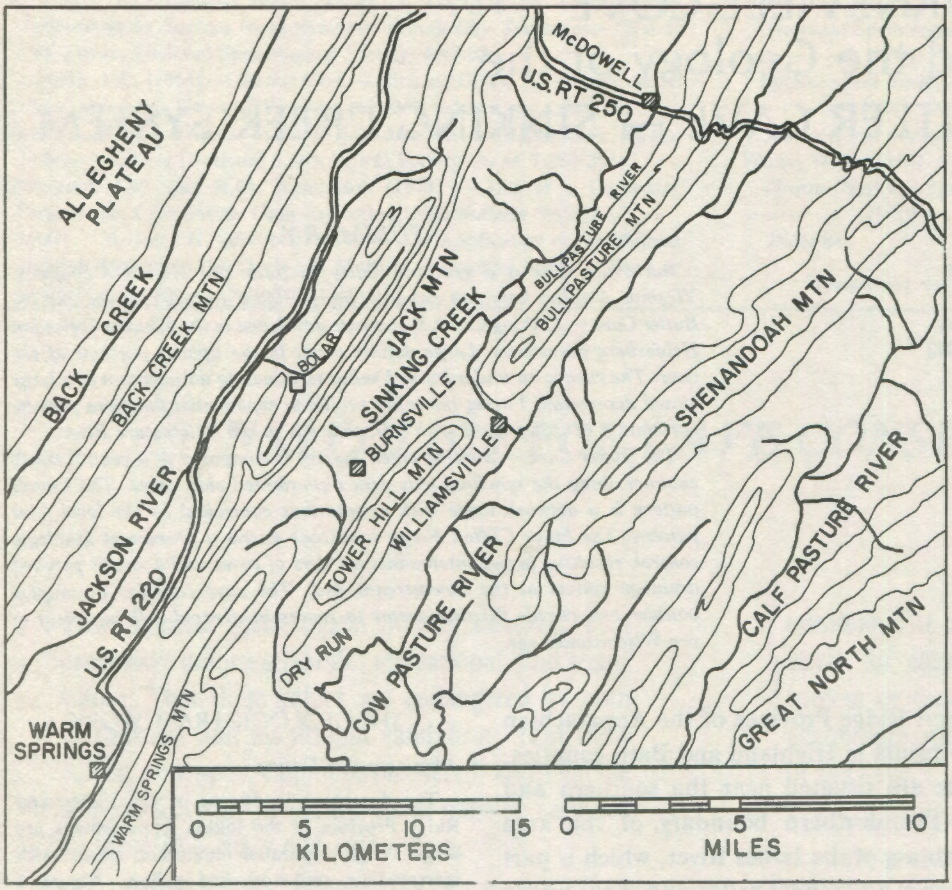
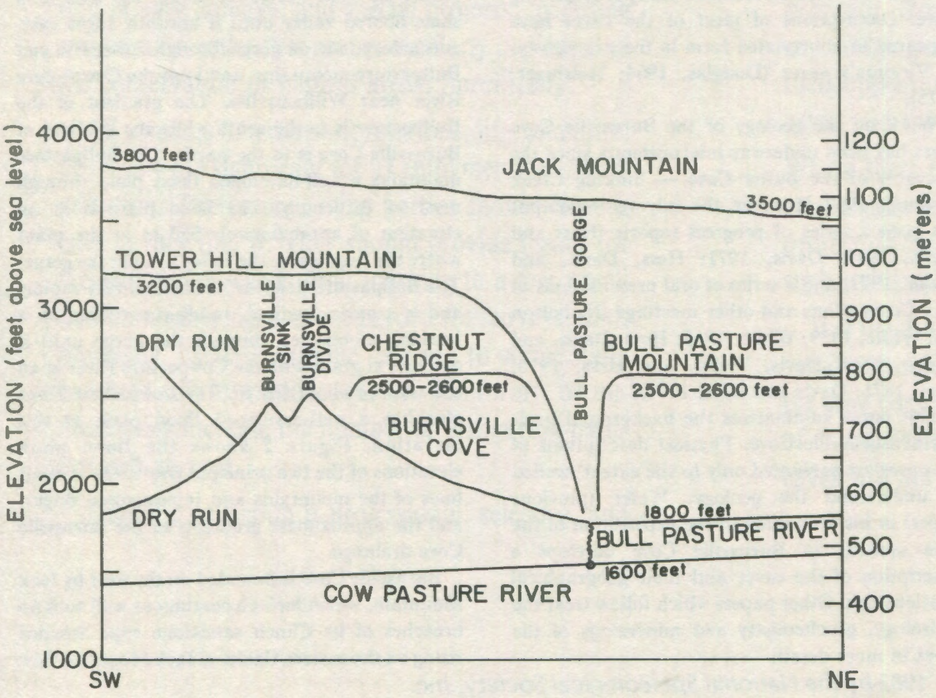


Figure 1. Sketch map derived from U.S. Geological Survey Charlottesville 1:250,000 sheet, showing drainage pattern and physiographic setting of Burnsville Cove.

Figure 2. River elevations, mountain summit elevations, and the valley profiles of Burnsville Cove and Dry Run Valley.



down into the cove, and many sink at the contact with the Helderberg limestone.

On the east, the boundary is Tower Hill Mountain. It is terminated on the north by the Bullpasture gorge and on the south by a nose. Some 4 km southwest of Burnsville, the complex folding caused by the arching axis of the Sinking Creek Syncline forms Warm Springs Mountain with a north-facing nose directed into the cove.

There is a drainage divide, now somewhat modified by karst processes, at Burnsville. North of Burnsville, Sinking Creek drains to the north and the valley thalweg joins the valley of the Bullpasture just upstream from the Bullpasture Gorge. Much of Sinking Creek is now underground, and the stream profile is broken at Water Sinks. South of Burnsville, Dry Run curves around the nose of Warm Springs Mountain, flowing first north and then near Burnsville flowing south to join the Cowpasture River around the southern nose of Tower Hill Mountain. Burnsville Cove is divided by Chestnut Ridge, formed by the Oriskany sandstone where it is brought to the surface by an intermediate anticlinal fold. Sinking Creek flows north along the west side of Chestnut Ridge; the valley on the eastern side, between Chestnut Ridge and Tower Hill Mountain, is drained by White Oak Draft which also heads near Burnsville.

General Structural Setting

The characteristic structural features are broad anticlinal and synclinal folds. These strike 40° NE and, as is characteristic of many Appalachian folds, are moderately dipping on the southeast limb and steeply dipping on the northwest limb. Some folds extend long distances, others plunge. There are numerous minor folds superimposed on the regional structural pattern. Small faults occur throughout the area, usually with throws of only a few meters.

The dominant structural feature in the area is the broad syncline underlying Shenandoah Mountain to the southeast of Burnsville Cove. Dips along the western limb of this syncline are gentle, and the valley of the Cowpasture River, west of the fold axis, is essentially a monoclinal structure. Dips steepen sharply under Tower Hill Mountain and under Bullpasture Mountain. Vertical to overturned beds are visible in the Bullpasture gorge. Bick (1962) maps a major fault that trends along the mountain crest.

Burnsville Cove is a complex structure. Chestnut Ridge on the southeast side is anticlinal with at least two distinct crests. The Sinking Creek Valley is a broad syncline. Jack Mountain, the northwestern margin of the area, is the southeast limb of a major anticline whose axis parallels Bolar Valley. In summary, reference will be made to these structures: The Shenandoah Mountain syncline, Bullpasture Mountain structural complex, Chestnut Ridge anticline, Sinking Creek syncline, and Bolar anticline. The Sinking Creek syncline plunges to the northeast, a structural feature of great importance in determining the pattern of the cave systems.

Deike (1960a) prepared a structural contour map of Burnsville Cove using the lower sandstone unit as a marker. Deike's map shows the Sinking Creek syncline, the double-humped character of the Chestnut Ridge anticline, and a second syncline under the valley of White Oak Draft. However, the structure is decidedly more complicated than the map indicates. Observations in the caves show very complex structure with many minor folds and small faults (throws from centimeters to meters). The lower limits of Breathing Cave are defined by a fold flexure that brings the sandstone ceiling down below the sediment level on the floor. Some crumpling of beds can also be observed.

The joint pattern in Burnsville Cove was also mapped by Deike (1960a). These data will be discussed later in conjunction with cave passage orientations. The dominant joints are oriented N50°W and are the dip joints of the region. Strike joints, oriented N40°E, occur but are less prominent.

Infrared aerial photographs taken on two northeast-southwest flight paths are available for the cove. These photographs reveal a number of lineaments that cross the cove more or less at right angles. Many of the tributary streams flowing from Jack Mountain seem to follow these lines of structural weakness. Mill Run, that carries the discharge from Lockridge's Aqua Cave, flows in a very straight valley that cuts across the bedrock structure and seems to be on a lineament. Cathedral Spring would appear on the same lineament if the lineament were extended across a meander bend of the Bullpasture River.

General Stratigraphic Setting

The rocks cropping out in Burnsville Cove and its immediate environs are limestones, shales, and sandstones of Silurian to lower Devonian age. The cave systems occur almost exclusively in the Helderberg group of limestones. The Helderberg rocks change rapidly in both thickness and lithologic character over short distances, and no detailed stratigraphic section is available for Burnsville Cove. Figure 3 shows a working nomenclature for the section, but it must be kept in mind that only approximate thicknesses are given for the individual units.

Two sections are given in Figure 3. The full section follows the traditional nomenclatures for these rocks drawn mainly from Swartz (1929) and Butts (1940). This is essentially the same column given by Deike (1960a), with several minor adjustments mainly in the placement of the Tonoloway-Keyser contact and in the placement of the Silurian-Devonian boundary. The thicknesses are also essentially those given by Deike. The detailed section of the Helderberg rocks (given at 2X scale) follows the nomenclature recommended by Head (1969) from his detailed investigation of the depositional environments of the Silurian-Devonian carbonate rocks.

Clinch Sandstone. The Clinch (Tuscarora) is a very hard light gray orthoquartzite with silica

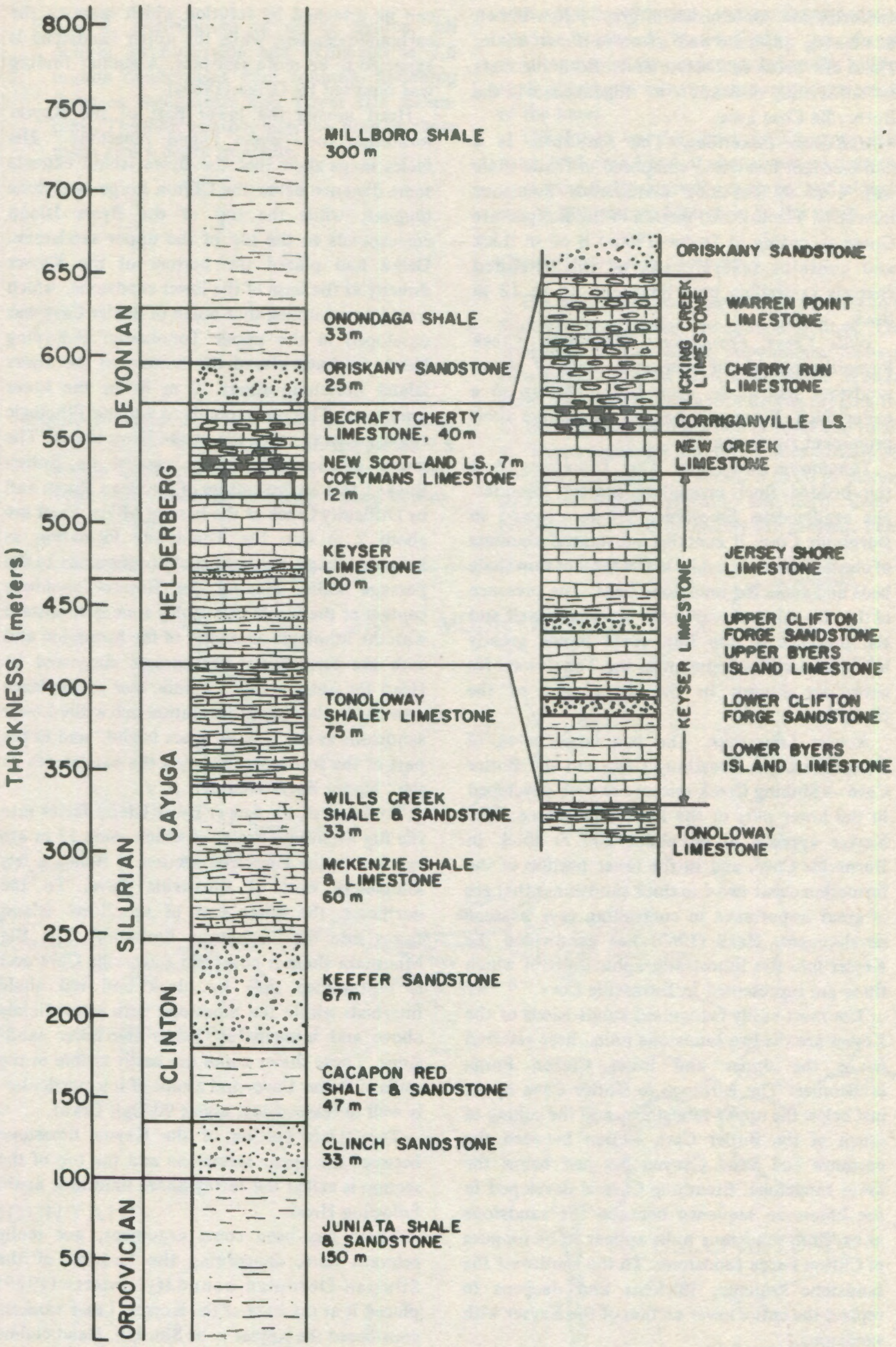


Figure 3. Stratigraphic section for the Silurian and lower Devonian rocks of Burnsville Cove. The left hand column is the traditional nomenclature following Swartz (1929) and Butts (1940). The right hand column is adapted from Head's (1969) lithostratigraphic descriptions of these rocks.

cement. It is one of the most resistent rocks in the Appalachians and is responsible for supporting the main mountain ridges. The Clinch forms the top of Jack Mountain and also appears along the crest of Tower Hill Mountain where it is brought up by the complex anticlinal folding. Clinch sandstone float occurs widely along the mountain slopes and is an important constituent of the cave sediments.

Clinton Formation. The Clinton in west-central Virginia is divided into the Cacapon and Keefer members. The lower contact with the Clinch sandstone is at the base of a red sandstone, siltstone and shale. The upper contact is at the base of the limestones of the McKenzie group. The Cacapon member is distinctive for deep red sandstones, siltstones and shales as distinct units. The Keefer member forms the upper two thirds of the formation and consists of gray, yellow-brown weathering quartzite and green-to-brown shale. These also occur as discrete units. Both members are sufficiently resistant to be ridgeformers in the Burnsville Cove area.

McKenzie Limestone. The McKenzie is a non-resistant formation composed of fissile shale with 4 to 60 cm-thick fossiliferous limestone interbeds. The exposed section in the Bullpasture Gorge according to Deike (1960a) is 60 m thick and contains several beds of thick-bedded coarsely crystalline blue limestone up to 12 m thick.

Wills Creek Formation. The Wills Creek formation consists of alternating beds of brown sandstone and shale, each bed being up to a meter thick. Some thin-bedded sandstones show prominent ripple marks.

Tonoloway Limestone. The Tonoloway is a thin-bedded, finely crystalline, sparsely fossiliferous argillaceous limestone. Where exposed in Burnsville Cove, it contains substantial amounts of clastic material usually in the form of thin shale beds and some red mudstone beds. The presence of the clay mineral within the limestone itself and the presence of the thin shale bands greatly inhibits karst development in the Tonoloway. No caves are known in the lower part of the formation.

Keyser Limestone. The two large caves of Burnsville Cove, Breathing Cave and the Butler Cave — Sinking Creek system are both developed in the lower part of the Keyser limestone. The Keyser appears to be about 100 m thick in Burnsville Cove, and in the lower portion of the formation occur two 4 m thick sandstones that are of great importance in controlling cave passage development. Head (1969) has subdivided the Keyser into five lithostratigraphic units of which three are represented in Burnsville Cove.

The most easily recognized subdivisions of the Keyser are the two sandstone units, here referred to as the upper and lower Clifton Forge sandstones. The entrance to Butler Cave opens just below the upper sandstone, and the ceiling of much of the Butler Cave section between the entrance and Sand Canyon lies just below the lower sandstone. Breathing Cave is developed in the limestone sequence between the sandstone units. Both sandstone units appear to be tongues of Clifton Forge sandstone. To the southwest the sandstone sequence thickens and deepens to replace the entire lower section of the Keyser with sandstone.

Thin section examination shows that the upper sandstone is a fine-grained orthoquartzite with sub-angular quartz grains held by a silica cement. Some carbonate cement and carbonate patches are present, but quartz cement is dominant. The lower sandstone is also a fine-grained orthoquartzite. The quartz grains are sub-angular and very similar to quartz grains from the upper sandstone, except that some have a wavy extinction. However, there is much more carbonate material and carbonate cement present in the lower sandstone. Thus, the lower sandstone can be attacked by solution which removes the carbonate cement, while the upper sandstone is expected to be more resistant. A similar finding was reported by Deike (1960a).

Head named the lower part of the Keyser formation the "Byers Island limestone." His facies maps show that the Byers Island extends some distance below the Clifton Forge sandstone tongues, while the top of the Byers Island corresponds to the top of the upper sandstone. Deike had placed the bottom of the Keyser directly at the base of the lower sandstone, which would have implied that much of Butler Cave was developed in the upper Tonoloway. Following Head, we have placed the bottom of the Byers Island limestone about 30 m below the lower sandstone. This corresponds to a major lithologic change seen in the walls of the Bean Room. The lowest stratigraphic levels reached by Rotten Rocks Creek in the bottom of the Bean Room and by Difficulty Creek at the base of Mikes Shaft are about 2 m into the Tonoloway formation as indicated by pronounced shale protrusions in the passage walls. Placing the Keyser-Tonoloway contact at the top of this shaley zone is consistent with the lithologic character of the formation and with the formational thicknesses suggested by Head for west-central Virginia. For convenience we refer to the Keyser formation below the Lower sandstone as the "Lower Byers Island" and to the part of the formation between the sandstones as the "Upper Byers Island."

To the west, the Lower Byers Island facies into the Big Mountain shale, of which some 12 m are exposed in the measured section at Bolar, a few kilometers west of Burnsville Cove. To the northeast, the lower part of the Byers Island facies into the Tonoloway limestone. The Big Mountain shale is absent in Burnsville Cove and is represented only by black and red shale interbeds within the limestone both immediately above and immediately below the lower sandstone. These shaley zones are easily visible in the walls of Butler Cave, and a zone of it is particularly well developed just above 90-Ugh Crawl.

The upper portion of the Keyser limestone between the upper sandstone and the top of the section is called the Jersey Shore limestone again following Head.

There has been some argument, not really relevant here, concerning the location of the Silurian-Devonian boundary. Swartz (1929) placed it at the base of the Keyser. Later workers considered the Keyser to be Silurian. Head claims on the basis of fossil evidence that the boundary is about one meter below the top of the Byers island limestone and it is so located in Figure 3.

Coeymans Limestone. The Coeymans overlies the Keyser limestone conformably. It is characteristically a massively bedded, medium gray, crinoidal, coarsely crystalline limestone. The best outcrop of the Coeymans limestone in Burnsville Cove is at Water Sinks, where the Siphon caves are developed at the Coeymans — New Scotland contact. It is called the New Creek limestone by Head.

New Scotland Limestone. The New Scotland is a medium brownish-gray, fossiliferous, finely crystalline limestone that appears to be only a few meters thick in Burnsville Cove. In the Bullpasture Gorge, it contains numerous thin cherty horizons. There is no evidence in Burnsville Cove for the Healing Springs sandstone that occurs at the base of the New Scotland in other parts of Virginia. Head advises that the term "New Scotland" be discontinued. His lithostratigraphic description of the Corriganville limestone is generally in agreement with the rock unit seen at the New Scotland horizon in Burnsville Cove.

Becraft Limestone. The Becraft is a gray, crystalline limestone with much interbedded black chert. It is exposed at Mill Run near the Bullpasture Gorge, where it appears to consist almost entirely of chert. Woodzell Sink, a large doline, has formed in the Becraft limestone. Deike (1960a) suggests 40 m of Becraft limestone in Burnsville Cove. This is in fairly good agreement with the total thickness of Head's "Licking Creek limestone" in this part of Virginia. To the north the Becraft facies into the Shriver chert.

Oriskany Sandstone. Overlying the limestone sequence is the Oriskany sandstone. It is a light gray, weathering to yellow-brown, medium to coarse-grained orthoquartzite. It becomes friable on weathering but is sufficiently resistant to support many of the upland areas of the Cove. The Oriskany caps a distinct hogback along the base of Jack Mountain and caps parts of Chestnut Ridge. The outcrop crosses the northern end of the Cove in an irregular line and caps many smaller hills. The Oriskany has likely played a key role in protecting many of the limestone foothills in the Cove as well as Chestnut Ridge and Bullpasture Mountain, permitting a number of limestone areas to stand out in high relief although the protective cap has now been removed.

Onondaga Formation. The Onondaga formation is an olive-green shale with beds of sandy shale, sandstone, and chert which unconformably overlies the Oriskany sandstone.

Millboro Shale. The Millboro shale is the lowest member of the thousands of meters of shales and siltstones that dominate the Devonian section in the Appalachians. It is a black fissile shale with large lenticular concretions. The Millboro outcrop occurs where the plunging Sinking Creek syncline carries the carbonate sequence below the land surface at the northeastern end of the cove and is the aquiclude responsible for artesian conditions in the carbonate aquifer.

KARST OF BURNSVILLE COVE

The karst of Burnsville Cove is bounded by the limestone contact at the foot of Jack Mountain on the west and the limestone contact at the foot of Tower Hill Mountain on the east. About a mile south of Burnsville, the rising axis of the Sinking Creek Syncline carries the limestone above the land surface, and the valley of Dry Fork is floored with middle Silurian shaley limestones and shales. North of Water Sinks, the plunging syncline carries the limestones below the Millboro shale thereby terminating any surface expression of the karst.

The karst on the crest of Chestnut Ridge extends along a band of nearly vertical limestone, across the Bullpasture River gorge, and along the top of Bullpasture Mountain to the north.

Closed Depression Features

The principal closed depression features in the Sinking Creek Valley are shallow dolines. There appear to be two doline populations. Some are very large, such as Burnsville Sink, Woodzell Sink, and several others with depths ranging from 15 to 50 m and with diameters from 100 to 1000 m. There occur few dolines of intermediate size; however, a number of small, 3 to 10 m diameter sinkholes which typically are fairly deep in proportion to their diameters are present. Few of

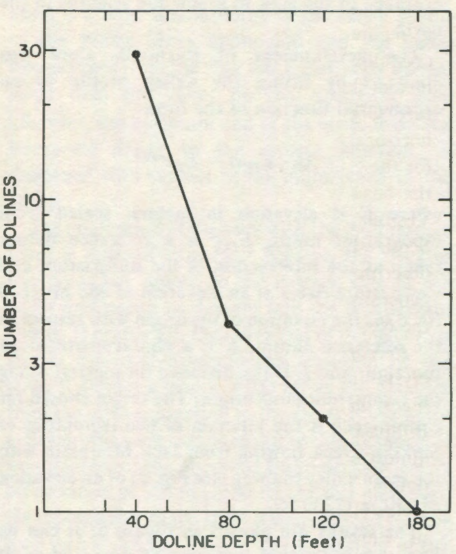


Figure 4. Distribution of doline depths. All dolines on Burnsville and Williamsville 7.5 minute quadrangles were counted, including those on Bullpasture and Tower Hill mountains. The 40-ft contour intervals used on these maps give 4 depth intervals.

