Geology of the Butler Cave—Sinking Creek System

19

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Abstract

The Butler Cave-Sinking Creek System is composed of a central trunk channel oriented along the axis of the Sinking Creek Syncline with dip-oriented side caves extending mostly up the western flank of the syncline. The overall patterns of the side caves are network mazes with orientations controlled by the local joint pattern. Much of the cave is in the Devonian Tonoloway Limestone with the two interbedded sandstones exerting an important influence. The result is two interconnected tiers of caves with 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. There three streams in the cave all of which ultimately drain to Aqua Spring. The streams are undersaturated with respect to calcite and have low CO_2 concentrations consistent with recharge from mountain runoff and from infiltration through thin organic-poor soils.

19.1 Introduction

Investigations of the geology and mineralogy of Butler Cave began shortly after its discovery in 1958. Some aspects of the geology were reported at meetings but the first formal publication appeared in the special issue of the NSS Bulletin in 1982 (White and Hess 1982). The NSS Bulletin also contained information on the chemistry of the cave waters (Harmon and Hess 1982). There have been continuing studies the cave geology, particularly the clastic sediments (Chess et al. 2010) as well as a variety of other observations. Finally, there came the revisions of the stratigraphic section and the revised placement of the caves in the carbonate rocks, which required some reworking of the geological relations of the cave. All of these have been combined to produce the present chapter.

19.2 Description of the Cave System

In 1985, Lester V. Good compiled all of the survey data on the Butler Cave-Sinking Creek System into a single folio of sectional maps. These maps appear in the electronic files accompanying this volume. The stick map of the entire system provides an index for the master set of maps (Fig. 19.1). Individual areas of the cave discussed in this chapter were all derived by copying appropriate bits of the master map folio. The index map also lists many of the place names that appear in the text.

The backbone of the cave is provided by the Trunk Channel that extends from southwest to northeast

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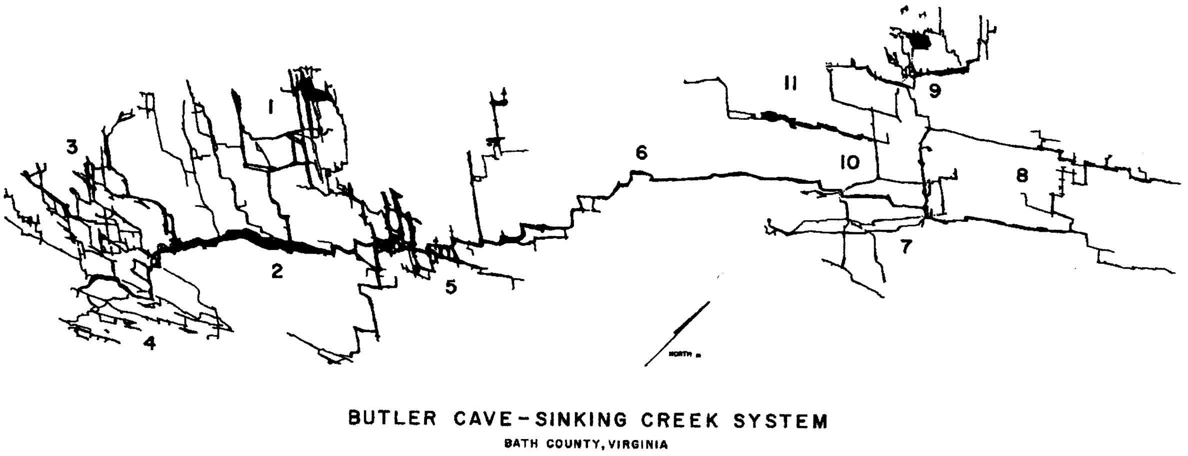


Fig. 19.1 Index map for the Butler Cave-Sinking Creek System. Numbered areas are: *1* Butler Cave Section: Entrance, Difficulty Creek, Complaint Cave, Pennsylvania Cave. *2* Sand Canyon Section: Upstream Trunk, Moon Room Section, Crystal Gallery, Sand Canyon Camp. *3* Huntley's Cave Section: Duke Dump, Birthday Passage, Penn State Lake, Natural Bridge. *4* Beyond the Lake Section: Alphabet Soup, Z-Section, Mbagintao Land, Barking Marshmallow. *5* Sinking Creek Section: Moon Room, Crystal Craters, Pat's Section, Downstream Trunk. *6* Sneaky Creek Section: Sinking Creek Siphon, Silt Crawl, Dry Sumps, Downstream Trunk. *7* Pool Room Section: Crisco Way, French Passage, Evasor Gallery, Pants-Off Crawl. *8* Downstream Loop Section: Dave's Lake, July 6 Room, Last Hope Siphon, Rat's Doom Siphon. *9* Dynamite Section: Frothing Slosh, Christmas Passage, Slippery Creek. *10* Marlboro Country Section-I: Ladder Room, Dude Ranch, Scrog Way, Canoe Passage. *11* Marlboro Country Section-II: Tombstone Territory, Bitter End, Doom Room, Candle Room

closely paralleling the surface valley of Sinking Creek but lying several hundred feet 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 and thus slope upward toward Jack Mountain. 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 also a side cave to the system except that it lies farther to the northeast and its downslope limits are beyond the terminal sumps of Butler Cave.

Other than the Trunk Channel, most of the cave system consists of isolated sections of network maze, mostly with the individual sections not well interconnected. There is a concentrated area of closely-spaced maze passages 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 these 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 called Mbagintao Land. The northern end of the cave system is underlain by a rather complex series of fairly large passages in Marlboro Country. 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 are frequently blocked by large infillings of clastic sediments.