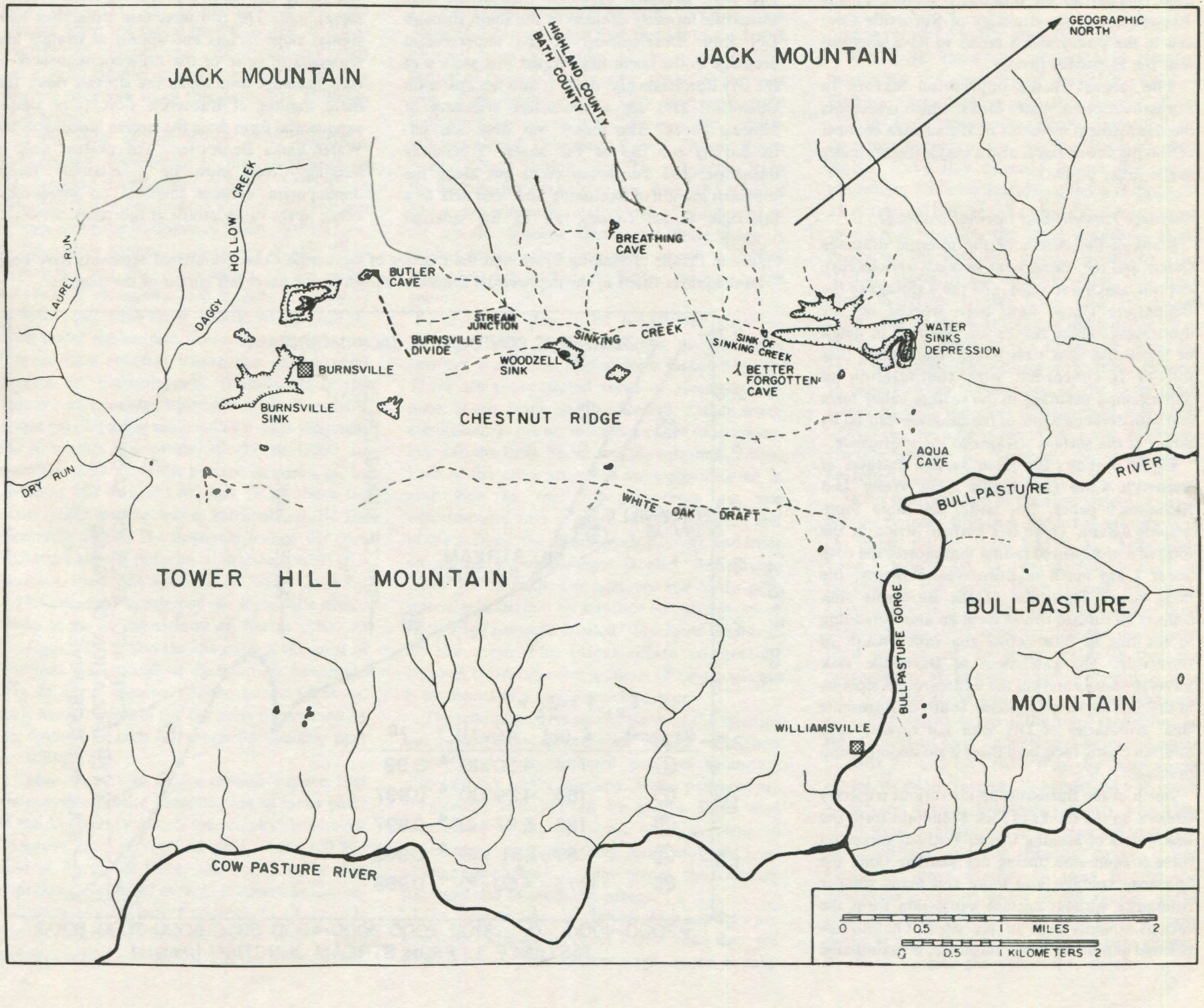


Figure 5. Burnsville Cove, based on U.S. Geological Survey Williamsville and Burnsville 7.5 minute quadrangles, showing drainage patterns, cave entrances and large closed depression features.

these are shown on topographic maps. The distribution of doline depths (Fig. 4) within Burnsville Cove appears to fit the general doline frequency-depth relations found in the Appalachian karst by White and White (1979) and in the Central Kentucky karst by Wells (1973), although the sample size is rather small for this sort of correlation. Many of the larger dolines occur at an elevation of about 760 m. Large dolines are also developed at this elevation on the crest of Bullpasture Mountain north of Bullpasture Gorge.

Very little is known about the internal structure of the Burnsville dolines. None occur in road cuts, and none have been excavated. Most are soil-filled and lie at fairly large distances above the known cave passages. The main passage of the Sinking Creek System passes directly under many of the smaller dolines, but radio location tests indicate depths of up to 100 m between the doline bottom and the cave.

The large sinks, particularly Burnsville Sink itself, appear to be intimately related to the development of the drainage of Burnsville Cove and to the piracy which seems to have occurred near the Burnsville divide.

The largest closed depression feature in Burnsville Cove is Water Sinks, which represents the downstream terminus of the surface channel of Sinking Creek and is also a major discontinuity in the valley profile.

Drainage Patterns and Internal Drainage

Many of the details of the internal drainage system and the connections between various cave streams, sinking streams, and the 4 springs in the Bullpasture Gorge have been worked out by dye-tracing. These results are reported in detail by Davis and Hess (this issue). The section that follows is concerned with the relation of underground drainage to the surface valley form and with derangements of the drainage caused by piracy of the surface streams to the subsurface.

Figure 5 shows the main surface features of Burnsville Cove (see Figure 1 in Wefer and Nicholson's paper, this issue, for more topographic detail). There is a surface divide in the form of a pronounced saddle that crosses the cove about 1 km north of Burnsville. However, the large closed depression of the Burnsville sink collects all surface runoff from an area extending to the line of hills across the valley south of Burnsville. The catchment of Burnsville sink forms the headwaters of the underground streams in the Sinking Creek System. South of Burnsville sink, tributaries of Dry Run fall rapidly onto Silurian clastic rock, and there is no underground drainage.

North of the Burnsville divide various tributary streams on the flanks of Jack Mountain form the headwaters of Sinking Creek. Without exception these streams sink during dry weather along the limestone contact, and these and many smaller tributaries without surface expression form the various streams seen in the cave. The surface channel of Sinking Creek, however, is maintained for a distance of 5 km along the axis of Burnsville Cove (more or less the axis of the syncline) to the ultimate sink point at the southern edge of the Water Sinks depression. Other tributary streams flowing into Water Sinks from the west also go underground at this point at the Siphon Caves. There is no surface channel downstream from the Water Sinks depression. The surface channel of Sinking Creek carries water only during periods of high runoff — spring snow melt or exceptional rains. Most seasons of the year the main stream bed is dry throughout its length.

On the east side of Chestnut Ridge, White Oak Draft also flows northward as a tributary of the Bullpasture River. This is a well-defined valley with a partial stream channel, but the entire upper reach of White Oak Branch is a dry or underdrained valley. The surface channel is degraded and the course of the valley is marked by a line of sinkholes.

Extension of the valley profiles of Sinking Creek and of Dry Run suggests that most of the area now occupied by closed depressions near Burnsville formerly drained to the south through Dry Run. Development of the underground drainage to the north has pirated this section of the Dry Run Basin and made it into the upstream catchment area for a subsurface tributary of Sinking Creek. The piracy was doubtless enhanced by the dip of the shaley Tonoloway limestone. The Tonoloway crops out along the southern margin of Burnsville Sink and acts as a lithologic funnel causing all of the internal drainage of the sink to follow the syncline to the north.

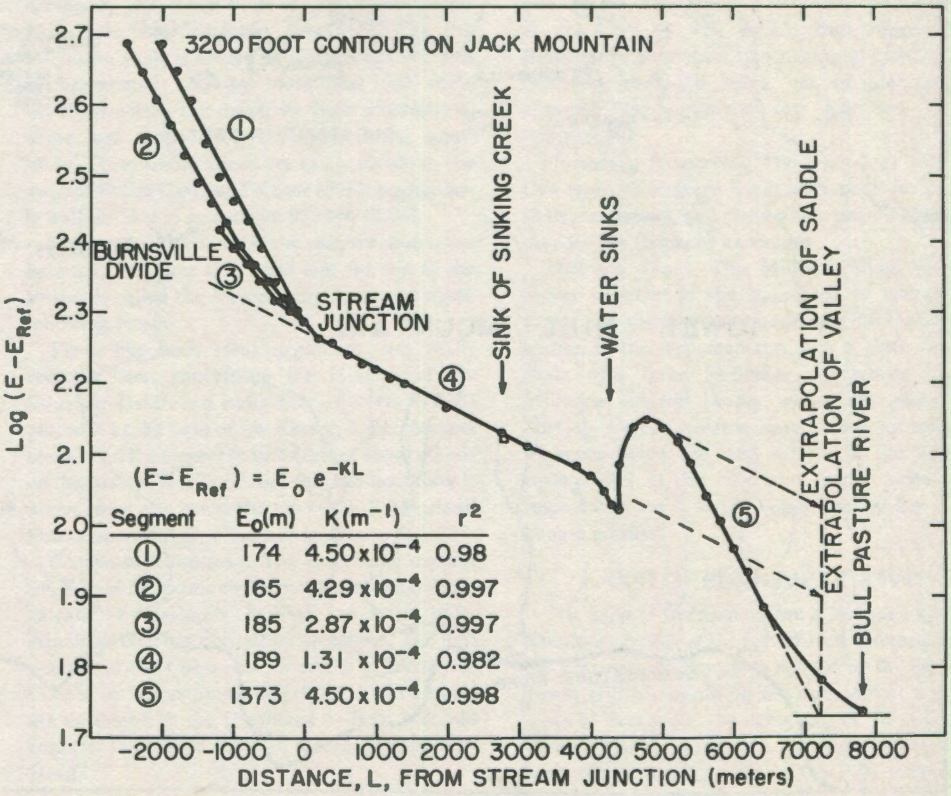
The development of Burnsville Cove was analyzed by fitting the valley profile to an exponential function of the form

$$(E - E_{ref}) = E_0 e^{-KL}$$

where E is elevation in meters, scaled from topographic maps, E_{ref} is a reference datum taken as the intersection of the Bullpasture and Cowpasture rivers at an elevation of 488 m (1600 ft), E_0 is the elevation of the origin with respect to the reference datum, K is a characteristic slope function, and L is the distance (in meters) along the valley from same origin. The origin chosen for convenience is the junction of two tributaries of Sinking Creek flowing from Jack Mountain with the main valley thalweg (see Fig. 5) at an elevation of 680 m (2230 ft).

The results are plotted in Figure 6. It can be seen that individual segments of stream channel and valley thalweg fit a simple exponential model rather well. The two mountain tributaries have similar slope factors and appear as straight line segments in spite of the different sequences of rock lithology over which the streams flow. The main thalweg of Burnsville Cove is of simple exponential form from the stream junction to the Water Sinks Depression. The present sink of Sinking Creek must be a relatively recent development because there is no measurable break in the valley profile at this point. However,

Figure 6. Profile of Sinking Creek and the thalweg of Burnsville Cove. Numbered segments have been least-squares fitted to the exponential functions shown in the lower left corner of the diagram.



there is a large discontinuity in the valley profile at the Water Sinks depression and the valley downstream from the sink has a distinctly steeper slope than the valley on the upstream side. Likewise, the upstream end of the cove, from the Burnsville divide to the stream junction, is steepened with respect to the main reach of the valley.

The confluence of the cove with the Bullpasture River is difficult to project because the river at this point has moved to the eastern side of the valley and begun its descent into the Bullpasture Gorge. If profile (5), the lower end of the valley, is simply extended down to the elevation of the river, it defines a length, 7200 m, as the distance from the stream junction to the river. If the main valley profile were extended out to this distance, it would intersect the ancestral Bullpasture River at an elevation of 566 m (1850 ft). At this elevation, the topographic maps show a well-defined terrace level into which the present day floodplain of the Bullpasture has been cut. It appears that the main valley floor of Burnsville Cove was left perched when the major portion of the drainage was diverted underground. The present day valley has a fossil profile, graded toward the position that the river had when this particular diversion took place.

If the crest of the Water Sinks saddle is extrapolated downstream to the bullpasture, it intersects the river position at 594 m (1950 ft), an elevation that corresponds to a series of accordant hilltops along the Bullpasture Valley to the north.

The saddle formed between the Water Sinks depression and the continuation of the valley occurs at an elevation of 628 m (2060 ft), only 37 m above the main valley profile when extrapolated under the saddle. However, this is in the downstream reaches where the exponential profiles are flattening out. If the crest of the saddle is extrapolated upstream to the Burnsville divide parallel to the main valley profile (Segment 4), it reaches the divide at 777 m (2550 ft) elevation, well above the present elevation at the divide at 750 m (2460 ft), and 76 m above the main valley profile when extrapolated to the Burnsville divide. The upstream end of the cove above the stream junction is oversteepened; if it were not, the divide would be at 704 m (2310 ft).

The ancestral location of the Burnsville divide seems to be in the vicinity of 760 m (2500 ft) elevation. This is also the elevation of the crest of Chestnut Ridge and of Bullpasture Mountain (Fig. 2), where numerous dolines occur. Likewise, there are remnants of the 760 m level preserved by the foothills to Jack Mountain particularly near Breathing Cave.

There appears to be an erosion surface that underwent extensive karstification in many parts of the Central Appalachians. In the Greenbrier limestone karst of West Virginia, some 100 km west of Burnsville Cove, the doline karst that appears as the Little Levels in Pocohantas County and parts of the Great Savannah in Greenbrier County occurs at or near the 760 m level. There are remnants of a doline karst in the Swago Creek Basin in Pocohantas County also at this elevation. It appears that the divide and ridge crests of Burnsville cove are correlated with a more regional epoch of karstification.

Further analysis of the valley profiles in Burnsville Cove and the relationships between the surface valley and the underground drainage system must await a more detailed leveling survey of the cave system, so that the actual slopes of the cave passages can be compared with the valley slopes in some detail.

GEOLOGY OF THE BUTLER CAVE — SINKING CREEK SYSTEM

Cave Patterns and Description

The physical description and general layout of the Butler Cave — Sinking Creek System are given by Wefer and Nicholson (this issue). Maps of the caves are given there.

The central feature of the cave is the trunk channel that extends from southwest to northeast closely paralleling the surface valley of Burnsville Cove but lying about 100 m below it. There are a series of tributary caves that slope into the trunk channel from both sides of the syncline. The largest of these tributary caves are all on the west side of the synclinal axis. They have been given individual names, such as "Butler Cave, "Pennsylvania Cave," "Huntley's Cave," "Moon Room Area," "Pat's Section," etc. The tributaries from the eastern side of the syncline, beneath Chestnut Ridge, are generally smaller and do not extend as far up the syncline flank. Breathing Cave is similar to the other side caves except that it is larger and has not thus far been connected to the system.

The overall pattern of the Butler Cave — Sinking Creek System, however, is that of a network maze (see Wefer, [this issue] Fig. 5). There are concentrated areas of closely-spaced maze south from Natural Bridge. Other maze areas occur at the northern end of the cave system between the Lake Room and the terminal sumps. Both of the areas are made more complicated in map view by the fact that there are two superimposed tiers of caves. At the southern end of the system, the main trunk passage underlies an upper tier of passages labeled "Mbagintao Land" on the map. The northern end of the cave system is underlain by a rather complex series of fairly large passages labeled "Marlboro Country" on the map. The intermediate connection between these extensive sections of cave passages is by means of a single trunk channel.

The tributary caves on the flank of the syncline are rather elongate network mazes with their largest and best-developed passages extending along the dip of the syncline. These passages are frequently interrupted by minor folds and contortions in the limestone bedding, some of which carry resistant ceiling beds below the level of the passage floor. At such places, the tributary passages end in sediment sumps.

The cross-sections of the tributary passages are generally rectangular, much higher than they are wide. A few elliptical tube passages occur, usually as cross passages connecting the main dip passages along the strike. The dip passages tend to be canyons 3 to 6 m in width and have ceiling heights ranging from 0 to perhaps 10 or 12 m. The cross passages in the mazes usually have lower ceiling heights.

The trunk passage has an extremely peculiar geometry. The cross-section from the Natural Bridge to a little below Sand Canyon is very large. There is an upper silt-filled level, of which Sand Canyon itself is a residual terrace, and there is an incised stream channel. This very large cross-section passage, 50 m in width, is broken by massive breakdown over which one must clamber in the reach of passage between Sand Canyon and Natural Bridge. Downstream from Sand Canyon the trunk passage first narrows, breaks into a distributary system, then widens again into another large breakdown complex in the Moon Room area. North of the Moon Room the trunk passage becomes considerably smaller, 3 to 6 m wide at the maximum, and 3 to 10 m high.

Structural and Stratigraphic Controls

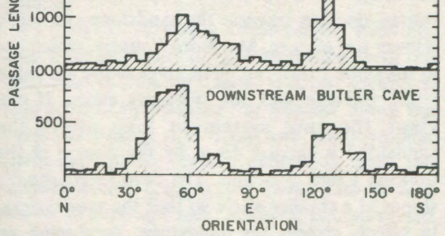
The most important stratigraphic elements controlling the geometry of the Butler Cave — Sinking Creek system are the fingers of the Clifton Ford sandstone which interrupt the limestone sequence (see Fig. 3). The entrance to Butler Cave lies directly below the upper sandstone. The cave descends quickly through the 21 m interval between the upper and lower sandstones and breaches the lower sandstone at the ceiling of the first Big Room. Breathing Cave (Deike, 1960a,b) lies entirely within this limestone horizon. Butler Cave and associated tributaries on the west flank of the syncline all lie in the Lower Byers Island limestone below the lower sandstone. The ceiling of the trunk channel at Sand Canyon is composed of the lower sandstone, so that the cave development essentially follows the bedding plane of the lower sandstone directly beneath it. However, the sandstone is breached again in two places.

In the southern end of the cave system, a single narrow passage breaches the lower sandstone to the upper tier of caves known as "Mbagintao Land," which lies in the intermediate 21 m interval of the upper Byers Island limestone. Downstream to the north, the trunk channel itself breaches the lower sandstone at the dry sumps (first pointed out by Haas, 1964) so that the northern end of the cave including several streams and the Last Hope and Rats Doom siphons are actually perched on top of the lower sandstone. In this area, the Lower Sandstone is breached again at Kutz Pit and by Crisco Way. By these access routes, one can traverse the sandstone and reach a lower tier of cave, Marlboro Country, which lies at the same stratigraphic interval as the upstream trunk passage and the tributary caves. If one views the cave system in long profile, the sandstone is carried down by the plunge of the Sinking Creek Syncline. The cave itself actually slopes at a smaller angle so that the cave system, in effect, crosses the sandstone, developing an additional upper tier at the upstream end and an additional lower tier at the downstream end.

Comparison of cave passage orientation with joint directions (Fig. 7) leaves little doubt about the joint control of passages in Butler and Breathing caves. There are two prominent joint directions, a strike set with a mean orientation of 50° and a dip set with a mean orientation of 130°. The deviation of dip joints about the mean is rather small, whereas the strike joints are broadly distributed from 30 to 70°. There is a similar distribution in the orientation of the cave passages.

Inspection of the Butler Cave map suggests that the passages upstream (south) of the Moon Room have a somewhat different orientation from those downstream. The passage orientation data were therefore plotted in two sets. The dip passage orientations are the same in both sections of the cave and also match those in Breathing Cave and the measured joint pattern. However, the upstream strike passages have a mean orientation of 65°, while the downstream passages have a mean orientation of 50° and well match the regional strike joints. The regional joint pattern was mapped by Deike, mostly from outcrops near Breathing Cave. It is possible that the fracture system that crosses the cave near the Moon Room marks the boundary between two joint blocks, and that the joint pattern south of the Moon Room has a somewhat different orientation. More data on the actual joint pattern are needed to resolve this point.

Figure 7. Comparison of cave passage orientations with joint pattern. The joint pattern and the orientations of Breathing Cave passages were scaled from rosettes published by Deike (1960a). The Butler pattern represents the accumulated survey length along each 5° orientation interval and were calculated by F.L. Wefer from the BCCS Survey data base. The upstream section contained 13,475 m of passage; the down stream section contained 7570 m of passage.



The general easterly dip of the rocks on the western flank of the syncline are broken locally by a large number of minor but highly contorted folds. Often the cave passages on the dip slope cut the folds without any evidence of interaction whereas the cross-passages sometimes are located directly along the minor fold structures. Sometimes the steeply plunging folds bring down the lower sandstone, which acts as a sediment trap. All dip passages in Breathing Cave are terminated in this manner.

Clastic sediments

The caves of Burnsville Cove contain a rich sequence of clastic sediments. On the west flank of the Sinking Creek Syncline, the dip-slope passages contain thick sequences of cobble and pebble fills which often block the passages completely. The trunk channel was at one time partly filled with cobble fills, and the present channel contains boulder-sized material. The passages on the east flank of the syncline where some cave passages extend upward into Chestnut Ridge contain mainly a sand and silt fill.

The cobble fills are found in Breathing Cave (Deike, 1960a) and in the Butler and Huntleys sections of the Butler Cave-Sinking Creek System particularly, although the fills appear in all passages on the west flank of the syncline. The thick sequences of silt, sand, and cobble material are generally very chaotic and very poorly and irregularly bedded. There is little in the way of well-developed stratigraphy that can be cross-correlated, and indeed definite beds are rarely developed. These materials have filled many of the dip passages all the way to the ceiling, and, even when the dip passages have been cleaned out by later processes, pockets of fill are frequently observed on walls and ceiling. The implication is that much of the tributary cave system was in fact filled with these materials sometime or times in the past, and that later processes have flushed them out to form the presently accessible cave.

The materials in the fills are sandstone pebbles and boulders probably derived from the Clinch, Cacapon, and Keefer sandstones on the flanks of Jack Mountain. Most of the boulders and cobbles are well-rounded implying transport by stream action. Angular fragments occur but are less common. The entire sequence is indicative of a catastropic infilling of the pre-existing cave system by colluvial materials flushed off the mountain sides.

There is a traceable terrace in the Trunk Passage near Sand Canyon that indicates that the trunk also might have been nearly but not completely filled with clastic sediment. Sand Canyon itself is a fragment of this terrace, a flat, silt-covered shelf at 713 m (2340 ft) elevation underlain by 2 to 3 m of cobbles. This terrace extends downstream for several hundred meters and can also be seen as the floor of the cut-around passage that leads to the rising of Sinking Creek and the Crystal Passage. Upstream from Sand Canyon, the upper level may be accordant with the top of the natural bridge, where there are several side passages that have thick cobble and boulder fills. Details are obscured by the massive breakdown that has occurred along this section of the Trunk Passage. Deike (1960a) mapped specific fill levels in Breathing Cave, particularly at 686 m (2250 ft) and 689 m (2260 ft). There appears to be a fill level at the Junction Room in Butler Cave marked by a remnant of flat gravel floor, now highly dissected (700 m, 2300 ft) and perhaps a second fill level at the top of the Bean Room (707 m, 2320 ft).

The upper reach of the trunk passage between Penn State Lake and the rising of Sinking Creek is dry during low flow conditions, but during periods of high runoff there is a large flow in the channel. The channel is cut 2 to 3 m below the terrace level. The channel has a boulder-choked bed with individual sandstone boulders up to a meter in diameter, suggesting something of the force of water needed to move the bedload. The walls of the channel are sharply cut through the pre-existing fills giving a good view of their stratigraphy. The fill material is seen (Fig. 8) to be composed of interbedded sand, gravel, and cobbles with little evidence for continuous beds or sequential deposition.

Although the source areas for the clastic sediments are fairly obvious, the time sequence of deposition is not. The very coarse size of the material, the lack of distinct bedding, and the choking of many tributary passages all indicate a catastrophic infilling by high velocity and high volume runoff from the mountain flanks. Present day runoff from the mountain does not have these characteristics, and indeed the evidence from the cave is that present day tributary streams coming down the dip passages are gradually removing the earlier fills. One might associate the fills with periglacial climatic conditions: times of intense weathering on the mountain flanks caused by deep freezing and frost pry of rocks during winters and rapid flushing of weathered material during cold and very wet summers. One must then ask: which glacial period? The evidence from the cave is that the clastic sediments are very old. Almost certainly they are older than Wisconsinan, and they may be very much older.

The channels that have been cut in the sediments in the Trunk Channel and in Huntley's Cave do not prove much; they could easily have been cut in post-Wisconsinan time. The main evidence comes from the Butler Cave Section, specifically the present day course of Rotten Rocks Creek. There are two major dip passages near the entrance of Butler Cave. The first (First Parallel Passage) is entered through the break in the Lower Sandstone at the top of Breakdown Mountain and can be followed down dip for 200 m until it is lost in a sediment sump. The second parallel passage heads in a terminal breakdown almost directly under the Butler entrance and can be followed down dip 150 m to an intersection where the usual route through the cave goes off to the south through a strike passage. If one crawls over the sediment mound that nearly blocks the Second Parallel Passage at the down-dip end, he abruptly comes out on an overhang of partly consolidated clastic sediment from which he can look downward to the present course of Rotten Rocks Creek flowing along the bottom of the Bean Room 30 m below. The field relations suggest that the Bean Room canyon passage has been cut *since* the deposition of the major influx of clastic sediments.