The cross-sections of the tributary passages are generally rectangular, much higher than they are wide. A few elliptical tube passages occur, usually as strike-oriented cross passages connecting the main dip passages. The dip passages tend to be canyons 5–20 feet wide and up to 30 or more feet high. The cross passages in the mazes usually have ceiling heights lower than those in the dip passages.

The Trunk Passage from the Natural Bridge to a little below Sand Canyon has a very large cross section. There is an upper, silt-filled level, of which Sand Canyon Camp is a residual terrace, and there is an incised stream channel (Fig. 19.2). This very large cross-section passage 50–100 feet wide, is broken by massive breakdown in the passage segment between Sand Canyon and Natural Bridge. The Natural Bridge itself is a remnant of the upper level portion of the passage. Downstream from Sand Canyon, the Trunk Passage first narrows, breaks into a distributary system (Fig. 19.3), then widens again into another large breakdown complex in the Moon Room area. Northeast of the Moon Room the trunk passage becomes considerably smaller, 10–20 feet wide and 10–30 feet high.

The complex history of cave development can be seen in a traverse of the Butler Cave portion of the system (Fig. 19.4). The Nicholson Entrance to Butler Cave is located directly beneath the Upper Breathing Cave Sandstone. The entrance pit, the Glop Slot, a climb-down, and the God-Is-My-Copilot climb collectively penetrate the entire thickness of the Tonoloway Limestone spanning the Breathing Cave horizon so that the final descent into the top of Breakdown Mountain is through a breach in the lower Breathing Cave sandstone. From Breakdown Mountain the main passage slopes downward following the dip of the bedding for 500 feet until it is blocked by fill. Near the lower end of the passage there is a climb-down to a strike-oriented cross canyon.

Fig. 19.3 Bifurcation of trunk passage at loop downstream from Sand Canyon. WBW photo

Fig. 19.2 Lower canyon upstream from Sand Canyon with breakdown from upper tube. Photo by Joe Kearns

The usual route through the cave leads off from the top of the fill bank below Breakdown Mountain through the Rabbit Hole, a crawlway that connects to the Second Parallel Passage. The Second Parallel Passage is also dip-oriented but instead of blockage by fill at its lower end, there is a cliff that drops about 100 feet into the Bean Room. Just before the drop-off, a short strike passage connects to a breakdown room (the Step-Across shown on Fig. 19.4). Across the breakdown is another dip-oriented passage leading down slope to a cross passage and down a fill bank to the Rimstone Passage. A climb down through the breakdown in the breakdown room connects to the same cross canyon that can be accessed from the main passage. Along the route between these points, the cross canyon crosses the Bean Room on a ledge below the overhang in the Second Parallel Passage above.

A different prospective may be obtained by entering the cave through the SOFA Entrance. The Lower Breathing Cave Sandstone can be seen in the cliff above the entrance. The SOFA Entrance gives direct access to the upper end of Dave's Gallery, also a sloping dip-oriented passage which connects directly with the Rimstone Pool Passage. Although all of the upper level