At the time of the influx of the cobble fills there were at least three major dip passages in the Butler Section to receive the deposits. These are the First and Second Parallel passages and Dave's Gallery, a third dip passage some distance to the south (see Fig. 4 in Wefer, this issue). All three received thick deposits of sediment. As the surface streams cut deeper, and the line of sinkholes at the foot of Jack Mountain also deepened, a small surface stream made its way into Dave's Gallery at its upstream terminus directly below the sinkhole at the Butler farmhouse. In time this stream opened a new more strike-oriented route to the north, crossing both the First and Second Parallel passages almost at right angles to and about 7 m below them. This passage (part of the original exploration route described by Wefer) also cuts across the Bean Room on a precipitous ledge some 7 m below the overhang described above and more than 20 m above the floor. From the crossing ledge, one can see masses of cobble fill wedged in alcoves and crevices near the ceiling of the Bean Room. Rotten Rocks Creek continued to deepen its channel, and at present it drops over Rotten Rocks Falls and flows across the bottom of the Bean Room, where it's course diverges from the top of the canyon high above. Overall, there appears to have been some 30 m of downcutting since the cobble fills were emplaced. It would seem to require that the cobble fills resulted from a Pleistocene event older than the Wisconsinan.

Where the fills are exposed in cross-section, there is no obvious evidence for more than one in-filling event. There are fill terraces at many different elevations that have been undercut by later events, but these have not been correlated in any quantitative way. Flowstone is sparse except in isolated localities, and datable interbedded flowstones have not been found. At the time this paper was written, the stratigraphy, lithology, and emplacement mechanisms of the fills are under investigation as an M.S. Thesis project at The Pennsylvania State University. Any further speculation on their origins seems premature at this time.

SOME UNANSWERED QUESTIONS

The objective of the collection of papers of which this geological discussion is a part was to present the state of knowledge of the Burnsville karst and caves as it had accumulated to the mid- to late-1970's. Many geological questions remain unanswered. It seems appropriate, therefore, to end this description of the geologic and geomorphic setting of the caves with a short list of what seem like productive questions for further investigation.

Sediment Depositional Sequences and Time Scale

The elaborate sedimentary sequence in the cave system should also be a time-climatic record of Pleistocene events. It will be necessary to devise some age-dating method so that the approximate time of sedimentation can be determined. If this can be done, an analysis of grain-size/passage-slope relations would provide information on the volumes of water necessary to transport the sediments, and this in turn could be related to precipitation and runoff conditions at the time.

Relation of Cave Development to Valley Development

The profile of Burnsville Cove (Fig. 6) has a simple exponential form in its main reach but is oversteepened at the head near the Burnsville divide and is disrupted by subsurface drainage at Water Sinks at the downstream end. The long profile of the cave (to the accuracy of the present survey data) appears to be largely an image of the surface valley lying 70 to 100 m above it. When extrapolated upstream, the cave shows the old position of capture of part of the Dry Run drainage from its former southward route to a north-bound path through the subsurface. Extrapolated to the northeast, the trunk (through Marlboro Country) seems to grade to Aqua Spring. The trunk passage, therefore, maintains at least in part a hydraulic profile with a slope related to the slope of the valley above. However, this simple picture is complicated by the influence of the lower Sandstone, which is responsible for the perching of the drainage in the July 6th Room — Dave's Lake — Last Hope Siphon area and perhaps for other irregularities in the channel as well. An accurate leveling survey and construction of a new long profile would be necessary to resolve the relative balance of hydraulic and lithologic controls on the development of the Trunk Channel.

Correlation of Burnsville Cove with Other Parts of the Appalachian Karst

There seems to be some special significance to the 760 m (2500 ft) elevation in central West Virginia-Virginia. In the Greenbrier limestone karst to the west, the most extensive karst area in the central Appalachians, there is a major karst surface at this elevation. An upland doline karst in the Swago Creek Basin, the doline karst of the Little Levels, and sections of the karst of the Great Savannah all occur at about 760 m. It has been correlated with the Harrisburg erosion surface said to be pervasive in eastern United States. A continuous correlation can be traced between the 760 m surface in Virginia-West Virginia and a valley upland surface at 366 m (1200 ft) in Central Pennsylvania which is also a major karst surface. It appears that this horizon of extensive karst development can also be extended south through Virginia and into the Cumberland Mountain karst of Tennessee, although relationships have not been worked out.

The Burnsville divide and many of the large closed depression features seem to occur not far below this horizon in Burnsville Cove. If there is such a thing as the Harrisburg Surface and if it is a horizon of extensive karst development in the central Appalachians, how does Burnsville Cove come into the picture?

Figure 8. Exposed section of sand and cobble fill in Trunk Channel 200 m downstream from Sand Canyon.

Where is the Third Tier?

There has been presented what is perhaps a deceptively simple model for the development of the caves of Burnsville Cove. The shaley Tonoloway limestone and the upper and lower Clifton Forge sandstones are folded into the shape of a trough sloping to the northeast. Runoff from the bounding mountain flanks drains into this trough and is carried down the sides of the trough to form the dip passages of the side caves. At the bottom of the trough, the flow makes a right angle turn and drains northeast toward the Bullpasture River and the spring outlets. Drainage from Jack Mountain now enters the limestone near the bottom of the cavernous zone, near the contact between the Lower Byers Island and Tonoloway limestones. At some time in the past, prior to the epoch of sediment infilling, the land surface was higher, the mountain slope had not retreated to its present position, and the drainage entered to carve out the major dip passages. These appear to reach the mountain side at the same elevation, about 732 m, and may represent a major period of cavern formation, taking place just below the 760 m karst surface.

Now consider a still earlier time when the land surface and the mountain slopes are even higher. Drainage coming from the mountain flanks would enter the system *above* the upper sandstone. The upper sandstone is less permeable than the lower one and one could imagine a perched system forming along the flanks of the syncline *above* the upper sandstone, a situation sketched in Figure 9. There are 50 to 100 m of limestone available for the cave to exist in. Where is the Third Tier?

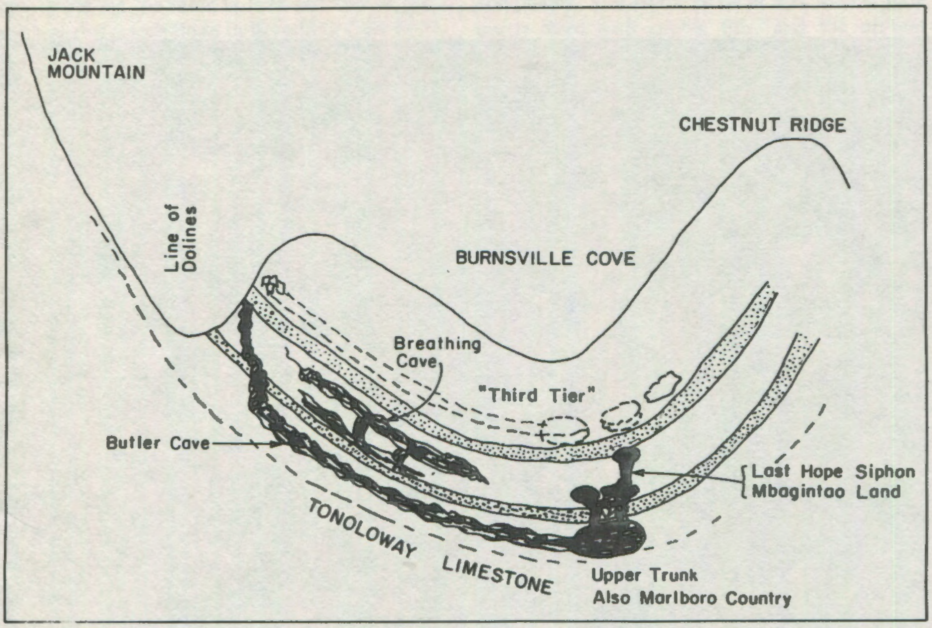


Figure 9. Cross-section sketch of the Sinking Creek Syncline, showing the relation of the caves to the upper and lower sandstones, and the proposed location of the hypothetical Third Tier.

(i) It may exist but have no entrance. Entrance formation seems to be an unlikely event in the geologic setting of Burnsville Cove.

(ii) The Third Tier did exist but has been completely choked with infiltrating sediment from the surface. The upper sandstone also acts to preserve the known cave, taking the same role as the sandstone caprocks in the Cumberland Plateau and southern Kentucky karsts. Passages remain open in the Butler Cave — Sinking Creek System because the sandstone prevents vertical piping and infiltration of soils from the valley above. The hypothetical caves in the Third Tier would not have this protection.

(iii) The Third Tier does not exist, at least as an integrated system, because the existing cave is related to the period of intense karstification associated with the 760 m erosion surface. The Third Tier would have been in a position for cave formation before the erosion surface was established.

Predicting un-discovered cave is a tricky business. Only future exploration will reveal whether or not a system exists above the Upper Sandstone.

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Hydrogeology of the Drainage System, Burnsville Cove, Virginia

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SUMMARY

A six year study was conducted to determine the recharge areas for the four major springs in the Bullpasture Gorge, West-Central Virginia. During this study, a total of 22 individual sink-to-spring dye tracings and 7 internal traces to the Butler Cave — Sinking Creek System were conducted. These enabled the determination of the spring recharge boundaries, which led to interesting observations of the interrelations between the basins and the spring flow characteristics. Included are descriptions of change in the flow regimes under flood and base flow conditions.

THE PROBLEM of the hydrogeology of Burnsville Cove, Virginia has attracted the attention of speleologists for many years. The first important study of the geology and hydrology of the area was done by Deike (1960), with particular emphasis on Breathing Cave. His study illuminated many topics concerning cave development and hydrology in the cove, but left many others untouched. Of particular interest was the relationship between the springs in the Bullpasture River Gorge and the sinking streams on the limestone uplands of the cove. The first stream tracing was done by Holsinger (1961) in December, 1960 and showed a connection between the Sinking Creek Cave System (E) and Aqua Spring (C) (Fig. 1). The question of what happens to the other sinking streams, how they relate to the geology and the springs, and how the springs behave under various flow conditions was not answered until this study, which began in 1967.

Carbonate aquifers and associated cave systems have been classified according to their flow types by White (1969) into three categories: diffuse flow, free flow, and confined flow. Each of these flow types is controlled by the hydrogeologic setting. The Sinking Creek Cave System in Burnsville Cove is an example of a confined flow artesian aquifer. Actually, only part of the drainage system is artesian today; the rest is free flow. The artesian flow situation is caused by an impervious bed that is folded in such a manner as to force ground water to flow at depth under hydrostatic pressure.

For detailed discussions of the geology and geomorphology of the cove and associated cave systems, see Deike (1960) and other articles in this Bulletin issue. In general, the carbonate aquifer consists of the Tonoloway and Keyser limestones, with two sandstone tongues of the Clifton Forge formation playing an important confining role.

Drainage from the clastic rock slopes of Jack and Tower Hill mountains (Fig. 1) encounters the limestone at altitudes of 600 to 750 m, where it usually sinks. The subterranean drainage from Aqua and Emory Spring drainage basins first flows down the dip of the enclosing limestones, where it is confined to particular beds. At some point, usually near the synclinal axis, the water flow assumes a direction parallel to the strike and then crosses the structural grain to emerge at the two springs in the Bullpasture River Gorge at elevations 540 m and 538 m respectively. Drainage from the Cathedral and Blue Spring drainage basins also appears to be influenced by structural and stratigraphic controls from its sources to springs on the Bullpasture River.

CLIMATIC SETTING

Burnsville Cove receives an average of 1051 mm of precipitation per year. It is fairly evenly distributed, but a maximum occurs during the early summer and a minimum occurs in late fall. The mean temperature is 10.7°C with a mean July temeperature of 21.3°C and a mean January temperature of 0.3°C. A summary of the monthly climatic conditions is given in Table 1. Using the Thornthwaite method (Thornthwaite, 1948), a potential evapotranspiration of 634.5 mm was calculated for the area. Using the above values for precipitation and evapotranspiration, the runoff can be calculated by subtracting the evapotranspiration from the precipitation. In this way, a mean annual runoff of 416 mm was calculated. The mean annual runoff for the Bullpasture River basin above Williamsville, Virginia is 389 mm based on 11 years of records (1961-1971). These two runoff values are in good agreement, considering that the 1960's was a period of below average precipitation.

GENERAL HYDROLOGY

Twenty-two individual sink-to-spring tracings and 7 tracings within the Sinking Creek Cave System were conducted over a 6 year period, using the tracing procedure described in the appendix. The results of these tracings are shown in tables 2 through 6.* The transit time for the dye is expressed, in most cases, as a time less than *t* number of days, since in most cases the dye had already passed when the detectors were recovered. In two cases, Sneaky Creek and Breathing Cave, detectors were changed every 12 hours and the actual time of the dye pulse peak was observed. It should be noted that

* Tables 2 through 6 have been deposited in the NSS Cave Files. Any reader may obtain free copies upon application to: Cave Files Committee, Cave Avenue, Huntsville, Ala. 35810.

TABLE I. Summary of Climatic Data for Burnsville Cove Area, Virginia.

	MEAN TEMPERATURE		MEAN PRECIPITATION	
	°C	°F	mm	in
January	0.3	32.6	76.5	3.01
February	0.9	33.6	72.1	2.84
March	4.5	40.1	99.8	3.93
April	10.5	50.9	79.2	3.12
May	15.6	60.1	93.2	3.67
June	19.6	67.2	105.9	4.17
July	21.3	70.3	106.2	4.18
August	20.5	68.9	118.1	4.65
September	17.1	62.7	81.8	3.22
October	11.4	52.6	74.7	2.94
November	5.3	41.6	70.4	2.77
December	0.8	33.4	73.2	2.88
Year	10.7	51.2	1051.0	41.38

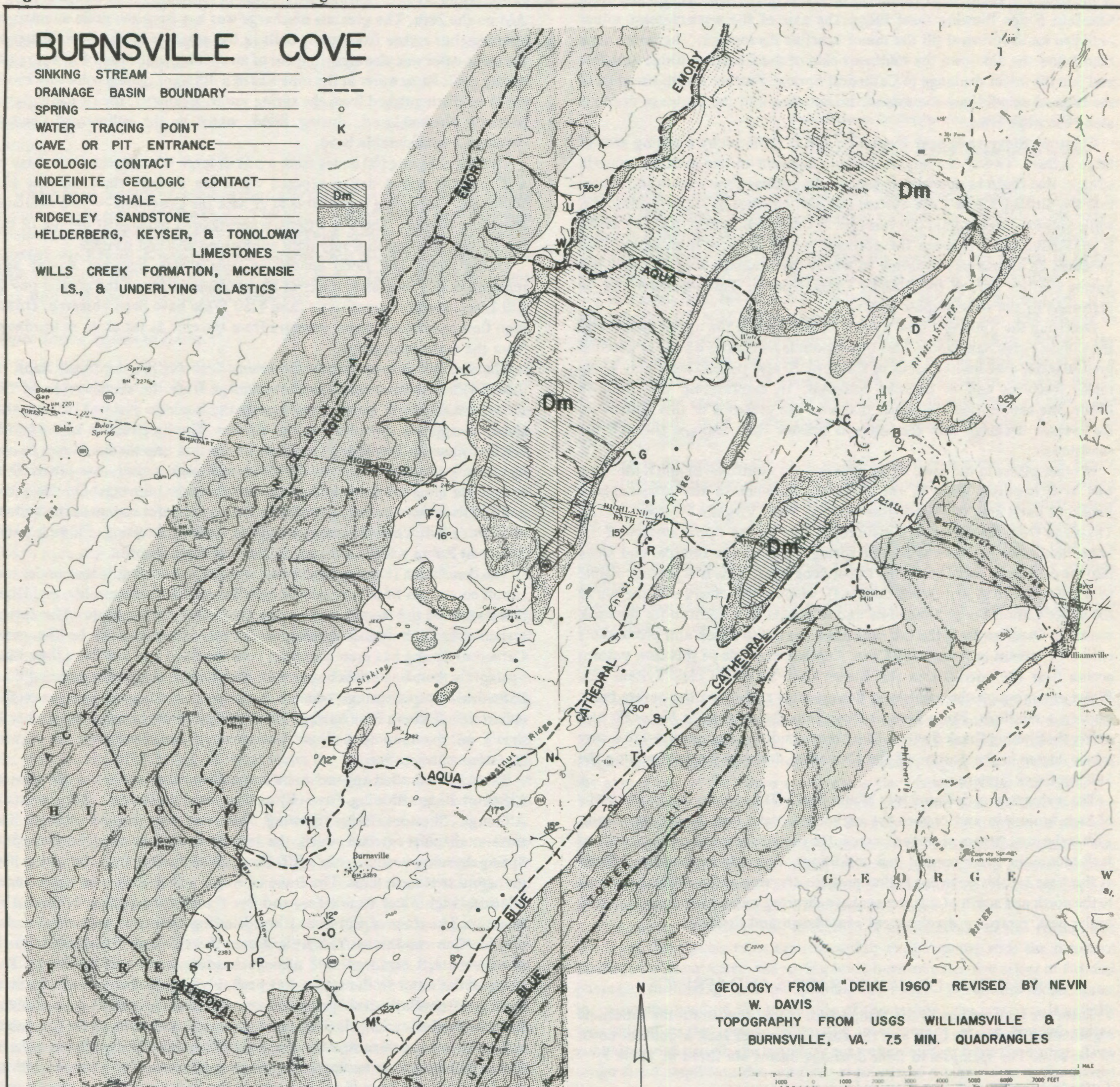
during a 6 year period, the stream discharge varied considerably and because the dye transit time is a function of discharge, the transit time also varied considerably. Tracings were attempted at medium and low flows to avoid dye loss due to adsorption on suspended clay and silt and to prevent large variations in the transit time.

Spring discharge measurements were made with a current meter; all of the discharge measurements indicated in tables 2 through 6 were estimated by measuring the channel cross-section at a place that was more or less uniform and timing the flow of water through a measured length of the channel.

The individual dye tracings, along with topographic and geologic considerations, were used to delineate the drainage basins of the four springs along the Bullpasture River. Drainage divides on the clastic rocks were simply the surface drainage divides. Divides on the carbonate rocks were not as obvious. Of particular interest was the drainage divide between Aqua and Cathedral Springs.

It was hypothesized that Chestnut Ridge, the anticlinal ridge that bisects Burnsville Cove, must be a divide between these two springs. If no artesian conditions exist under the ridge, clastic rocks underlying the carbonate rocks

Figure 1. Burnsville Cove and environs, Virginia.



should act as a block to water crossing the regional strike. Dye tests in Better Forgotten Cave (I), Chestnut Ridge Blowing Cave (R), Woodsal Sink (L), and Burn's Chestnut Ridge Cave (N) placed the divide between Better Forgotten and Chestnut Ridge Blowing Cave and between Burns' Chestnut Ridge and Woodsal Sink. A check of the dip and strike near Chestnut Ridge Blowing Cave showed that, even though it is on the northwest side of Chestnut Ridge, it is near the crest of a local anticline. Deike (1960, p. 31) indicates a minor syncline plunging northeast in the crest of the Chestnut Ridge anticline at this point, effectively breaking the crest of the major anticline into two minor anticlines and a minor syncline. This minor flexure in the structure could help explain the direction of the drainage. Water from Chestnut Ridge Blowing must follow the axis of the western-most minor anticline southwestward till the minor syncline disappears. The water must then follow the dip down the southeast side of the Chestnut Ridge anticline and join the major drainage to Cathedral Spring. Further south, the crest of the ridge closely follows the axis of the anticline and the drainage divide is along the ridge crest.

Chestnut Ridge ends near Burnsville and is replaced by a rolling area of large dolines. Two of the largest dolines, adjacent to one another, contain streams that drain in opposite directions. Boundless Cave stream (H) drains into the Sinking Creek Cave System (E) and emerges at Aqua Spring (C), while Jackson Cave stream (O) resurges at Cathedral Spring (B). The divide is considered to be between the drainage basins of these large sinks. This produces an anomalous situation in which the drainage area of Cathedral Spring overlies part of the Sinking Creek System. This situation can be explained by the stratigraphic setting.

Overlying the Sinking Creek System in this area is the upper member of the Clifton Forge Sandstone. This impervious layer creates a body of perched ground water over limited areas of the cove. Water penetrates it only along major fractures and at massive collapses. In determining the drainage divide, the assumption was made that with the presence of this aquiclude, the surface drainage into the sinks is greater than leakage through the sandstone.

In other places in the cove, water bypasses the sandstone in much the same way as it bypasses shale in the Pickaway member in the Mississippian limestone karst area of Pocahontas County, West Virginia (Werner, 1972). The water from the upper carbonate rocks flow on the upper surface of the impervious layer to a nearby hillside spring, flows on the surface, and sinks into the carbonate rocks below the impervious layer. This is especially visible near the entrance to Armstrong Cave (M), where water emerges at the top of the upper Clifton Forge Sandstone and is caught in a bathtub for livestock watering. Overflow from the tub runs down the hill to a sink and presumably enters the stream in Armstrong Cave. Another example of this flow pattern occurs near the entrance to the Butler Cave-Sinking Creek System (E). Water emerging on the sandstone flows across and down the access road, causing a mudhole. From here, it flows into the Burnsville Sink (H) and enters the Sinking Creek System. The above condition was observed to a very minor degree in the portion of the Cathedral drainage basin overlying the Sinking Creek System.

The major stream draining into Water Sinks (J) heads on the clastic rocks of Jack Mountain and crosses the carbonate rocks next to the mountain. This is the only stream observed to cross the carbonate rocks on the flanks of Jack Mountain under normal flow conditions. The only explanation offered at this time for this behavior is that perhaps the very active sinking streams to the north and south of this stream have diverted water away from this area in the past, retarding development of underground drainage.

INDIVIDUAL DRAINAGE BASINS AND SPRINGS

There are four springs in the Bullpasture Gorge that drain the limestone highlands of Burnsville Cove and the eastern flank of Jack Mountain north of the cove. The springs and their drainage basins are listed in Table 7.

Cathedral Spring and Blue Spring Drainage Basins

The boundaries of the basins are shown on Figure 1. The combined basins stretch from the crest of Jack Mountain on the west to the crest of Tower Hill Mountain on the east and include the valley southeast of Chestnut Ridge. Both Cathedral (B) and Blue (A) Springs are included in one discussion because their drainage bains are closely interrelated.

Blue Spring (A) emerges from a submerged solution passage about 1.2 m high and 0.8 m wide. The passage floor slopes steeply downward out of sight. Divers have penetrated the spring to a depth of 15 m and report that it continues along a joint on a bearing of 290°. The middle Keyser Limestone at the spring dips 75° northwest.

After a storm on 27-28 May 1973, Blue Spring was observed discharging orange-brown water at a rate of 910 l/sec. Precipitation during the storm ranged from 50 to 75 mm and fell from approximately 5 PM on the 27th to 7 AM on the 28th. The greatest discharge was not from the main submerged opening, but rather from many boils in the adjacent spring pool. Water of the same color was also squirting out of an opening in the road 1 m above the spring pool. River water at the time was of a different muddy color and could easily be distinguished from the spring water. Evidently, the spring outlet is partially blocked, and, during flood, water in the submerged conduit develops a considerable head.

Cathedral Spring (B) issues from a pile of large talus blocks at the base of a 27 m cliff whose upper exposed parts are Becraft chert dipping 12° southeast. The spring is probably at or near the Coeymans — New Scotland limestone contact. There is a tight, water-floored passage at the top of the talus slope, leading to a very tight submerged solution passage.

Under storm and flood conditions, this spring becomes muddy and remains cloudy long after the river has cleared. Although the normal flow is 130 l/sec, storm flows of more than 4250 l/sec have been observed. Under high flow conditions, water emerges from the cliff as far as 45 m upstream from the main resurgence.