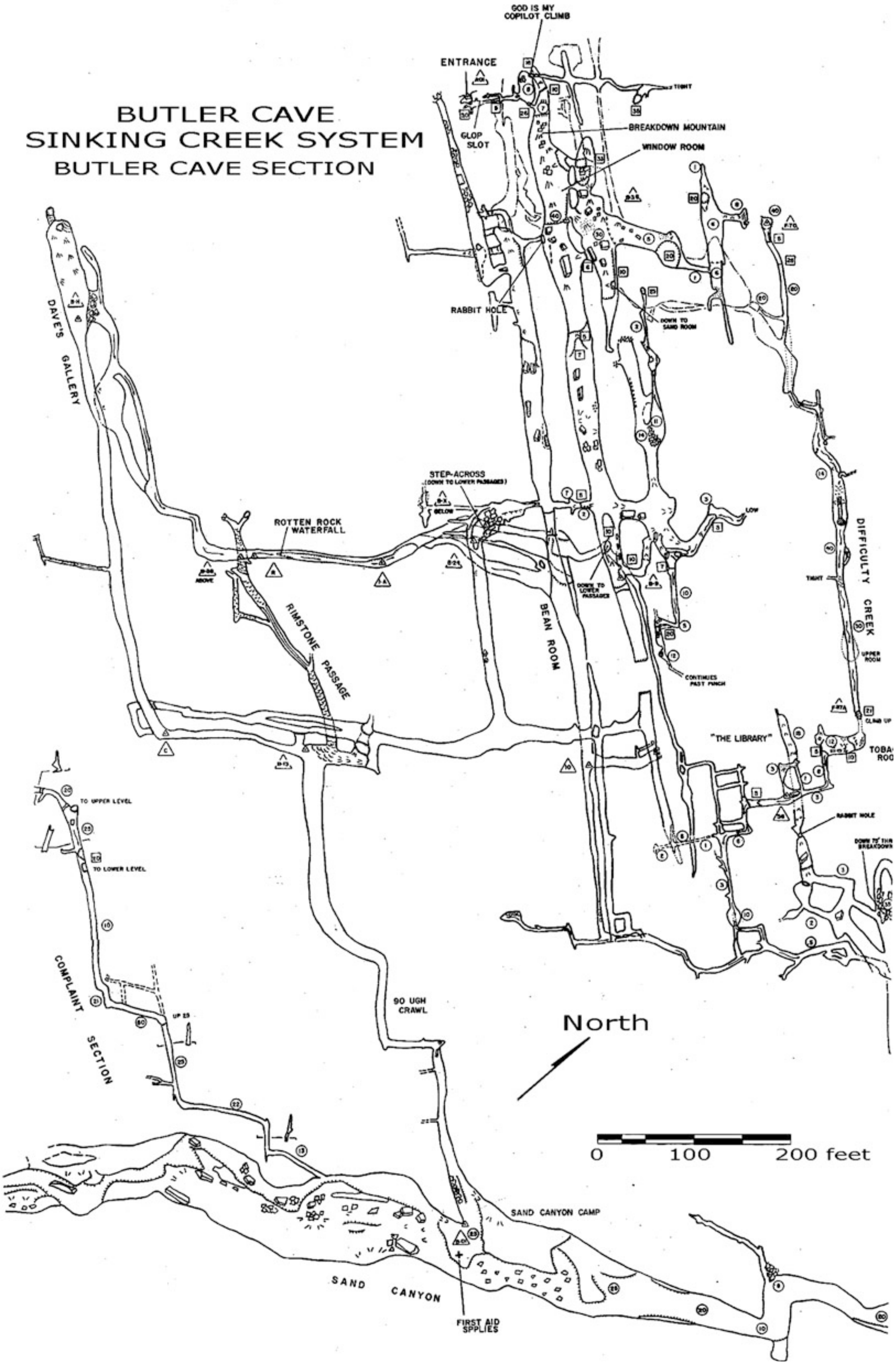


Fig. 19.4 Detailed map of the Butler Cave Section

passages in the Butler Cave Section are dry, the Rimstone Pool Passage is wet with active rimstone pools. It extends up dip several hundred feet to a blockage. The strike passage at the Rimstone Pools connects the lower end of Dave's Gallery with the Fill Bank and the passage from the historic portion of Butler Cave. From the Rimstone Pools, the main passage continues down dip to connect to the Trunk Channel at Sand Canyon. About mid-way along this passage, the cross-section narrows and the ceiling lowers to a crawlway—90 Ugh Crawl. An intriguing—and unanswered—question is: Did bedrock walls of this large cross-section passage really narrow to a crawlway, or was the passage entirely filled with sediment leaving only 90-Ugh Crawl as a small channel in the ceiling?

A short distance inside the SOFA Entrance, it is possible to descend an opening in the side of the passage and reach an active streamway, Rotten Rocks Creek. The stream passage follows a different route and crosses the upper end of the Rimstone Passage suggesting that the water in the Rimstone Passage is leakage from Rotten Rocks Creek, an example of an active streamway crossing an air-filled underlying passage. Downstream from the crossing, Rotten Rocks Creek descends over a waterfall and flows at the bottom of a high canyon, first into the Bean Room and then to join Difficulty Creek. The combined flows enter Sinking Creek near the Moon Room. The passage at the top of Rotten Rocks Waterfall continues as a ledge near the top of the high canyon, then becomes a separate passage beneath the breakdown of the Breakdown Room where it is seen to be the upstream end of the cross canyon first seen from the Main Passage. The cross canyon is revealed as a now-abandoned downstream channel of the ancestral Rotten Rocks Creek.

The sequence of passages from the SOFA Entrance to Difficulty Creek crosses the entire Lower Tonoloway Limestone. The SOFA Entrance is just below the Lower Breathing Cave Sandstone. The passage walls in the downstream section of Rotten Rocks Creek and the lower part of the Bean Room are in the thin-bedded units of the Tonoloway. Observations by Nevin Davis suggest that Difficulty Creek has reached the bottom of the Tonoloway, cut through the underlying thin Wills Creek Formation and is flowing on top of the Williamsport Sandstone.

A rather different pattern appears in the Upstream Maze (Fig. 19.5). The Upstream Maze lies closer to