The vertical to near-vertical limestone beds on the northwest flank of Tower Hill Mountain capture the drainage from the clastic rocks of the mountainside. Most water flows among the boulders just out of view and slowly disappears upon leaving the clastics. The limestone is covered with clastic colluvium that sharply restricts infiltration into the limestone. In one dye tracing of a surface stream (T) which splits and sinks in two places 30 m apart, dye emerged from both Blue and Cathedral Springs. On the other hand, during wet weather, dye placed in an ephemeral stream at the bottom of Robin's Rift Cave (S) emerged only at Cathedral Spring. Flowing water occurs in Robin's Rift Cave only in times of high runoff.

The conclusion that can be drawn from the dye tracing is that under low runoff conditions Blue Spring drains the Tower Hill mountainside. At higher flows some of the runoff reaches the Cathedral Spring basin. The spring response to high runoff conditions further shows this to be the case. Cathedral Spring has more variation between flood and low flows than Blue Spring; further, bacterial counts show that Blue Spring is less polluted than Cathedral or Aqua springs, because there are no dwellings or pastures on the mountainside above Blue Spring. The drainage divide between the springs is shown on the map to be just downslope of the Tonoloway — Keyser limestone outcrop line.

Table 3 shows what appears to be anomalous behavior for the dye trace in Chestnut Ridge Blowing Cave (R) as compared to Robin's Rift Cave (S). Although Chestnut Ridge Blowing Cave has the shortest straight-line traverse distance, it had nearly the longest transit time in the Cathedral Spring drainage basin. Robin's Rift Cave, 900 m further from the spring had the shortest transit time. The trace of Robin's Rift Cave was done under relatively high water conditions, and dye transit time is directly related to flow rate.The trace of Chestnut Ridge Blowing Cave was performed under very low flow conditions. This little stream flowed slowly from pool to pool, to where it left explored cave passage heading south and southeast. The route of the water to the spring was probably long and circuitous. In fact, detectors from Cathedral Spring still tested positive 14 and 39 days after the first positive indication, showing the dilution and stretching of the dye pulse.

There are no surface streams of any significant size on the clastic rocks of Tower Hill Mountain except during flood conditions. The average width of the drainage area from the ridge crest to the first limestone outcrop is only 550 m whereas on Jack Mountain this distance is 1200 m. A distance of 550 m must not be sufficient to support a perennial stream.

TABLE 7. Spring Drainage Basins of Burnsville Cove.

Basin	Spring[3] Horizon	Altitude[3] (meters)	Drainage Area (Km^2)	Low Flow Discharge (1/sec) 28 Oct 72	25 Aug 73	Discharge Per Unit Area (1/sec/km^2)		Coliform[4] Count MPN/100ml
Blue Spring	Keyser limestone	519	3.8	52	60	13.7	15.8	11
Cathedral Spring	Coeymans-New Scotland contact	522	10.9	131	170	12.0	15.5	33
Aqua Spring	Keyser limestone	540	20.0	273	138	13.6	6.9	79
Emory Spring	New Scotland-Becraft contact	538	12.1 (±10%)	163	109	13.4	9.0	8
Bullpasture River below springs			284.9	3370[1] 1458[2]		11.8 5.1		

1. Mean discharge over 5 years August 1960 — September 1965
2. Mean discharge for October over 5 years 1960 — 1964
3. Deike (1960)
4. Most probable number of coliforms per 100 ml of water.

Under flood conditions, some of the water falling on the Cathedral Spring drainage basin escapes to the south. This water is from the 3.9 km^2 drainage basin of Daggy Hollow Run (P) and the small stream to the southwest. Under normal flow, all water in these streams sinks into the carbonate rocks and emerges at Cathedral Spring. Overflow during flood conditions enters Dry Run and flows south to the Cowpasture River.

Aqua Spring Drainage Basin

Aqua Cave Spring (C) flows from an underwater opening 0.6 m high and 2.7 m wide at the base of a 9 m cliff of Keyser limestone, which dips 22° southeast. Diving in the spring led to the discovery of Aqua Cave. The stream that feeds the spring can be followed 0.6 km through a vadose passage, which averages 9 m wide and high, to a sump. Here, the upper Clifton Forge sandstone dips downward toward the axis of one of the many minor folds which complicates the structure and the passage is constrained to follow the sandstone downward. The siphon has been penetrated 120 m to a depth of 25 m by Hank Hoover. At this point the passage is 1.5 m high and 3.6 m wide and still leading downward. A map by Hoover and Kutz (1962) shows the terminal siphon to be 12 m above the spring. The water from the spring drops another 21 m in reaching the river.

After any storm, Aqua Spring rapidly becomes muddy. Flow has been measured at 4810 1/sec. Greater flow rates have been observed but not measured.

The boundaries of the Aqua Spring Drainage Basin are shown in Figure 1. These boundaries are essentially the same as those of the surface Sinking Creek, with the inclusion of the Burnsville Sink (H) and the Mill Run valley. Unlike the other drainage basins studied, this one has but one outlet. Except for evapotranspiration losses, no water leaves the basin except through Aqua Spring (C) under all flow conditions. Even when the sinks on the flanks of Jack Mountain are unable to carry flood flows, the overflow streams sink at either Water Sinks (J) or the Sink of Sinking Creek (surface) (G).

In at least three cases, Sink of Sinking Creek (surface) (G), Water Sinks (J), and Woodsal Sink (L), the sinking streams go underground in formations stratigraphically higher than those containing Breathing Cave (F), the Sinking Creek System (E), and Aqua Spring (C). This indicates that the water is able to penetrate the upper Clifton Forge sandstone in places.

On 23 and 24 October 1970, a tracing experiment was run to determine which, if any, of the major streams in the Sinking Creek System traveled through the stream passage in Better Forgotten Cave (I). To this end, different tracers were placed in the three major streams in the Sinking Creek System: 11 kg of NaCl in Sneaky Creek, 160 g of fluorescein in Sinking Creek, and 250 g of Rhodamine B in Slippery Creek. A careful measurement of the stream flows was made at the same time. Twenty-four hours later the stream in Better Forgotten was tested for the presence of tracers. None were found. Experience has indicated that under the existing gradient, the dye pulse should have passed in 24 hours and the duration of the pulse of detectable dye should be at least 10 hours. The above results are inconclusive. Convincing evidence that the Better Forgotten stream is independent of the Sinking Creek System water is that the stream discharge at Better Forgotten was smaller than that of any of the streams leaving the Sinking Cree System. It is possible that the source of the stream in Better Forgotten is Woodsal Sink. This relationship has not been verified.

The tracing from the stream at the bottom of Better Forgotten Cave (I) to Aqua Spring (C) is of interest because of the low gradient. The change in elevation from Better Forgotten stream to Aqua Spring is 18 m; however, the change in elevation to the sump at the upstream end of Aqua Cave is only 6 m. This gives a gradient of about 3.4 m/km, compared to the 33.6 m/km gradient of the vadose portion of Sinking Creek in the Sinking Creek Cave System. Surely most of the passage from Better Forgotten to Aqua is completely flooded.

There is evidence in the form of obliterated footprints that the Better Forgotten stream passage floods to a depth greater than 12 m. This flooding could come from two causes: If there is a constriction in flow downstream of the sump in the cave, flood waters entering the cave could simply pool behind it. Another explanation is that since Better Forgotten is only 6 m above the upstream sump in Aqua, flood waters from all the major streams feeding Aqua Spring simply back up into Better Forgotten Cave. In either case, the cave acts as a reservoir and feeds water to Aqua Spring as the other inputs begin to recede.

Emory Spring Drainage Basin

Emory Spring issues from the base of a cliff of Becraft chert at its contact with the New Scotland limestone. State route 678 runs along the base of this cliff at the river's edge, and the spring opening is buried by the road fill. Fifty meters northeast of the spring, the Becraft dips 11° northwest toward the axis of one of the minor synclines on the Chestnut Ridge anticline.

The response of this spring to a flood pulse can best be illustrated by observations made during a storm on 8-9 July 1970, when it rained 100 mm in 19 hours. Between 17 and 41 hours after the rain stopped, Emory was observed to be gushing clear water. Afterward, the spring became muddy with a very high flow rate. Ten days after the rain stopped, Emory spring had resumed normal flow but the water was still murky.

This storm response is very indicative of the structure of this spring. For the input flood pulse to be carried rapidly to the spring with the resultant discharge of clear water, the spring must have an extensive series of flooded passages containing a large quantity of water. When the flood water increases the head on the input side of the system, the response is rapidly transmitted to the spring. When the total storage of the flooded spring conduits is exhausted, the muddy input water emerges from the spring. Even under flood conditions the complete expulsion of all the water in the system required more than 60 hours. A quick calculation indicates a flooded volume of between 10^4 and 10^5 m^3.

Observations of Aqua and Emory springs after a storm on 5-6 October 1972, which yielded 122 mm, indicate a similar response. Less than 12 hours after the rain started, Aqua was gushing chocolate-colored water and Emory was spouting clear water. In the 1970 storm, the river crested 1.5 m above normal, about one hour after the rain stopped. Forty hours later, the river had dropped to within 0.2 m of normal level but was muddy with water from springs. Obviously, Aqua Spring has either a shorter series of submerged passages than Emory or has an input close to the spring. The river has a faster response to flood waters than either of the springs.

Bacterial counts show Emory spring to be the least polluted of the four springs, indicating that the recharge area for this spring is similar in character to that of Blue Spring. The drainage basin for Emory Spring is shown on the map (Fig. 1). Located north of the Aqua Spring basin, it extends from the crest of Jack Mountain down the southeast flank to the Ridgeley Sandstone outcrop. Streams originating on the Clinton formation sink on the limestone outcrop under normal flow conditions. Under flood conditions, the sinks overflow and the water crosses the Millboro Shale and empties directly into the Bullpasture River. Four dye tracings were conducted in the Emory Spring basin. These tracings were sufficient to accurately determine the southern boundary of the basin. The northern boundary was not determined as accurately because of an apparent shift in the basin boundary at different recharge rates. This area is now being more intensively studied. Sufficient information exists, however, to determine the basin area to within 10%, as shown in Table 7. The last two tracings listed in Table 5 are identified only by coordinates, since they lie north of the area shown on the map (Fig. 1).

INTERNAL DRAINAGE OF BUTLER CAVE — SINKING CREEK SYSTEM

Some interesting observations have resulted from dye tracing and visiting the Sinking Creek Cave System (Fig. 2, p. 87) at various water levels. Difficulty Creek, which collects water from the sink at the entrance of the cave, disappears into a small passage at (5). This water crosses under the main stream passage and emerges at (10), the Sinking Creek resurgence. About 250 m from the main stream passage, water following the Complaint Section Canyon (11) drops down a pit and disappears into a hole too small to explore. This water evidently follows the same pattern as Difficulty Creek, even though the dry passage continues to its intersection with the main stream passage near Sand Canyon (12).

Water from near Penn State Lake (3) and from the sumps beyond Natural Bridge (4) both emerge at the Sinking Creek Resurgence (10). These streams completely fill the passages they follow. The water during base flow conditions has found a new lower route around the main stream passage from Penn State Lake to the Sinking Creek Resurgence. Under flood conditions, the small bypass passages cannot transmit all the flow. The water in Penn State Lake rises about 3 m and a stream flows from it to the sump beyond Natural Bridge (4). When the small passages in this area can no longer handle the flow, water backs up and floods the passages to a depth of about 3 m. Water then flows out of these passages, under the Natural Bridge, and down the main stream passage past Sand Canyon (12) to join the waters from the Sinking Creek Resurgence.

Downstream, Sinking Creek disappears into a passage too small to explore (1). It reappears in several side passages further downstream and finally disappears near the Dry Sumps (13), only to reappear in Marlboro Country as Stream #1 (7). This passage to Marlboro Country is too small to explore, but is large enough to carry all the water under most flood conditions. This passage is probably much more recent than the large passage through the Dry Sumps (13) and down Sneaky Creek (14). Probably, the ancient flow direction was up through the Dry Sumps and down the French Passage (14). This would be very similar to the flow conditions described previously in the upstream sections of the cave.

Sneaky Creek (14) now flows to Rats Doom Siphon (15) and on to Aqua Spring. The cross-sectional area of the passage near Rats Doom Siphon is small compared to that near Last Hope Siphon (2). Most likely, in times past, water in the passage now containing Sneaky Creek went through Dave's Lake (9) and on to Last Hope Siphon (2). High flood water even now may do the same.

The dye tracings from the Hanging Rock Room (8) to Dave's Lake Area (9) and eventually to Last Hope Siphon (2) show that the present low-water streams do not flow preferentially through the large passages. They cut beneath passages and through walls seemingly at random. It would appear that the cave is still undergoing a period of active stream downcutting and solution below the present vadose levels.

Water leaves the explored passages in the Sinking Creek System through 5 sumps. Two of these, Last Hope (2) and Rat's Doom Siphons (15), are the most accessible and are well known to most explorers of the cave. These sumps are above the lower Clifton Forge sandstone, which separates Marlboro Country from the overlying French Passage (14). Last Hope Siphon occurs when the upper Clifton Forge Sandstone ceiling dips below the water level.

In Marlboro Country (16), Sinking Creek is joined by a stream of equal size and by another, smaller stream, to form the largest stream in the cave. This exits the cave through a sump (17) and flows to Aqua Spring. Two other sumps (18, 19) terminate canyons carrying smaller streams in the poorly explored Marlboro Country section of the cave. They join the Sinking Creek Stream beyond their sumps.

CONCLUSIONS

The carbonate aquifer of Burnsville Cove is developed in folded and jointed Tonoloway and Keyser limestones, with two sandstone tongues of the Clifton Forge formation acting as confining layers. Surface drainage from the clastic rock slopes of Jack and Tower Hill Mountains generally sinks upon encountering the carbonate rocks. Subterranean drainage in general follows structural and stratigraphic controls from its source to springs along the Bullpasture River.

Drainage basins of four major springs along the Bullpasture River (Blue, Cathedral, Aqua Cave, and Emory springs) have been delineated by dye-tracing experiments and characterized by observations of spring discharge behavior. Results of these measurements are summarized in Table 7. Two low-flow measurements and their resulting discharges per unit area are given because of the different results under different flow rates. They apparently indicate two different sets of flow conditions or basin characteristics in response to past precipitation events. On 28 October 1972, the discharges per unit area were essentially the same for all 4 drainage basins, but on 25 August 1973, they were different, those for Aqua and Emory springs being significantly lower than those for Blue and Cathedral springs.

Three major factors control the discharge pattern of a spring: 1) precipitation amount and distribution, 2) surface basin characteristics, and 3) aquifer characteristics. The interaction of these factors may vary between basins, causing the springs to behave differently, and explains why two different sets of values were obtained for the springs along the Bullpasture River.

Precipitation amounts and distribution within time and space were different before the two sets of measurements. Previous to the 28 October 1972 measurements, it rained 16 mm after a relatively dry three-week period. Prior to the 25 August 1973 measurements, it rained 6 mm after a relatively moist previous month.

Surface drainage basins can vary in percentage of carbonate and non carbonate rock, which will affect the rates and volumes of recharge. An individual carbonate basin can vary in size and point of recharge to the aquifer. Surface and subsurface divides do not necessarily correspond. A change in the point of sinking of a surface stream may change the underground basin that it recharges, thus affecting the drainage area of the spring and its apparent discharge per unit area. The surface basins of Burnsville Cove do vary in the above ways, which helps to explain the variations observed between springs.

Carbonate aquifer characteristics, such as length and openness, flow path, and storage, will affect the rate and volume of water movement within it. Differences between springs thus might be explained by the amount of water in storage and the openness of the flow path. It has been shown that the Burnsville Cove springs do behave differently under high flow conditions, indicating variations in flow path and storage characteristics between basins.

The carbonate basins studied represent 17% of the Bullpasture River drainage basin. Large portions of the basin are composed of clastic rocks, most notably the Millboro shale. Flood overflow from subbasins, such as that of Emory Spring, drains directly to the river. It is not suprising, therefore, that the river exhibits flood characteristics intermediate between that of totally carbonate and totally clastic basins. The mean-annual flood peak discharge per square kilometer is 339 1/sec. This value is higher than those for limestone basins reported by White and Reich (1970) (96 to 212 1/sec km^2) but lower than their value of 437 1/sec/km^2 for the Jordan Creek carbonate basin. The Jordan Creek basin has a low percentage of carbonate to clastic rock, as does the Bullpasture River basin.

APPENDIX I. Dye Tracing Techniques

To determine the drainage basins in the Burnsville Cove, a method of tracing the sinking water to the springs in the gorge was needed. Because of the expected long transit times and the fact that the area was visited only an average of once every two weeks, it was necessary to have some method of introducing a tracer at one time and recovering it at the suspected resurgences at any convenient time after it passed. The Dunn (1957) method allows this field procedure and was used with Zotter's (1961) detector bug variation. Refinements of the techniques used are briefly as follows:

1. Place "bugs" consisting of about 20 gm of activated coconut charcoal enclosed loosely in pieces of nylon stockings, secured with nylon cord to an anchor, in the main flow of *all* suspected resurgences.
2. Inject a tracer into the source to be investigated. Dyes suitable for use as tracers include fluorescein and Rhodamine WT. The less expensive fluorescein was used in most of the work reported here.
3. After allowing sufficient time, collect all bugs from the resurgences and replace them with fresh ones.
4. Place 10 gm of the exposed charcoal in a test tube.
5. Release the dye with a 5% solution of KOH in ethyl alcohol, using only enough to cover the charcoal by 5 mm.
6. Use an intense blue-white light, not an ultraviolet lamp or the sun, to look for the dye. A penlite flashlight with fresh cells will work. Observe the green fluorescence at a right angle to the beam. For very weak tests wait 24 hours before concluding that the trace is negative.
7. If the test is positive, repeat steps 3 through 6 until all springs are negative before resuming the tracing program. If the test is negative, repeat steps 3 through 6 until confident the dye has not and will not appear in any of the springs before resuming the tracing program.

For small dye concentrations (less than the easily visible 0.1 ppm) and constant flow rate, the amount of dye captured is directly proportional to the amount of dye that passes through the bug. Dilution of the dye in the flow system is not important as long as no dye is lost in the system. The cove drainage is mainly conduit flow, and apparently very little dye was lost to adsorption on sediments.

In the tracing program in the cove, as little as 10 gm and as much as 160 gm of dye were used for a single trace. An amount of 80 gm (one sea dye marker) was determined to be sufficient to trace path lengths as long as 8.km and dilutions from a 3×10^{-2} 1/sec stream to a 3×10^{2} 1/sec resurgence. In one dye tracing, 160 gm of dye was used to dye an estimated 8×10^{5} m^3 of water. This was the amount of water that issued from the spring while the bugs still indicated a positive test. As far as is known, dye was never present in visible concentrations in any of the springs.

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Ground Water Geochemistry of the Burnsville Cove Area, Virginia

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SUMMARY

The chemical composition of 56 surface and ground waters from the Burnsville Cove area suggests that solution of carbonate rock in the Sinking Creek drainage basin has largely occurred during sustained contact of the water with a CO_2 reservoir of about $10^{-2.5}$ atm partial pressure. Ca^{2+} concentrations are generally less than 40 mg/1 and, as a result, most groundwaters are greatly undersaturated with respect to calcite. The only waters found to be saturated with respect to calcite were seepage waters collected from active soda-straw stalactites in the Butler Cave — Sinking Creek Cave System. The data further suggest that: 1) a greater amount of carbonate solution occurs during times of high flow, when the Ca^{2+} gradient from input to spring is on the order of 10 mg/1, than during base flow periods, when the gradient is 1 to 2 mg/1; 2) that most carbonate solution by ground water occurs very near the point of recharge; 3) little additional solution takes place during the remainder of subsurface flow, although the waters remain calcite undersaturated; and 4) spring flow includes both conduit and artesian components.

CARBONATE AQUIFERS are unique because of the complex interaction between the rock and the ground water. There has been much interest over the past few years in using information obtained from chemical analysis of the ground water to deduce information concerning flow paths and residence times, as well as information about the chemical reactions taking place at depth. The most comprehensive work has been in the limestone peninsulas of Florida and Yucatan (Back and Hanshaw, 1970), the folded carbonates of Central Pennsylvania (Jacobson and Langmuir, 1970; Langmuir, 1971; Shuster and White, 1971, 1972; Jacobson and Langmuir, 1974) and the flat lying carbonates of central Kentucky (Thrailkill, 1972; Hess, 1974; Hess and White, 1974).

This study was undertaken to determine the conditions under which dissolution of carbonate rock was occurring in the Burnsville Cove area of Virginia. We had particular interest in the detailed chemical evolution of subsurface waters in the Sinking Creek Cave System drainage network and in interpreting the hydrologic nature of the flow path.

In carbonate terranes, the dissolved carbonate species H_2CO_3, HCO_3^-, and CO_3^{2-}, in pristine ground waters are derived primarily from two sources: 1) an external CO_2 reservoir, such as the atmosphere or soil zone, and 2) the dissolution of carbonate rock. The dissolution of carbonate rock may occur either where the ground water is always in contact with the CO_2 reservoir or where the recharge waters are initially in contact with the CO_2 reservoir, but become isolated from it before solution of carbonate rock begins. These external conditions, termed the "open" and "closed" system cases by Garrels and Christ (1965, pp. 74-93), represent idealized limiting circumstances. Any natural situation is most likely an intermediate case, but probably is biased toward one or the other end members. Previous studies by Langmuir (1971) and by Deines, *et al.* (1974) have shown that solution of carbonate rock in the Nittany Valley of central Pennsylvania occurs under conditions where the ground water is isolated from the soil CO_2 reservoir with which it had initially equilibriated.

CHEMICAL EQUILIBRIA AND SOLUTION MODELS

The chemical relationships in the system CO_2-H_2O-$CaCO_3$ can be described by the following equilibrium expressions:

$$K_w = [H^+][OH^-] \quad (1)$$

$$K_{CO_2} = [H_2CO_3]/P_{CO_2} \quad (2)$$

$$K_1 = [H^+][HCO_3^-]/[H_2CO_3] \quad (3)$$

$$K_2 = [H^+][CO_3^{2-}]/[HCO_3^-] \quad (4)$$

$$K_c = [Ca^{2+}][CO_3^{2-}]$$

$$SI_c = \log([Ca^{2+}][CO_3^{2-}]/K_c) \quad (5)$$

where brackets denote the ion activity of the enclosed species. The carbonate solution model discussed below is similar to those described by Holland, *et al.* (1964), Thrailkill (1968), and Langmuir (1971), except that ion activities (rather than ion concentrations) were used to construct the models. Because of the complexities introduced in the consideration of ion-pairs, they have been ignored in the models.

The basic approach used to model the chemical changes occurring during the passage of water through a carbonate aquifer involves computing the chemical composition of a water initially in equilbrium with a CO_2 reservoir of defined partial pressure at a given pH. By permitting pH to vary independently of initial CO_2 partial pressure, the model approximates natural conditions. However, doing so invalidates the charge-balance relationships normally used to construct such models (Holland, *et al.*, 1964; Thrailkill, 1968).