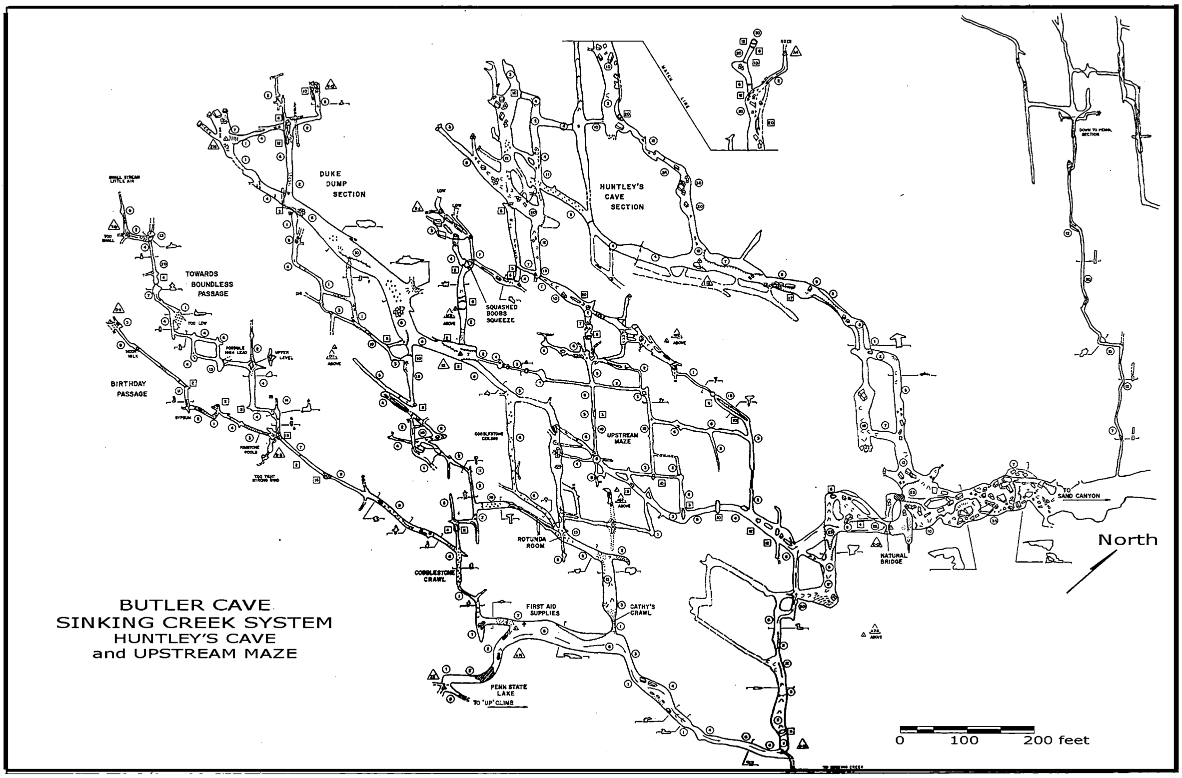


Fig. 19.5 Detailed map of the Upstream Maze Section

the axis of the syncline. Dips are lower and passage gradients less steep. Passages trending along the northwest-southeast joint set are smaller and appear as minor cross passages in the Upstream Maze. Dominant passage trends are on an east-west joint set. The Trunk Channel essentially ends at the Upstream Maze. The single large passage splays into a multiple of passages all cross-linked in the maze. The flood-overflow route of the stream channel skirts the eastern side of the maze to Penn State Lake, a segment of low passage with standing water. At the western side, the Upstream Maze terminates against the side of Burnsville Sink, a large closed depression that is the likely catchment area for the headwaters of Sinking Creek.

On the northern side of the maze, Huntley's Cave is transitional. It partly follows the same northwest-southeast joint set as Butler Cave and the other side caves and partly follows the east-west joint set of the Upstream Maze. Most of the Huntley's Cave passage is dry and contains some small gypsum flowers. A small stream enters at the extreme upper end and is quickly lost to an inaccessible lower level.

The Moon Room Section (Fig. 19.6) is one of considerable complexity. The view, if one were to walk downstream from Sand Canyon to reach the center-left edge of Fig. 19.6, would be the photograph shown in Fig. 19.3. On the lower leg of the Loop, Sinking Creek emerges into the larger cave passage (Fig. 19.7). Near the bottom of Fig. 19.6 is the Crystal Gallery, a well-decorated narrow passage that extends up the southeast side of the syncline to the point in the cave closest to Barberry Cave. The passages to the northwest rise steeply over silt-covered breakdown, some with multiple levels. The Crystal Craters passage lies above the stream channel which is incised deeply below the maze pattern shown in Fig. 19.6, again illustrating the extensive downcutting that has taken place since the primary cave system was formed.

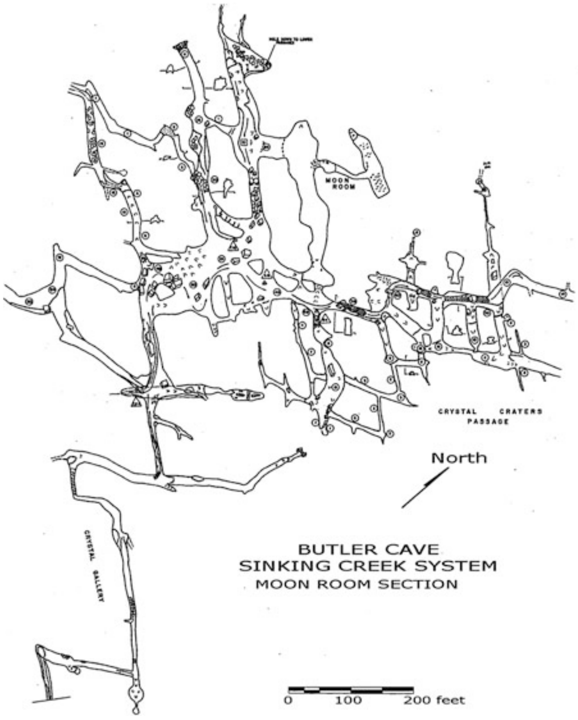


Fig. 19.6 Detailed map of the Moon Room Section

Fig. 19.7 The internal "spring" where the active flow of Sinking Creek emerges into open cave passage. WBW photo

For a considerable distance downstream from the Moon Room Section, the cave consists of only the trunk channel. The gradient of the trunk channel is less that the dip of the plunging syncline so that at the Dry Sumps, the trunk channel climbs up section through the Lower Breathing Cave Sandstone and continues downstream in the Tonoloway beds of the Breathing Cave horizon. The downstream section will be described as part of the hydrologic interpretation.

19.3 Geologic Controls on Passage Development

The most important stratigraphic elements controlling the geometry of the Butler Cave—Sinking Creek system are the interbeds of sandstone which occur within the Tonoloway Limestone sequence. In the earlier report (White and Hess 1982) these were thought to be tongues of the Clifton Forge Sandstone. New mapping (see Chap. 16) shows that Butler Cave is formed in the Tonoloway Limestone which also contains sandstone beds. These beds have no formal name but since they were first identified in Breathing Cave (Deike 1960) they are here informally called the Upper and Lower Breathing Cave sandstones.

The entrance to Butler Cave lies directly below the upper sandstone. The cave descends quickly through the 77 foot interval between the upper and lower sandstones and breaches the lower sandstone at the ceiling of Breakdown Mountain. Breathing Cave lies entirely within the limestone interval between the sandstones. Butler Cave and associated tributaries on the west flank of the syncline are all formed in the Tonoloway 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 in several places.

In the southern end of the cave system, a single narrow passage breaches the lower sandstone to connect to the upper tier of caves known as Mbagintao Land which is formed in the intermediate 77-foot interval of limestone. Downstream to the north, the trunk channel itself breaches the lower sandstone at the dry sumps so that the northern end of the cave including several streams and the Last Hope and Rats Doom sumps 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 cross the sandstone and reach the lower tier of cave, Marlboro Country, which is formed in 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.

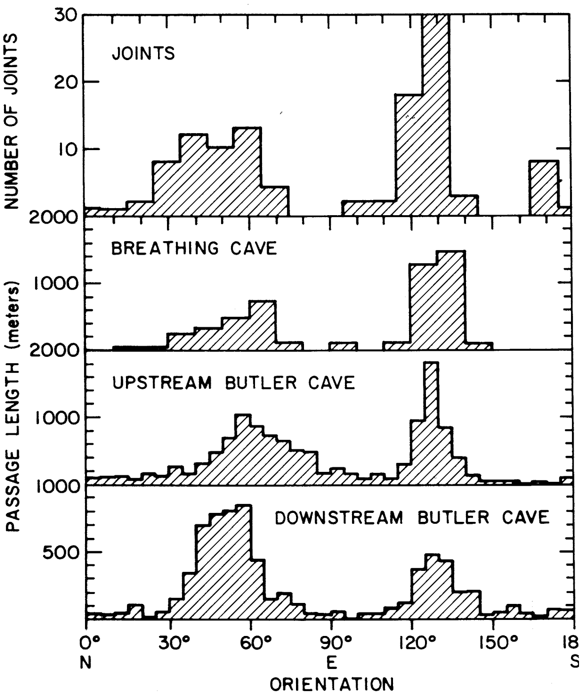


Fig. 19.8 Comparison of passage development with joint patterns. From White and Hess (1982)

Comparison of cave passage orientation with joint directions (Fig. 19.8) 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 match the regional strike joints fairly well. The regional joint pattern was mapped by Deike (1960) mostly from outcrops near Breathing Cave. There appears to be a major fracture system that crosses the cave near the Moon Room and this may mark the boundary between two joint blocks, so that the joint pattern south of the Moon Room has a somewhat different orientation from the joint pattern to the north.

The southeasterly dips 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 these minor fold structures. Sometimes the steeply plunging folds bring down the lower sandstone, which then acts as a sediment trap. Dip passages in Breathing Cave are blocked by a fold that Deike referred to as the "monocline". The connection from the Rimstone Pools and Dave's Gallery to Sand Canyon only exists because of the survival of 90-Ugh Crawl which is a short strike-oriented segment connecting two much larger offset dip passages.

19.4 Clastic Sediment Infilling

19.4.1 Description and Classification of the Clastic Sediments

In broad terms, the Butler sediments consist of breakdown, calcite and gypsum speleothems, and fluvial sequences of various kinds. The speleothems are described in Chap. 23. Concern here is with the fluvial deposits—the clastic sediments. These consist mostly of silt, sand, pebbles and cobbles with a wide range of particle sizes and degrees of sorting. The fine grained fraction consists almost entirely of quartz while there is a mix of sandstone and limestone fragments in the large-grained fraction. Discussion of transported detrital sediments in caves in terms of their stratigraphy has not proved to be useful. The facies concept is more helpful. Sediment facies in the Butler Cave-Sinking Creek System are described using the labeling based on grains size and sorting (Fig. 19.9).

Definitions for the facies sketched in cartoon fashion in Fig. 19.9 are:

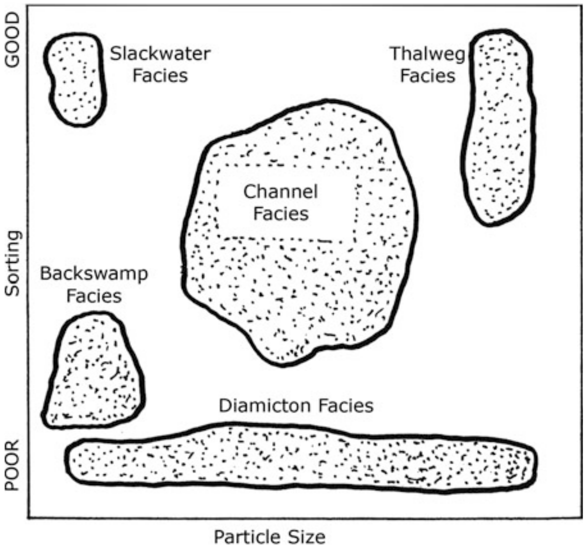


Fig. 19.9 Sketch of clastic sediment facies based on Bosch and White (2004). *Note* The areas between facies types are not blank spaces; they represent a fuzzy transition between the facies. Note also that the diagram has no scale; it is entirely schematic

(i) Slackwater facies: Fine-grained clays and silts that have settled out of muddy flood waters. Often these show a fine layering or varving. Usually they occur at the top of sediment piles.
(ii) Channel or Bank facies: Interbedded sands, silts, possibly with pebbles. Some stratification with substantial sorting between layers. These are most clearly stream deposits that, although stratified, show rapid changes in stratification over short horizontal distances.
(iii) Thalweg facies: Well-winnowed gravel, cobbles and sometimes boulders with most fine-grained material removed. These are stream bed deposits not particularly different from the bed armoring found in surface streams.
(iv) Diamicton facies: chaotic, unsorted mélange of silt, sand, pebbles and cobbles. Little or no statification. Diamicton facies are the remnants of debris flows. They were originally described for high gradient caves in New Guinea (Gillieson 1986).
(v) Backswamp facies: Uncommon in Butler Cave, these are usually fine-grained, poorly stratified muds, silts and sometimes chert fragments that accumulate as the insoluble fraction of the limestone. This facies shows little evidence of transport and the caves in which they are found usually have little evidence of stream action.