Given an initial pH and P_{CO_2}, the individual ion activities are calculated (equations 1 to 4). Ionic strength is then estimated, assuming activities equal molalities, and initial activity coefficients calculated. Using these first activity coefficients, a second value for ionic strength is calculated and a second set of activity coefficients estimated. This procedure is continued until ionic strength remains constant. The molality of total dissolved carbonate species before the solution of any $CaCO_3$ is then given by the relationship:

$$MC_T = mH_2CO_3 + m\,HCO_3^- + mCO_3^{2-} \quad (6)$$

The next step is to assume the solution of a small amount of $CaCO_3$, which is accomplished by increasing pH slightly above its initial value. The change in the molalities of the various species in solution can then be determined for other "open" or "closed" system conditions, assuming that the pH change is due only to solution of $CaCO_3$ according to the reaction:

$$CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca^{2+} + 2HCO_3^- \quad (7)$$

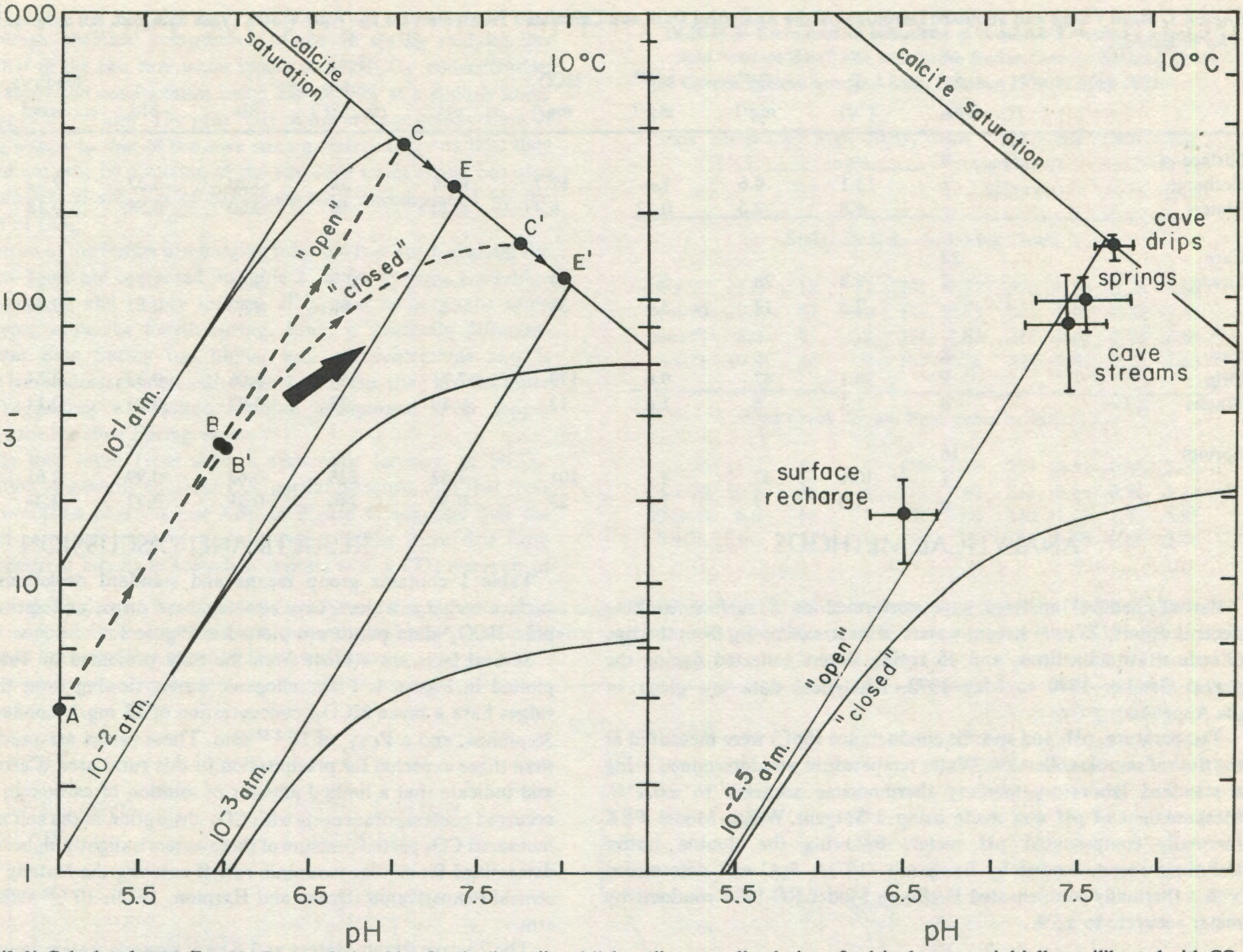

Figure 1. *(left)* Calculated HCO_3^- - pH - P_{CO_2} relationships for the "open" and "closed" system dissolution of calcite by waters initially equilibrated with CO_2 reservoirs of 10^{-1}, 10^{-2}, and 10^{-3} atmospheres partial pressure at 10°C and a pH of 5.0. Details for the case of an initial P_{CO_2} value (also shown) are discussed in the text. *(right)* HCO_3^- versus pH for the group means for the four water types sampled. The calculated HCO_3^- - pH relationships are also shown for the "open" and "closed" system dissolution of calcite at a $P_{CO_2} = 10^{-2.5}$ atmospheres at 10°C and an initial pH of 5.0. See text for discussion.

having again estimated ionic strengths and activity coefficients per this new condition by iteration. Computations are then carried out for a series of increasing pH values until calcite saturation ($SI_C = 0$) is reached. Further details of the solution model are given by Deines, *et al.* (1974).

The results of a set of calculations for an initial P_{CO_2} of $10^{-1.5}$ atm and initial pH of 5 are shown in Figure 1. Point A represents the water at the time of its equilibration with the CO_2 reservoir. At this point, $mHCO_3^- = 3.6$ mg/l.

The path A - B - C in Figure 1 shows the progressive changes in chemical composition of a water evolving to calcite saturation under "open" system conditions; path A - B' - C' shows the "closed" system evolution of a water starting from the same initial conditions. It is clearly seen that the solutional capacity of a ground water in a carbonate terrane is not only a function of its initial CO_2 concentrations but, also, of the extent to which CO_2 consumed during the dissolution of carbonate rock is replenished. For an "open" system case where pH = 7.03, $mHCO_3^- = 390$ mg/l at calcite saturation, whereas for the "closed" system case where pH = 7.73, $mHCO_3^- = 192$ mg/l.

Let us now consider the effect of encountering an air-filled cave on ground waters evolving under these two sets of conditions. If the cave is encountered after the waters have reached calcite saturation, precipitation of calcite will occur if the CO_2 partial pressure of the cave is less than that of the water. Ignoring possible kinetic effects, the chemical composition of the waters would then follow the saturation curve toward the lower P_{CO_2} value and would reach equilibrium with the cave atmosphere. The paths C - E and C' - F indicate such an evolution. At points E and F, no further change in the chemical composition of the water is possible with further subsurface residence time, unless the system is disturbed by the addition of water of a different chemical composition or by a change in external boundary conditions, such as temperature, CO_2 partial pressure, or flow volume.

Consider now the evolution of waters that for both the "open" and "closed" system situations encounter a cave before reaching calcite saturation. These waters would be undersaturated with respect to calcite and, thus, no calcite precipitation would occur. As both carbonate dissolution and CO_2 exsolution occur while these waters flow through the cave, the chemical composition of the waters would move from position represented by points B or C' upward and to the right on the diagram and would approach the saturation curve, then move along this curve toward equilibrium with the cave atmosphere. The exact path is a function both of the rate of CO_2 loss from solution and of the rate of carbonate dissolution and could vary in a complex manner for various combinations of these conditions.

TABLE 1. Mean Values and Standard Deviations of the Analytical Data and Calculated Parameters for the Four Water Types Sampled. All data are corrected for complexes.

	# Obs.	T (°C)	Ca^{2+} mg/l	Mg^{2+} mg/l	HCO_3^- mg/l	pH	SpC µmhos (@ 25°C)	SIc	SId	log P_{CO_2} (atm)	$\frac{Ca^{2+}}{Mg^{2+}}$
Surface	9										
Recharge	$\bar{x}$	13.1	4.6	1.4	17.7	6.49	36	-3.20	-3.32	-2.32	1.97
Waters	σ	4.8	2.5	0.72	6.4	0.20	16	0.60	0.58	0.18	0.75
Cave	23										
Streams	$\bar{x}$	9.8	28	5.7	89	7.47	179	-0.85	-1.14	-2.61	3.62
	σ	2.3	12	3.5	38	0.23	66	0.40	0.57	0.30	1.30
Cave	8										
Drip	$\bar{x}$	10.1	47	9.0	170	7.71	333	-0.06	-0.33	-2.54	3.20
Waters	σ	1.1	6	1.6	13	0.10	24	0.02	0.03	0.14	0.20
Springs	16										
	$\bar{x}$	10.6	32	4.1	101	7.52	228	-0.62	-0.99	-2.61	6.50
	σ	1.0	7	2.6	25	0.30	146	0.31	0.33	0.34	4.18

ANALYTICAL METHODS

Partial chemical analyses were performed on 9 surface (sinking stream) waters, 23 cave stream waters, 8 waters dripping from the tips of soda-straw stalactities, and 16 spring waters collected during the period October 1970 to May 1972. Analytical data are given in the Appendix.

Temperature, pH, and specific conductance (SpC) were measured at the time of sample collection. Water temperature was determined using a standard laboratory mercury thermometer accurate to ±0.2°C. Measurement of pH was made using a Sargent Welch Model PBX thermally compensated pH meter, following the double buffer technique recommended by Langmuir (1971). SpC was determined with a thermally compensated Beckman Model RC-1982 conductivity meter accurate to ±5%.

At each sample site, a 750 ml sample was collected in a polyethylene bottle for later laboratory analysis. Sample acidification was not necessary for samples analyzed within a few hours of collections. Ca^{2+} and Mg^{2+} concentrations were determined by EDTA titration, using the procedure of Lewis and Melnick (1960), and are accurate to ±1 mg/l. HCO_3^- concentrations were measured, using the potentiometric technique of Barnes (1964), and are accurate to ±2 mg/l. All laboratory analyses were made within 24 hours of collection, except for those samples collected on 3 October 1970, which were analyzed within a week of collection.

Chemical equilibria calculations were made on an IBM 360-67 computer, using a program described by Jacobson and Langmuir (1972, 1974). The program determines an anions versus cations equivalents balance from temperature, pH, SpC, and measured ion concentrations. The ion pairs $CaCO_3^0$, $MgCO_3^0$, $CaHCO_3^+$, and $MgHCO_3^+$ are then corrected and ionic strength calculated from the measured SpC (Langmuir, 1971). Activity coefficients are subsequently estimated from the extended Debye-Huckel relationship (Klotz, 1964) and ion activities determined. Finally, theoretical CO_2 partial pressure (P_{CO_2}) and saturation indices of water with respect to calcite (SIc) and dolomite (SId) are calculated. Waters having SIc or SId values within ±0.1 units of zero are considered saturated with respect to the carbonate mineral involved (Langmuir, 1971). Values of the equilibrium constants used in these calculations (K_W, K_{CO_2}, K_1, K_2, K_C, $K_{CaCO_3^0}$, $K_{CaHCO_3^+}$, and $K_{MgHCO_3^+}$) are those recommended by Jacobsen and Langmuir (1974).

RESULTS AND DISCUSSION

Table 1 contains group means and standard deviations for the surface recharge waters, cave streams, cave drips, and springs whose pH - HCO_3^- data points are plotted in Figure 1.

Several facts are evident from the data presented in Table 1 and plotted in Figure 1. First, allogenic waters flowing from the clastic ridges have a mean HCO_3^- concentration of 18 mg/l, conductance of 36 µmhos, and a P_{CO_2} of $10^{-2.32}$ atm. These values are much greater than those expected for precipitation in this rural area (Carroll, 1962) and indicate that a limited amount of solution of carbonate rock has occurred contemporaneously with CO_2 absorption in the soil zone. The measured CO_2 partial pressure of these waters is slightly higher than that determined for similar mountain runoff entering the Nittany Valley of central Pennsylvania (Drake and Harmon, 1973), $10^{-2.32}$ versus $10^{-2.63}$ atm.

The 23 cave stream waters and 8 cave seepage waters sampled have mean P_{CO_2} values of $10^{-2.61}$ and $10^{-2.54}$ atm for corresponding mean HCO_3^- concentration, and conductances of 89 and 170 mg/l and 179 and 333 µmhos, respectively. It is evident that solution of carbonate rock has occurred, although P_{CO_2} has remained almost constant throughout the transition from surface stream to cave water.

TABLE 2. Comparative Chemistry of the Four Springs Which Discharge into the Bullpasture River above Williamsville, Virginia

	Cathedral Spring	Lockridge's Aqua Spring	Blue Spring	Emory Spring
# Obs.	3	5	2	4
T (°C) $\bar{x}$	10.7	9.8	11.5	10.7
σ	0.8	1.3	0	0.5
$Ca^{2+}\bar{x}$	34	30	44	29
σ	3.2	0.7	4.2	3.2
$Mg^{2+}\bar{x}$	3.0	3.2	6.5	3.5
σ	0	1.0	0.7	1.0
$HCO^{3-}\bar{x}$	96	99	134	90
σ	11	36	20	11
SIc $\bar{x}$	- 0.66	- 0.46	- 0.26	- 0.58
σ	0.44	0.15	0.20	0.24
log $P_{CO_2}\bar{x}$	- 2.54	- 2.76	- 2.55	- 2.63
σ	0.53	0.34	0.35	0.29
$Ca^{2+}/Mg^{2+}\bar{x}$	7.1	6.2	4.2	5.9
σ	0.7	2.0	0.8	1.8

The average chemical composition of the 16 spring samples lies between that of the two cave water types, mean HCO_3^- concentration being 101 mg/l and conductance being 228 μmhos, at a slightly lower P_{CO_2} value of $10^{-2.61}$ atm. The proximity of the average composition of the spring waters to that of the cave stream waters suggests that they are derived not only by a mixing of the two cave water types, but also through additional solution of carbonate rock accompanied by the exsolution of CO_2.

Chemistries of the waters discharging from the four springs along the Bullpasture River are compared in Table 2. Three springs, Lockridge Aqua, Cathedral, and Emory springs, all appear to be of the same conduit type, while the fourth spring, Blue, is distinctly different. Water from Blue Spring has higher ionic concentrations and is somewhat less undersaturated with respect to calcite than are the other springs, suggesting a possible artesian component with longer residence time for Blue Spring waters.

That the four water types show a systematic increase in HCO_3^- concentration at a nearly constant CO_2 partial pressure, and that their chemical evolution parallels line ABC in Figure 1, suggests that the solution of carbonate rock by ground waters in the Burnsville Cove area has occurred largely in sustained contact with a CO_2 reservoir of

TABLE 3. Comparative chemistry of a selected "vadose seepage" and "vadose flow" site within the Butler Cave — Sinking Creek Cavern System sampled from October 1970 to May 1971.

date	temp (°C)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	HCO_3^- (mg/l)	pH	SpC μmhos @25°C	SIc	SId	log P_{CO_2} (atm)
Stalactite Drip — Sinking Creek									
3-x-70	11.0	58	12	197	7.57	370	-0.04	-0.28	-2.36
24-x-70	10.7	52	10	179	7.63	356	-0.07	-0.32	-2.45
20-ii-71	8.3	41	8	171	7.82	312	-0.02	-0.29	-2.68
8-v-71	10.4	46	9	163	7.76	324	-0.03	-0.28	-2.63
Sinking Creek Stream Emergence in Butler Cave									
3-x-70	11.0	40	5	118	7.45	221	-0.51	-0.86	-2.45
24-x-70	10.5	36	5	110	7.40	215	-0.64	-0.96	-2.43
20-ii-70	6.0	16	3	52	7.60	110	-1.15	-1.43	-2.97
8-v-71	11.0	24	4	78	7.76	180	-0.58	-0.86	-2.94

Figure 2. The Butler Cave — Sinking Creek Cave System, showing selected sites sampled during base flow (10-iii-70) and during high flow (20-ii-71). Shown for each site sampled are measured calcium concentration (mCa^{2+}) and calculated saturation index (SIc). See text for discussion. Numbers 1-19 refer to sites discussed in the preceeding paper by Davis and Hess.

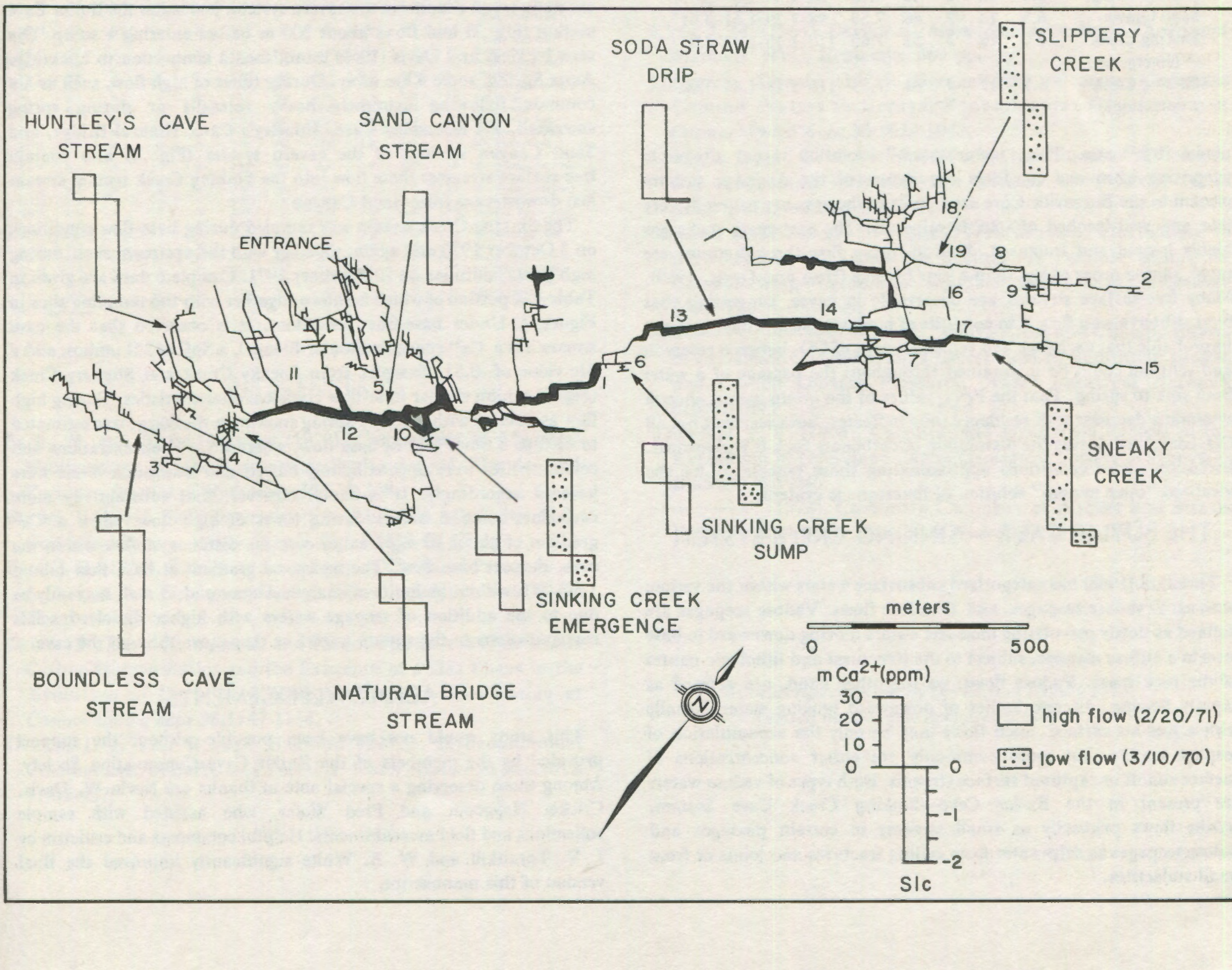

TABLE 4. Analytical data for selected sites within the Butler Cave — Sinking Creek Cavern System on 3 October 1970 and 2 February 1971.

sample site	temp (°C)	Ca^{2+}	Mg^{2+} mg/l	HCO_3^-	pH	SpC μmhos @25°C	SIc	SId	log P_{CO_2} (atm)
3 October 1970 (low flow conditions)									
Sinking Creek (emergence)	11.0	40	5	118	7.45	221	-0.51	-0.86	-2.45
Sinking Creek (sump)	12.0	43	6	122	7.30	223	-0.61	-0.92	-2.29
Slippery Creek	10.8	35	7	90	7.35	160	-0.79	-1.03	-2.47
Sneaky Creek	12.0	53	13	191	7.30	299	-0.47	-0.66	-2.23
20 February 1971 (high flow conditions)									
Boundless Cave Stream	5.0	6	1	21	6.92	47	-2.52	-2.78	-2.65
Huntley's Cave Stream	6.0	10	1	32	7.48	73	-1.66	-2.08	-3.06
Natural Bridge	6.1	12	1	43	7.55	84	-1.39	-1.85	-2.95
Sand Canyon	6.5	13	2	46	7.59	98	-1.29	-1.61	-3.01
Sinking Creek (emergence)	6.0	16	3	52	7.60	110	-1.15	-1.43	-2.97
Sinking Creek (sump)	6.5	17	3	54	7.63	115	-1.11	-1.40	-3.00

about $10^{-2.50}$ atm. This "open system" evolution is not altogether surprising when one considers the nature of the drainage systems present in the Burnsville Cove area. Soils in the area are generally very thin and well leached of soluble minerals. The carbonate rocks are highly jointed and fractured. Sink-to-spring flow-through times are rapid, on the order of less than 4 km/2 weeks (Hess and Davis, 1969). Many free-surface streams are observable in caves, suggesting that most subterranean flow is in conduits of moderate size. Thus, it is not improbable that exchange and replenishment of CO_2 between reservoir and solution could be maintained throughout the passage of a water from sink to spring. That the P_{CO_2} values of the group means show a systematic decrease with residence time indicates, however, that not all CO_2 consumed during the dissolution of carbonate rock is replenished. Evolution under conditions approximating those postulated for the idealized "open system" solution of limestone is evident.

THE BUTLER CAVE — SINKING CREEK SYSTEM

Thrailkill (1968) has categorized subsurface waters within the vadose zone as: 1) vadose seepages, and 2) vadose flows. Vadose seepages are defined as slowly percolating meteoric waters moving downward to base level in a diffuse manner, subject to the structural and lithologic nature of the rock mass. Vadose flows, on the other hand, are defined as rapidly flowing, discrete bodies of downward moving water, usually with a free-air surface. Such flows may be only the accumulation of seepage waters, but more commonly are either concentrations of surface runoff or captured surface streams. Both types of vadose waters are present in the Butler Cave—Sinking Creek Cave System, vadose flows primarily as small streams in certain passages and vadose seepages as drip-water from ceiling fractures and joints or from small stalactites.

The chemical compositions of a typical vadose seepage and of a typical vadose flow, each sampled four times during the period from October 1970 to May 1971, are given in Table 3. From this comparison, it is seen that the concentrations of all dissolved species were at all times greater for the seepage waters than for the cave stream waters. The seepage waters are within the accepted limits of error of SIc (±0.1 units), thus are saturated with respect to calcite. These 8 waters were the only ones among the 56 samples found to be saturated with respect to calcite. No waters sampled were found to be supersaturated. Jacobson and Langmuir (1970) have shown that SIc is a reliable measure of the residence time of a ground water in a carbonate drainage basin. Thus, the higher saturation indices and more stable nature of the chemical character of the seepage waters compared with those of the cave stream waters is readily explained in terms of the longer residence time of these waters in the subsurface before encountering the cavern system.

The final portion of the study was to measure the chemical changes in the stream waters as they moved through the cave. The Sinking Creek section of the cavern system was chosen because of its relatively great length (≃750 meters), its relative accessibility, and the fact that the upstream portions of the cave were known to conduct water during times of high flow.

The stream flowing in the Sinking Creek section of the cave is in all likelihood the subsurface equivalent of (surface) Sinking Creek. The subsurface stream emerges into the cave at the upstream end of the main truck channel of the cavern system, just below the Butler Cave section (Fig. 2) and flows about 500 m before entering a sump. Dye tests by Hess and Davis (1969) established a connection to Lockridge Aqua Spring, some 4 km away. During times of high flow, such as are common following extremely heavy rainfalls or during spring snowmelt, the Boundless Cave, Huntley's Cave, Natural Bridge, and Sand Canyon sections of the cavern system (Fig. 2) also contain free-surface streams: these flow into the Sinking Creek section stream just downstream from Sand Canyon.

The Sinking Creek stream was sampled during base-flow conditions on 3 October 1970 and again, together with the upstream sites, during high-flow conditions on 20 February 1971. Complete data are given in Table 4, a portion of which is shown together with the sampling sites in Figure 2. Under base-flow conditions, it is observed that the cave stream has a Ca^{2+} concentration of 40 mg/l, a SpC of 221 μmhos, and a SIc value of -0.51. Samples from Sneaky Creek and Slippery Creek (Fig. 2) exhibit similar base-flow chemical characteristics. During high flow associated with the 1971 spring snowmelt, discharge was estimated to be 3 to 5 times that of base flow, whereas Ca^{2+} concentrations and conductivities were approximately halved and saturation levels were lowered accordingly. It is likely, however, that substantially more carbonate solution occurs during times of high flow, when a Ca^{2+} gradient of about 10 mg/l exists over the distance of flow within the cave, than at base flow. The measured gradient at base flow (about 1 mg/l) is within the limits of analytical error and, if real, may only be due to the addition of seepage waters with higher dissolved solids concentrations to the stream waters as they move through the cave.