Fig. 19.10 Gravel and cobble fills in stream channel near Sand Canyon Camp. WBW photo

Fig. 19.12 Manganese oxide-coated boulders in stream channel near Sand Canyon. WBW photo

Sediments of the thalweg facies are found in the normally dry stream channel from Penn State Lake down to the Sinking Creek Sump. The channel bed is floored with a well-winnowed assortment of cobbles (Fig. 19.10). Some "grains" are in the boulder size range. Both limestone and sandstone boulders occur (Fig. 19.11). The sandstone can be recognized by its coating of black manganese oxides. The Trunk Channel in this reach is a spillover route used only by floods of sufficient magnitude to exceed the carrying capacity of the lower (but unidentified) route of Sinking Creek. The source of the sandstone must be Jack Mountain. Flood flows must have sufficient energy to move these boulders down into the cave and then transport them along the relatively low gradient trunk passage for distances of several thousand feet (Fig. 19.12). The most extreme example of boulder transport in the system was a set of sandstone boulders almost two meters in diameter that had apparently been forced up the lift tube at the drainage outlet in Lockridge Aqua Cave (see Fig. 4.8).

Channel facies occur in many places in the cave but are best displayed 300 feet downstream from Sand Canyon. A deep sediment infilling has been cut by later stream action exposing interbedded sand and gravel (Figs. 19.13 and 19.14). Evidence that the channel was filled with sediment that was later excavated is provided by a column of sediment remaining on top of a large breakdown block (Fig. 19.15). There

Fig. 19.11 Close up of large cobbles in stream channel. Note both sandstone and limestone are present. WBW photo

Fig. 19.13 Channel facies. Bedded sand and cobbles at the upstream end of the Loop. WBW photo

Fig. 19.14 Close-up, bedded sand over cobbles at upstream end of loop. WBW photo

is a large range in particle size with substantial sorting and stratification.

Most remarkable of the Butler sediments are the diamicton facies. These are unsorted and unstratified mixtures of sand, pebbles, and cobbles. These seem to have infilled all of the side caves on the western side of the system. Masses of this sediment occur in pockets along Dave's Gallery (Fig. 19.16). Similar fills have been described in Breathing Cave (Chap. 18). Diamicton facies implies a debris flow. It is not obvious whether the sediment-filled pockets were left behind as the debris swept past or whether they are remnants of a passage infilling that was later excavated. The debris flow sediments are observed mainly in the high gradient dip passages.

Slackwater facies are found in many parts of the cave but occur only as a thin layer of clay and silt overlying much coarser clastic material. In the side caves, the slackwater facies sediments are coated with an extremely thin layer of black material thought to be manganese oxides but might be carbon from decay of a final layer of organic material. They were never analyzed. Most of these delicate coatings no longer exist; they were destroyed by careless cavers who tramped all over the passage floors instead of remaining on the trail. The absence of substantial

Fig. 19.15 Mass of cobble fill remaining on large breakdown block in trunk passage below Sand Canyon. WBW photo

Fig. 19.16 Possible diamicton facies wedged into alcove on wall of Dave's Gallery. WBW photo

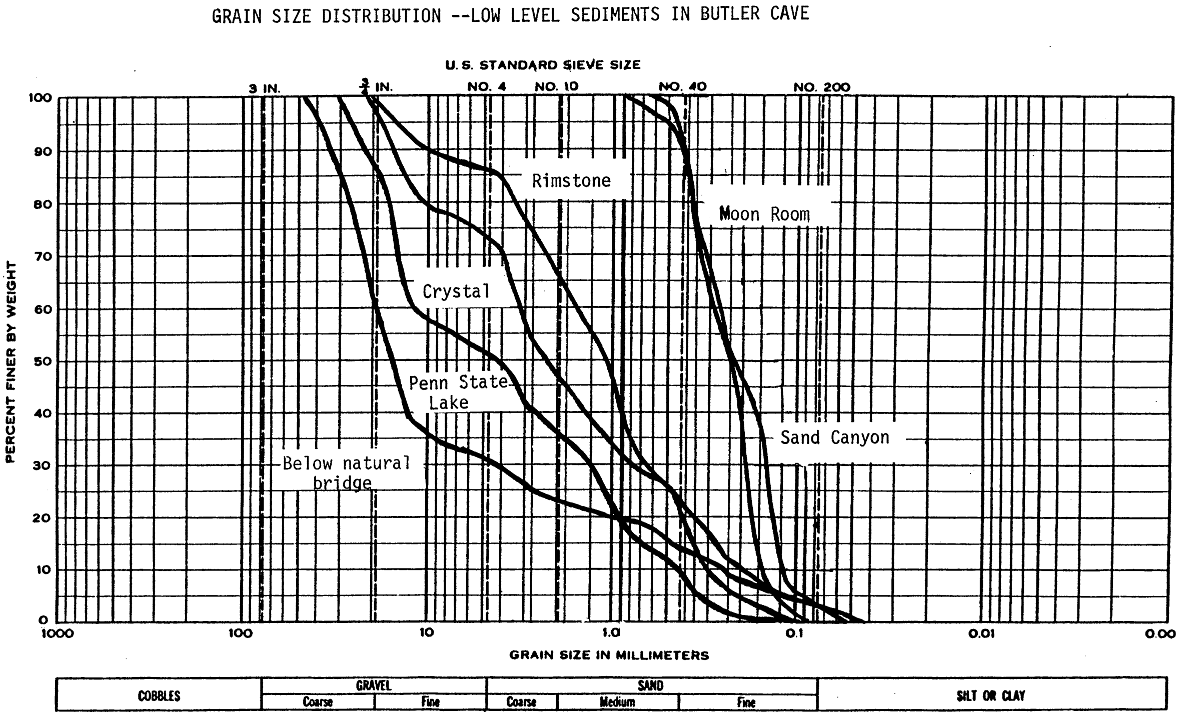


Fig. 19.17 Particle size distribution for low level sediments

slackwater facies development in Butler Cave may be evidence that, in spite of evidence for extensive floodwater action, ponded, muddy floodwater has been relatively uncommon. The caves appear to have drained rapidly during and following flood events with little evidence of ponding. This is in contrast to the Chestnut Ridge System and some of the northern caves where contemporary flooding is common and with it the characteristic fine-grained, sticky muds.

Dan Chess collected thirty two samples of cave sediments from various locations throughout the southern (upstream) and mid-sections of the cave (Chess et al. 2010). These included one eastern-most and one western-most point. Sample locations chosen were from the major passages within the cave and in some cases several sediment samples were taken from the same passage. It was intended that these samples would represent the different sediment facies and perhaps different ages of deposition. The discriminating factor used in sample selection was "low and wet" versus "high and dry" locations. The geologic sources include areas lower in the cave known be the recent depositional environments as expressed by active streams and seeps and higher, drier areas which should be older and removed from present day stream action.

The sediment samples were dried, placed in the top of a sequence of eight sieves with calibrated spacings, and shaken. The material remaining on each of the sieves was then weighed to determine the size distribution (Figs. 19.17 and 19.18).

The low level materials are much more variable than the high level materials. The sediments from the Moon Room and Sand Canyon appear to be well sorted sands, while the others show a wide range of particle sizes. The samples of high level sediments are similar to each other but show a wide range of particle sizes, including a substantial fraction of gravel. The sieve analysis, of course, does not include the cobble to boulder size material found in the thalweg facies.

19.4.2 Paleomagnetic Investigations

Although the morphology of the cave and the sequences of sediment imply a very extensive and complex developmental history, hard dates when these

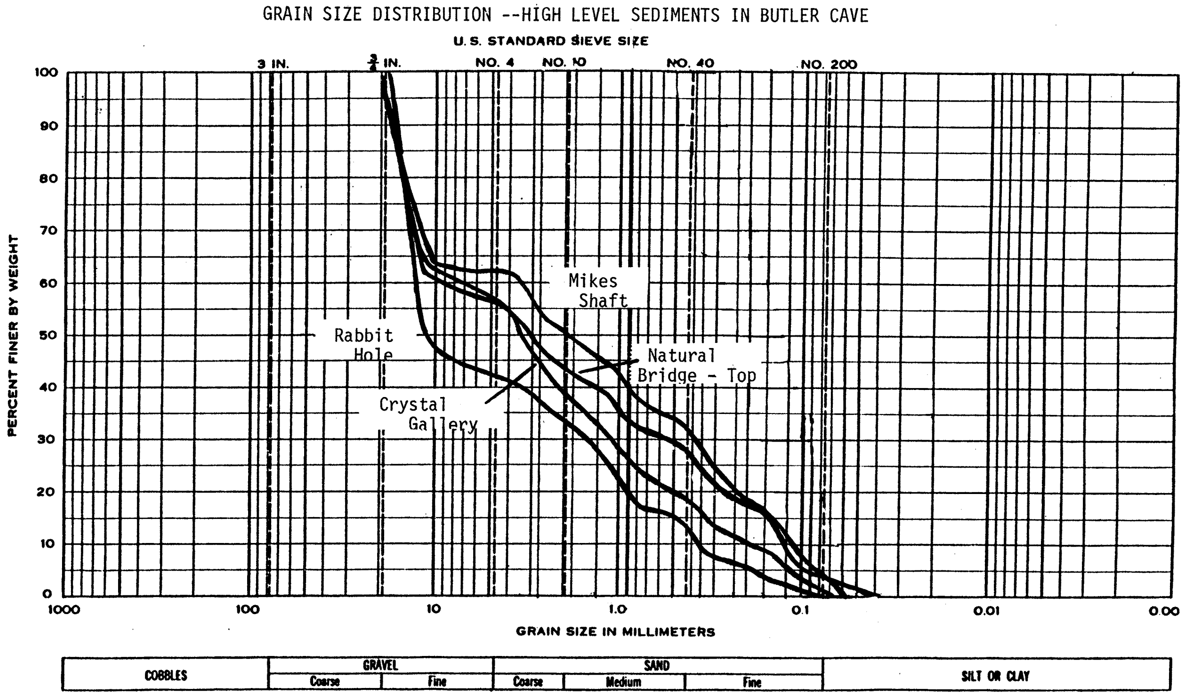
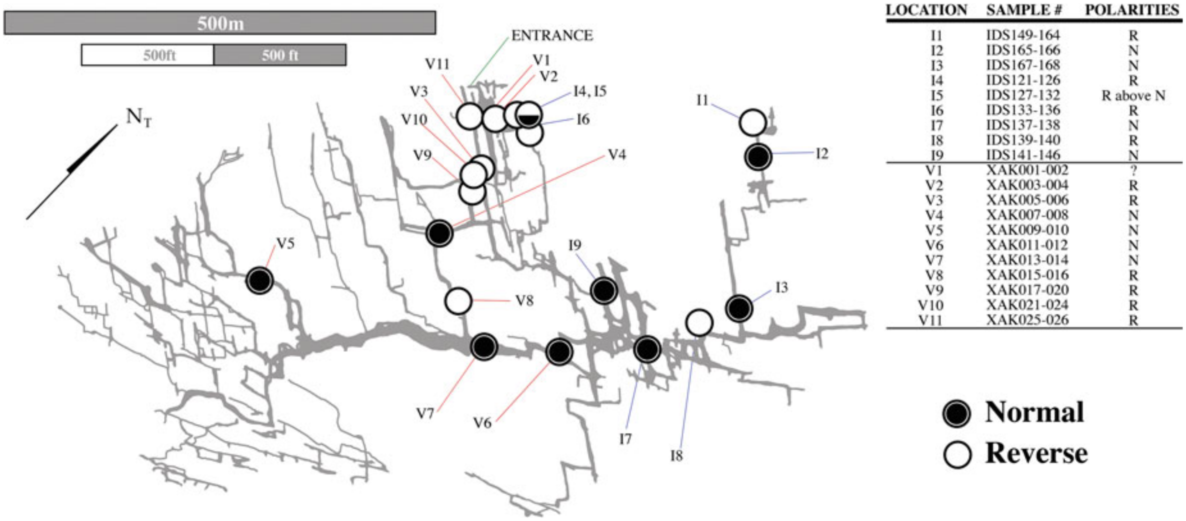