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APPENDIX. BURNSVILLE COVE WATER CHEMISTRY DATA (complex corrected)

Date Collected	Temp (°C)	Ca^{2+} mg/l	Mg^{2+} mg/l	HCO_3^- mg/l	pH	SpC μmhos (@ 25°C)	SIc	SId	log P_{CO_2} (atm)	$\frac{Ca^{2+}}{Mg^{2+}}$	Description
24.x.70	11.5	37	3	101	7.57	205	-0.48	-0.91	-2.64	7.6	Cathedral Spring
24.x.70	10.5	36	4	106	7.78	152	-0.28	-0.64	-2.83	5.5	Lockridge Aqua Spring
24.x.70	11.0	31	4	104	7.72	162	0.39	-0.73	-2.77	4.8	Emory Spring
24.x.70	11.0	40	10	130	7.65	247	-0.28	-0.47	-2.61	2.5	Breathing Cave Stream
24.x.70	11.5	28	7	104	7.05	204	-1.10	-1.29	-2.10	2.5	Breathing Cave Stream
24.x.70	10.5	36	5	110	7.49	215	-0.55	-0.87	-2.54	4.4	*BC—Sinking Creek Emergence
24.x.70	11.0	40	10	129	7.40	279	-0.53	-0.72	-2.37	2.5	BC—Sinking Creek Sump
24.x.70	10.8	35	7	90	7.35	160	-0.78	-1.03	-2.47	3.1	BC—Slippery Creek
24.x.70	11.0	52	10	179	7.63	356	-0.06	-0.31	-2.46	3.2	BC—Soda Straw Drip
24.x.70	11.8	53	11	185	7.60	363	-0.06	-0.29	-2.41	3.0	BC—Soda Straw Drip
24.x.70	15.6	2	1	15	6.30	34	-3.70	-3.72	-2.15	1.2	Surface Stream
24.x.70	16.0	8	2	25	6.74	53	-2.45	-2.61	-2.37	2.4	Surface Stream—Water Sinks
19.xii.70	10.6	51	10	175	7.65	341	-0.06	-0.31	-2.49	3.1	BC—Rimstone Pool
19.xii.70	10.7	52	10	179	6.63	356	-0.07	-0.32	-2.46	3.2	BC—Soda Straw Drip
19.xii.70	10.8	23	3	81	7.26	168	-1.08	-1.41	-2.42	4.7	BC—Sinking Creek Emergence
19.xii.70	10.5	26	4	86	7.34	183	-0.93	-1.23	-2.45	4.0	BC—Sinking Creek Sump
19.xii.70	11.1	32	9	116	7.62	250	-0.44	-0.61	-2.62	2.2	BC—Moon Room Cave Stream
19.xii.70	11.3	33	10	101	7.30	206	-0.81	-0.96	-2.37	2.0	BC—Sneaky Creek Emergence
19.xii.70	10.9	35	11	109	7.42	232	-0.64	-0.78	-2.45	2.0	BC—Sneaky Creek Emergence + 450 m
4.x.70	11.5	47	6	148	7.40	265	-0.40	-0.73	-2.30	4.8	Blue Spring
4.x.70	9.9	36	3	104	6.90	207	-1.16	-1.61	-1.96	7.4	Cathedral Spring
4.x.70	9.9	38	4	156	7.40	217	-0.48	-0.87	-2.20	5.9	Lockridge Aqua Spring
4.x.70	10.2	32	4	94	7.30	216	-0.85	-1.20	-2.40	4.9	Emory Spring
3.x.70	11.0	40	5	118	7.30	221	-0.66	-1.00	-2.30	4.0	BC—Sinking Creek Emergence
3.x.70	12.0	43	6	122	7.45	223	-0.45	-0.77	-2.43	4.4	BC—Sinking Creek Sump
3.x.70	12.0	53	13	181	7.30	295	-0.35	-0.54	-2.09	2.5	BC—Sneaky Creek
3.x.70	12.0	35	7	90	7.35	160	-0.77	-1.00	-2.46	3.1	BC—Slippery Creek
20.ii.71	7.5	22	4	62	7.88	103	-0.64	-0.92	-3.16	3.4	Lockridge Aqua Spring (high flow)
20.ii.71	8.4	35	6	143	7.90	298	-0.07	-0.36	-2.83	3.6	BC—Rimstone Pool
20.ii.71	8.8	41	8	171	7.82	312	-0.02	-0.28	-2.67	3.2	BC—Soda Straw Drip
20.ii.71	6.0	16	3	52	7.60	110	-1.15	-1.43	-2.97	3.3	BC—Sinking Creek Emergence (high flow)
20.ii.71	6.5	17	3	54	7.63	115	-1.07	-1.36	-2.98	3.5	BC—Sinking Creek Sump (high flow)
20.ii.71	5.0	6	1	21	6.92	47	-2.63	-2.94	-2.67	3.6	BC—Boundless Cave Stream (high flow)
20.ii.71	6.0	10	1	32	7.48	73	-1.66	-2.08	-3.05	6.1	BC—Huntley's Cave Stream (high flow)
20.ii.71	6.1	12	1	43	7.55	84	-1.39	-1.84	-3.00	7.3	BC—Natural Bridge Cave Stream (high flow)
20.ii.71	6.5	13	2	46	7.59	98	-1.28	-1.61	-3.01	4.0	BC—Sand Canyon Cave Stream (high flow)
20.ii.71	5.0	3	1	9	6.37	25	-3.84	-4.00	-2.49	1.8	Surface Sinking Creek
20.ii.71	4.8	2	1	8	6.42	18	-4.01	-4.09	-2.59	1.2	Surface Sinking Creek
8.v.71	10.8	31	3	83	7.86	175	-0.35	-0.75	-3.01	6.3	Cathedral Spring
8.v.71	10.0	28	2	85	7.81	160	-0.44	-0.91	-2.95	8.6	Lockridge Aqua Spring
8.v.71	11.5	41	7	120	7.82	240	-0.12	-0.39	-2.81	3.6	Blue Spring
8.v.71	10.5	26	2	79	7.81	170	-0.50	-0.95	-2.98	8.0	Emory Spring
8.v.71	10.3	46	8	166	7.71	320	-0.07	-0.34	-2.57	3.6	BC—Rimstone Pool
8.v.71	10.4	46	9	163	7.76	324	-0.03	-0.28	-2.63	3.2	BC—Soda Straw Drips
8.v.71	11.0	24	4	78	7.76	180	-0.58	-0.86	-2.94	3.7	BC—Sinking Creek Emergence
8.v.71	11.1	25	4	80	7.80	184	-0.51	-0.80	-2.97	3.8	BC—Sinking Creek Stream + 250 m
8.v.71	10.8	26	5	84	7.83	190	-0.45	-0.70	-2.97	3.2	BC—Sinking Creek Sump
8.v.71	17.0	4	1	19	6.30	32	-3.28	-3.44	-2.05	2.4	Surface Sinking Creek
8.v.71	13.0	6	1	20	6.42	40	-3.03	-3.30	-2.16	3.6	Boundless Surface Stream
8.v.71	16.5	9	3	27	6.81	65	-2.30	-2.40	-2.41	1.8	Surface Water Sinking
8.v.71	14.2	3	1	16	6.52	21	-3.25	-3.36	-2.40	1.8	Surface Sinking Creek
8.v.71	15.8	5	2	20	6.57	34	-2.92	-2.98	-2.30	1.5	Surface Stream
2.v.72	11.2	26	4	82	7.22	180	-1.06	-1.36	-2.38	4.0	Emory Spring
2.v.72	11.0	25	2	85	7.37	187	-0.91	-1.35	-2.59	7.7	Lockridge Aqua Spring
2.v.72	11.5	33	1	112	7.26	230	-0.79	-1.44	-2.28	20.3	Williamsville Spring
2.v.72	11.8	24	12	88	7.24	193	-1.09	-1.05	-2.37	1.23	Coursey Spring

*BC = Butler Cave

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MINERALOGY of the BUTLER CAVE — SINKING CREEK SYSTEM

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SUMMARY

The Butler Cave — Sinking Creek System is characterized by scattered areas in which flowstone and dripstone occur and by a few more localized areas in which complex erratic speleothems containing aragonite and hydromagnesite occur. The aragonite occurs mainly in nodular speleothems of various sizes and shapes. Hydromagnesite occurs as moonmilk which appears to be a residual deposit formed from solutions depleted in calcium by the precipitation of aragonite. Gypsum occurs as wall crusts apparently formed in situ *by oxidization and transport of sulfide minerals finely dispersed in thin shale bands in the limestone. Poorly crystallized goethite has been identified. A complex group of phosphate minerals occurs mainly in pockets and vugs in the clastic sediments of the Butler Cave section. Taranakite, hydroxyapatite, crandallite and perhaps sasaite have been identified.*

THE CAVES of Burnsville Cove, and of the Butler Cave-Sinking Creek System in particular, contain widely distributed, if rather sparse, secondary mineral deposits. Massive flowstone and dripstone occur only in very localized areas, perhaps reflecting the protective influence of the upper sandstone. Helictites, nodular speleothems, crusts and other mineral formations occur widely but are small in volume.

The minerals found in the caves of Burnsville Cove are typical of those found in other Appalachian caves. The percentage of aragonite is somewhat higher. Unusual minerals include gypsum, which seems to be associated with shaley layers in the Keyser limestone, and a suite of phosphate minerals. Explanations are offered for these occurrences.

The purpose of this paper is to give an inventory and description of the cave minerals, mostly from the Butler Cave-Sinking Creek System. For general reviews of cave mineralogy, see Hill (1976) and White (1976). The classification of speleothems used in this paper follows the system outlined in the latter reference.

METHODOLOGY

The results in this paper are based on an examination of some 66 specimens collected from the cave system at various times between 1958 and 1980. Most of the materials collected were small chips and fragments found loose on the cave floors. The numbers that appear in the tables and text of this paper are sample numbers assigned to the specimens which are now a part of a permanent collection of cave materials held at The Pennsylvania State University by the author.

All specimens were examined under the binocular microscope, and descriptions were written. The minerals comprising the specimens were identified by powder X-ray diffraction (Table 1). The expected minerals, calcite, aragonite, hydromagnesite, and gypsum, were easily identified by comparison of the diffraction patterns with those on a reference chart. The scanning electron microscope with an energy-dispersive X-ray detector was used to identify crystal morphology and to determine bulk chemical composition.

The chemical composition of five specimens, three calcites and two aragonites, was determined by emission spectroscopy (Table 2).

DRIPSTONE AND RELATED CALCITE DEPOSITS

Flowstone and dripstone occur in the Moon Room area and in a few other scattered localities throughout the cave. Most of the speleothems are relatively small and many appear to be actively depositing at the present time.

The sparse dripstone and flowstone decoration in both the Butler Cave-Sinking Creek System and in Breathing Cave must be attributed to the effectiveness of the upper sandstone (see White and Hess, this issue, for a description of the stratigraphy) as an aquaclude. The lower sandstone is breached in many places in the cave, but the upper sandstone is usually intact. The largest stalactites and stalagmites in the cave are in the Moon Room area. These may well be associated with a major fracture system which crosses the cave in this area. The fracture zone could allow surface water to pass through the upper sandstone.

In the main cave passage just west of the Natural Bridge were found several stalagmites. These were cylindrical speleothems about 5 cm in diameter. Their interiors were composed of clear, colorless calcite, but the surfaces of the speleothems were layers of loose white powder ranging up to 5 mm in thickness. X-ray diffraction shows both the outer coating and the clear interior to be calcite. Segments could be cut and polished into completely water-clear slabs. Microscopic observation of these thin sections (Fig. 1) showed a very densely packed arrangement of interlocked, randomly oriented grains. Any weathered or modified zones at grain boundaries were very thin and not obvious in the light microscope. The stalagmites broke with brittle fracture, and there were no traces of the calcite cleavage faces that usually appear on broken speleothem surfaces. No growth banding was in evidence.

Straw stalactites occur in scattered locations perhaps indicative of the most recent speleothem growth in the cave. Specimens examined were of coarse-grained clear white calcite. The grains making up the outer shell were elongate with their c-axis parallel to the stalactite axis. The central canal contained a loose agglomeration of scalenohedral calcite crystals.

Helictites in Butler Cave take on several forms. Some are massive clear calcite with a sugary surface texture (Fig. 2). Others are more filiform with many twisting filaments of small diameter. These also appear to be composed of calcite; however, no loose fragments were found that could be used for analysis. The filiform helictities are similar to those described by Geze (1957) from the Moulis Cave in France. These forms are of interest because their diameters are less than the 5 mm calculated by Curl (1972) to be the minimum diameter of stalactites formed by deposition from free-hanging drops. The small sizes of the filiform helictities are evidence that growth takes place by slow seepage along the central canal without the formation of free drops. The contrast between the helictites and a straw stalactite growing from the same feeder system is apparent in Figure 3. However, the flow must be continuous for the helictite to be bathed in fluid, so that the continuity of the calcite crystal is maintained.

Fragments of nearly clear calcite crystals have been found in the Christmas Passage of Butler Cave. These fragments were broken along cleavage planes, indicating that the original speleothem was a single massive calcite crystal.

DEPOSITS CONTAINING OTHER CARBONATE MINERALS

Nodular Speleothems

Nodular speleothems exhibit a spectrum of shapes including tufts of acicular needles radiating outward from cave walls, speleothems

Table 1. Minerals Identified in the Butler Cave — Sinking Creek System.

Mineral	Composition	Occurrence
Calcite	$CaCO_3$	Dripstone, flowstone, helictites, nodular speleothems, pool deposits
Aragonite	$CaCO_3$	Nodular speleothems, wall crusts
Hydromagnesite	$4MgCO_3 \cdot Mg(OH)_2 \cdot 4H_2O$	Moonmilk residues associated with aragonite, Thin coatings on walls
Gypsum	$CaSO_4 \cdot 2H_2O$	Wall crusts
Goethite	$FeOOH$	Wall crusts
Hydroxyapatite	$Ca_5(PO_4)_3(OH)$	Nodules in clastic sediments
Taranakite	$H_6K_3Al_5(PO_4)_8 \cdot 18H_2O$	Wall crust and vein fillings in clastic sediment
Crandallite	$CaAl_3(PO_4)_2(OH)_5 \cdot H_2O$	Nodules in clastic sediment
Sasaite(?)	$Al_{14}(PO_4)_{11}(SO_4)(OH)_7 \cdot 83H_2O$	Crevices and veins in clastic sediment

Table 2. Composition of Selected Speleothems.

Specimen	Mineral	SiO_2	Al_2O_3	MgO	SrO
Stalagmite Natural Bridge Area 1238	Calcite	<0.01	0.002	1.42	1.00
Soda Straw Stalactite Sneaky Creek Area 73 BC 002	Calcite	0.10	0.005	0.85	0.10
Massive Crystals 76 BC 002	Calcite	0.02	0.005	0.08	<0.01
Nodular Speleothem 90-Ugh Crawl 200	Aragonite	2.90	0.01	2.15	4.42
Nodular Crust Crystal Passage 299	Aragonite	9.85	0.002	5.15	2.75

All concentrations are given as weight-percent oxide. Elements sought but not found: Mn, Fe, Ti, B, V, Ni, Cr.

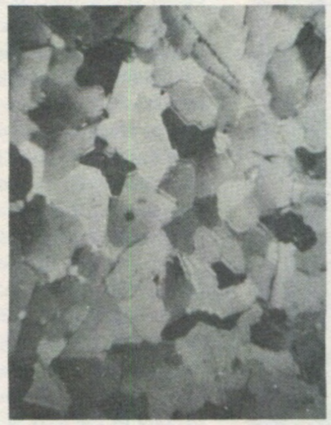
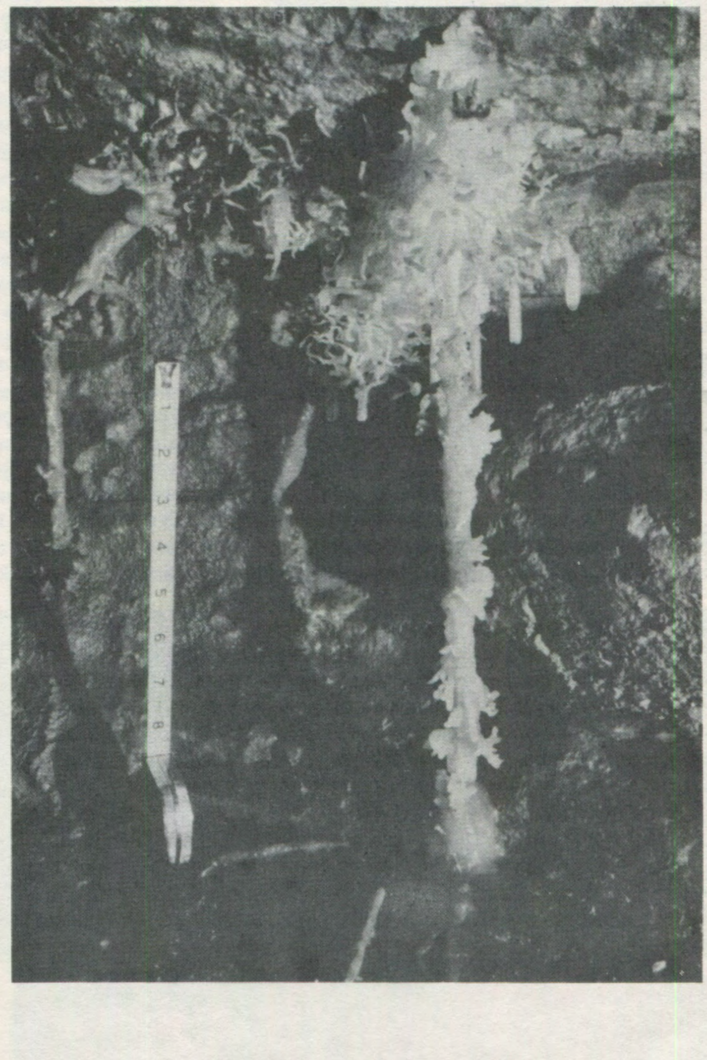
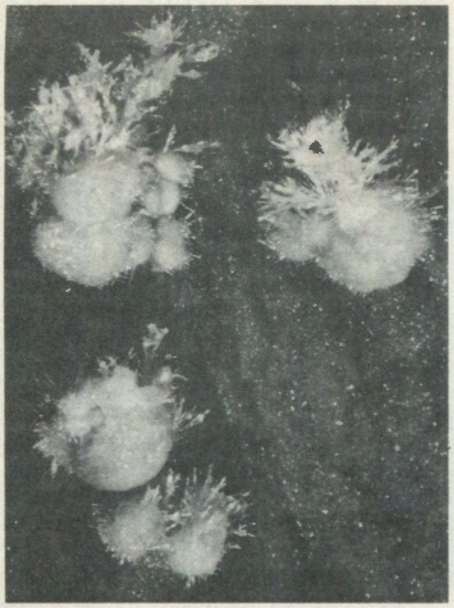
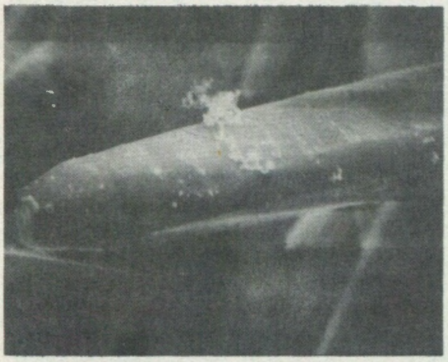


Figure 1. [*above, left*] Photomicrograph of stalagmite texture. Crossed polarizers. Specimen 1238. **Figure 2.** [*above, right*] Massive helictites near entrance to Crystal Passage. **Figure 3.** [*below*] Filiform helictites near Entrance Room. Compare helictite diameter to diameters of the small soda straw stalactites. Scale in inches.







shaped rather like helictities but composed of masses of tightly packed crystal rods, globular objects supported on necks or stalks protruding from the walls, and masses of material that appear as lumps or nodules plastered against the cave walls. All of these contain aragonite as an essential constituent.

Tufts of acicular crystals are found in Breathing Cave and very sparsely in Butler Cave. The individual crystals range around one cm in length and less than a mm in cross-section. They consist mostly of aragonite, but include considerable quartz probably from the soils from which they grew. There do not appear to be any crystallographic relationships among the individual needles in the cluster.

Helictite-like speleothems were observed in 90-Ugh Crawl in Butler Cave. They are one to two cm in length, 0.5 cm in cross-section and consist of an inner aragonite core around which is laid a close-packed mat of acicular aragonite crystals. The long axes of the aragonite crystals are nearly parallel to the axis of the speleothem, so that it has an external nodular shape. Most of these are also coated with a dusting of dry moonmilk. Both these speleothems and the acicular tufts would be considered a style of anthodite.

In the Crystal Passage are sections of wall on which occur nodular speleothems, many of which have clusters of acicular aragonite needles growing from them (Fig. 4). all nodules including those that lack the well developed needles are coated with a mat of white aragonite crystals a few hundred micrometers in length. Shapeless blobs of dry or wet moonmilk are draped over the aragonite needles in many of the speleothems.

The nodular speleothems with aragonite clusters are nearly spherical, but in the same section of cave wall occur other more elongate speleothems. All of those examined were found to be formed on angular projections of limestone wall rock. The speleothems were built up in layers from the initial projection. Most were composed of fine needles of aragonite with the long axes of the needles along the growth direction (that is, perpendicular to the speleothem surface). Interlayers of calcite were found in a few cases.

Speleothems that appear as lumps or nodules on the cave walls have an internal structure much like that of the more highly developed speleothems. They also form over initial projections in the limestone bedrock and have a layered structure. All of the nodules examined were composed of layers of fine-grained aragonite.

Crusts

In many regions of the cave there are white coatings directly over bare limestone. X-ray diffraction analysis of a few selected examples shows them to be composed of aragonite. The scanning electron microscope (Fig. 5) reveals a mass of acicular crystals 0.5—1 mm in length and 5—10 μm in diameter, without any particular orientation. High magnification images of the needles shows that some (Fig. 6a) have the pseudo-hexagonal outline often found in large crystals of aragonite. Others (Fig. 6b) are more rounded, with tapering rounded tips. There is some evidence for growth striations on this crystal as well. Small bulbous objects appear on the sides of some of the needles (Fig. 7). This may be a second mineral deposited on the sides of the aragonite needles, but the composition and structure of the phase is not known.

The tiny aragonite needles appear to grow outward directly from bare bedrock. Although growth from films of downward-flowing water cannot be excluded, it seems more likely, considering the distribution of the coatings over the walls, that the solutions that deposit the coatings ooze directly from the rock behind the coating. Sufficient moisture is present, at least, to allow the well developed crystals seen in the SEM images to grow.

Moonmilk

Moonmilk occurs as a dry powder dusted over the surfaces of stalactites and some bedrock surfaces in many parts of the cave. It also occurs as sticky white blobs associated with acicular aragonite. All specimens of moonmilk examined yielded the X-ray diffraction patterns of hydromagnesite, $4MgCO_3 \cdot Mg(OH)_2 \cdot 4H_2O$. It should be noted that samples were removed from the cave in ordinary plastic vials and transported to the laboratory unrefrigerated. The X-ray patterns were not run until some weeks (or longer) after collection so that the possibility cannot be excluded that the hydromagnesite observed in the laboratory was an alteration product of some other mineral that actually occurs in the cave.

The crystals of hydromagnesite are in the range of 1 to 10 micrometers. Some are well-formed and some are irregular grains (Fig. 8). Most appear as well developed rhombs.

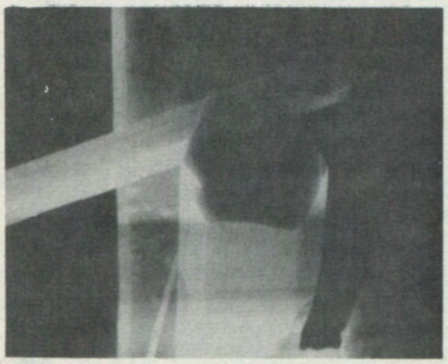


Figure 4. [*top left*] Globular speleothems with aragonite overgrowths. Crystal Passage. Speleothems are 1 to 5 cm in diameter. **Figure 5a.** [*upper center*] SEM image at 135x of mat of aragonite needles coating limestone wall of Crystal Passage. Specimen 73BC003. **Figure 5b.** [*lower center*] Specimen 303. **Figure 6a.** [*bottom left*] Pseudohexagonal cross-section on aragonite needle, 1325x. **Figure 6b.** [*bottom right*] Tip of aragonite needle, 2675x.

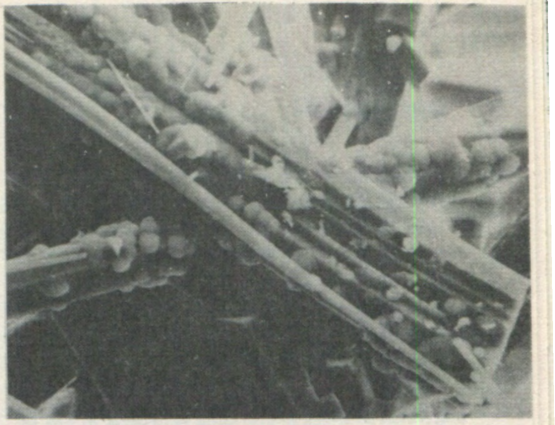
The association of hydromagnesite with aragonite is very common in Butler Cave but is by no means a unique occurrence. Similar soft, wet, daubs of hydromagnesite on tufts of aragonite needles were found in Timpanogos Cave (White and Van Gundy, 1974), in various Missouri caves, and in other localities.

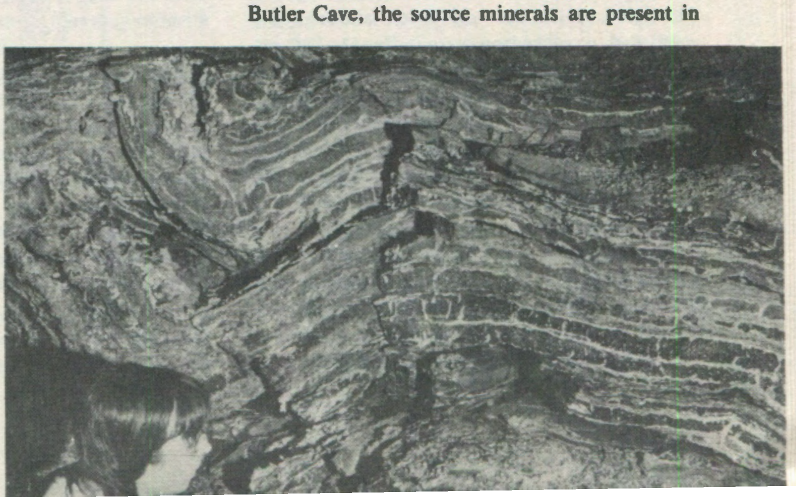
Many of the nodular and anthoditic speleothems have a core of calcite and an outer sheath of aragonite. So long as calcite is deposited as the primary phase, the magnesium in the percolating water is also deposited in the form of a few percent magnesium solid solution in the calcite (see Table 2). When, for whatever reasons, the supersaturation reaches a level where aragonite becomes the depositing phase, magnesium is no longer readily incorporated into the growing aragonite crystal because of the size mismatch between Mg^{++} and Ca^{++}. Magnesium is preferentially excluded from the crystal and accumulates in the small amount of residual solution at the tip of the speleothem. As the residual solutions gradually evaporate, a pure magnesium phase deposits, the calcium having been previously deposited in the aragonite. What remains unanswered in this proposed mechanism is the question of crystal habit. Aragonite comes down as large, well-developed crystals. Hydromagnesite occurs as a fine-grained, ill-defined pasty mass. Whether this implies some more complicated mechanism or possibly the intervention of microbiological processes is not known.

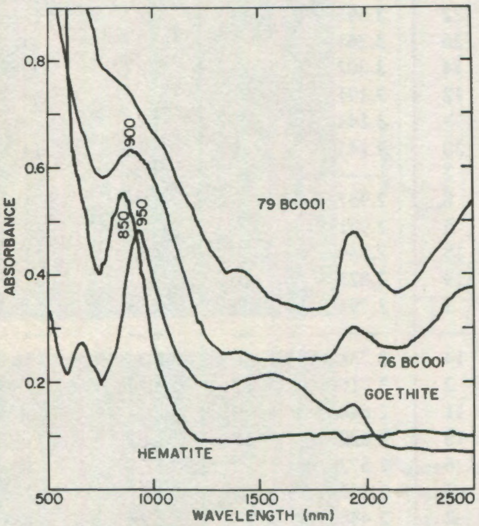
EVAPORITE MINERALS

Gypsum crusts occur on the cave walls, and there are thin gypsum crusts mixed in with other coatings on the surface of the soils in many places. Figure 9 illustrates a section of the wall where the limestone is strongly folded. Gypsum is seen deposited on bedding planes and in joints, with the line of the gypsum following all details in the bedrock folding.

It is argued, following a suggestion originally put forth by John Haas, that the primary source of the gypsum is from the oxidation of minor amounts of sulfide minerals contained in the shaley partings within the limestone. The lower Keyser limestone has many of these, and some regions of the cave, such as the strongly folded section in Butler Cave just above the 90-Ugh Crawl, have many red beds with dark shales interbedded in the limestone. As the bedrock is removed by solution, the fine-grained sulfides are exposed to oxygen-carrying water. The reaction between the sulfides (whose mineralogy is unknown but might be pyrite or other iron sulfides) and water may be enhanced by the presence of sulfur-oxidizing bacteria. In this respect, the origin of the gypsum in the Butler Cave-Sinking Creek system is like that proposed for the gypsum in the Flint Mammoth system of Kentucky (Pohl and White, 1965). However, in Butler Cave, the source minerals are present in







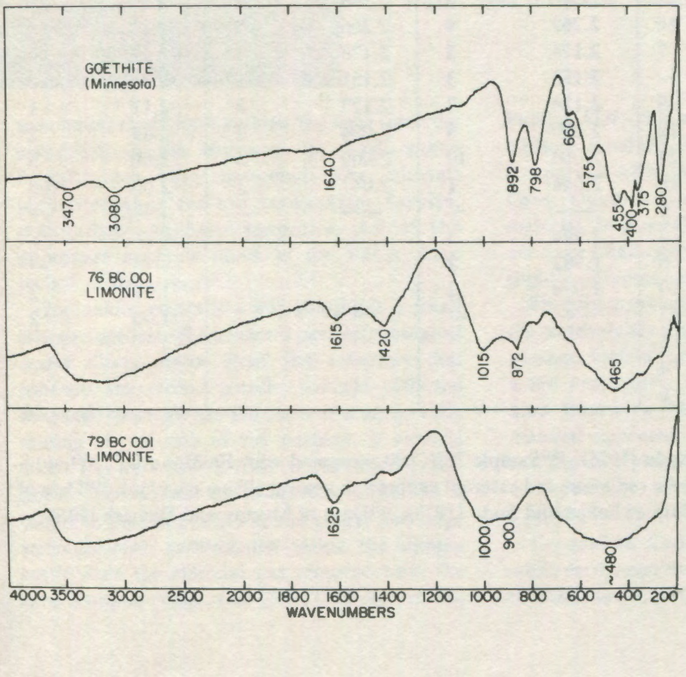


Figure 7. [*top, right*] Nodular lumps (second phase?) on aragonite needles, 660x, Specimen 73 BC 003. **Figure 8.** [*center, right*] SEM image of hydromagnesite crystals, 660x. **Figure 9.** [*bottom, right*] Bands of gypsum crust following the bedding planes. **Figure 10.** [*top, left*] Diffuse reflectance spectra of iron oxide minerals in comparison with the spectra of goethite and hematite. **Figure 11.** [*bottom, left*] Infrared absorption spectra of iron oxide minerals in comparison with goethite.

the limestone of the cave walls and not in the overlying sandstones. There is no need, therefore, for any mechanism of transport and redeposition. The oxidized sulfide produces sulfuric acid which reacts with the calcite in the adjacent limestone to release carbon dioxide into the cave atmosphere. Migration of solutions out of the wall and their consequent evaporation in the cave passage is sufficient to produce the observed gypsum. Since migration of these percolating solutions would be along bedding plane partings and joints, the pattern of gypsum deposits shown in Figure 9 is accounted for.

RESISTATE MINERALS

Resistates are residual minerals formed during the weathering process. Two resistates occur in Butler Cave, hydrated iron oxide and black manganese oxide.

Two locations were discovered where occur yellow to red-brown platy masses answering the usual description of limonite: 79BC001, Huntley's Cave Section; and 79BC001, Evasor Gallery. Specimen 79BC001 had a complex layered structure, an alternation of deep brown, homogenous, layers that had a vitreous luster and broke with a conchoidal fracture and yellow layers with some internal banding and a satiny texture. Specimen 76BC001 was also layered but with a less complex structure. Both samples were essentially amorphous to X-rays, although 76BC001 yielded an X-ray pattern with a few weak and broad peaks to identify the mineral as goethite, FeOOH.

Diffuse reflectance spectra in the near-infrared show a characteristic band at 900 nm that is very similar to the spectrum of goethite (Fig. 10). This band has been observed previously in karst soils (White, 1977) and in other iron oxide speleothems (White, 1981). It is quite distinct from the spectrum of hematite and indicates that the immediate environment of the Fe^{3+}ion in these crusts is similar to the local environment of iron in crystalline goethite. The infrared spectra of the Butler Cave samples (Fig. 11) consist of only two broad ill-defined bands, whereas the spectrum of crystalline goethite is sharper and better resolved. The implication is that the cave materials are disordered at the unit cell level, although the coordination polyhedron surrounding the Fe^{3+} ion is not very different from the arrangement found in crystalline goethite.

Black coatings occur on stream cobbles throughout the cave, and there is a thin black coating that occurs as the uppermost layer on the crusts that cap the clastic sediments in the Butler Cave section of the system. These are of very similar appearance to other black coatings that have been identified as manganese oxide minerals of various kinds. The Butler Cave-Sinking Creek System coatings are very thin, and no identification of the specific minerals has been made.

Table 3. Comparison of Taranakite X-ray Data.

(a)			Butler Cave (b)		Castellana Cave (c)		Onino-Iwaya Cave (d)		Pig Hole Cave (e)	
h	k	l	d(Å)	I/Imax	d(Å)	I/Imax	d(Å)	I/Imax	d(Å)	I/Imax
0	0	6	15.77	56	15.89	100	15.87	100	15.49	100
0	0	12	7.904	32	7.94	26	7.957	21	7.82	23
			—	—	7.62	9	—	—	—	—
0	1	2	7.428	36	7.46	30	7.487	15	7.43	18
1	0	4	7.173	7	7.20	7	7.225	3	7.13	6
1	0	10	5.896	24	5.92	18	5.930	10	5.82	13
0	1	14	5.039	9	5.06	4	5.068	2	5.01	4
1	0	16	4.662	7	4.68	3	4.683	3	4.62	3
1	1	0	4.344	18	4.36	13	4.366	6	4.27	12
1	1	3	4.301	30	4.32	20	4.322	10	—	—
1	1	6	4.191	7	4.19	4	4.206	1	4.15	2
0	1	20	4.012	15	4.03	9	4.029	5	4.00	3
1	1	12	3.804	100	3.82	34	3.824	25	3.79	25
1	0	22	3.742	28	3.76	11	3.753	9	3.72	11
2	0	8	3.578	51	3.59	22	3.596	13	3.57	15
1	1	18	3.348	37	3.35	26	3.365	7	3.34	9
2	0	14	3.288	37	3.30	14	3.302	8	3.27	10
0	2	16	—	—	3.18	12	3.191	7		
0	0	30	3.172	29	—	—	3.143	7	3.16	9
1	1	21	3.130	83	3.14	30	3.143	19	3.12	19
			—	—	3.04	2	—	—	3.06	1
2	0	20	2.948	22	2.957	8	2.957	3	2.94	4
1	1	24	2.920	11	2.929	5	2.931	3	—	—
0	2	22	2.837	46	2.844	15	2.844	9	2.83	12
1	2	5	2.811	62	2.822	19	2.823	10	2.81	12
2	1	7	2.784	21	2.791	3	2.794	3	—	—
			2.758	9	—	—	—	—	—	—
2	1	10	2.728	32	2.739	14	2.738	6	2.73	8
1	2	11	2.698	12	2.709	3	2.710	2	2.70	3
0	0	36	2.636	40	2.643	11	2.644	9	—	—
2	0	26	2.618	43	2.627	15	2.628	10	2.62	13
2	1	16	2.564	23	2.571	8	2.572	3	2.55	3
1	2	17	2.532	11	2.542	4	2.542	2	2.53	2
0	3	6	2.478	12	2.486	2	2.485	1	2.48	1
			2.436	5	2.462	1	—	—	2.44	0.5
3	0	12	2.390	39	2.398	11	2.398	6	2.38	7
1	2	23	2.341	17	2.348	4	2.348	2	2.34	2
0	0	42	2.260	16	2.267	4	2.266	2	2.26	3
2	2	0	2.167	7	2.174	3	2.173	1	2.17	2
1	2	29	—	—	2.153	3	2.151	1	2.14	2
3	0	24	2.118	9	2.124	2	2.123	2	2.12	1
2	1	31	2.086	12	2.090	5	2.094	2	2.09	2
1	3	7	2.063	24	2.068	10	2.069	5	2.06	5
3	0	27	2.055	18	2.044	1	2.047	2	2.00	0.5
			2.035	6	—	—	—	—	—	—
			2.005	2	1.994	3			—	—
			1.976	8	1.982	2			—	—
			1.956	10	1.970	2			1.96	2
			1.903	13	—	—			1.90	2
			1.861	5						
			1.843	4						
			1.820	6						

(a)Indexing from Sakae and Sudo (1975). (b)Sample 78BC003 measured with Phillips ADP3500 automated diffractometer using CuKα radiation and external calibration against silicon standard. (c)Data of Balenzano, *et al.* (1976). (d)Data of Sakae and Sudo (1975). (e)Data of Murray and Dietrich (1956).

PHOSPHATE MINERALS

Phosphate minerals occur in many cave localities and are usually associated with guano deposits. Leachates from the guano react with limestone wall rock to produce a suite of calcium phosphates such as brushite, whitlockite, crandallite, and hydroxyapatite along with magnesium phosphates, ammonium compounds, and some organic minerals such as urea and guanine. Detailed descriptions of these assemblages have been published for caves in Puerto Rico (Kaye, 1959), Western Australia (Bridge, 1971, 1973-a,b, 1974), and South Africa (Martini, 1978).

The phosphate minerals that occur in Butler Cave are unusual in that they are primarily hydrated aluminum phosphates, and they are not associated with guano deposits. Butler Cave has no natural entrance. Thus only a very small bat population could have entered the cave since the excavation of the entrance; no fossil guano deposits have been discovered. The minerals identified thus far are taranakite, sasaite, crandallite and hydroxyapatite. All of the phosphate minerals occur in the Butler Cave section of the system.

Taranakite occurs as a wall coating in a small side passage just off the second parallel passage of Butler Cave, across from the crawlway that connects the second parallel passage with the Entrance Room. It has the form of a pasty white coating on the wall of the passage, it extends about 1 m up from the floor and is about 5 mm thick. The material resembles moonmilk. As it occurs in the cave, it is wet and pasty, and large water droplets accumulated inside the sample bottle when the material was removed from the cave. Samples of the crust (78BC003) gave sharp, well-defined X-ray diffraction patterns that matched well the pattern published by Murray and Dietrich (1956) for taranakite from Pig Hole Cave, Virginia and by Balenzano, *et al.* (1976) for taranakite from the Castellana caves in Italy (also reproduced as JCPDF X-ray Pattern 29-981).

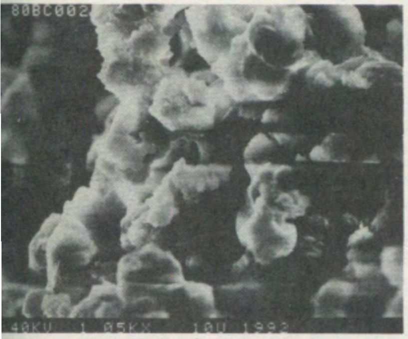
The drops of water which collected in the sample bottle suggest dehydration of the sample, but the X-ray pattern of material air-dried for one year was the same as that of the original except for some small changes in peak intensity. Both fresh and dried material had the characteristic 15.8 Å basal spacing of taranakite; there was no evidence for dehydration to francoannellite with a 13.7 Å basal spacing, as was observed in the Castellana Cave minerals (Balenzano, *et al.* 1976). Because the Butler Cave taranakite seemed to be exceptionally well-crystallized, refined X-ray powder diffraction data were collected using a Phillips ADP-3500 automated diffractometer and a silicon standard. Table 3 displays these data in comparison with powder data for the Castellana Cave, Onino-Iwaya Cave, and Pig Hole Cave material. In general, agreement is good but there are some small systematic shifts that may reflect a slightly different composition.

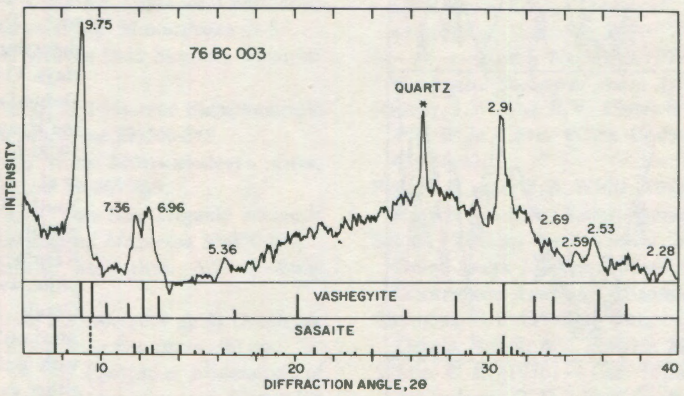
Phosphate minerals occur in isolated pockets in the relatively dry sandy soils of the second parallel passage. One of these (76BC004) was in a pocket a few centimeters in diameter filled with loose deep brown to black material. Much of the material appeared to be amorphous to X-rays, and the only identifiable lines could be assigned to poorly crystallized hydroxyapatite, $Ca_5(PO_4)_3(OH)$.

Crandallite, $CaAl_3(PO_4)_2(OH)_5 \cdot H_2O$, occurs as white earthy nodules mixed with a black material, in loose masses in the clastic sediment at the top of the fill bank at the head of the second parallel passage. The X-ray diffraction pattern is sharp and well-resolved, indicating a well-crystallized material. SEM images of sample 80BC002 (Fig. 12) show a nodular texture. EDX analysis of the nodules indicates a calcium-aluminum-phosphate of quite uniform composition. Scattered through the nodules are small acicular crystals which have essentially the same chemical composition as the bulk crandallite (Fig. 12b). The X-ray diffraction pattern is also a fairly good match to the pattern for woodhouseite, $CaAl_3(PO_4)(SO_4)(OH)_6$, which is both chemically and structurally very similar to crandallite. However, the EDX analysis reveals no trace of sulfur, thus limiting the choice to crandallite.

An unusual phosphate mineral occurs in a small pocket in partially indurated sandy soil. This material (76BC003) was a homogeneous white powder either mixed with sand grains or filling small cracks and voids in the bedded sediments. It appears to be the mineral sasaite, $Al_{14}(PO_4)_{11}(SO_4)(OH)_7 \cdot 83H_2O$ recently described as a new mineral from the West Driefontein Cave, South Africa (Martini, 1978). However, the identification of this mineral is less certain than those described above. If the Butler Cave material really is sasaite, it will be only the second recorded occurrence of the mineral.

Figure 13 shows the X-ray diffraction pattern for sample 76BC003. Some quartz is admixed with the white phosphate mineral and appears in the diffraction pattern as the intense $10\bar{1}1$ reflection at 26.66° 2Θ, thus forming a convenient internal standard. Several very broad diffraction features underlie the sasaite diffraction peak, indicating that there is also present a nearly amorphous phase in addition to the crystalline





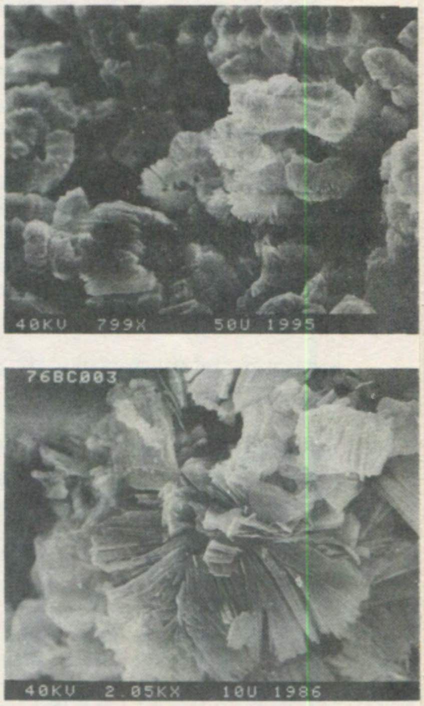


Figure 12a. [*top, left*] SEM image of nodular crandallite. **Figure 12b.** [*bottom, left*] Acicular crystals mixed with crandallite nodules. **Figure 13.** [*above*] X-ray diffraction powder pattern for sample 76 BC 003, thought to be sasaite. For comparison, the patterns of fresh and dried sasaite (Martini, 1978) and vashegyite (JCPDF card 29-68) are shown. **Figure 14.** [*right*] SEM images of "sasaite," showing expanded platelet structure.

phosphate. Sasaite is a highly hydrated phase and some of the water is easily lost. Martini reports substantial changes in the basal spacings when the material is dried over silica gel. The bar graph in Figure 13 reproduces Martini's diffraction pattern. The dashed line on the bar graph shows the shift that occurs when the material is dehydrated. It can be seen that the pattern of the Butler Cave sample is similar but not identical to Martini's pattern. Sasaite has apparently an expandable layer structure which produces crystals in the form of swelled stacks, as shown in the SEM image (Fig. 14). Martini found an almost identical microstructure; compare Figure 14 with Figure 1 of Martini's paper. Indeed, the SEM image is the best evidence that the Butler Cave mineral is identical to sasaite as originally described. The structure of the mineral is unknown but is apparently related to that of vashegyite, $Al_4(PO_4)_3(OH)_3 \cdot 11H_2O$. The powder diffraction patterns of the two minerals are rather similar.

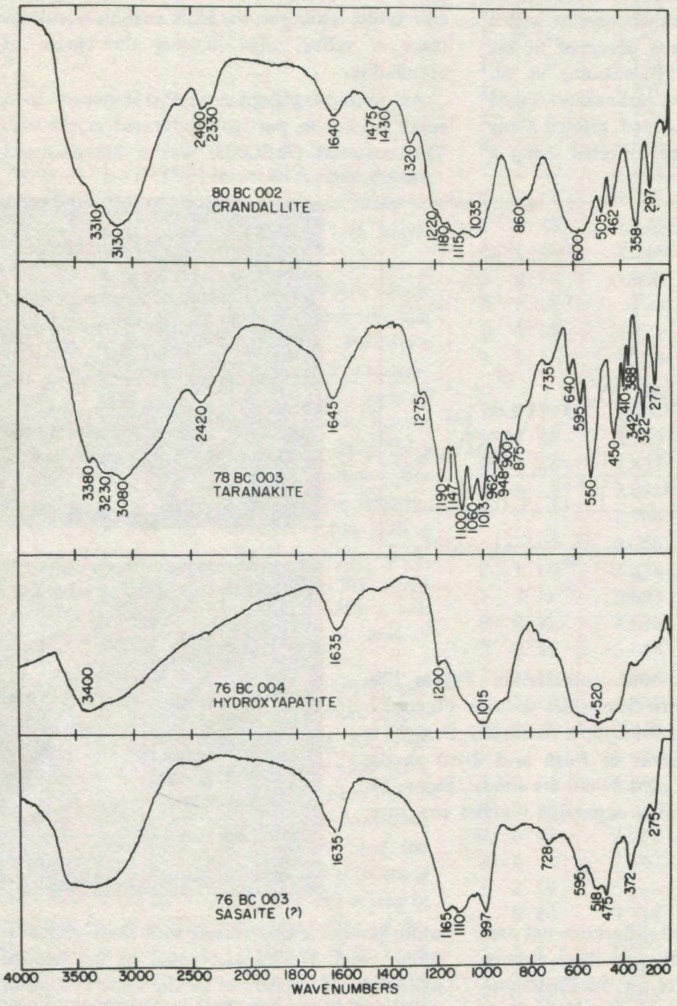


Figure 15. Infrared absorption spectra of the Butler Cave phosphate minerals.

The question remains as to whether the mineral discovered in Butler Cave is identical to the new mineral described from South Africa. The X-ray diffraction patterns are too variable and too ill-defined to allow a definitive match. The microstructures are very similar. However, Martini's mineral has an essential sulfate group, and he says that the sulfur content is very constant for samples collected in different parts of the cave. EDX analysis of sample 76BC003 showed some calcium and some iron in all grains examined but no trace of sulfur. Perhaps the Butler Cave mineral is simply a sulfate-free end-member of a solid solution in which SO_4 replaces PO_4 with charge balance maintained by adjusting the OH^- content. Perhaps the Butler Cave mineral is a distinct mineral similar in composition, structure (having the same expandable hydrated layer characteristics) and high degree of hydration as sasaite and vashegyite but is not identical to either of them. More data must be obtained and more work on synthetic phases in the system Al_2O_3—P_2O_5—H_2O must be accomplished before definitive answers can be made.

Figure 15 shows the infrared absorption spectra of the phosphate minerals. The taranakite spectrum shows much sharp detail and is in good agreement with that published by Sakae and Sudo for taranakite from the Onino-Iwaya cave in Japan. The spectrum of sasaite is here published for the first time. The very broad and intense band near 3000 cm $^{-1}$ is indicative of the large amount of water of crystallization present in this structure. Weak bands near 1400 cm $^{-1}$ in the spectrum of hydroxyapatite indicate that some carbonate is also included in this structure. Therefore the mineral from Butler Cave is an intermediate compound between carbonate-apatite (dahllite) and hydroxyapatite. The exact composition could not be determined. Similar mixed apatites have been found in other caves, for example the et-Tabun cave in Israel (Goldberg and Nathan, 1975).

Aluminum phosphates do not occur commonly in caves. Murray and Dietrich (1956) originally described taranakite from Pig Hole Cave, where they ascribed its origin to the reaction of leachate from the guano with clay minerals in the cave soils. The guano provides the phosphorus and potassium while the aluminum is supplied by the clays. Other occurrences of taranakite are in the Onino-Iwaya cave, Japan (Sakae and Sudo, 1975) the Hoan Seon-gul cave, Korea (Kashima, *et al.* 1978) in the Castellana Caves, Italy (Balenzano, *et al.* 1976) and in several of the Transvaal caves, South Africa, where several other aluminum phosphate minerals are also found (Martini and Kavalieris, 1978). The iron analog, leucophosphite, was reported from the Canga Caves, Minas Gerais, Brazil by Simmons (1963). All of these previously described occurrences are associated with guano deposits, and the various authors either explicitly or implicitly agree with Murray and Dietrich's original explanation for the origin of the mineral.

The difficulty with the Butler Cave occurrences of the aluminum phosphates is that they occur as nodules within the clastic sediments and as wall coatings and have no association with organic materials. Aluminum phosphates are extremely insoluble in the neutral pH range expected in the cave environment and there is the question of how they could have been transported to the sites where they are found.

It is perhaps significant that the phosphate minerals are found in the sloping passages that lie on the west flank of the syncline, passages that in times past have taken extensive surface runoff from the flanks of Jack Mountain. The sediments in which they are found are associated with the boulder and cobble infillings. Several hypotheses are then possible. One is that there were open cave entrances at the heads of these passages at some time in the past, and that these entrance areas had bat populations with associated accumulations of guano. The leachate from the guano was then extracted and moved down slope through the clastic sediments, not coming into contact with the limestone wall rock until by gradual reaction of the leachate solutions with the clay minerals in the soil, the aluminum phosphate minerals were formed. Alternatively it could be argued that sinkholes that formed where the surface water from Jack's Mountain went underground acted as traps for buildup of organic material and that the leachate from these sinkhole fillings provided the source of phosphate. Since no trace of the percolating solutions remain, and since surface conditions are much different now than at the time of the deposition of the boulder and cobble fills, there is little other than speculation to suggest an origin for the minerals.

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A Preliminary Report on the Cave Fauna of Burnsville Cove, Virginia

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SUMMARY

Nineteen species of cave animals — 11 invertebrates and 8 vertebrates — are recorded from the caves of Burnsville Cove. Six species are troglobites, two are questionable troglobites, and the remainder are troglophiles, trogloxenes, and accidentals. The troglobitic fauna includes single species in the following groups: snails (?), amphipods, isopods, mites (?), spiders, millipeds, collembolans, and beetles. In comparison to large cave systems in the Greenbrier, Clinch, and Powell river basins of Virginia and West Virginia, the cave species diversity of Burnsville Cove is low. The geological isolation of this system is offered as an explanation for its impoverished cave fauna.

THIS REPORT consists of an annotated list and brief discussion of species recorded from the caves of Burnsville Cove during the past 15 years. Five caves — Aqua, Better Forgotten, Boundless, Breathing, and Butler — are considered. Despite visits to all five of these caves by biologists, the list of fauna is preliminary. Some of the earlier trips to the system by the writer and his associates were made for physical exploration as well as for biological investigation and only two trips (Aqua Cave in July, 1967 and Butler Cave — Sinking Creek System in November, 1968) were made purely for biological reconnaissance. A more definitive list of cavernicoles can be compiled after the entire system is thoroughly explored biologically.

Despite the preliminary nature of the list, the fauna of the Sinking Creek Cave System is believed to be well-enough known for a meaningful comparison to other large cave systems in the Appalachians of Virginia and West Virginia. In this context, its fauna does not appear to be very diverse or characterized by many large populations of individual species. Only eight troglobites (two of which are questionable) are recorded, and only two of them are endemic to the system; the remainder are represented largely by species with wide regional distributions.

ANNOTATED LIST OF SPECIES

The following abbreviations are used in the list below: TB, *troglobite* (obligatory cavernicole); TP, *troglophile* (facultative cavernicole); TX, *trogloxene* (occasional cavernicole), *Accidental* refers to a species not usually associated with a cave.

PHYLUM MOLLUSCA
CLASS GASTROPODA (SNAILS)
ORDER MESOGASTROPODA

Family Hydrobiidae
***Fontigens orolibas* (?) Hubricht (TB or TP)**
This species, tentatively determined as *F. orolibas* but, possibly, an undescribed form, is fairly common under flat rocks in parts of Sinking Creek in Butler Cave. *F. orolibas* was originally described by Hubricht (1957), from springs above 610 m elevation in Shenandoah National Park but has since been tentatively identified from several cave streams in the Appalachian Valley of Virginia. The spring populations contain animals with light pigmentation and tiny eyes, however, in contrast to the cave populations which usually contain blind, white animals. The entire *Fontigens* complex needs further study before specific determinations of the cave forms can be made with assurance.

PHYLUM ARTHROPODA
CLASS CRUSTACEA
ORDER AMPHIPODA (AMPHIPODS)

Family Crangonyctidae
***Stygobromus conradi* (Holsinger) (TB)**
This rare species was originally described by Holsinger (1967) from two specimens collected from a small stream on the lower level of Breathing Cave. Two more specimens were found in Sinking Creek, in Butler Cave, in November, 1968. To date, this species is known only from the Sinking Creek Cave System, although it is closely related to a species (*Stygobromus gracilipes*) which inhabits caves in the Shenandoah Valley of northwestern Virginia, eastern West Virginia, central Maryland, and southern Pennsylvania. Although *S. conradi* was originally assigned to the genus *Stygonectes*, this genus is now considered a synonym of *Stygobromus* (Holsinger, 1977).

ORDER ISOPODA (ISOPODS)

Family Asellidae
***Caecidotea holsingeri* Steeves (TB)**
This species is fairly common under rocks and between gravels in Sinking Creek, where it is often associated with *Fontigens*. A few specimens (undetermined females but, presumably, this species) also have been collected from Aqua and Better Forgotten caves. The range of *C. holsingeri* (originally described from the Organ Cave System in Greenbrier Co., West Virginia by Steeves [1963]) extends from the extreme western part of Maryland southward through West Virginia to Monroe County. The discovery of this species in Butler Cave, in 1968, extended its range east for approximately 40 km into the upper James River basin (Holsinger and Steeves, 1971).

CLASS ARACHNIDA
ORDER ACARINA (MITES AND TICKS)

Family Rhagidiidae
***Rhagidia* sp. (TB or TP)**
Several specimens of an undetermined species of this genus have been collected from under damp rocks near Sinking Creek, in Butler Cave, and from near the stream in Aqua Cave. This genus of mites, which is widely distributed in caves, is represented by a number of undescribed species, some of which are apparently troglobitic.

ORDER ARANEAE (SPIDERS)

Family Linyphidae
***Phanetta subterranea* (Emerton) (TB)**
This common cave spider has been collected from Butler, Breathing, and Boundless caves. The species is widely distributed in caves of the eastern United States and is probably only a marginal troglobite. Four specimens were collected from the garbage dump at the camp site in Sand Canyon, in Butler Cave, in April, 1961.

Butler - Bath Co.
Breathing - Bath Co
Boundless - Bath Co.

Aqua - Highland
Better Forgotten - Highland

CLASS DIPLOPODA (Millipeds)

ORDER CHORDEUMIDA

Family Trichopetalidae

Trichopetalum weyeriensis **(Causey) (TB)**

This species (formerly placed in the genus *Zygonopus* [see Shear, 1972]) is recorded from Butler and Boundless caves but is reported, also, from many caves in westcentral Virginia and adjacent West Virginia (Holsinger, 1963a, 1963b; Holsinger *et al.*, 1976). It was originally described from Grand Caverns (Weyers Cave) in Augusta Co., Virginia, by Causey (1960). In addition to living specimens, molt skins were observed on a clay bank in the Penn State Lake area of Butler Cave, in March, 1963.

CLASS INSECTA

ORDER COLLEMBOLA (SPRINGTAILS)

Family Entomobryidae

Sinella hoffmani **Wray (TB)**

This species is recorded from Butler, Breathing, and Boundless caves. In April, 1961, a large population, numbering several hundred, was observed on the garbage dump in Sand Canyon (Butler Cave), apparently attracted by the decaying food. In Boundless Cave, the species was found around decaying leaves in a dry (but damp) stream bed, distant from the entrance. *S. hoffmani*, originally described by Wray (1952) from Lowmoor Cave in Alleghany Co., Virginia, is a fairly common troglobite in many caves of westcentral Virginia and adjacent West Virginia (Holsinger, 1963a, 1963b; Holsinger *et al.*, 1976).

Family Sminthuridae

Arrhopalites benitus **(Folsom) (TX or Accidental)**

In the Burnsville Cove area, this species is known only from a single specimen collected from Breathing Cave, in August, 1958 (Christiansen, 1966). The species also has been collected from McClungs Cave, in Greenbrier Co., West Virginia, but is otherwise reported from epigean habitats and is generally distributed over North and Central America (Christiansen, 1966).

ORDER ORTHOPTERA (CRICKETS, GRASSHOPPERS, ETC.)

Family Rhaphidophoridae

Ceuthophilus pallidipes **Walker (Accidental)**

This species of camel cricket was collected from just inside of the entrance to Better Forgotten Cave. It is ordinarily an inhabitant of mesic forests (Hubbell, 1936) and its presence in a cave is probably accidental. A more common inhabitant of cave entrance zones is *Ceuthophilus gracilipes*, a congerneric relative of *C. pallidipes*.

Hadenoecus puteanus **Scudder (TX or Accidental)**

This species was also collected from near the entrance to Better Forgotten Cave and is primarily an inhabitant of cliffs, talus slopes, mesic forests and cave entrance zones. It is widely distributed throughout the Appalachian region of the eastern United States and is related to several troglophilic species of the same genus (T.H. Hubbell, in litt.).

ORDER COLEOPTERA (BEETLES)

Family Carabidae

Pseudanophthalmus **sp. (TB)**

This undescribed species is, apparently, an extremely rare form of the almost exclusively cave-adapted genus *Pseudanophthalmus*. The species is known only from single specimens collected from Breathing and Butler caves, respectively. The genus, however, is represented by numerous troglobitic species in the Appalachian and Interior Low Plateau regions (Barr, 1965).

PHYLUM CHORDATA

CLASS AMPHIBIA

ORDER ANURA (FROGS AND TOADS)

Family Ranidae

Rana sylvatica **LeConte (Accidental)**

A single specimen of the Wood frog was observed in a small pool about 60 m from the entrance in Better Forgotten Cave, in February, 1961.

ORDER URODELA (SALAMANDERS)

Family Plethodontidae

Plethodon wehrlei wehrlei **(Fowler and Dunn) (TX)**

Two specimens of Wehrle's salamander were taken just inside of the entrance to Butler Cave, in December, 1960 (Cooper, 1962a). This species is also reported from several other caves in Virginia (see remarks by Cooper, 1962a, 1962b).

Pseudotriton ruber ruber **(Sonnini) (Accidental)**

A single specimen of the Northern Red salamander was collected from the "back reaches" of Aqua Cave, in September, 1960 (Cooper, 1960).

Eurycea longicauda longicauda **(Green) (TX)**

A large population of the Long-tailed salamander was observed on two different occasions along the stream passage, in Aqua Cave, by Cooper (1960, 1962b), in September, 1960, and by the writer, in July, 1967. The salamanders appeared to be moving upstream (from the entrance) and were, possibly, migrating into the cave to escape the heat on the surface.

CLASS MAMMALIA

ORDER CHIROPTERA (BATS)

Family Vespertilionidae

Several species of bats have been reported from the caves of Burnsville Cove, including: Pygmy bat, *Pipistrellus subflavus* (Cuvier); Social bat, *Myotis sodalis* (Miller and Allen); Long-eared bat, *Plecotus townsendii virginianus* (Handley); and Little Long-eared bat, *Myotis kennii septentrionalis* (Trouessart). The Big Brown bat, *Eptesicus fuscus fuscus* (Beauvois), and the Little Brown bat, *Myotis lucifugus lucifugus* (LeConte), probably also sporadically inhabit some of the Burnsville Cove caves, but specific records are not available. The Little Long-eared bat is quite rare in Virginia caves, but a single female was reported from Breathing Cave (Holsinger, 1964). The Long-eared bat, which is known from a few scattered populations in Virginia and West Virginia caves at elevations about 610 m, was presumably sighted at least once near the entrance to Better Forgotten Cave (Lyle G. Conrad, pers. comm.).

DISCUSSION

In order to put the cave-limited fauna of the Sinking Creek System into proper regional perspective, its species diversity has been compared to those of some other large, hydrologically integrated cave systems in the Appalachian Valley and Ridge Province of Virginia and West Virginia, specifically: systems in the Greenbrier, Clinch, and Powell valleys (Table 1). In comparison, the Sinking Creek System has a much lower species diversity. The relative sizes of these cave systems (lengths determined by surveys) appear to have little, if any, bearing on their respective species diversities. Organ, the largest (about 58 km) of the four systems compared, and Fallen Rock, the third largest (about 11 km), both have a species diversity 53% greater than the Sinking Creek System, which is the second largest (about 35 km). Surgener-Gallohan, the smallest (about 4.5 km) of the four systems, has a species diversity that is 47% greater than that of the Sinking Creek System and nearly as great as those of Organ and Fallen Rock.

In addition to low species diversity, the number of locally endemic cave species (i.e., species that are restricted to one cave system or a series of caves in a single karst area) is also quite small in the Sinking Creek System. Only two endemics — the amphipod *Stygobromus conradi* and the beetle *Pseudanophthalmus* sp. — are recorded. In contrast, Organ contains six endemic species, Fallen Rock four endemics, and Surgener-Gallo-

TABLE I. Comparison of species diversity in selected cave systems of the Appalachian Valley and Ridge Province of Virginia and West Virginia.

Cave system	Approximate surveyed length (km)	Drainage basin	Number of species[1] (endemics in parenthesis)		
			Aquatic	Terrestrial	Total
Organ Cave[2], Greenbrier Co., W. Va.	58.0	Greenbrier	7(1)	10(5)	17(6)
Sinking Creek System[3], Bath and Highland cos., Va.	35.0	James (upper)	3(1)	5(1)	8(2)
Fallen Rock[4], Tazewell Co., Va.	11.0	Clinch (upper)	8(1)	9(3)	17(4)
Surgener-Gallohan[5], Lee Co., Va.	4.5	Powell	7(2)	8(5)	15(7)

[1]Includes troglobites and a few habitual troglophiles represented by species with cave-limited populations in these systems.
[2]Includes the Hedricks, Humphreys, Lipps, and Organ sections.
[3]Includes Aqua, Better Forgotten, Boundless, Breathing, and Butler caves.
[4]Includes Fallen Rock, Gillespies Water, and Hugh Young caves.
[5]Includes Gallohan Nos. 1 and 2, Smith Milk, and Surgener caves.

han seven endemics. Populations sizes of the Sinking Creek System endemics, as measured by direct observation, are very small; only a few specimens of either species have been observed or collected. However, some of the local endemics in the other systems are represented by relatively large populations.

It also may be significant that most of the troglobitic species found in the Sinking Creek System are fairly widespread. Species such as *Caecidotea holsingeri, Trichopetalum weyeriensis, Sinella hoffmani*, and *Phanetta subterranea*, for example, are common in caves throughout most of westcentral Virginia and southern West Virginia and range over parts of several drainage basins and karst areas. The spider *P. subterranea*, moreover, is found in caves over much of the eastern United States. The collembolan *S. hoffmani* has been found once on the surface in a non-limestone area (the Yew Mountains of Pocahontas Co., West Virginia — Barr, 1967a), where it was represented by a troglomorphic population living under rocks along a small stream. This species apparently can disperse overland between cave and karst areas through endogenous routes (Holsinger *et al.*, 1976). It is, therefore, at best a marginal troglobite.

The decreased cave species diversity in the Sinking Creek System is attributed primarily to the physically isolated nature of the system. This system and other large caves in the upper James River basin of westcentral Virginia, as well as a number of large caves in the upper Potomac River drainage of nearby Pendleton Co., West Virginia, are geologically isolated from each other in relatively small, local exposures of Silurian-Devonian limestone. In contrast, the large caves of the Greenbrier, Clinch, and Powell basins are, by and large, developed in extended belts of Ordovician and Mississippian limestones which form elongate dispersal corridors that, theoretically, facilitate the movement of cavernicoles along subterranean routes. Cave interconnectivity is regionally high in these areas while in contrast, it is regionally low in the upper James and Potomac basins. Differences in cave species diversity, population size, and community structure in areas of low cave interconnectivity vis-a-vis areas of high cave interconnectivity have been discussed by Barr (1967b, 1968), Poulson and White, (1969), Barr and Holsinger (1971), and Holsinger (1976), and it is becoming increasingly clear that areas with low cave interconnectivity frequently, if not invariably, have fewer troglobites and smaller troglobite populations than areas with high cave interconnectivity. In isolated caves with impoverished faunas, the few troglobitic species present are usually represented by a combination of good dispersers and rare, highly localized endemics. This is clearly the case with the cave-limited fauna of the Sinking Creek System.

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A narrative style of writing is preferred. Fine prose is terse yet free from lacunae, sparkles without dazzling, and achieves splendor without ostentation. Data and interpretations blend effortlessly along a logical continuum so that the reader, having read, neither knows nor cares how many pages he may have turned while following the author's exposition.

As written language must communicate through time as well as across space, neologisms should be introduced only if needed to express new concepts or to record new percepts. Standard usage, therefore, is required of all authors. For general style, refer to papers in this *Bulletin* and to the following handbooks: "Suggestions to Authors" (U. S. Geological Survey), "Style Manual for Biological Journals" (American Institute of Biological Sciences, Washington, D. C.), and "A Manual of Style" (The University of Chicago Press).

Articles on earth sciences (including pseudokarst), life sciences, conservation, social science (including history), and exploration should be sent directly to the appropriate specialist on the Board of Editors (see masthead); articles not clearly falling into any of those categories may be sent to the Managing Editor. Potential contributors, especially those not professional scientists or writers, are invited to consult with the editors for guidance or aid in the presentation of their material.

Two double-spaced, typewritten copies of each manuscript, including all illustrations, are required. Manuscripts should not exceed about 10,000 words in length (approximately 40 pages of typescript), although this limit may be waived when a paper has unusual merit. Photographs must be sharp, high in contrast, and printed on glossy paper. All line drawings should be neatly rendered in "india" ink or its equivalent; the smallest lettering must be at least 2 mm high after reduction. Typed lettering is not satisfactory. Captions will be set in type and added in proof. The dimensions of original drawings and of cropped photographs should be made some multiple of the length and width of a column or of a page, when possible, in order to avoid problems with the layout. In case of doubt regarding length or illustrations, consult with the editors.

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By act of the Board of Governors of the NSS (#81-277, dated 8-12-74), a charge of not less than $25 per printed page will be levied against the author's institution or other funding agency after a paper has been refereed, edited, and accepted for publication. Payment will not be expected of scholars whose research was not sponsored or whose budgets do not include money earmarked to subsidize publication. In no event, will the ability to pay page charges be discussed until after final acceptance of a manuscript.

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Summary: (1) data and/or interpretations must be original; (2) use a narrative style of writing; (3) follow standard English usage; (4) do not exceed 10,000 words (40 double-spaced pages of typescript) without receiving permission from the Managing Editor in advance) (5) submit two complete copies, including abstracts and all illustrations; (6) enclose a self-addressed, stamped envelope for the return of your manuscript.

TECHNICAL NOTE

Style books, to guide authors in preparing their manuscripts, have been published by many journals and professional associations. *The NSS Bulletin* has none. We believe that yet another style book would be superfluous; moreover, we consider written language to be an art form which should not be made to lie in a Procrustean bed.

Style, in one sense, is a series of rules ensuring that communication is complete and effective, that the data and interpretations are adequate, logically expounded, and fully documented. Following these rules is the author's responsibility, and they can be learned from any style book. We find the University of Chicago Press "A Manual of Style" to be suitable for most purposes.

In another sense, style has to do with the arbitrary arrangement of headings, footnotes, citations, etc. within a publication. The typist should look at a recent issue of the journal to which the manuscript is to be submitted, in order to learn the correct form of presentation, before commencing the final draft.

Those are the mechanical forms of "style," ones which are verified by editors before a manuscript is sent to the printer. All too many writers (and editors!) act as though there were nothing further to do. In fact, the most important part of the author's job remains: That of making his story interesting, compelling, aye (!) irresistible. The most closely reasoned argument will fail if no one pays attention to it. Style, as artistry, must be developed by practice, by reading and emulating the work of good writers.

We realize that many *Bulletin* contributors are inexperienced. The editors are sometimes very heavy handed with poorly done manuscripts; such manuscripts tend to be recast in the mould of the individual editor. Where, however, it is clear that an author has definite ideas about style, we grant him full measure of independence. So long as the first two considerations of style (above) are satisfied, the third, artistic, element is his alone to decide.

A helpful brief source of information is the "MLA Stylesheet," published by the Modern Language Association. The "Instant English Handbook," published by the Career Institute, Mundelein, Illinois, is a comprehensive grammatical guide; another comprehensive work, one generally available in college bookstores, is the "Harbrace College Handbook," published by Harcourt Brace Jovanovich, NYC. The latter has the advantage of being revised every few years to accommodate changing literary fashions. Courses in technical writing are available through the extension divisions of some colleges. All of these sources should help the prospective author achieve a more artistic product.

The relationship between clear writing and sound logic is well stated in articles such as "Sounder Thinking Through Clearer Writing" by F.P. Woodford (*Science,* ns 156:743-745), "Freight Trains" by J.A. Peoples (*Science,* ns 153:480), and "Little Thought Given to Requirements of Good Writing" by Norman Cousins (*Saturday Review,* 8 June 1963).

Writing styles, like clothing fashions, change with time. Thus, one should not spend time cultivating a literary style but try instead to make one's writing as clear as possible. For example, geologists seldom read Hutton; they read Lyell. Hutton used a style of writing which overlaid many of his ideas (however good the ideas were!) and confused rather than enchanted his readers. Lyell took nearly those same ideas, and he made them so simple and clear that 150 years later he is still read.

Authors should remember that written language must communicate through time as well as across space. The more traditional and general the style, the longer your paper will be intelligible to posterity. The editors intentionally discourage the use of hip jargon and the latest fads, although we realize that, should we drag our feet too hard, we won't be understood by our contemporaries, much less by future generations. *JH, Oscar Hawksley (Central Missouri State University), Donald W. Ash (Indiana State University), Karl Barnaby (Indiana State University)*

ADDITIONAL READINGS

American Chemical Society (1978)—*Handbook for Authors.* $7.50

American Medical Association (1976)—*Stylebook—Editorial Manual.* $7.50

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