Fig. 19.18 Particle size distribution for high level sediments

events occurred are extremely difficult to obtain. In the mid-1980s Victor Schmidt of the University of Pittsburgh collected sediment samples for paleomagnetic dating in Butler Cave and in Breathing Cave. After Schmidt's untimely death in 1993, Ira Sasowsky reactivated the project and collected further samples in Butler Cave. The sediment project was finally brought to a conclusion (Chess et al. 2010). The following is a summary of the paleomagnetic results.

The principle of paleomagnetic dating is relatively simple although the details are complicated and some very expensive magnetometers are required. The procedure is to carve a one-inch cube of sediment from an exposed bank. A plastic box is slipped over the cube and its orientation carefully marked. The sample boxes with their content of undisturbed sediment were taken to the Paleomagnetism Laboratory at the University of Pittsburgh where influences of current magnetic fields were removed and the average orientation of magnetic particles within the sediment determined in a highly sensitive magnetometer at liquid helium temperature. A great deal of sample preparation and special high-sensitivity equipment is needed because the magnetic signal from cave sediment is usually very weak. The end result of these measurements is a determination of whether the north pole of the sediment sample is aligned with the Earth's present North Pole (called "normal") or aligned with the Earth's present South Pole (called "reversed"). The discovery of reversed sediments means that the sediments were deposited at a time when the Earth's magnetic field was oriented opposite to its present orientation. The chronology of magnetic field reversals is well-established. The problem is to correlate the reversed sediments with a specific period of reversed polarity.

Figure 19.19 shows the locations from which sediment samples were taken and the polarity as measured in the laboratory. The pattern of reversals is not distributed by elevation as would be the case of ordinary sediment layering. Instead, reversed sediments are found high in the dip passages as well as on remnant sediment terraces near present day stream levels. The reversed sediments are located in the massive in-filled sediment. Sediments associated with present day stream activity are normal but normal sediments from abandoned cave passages could easily belong to an



LOCATION	SAMPLE #	POLARITIES
I1	IDS149-164	R
I2	IDS165-166	N
I3	IDS167-168	N
I4	IDS121-126	R
I5	IDS127-132	R above N
I6	IDS133-136	R
I7	IDS137-138	N
I8	IDS139-140	R
I9	IDS141-146	N
V1	XAK001-002	?
V2	XAK003-004	R
V3	XAK005-006	R
V4	XAK007-008	N
V5	XAK009-010	N
V6	XAK011-012	N
V7	XAK013-014	N
V8	XAK015-016	R
V9	XAK017-020	R
V10	XAK021-024	R
V11	XAK025-026	R

Fig. 19.19 Location of sediment samples for paleomagnetic measurement and their magnetic orientation. From Chess et al. (2010)

earlier normal. With only this information, the reversed sediments, at the youngest, would date from sometime in the Jaramillo Reversed Period which ended 780,000 years ago.

At only one location (I-5 in Fig. 19.19) were sediments of different polarity found in continuous stratigraphic sequence. Three layers of clay were sampled of which the upper two layers were reversed while the lower layer was normal. The lower normal layer is, therefore, older than the reversed layers above it which places the minimum age at the Jaramillo/Matayuma boundary, 990,000 years ago.

Because of the limited number of reversals and the lack of tight stratigraphic control, sediment ages range from at least the mid-Pleistocene. They could easily be older.

19.5 Present Day Drainage Patterns

19.5.1 Internal Drainage

The present day drainage through the cave is complex and probably of recent development. Surface streams draining from the flanks of Jack Mountain are the source waters for the infeeder streams such as the Huntley's Cave stream, Rotten Rocks Creek and Difficulty Creek. The headwaters of Sinking Creek are a combination of precipitation collected in and around the Burnsville Depression and a small stream flowing from the flank of Jack Mountain. Sinking Creek flows along the floor of the trunk passage from its rise (Fig. 19.7) to its disappearance into the Sinking Creek sump. The water of Sinking Creek has been dye-traced to a stream in Marlboro Country which can be followed to the Marlboro Sump. Just upstream from the sump, a second stream enters which rises from a sump but may be the same stream that sumps northeast of the Four-Way Stop. Both streams are lost at the Marlboro Sump (Fig. 19.20).

Sneaky Creek enters the system from an unknown source at the Showers where it drains from the ceiling. At this point the trunk passage has breached the lower sandstone so that Sneaky Creek flows in a cave passage above the lower sandstone. Sneaky Creek can be followed through the French Passage, the Lake Room, and the July 6 Room until it is lost in a sump at the Rats Doom Siphon.

A third parallel stream is Slippery Creek which appears near the northwest end of Pants-Off Crawl and flows along the northwestern-most of the downstream passages ultimately to enter Last Hope Siphon and the ultimate sump at the end of the Good News Passage (Fig. 19.21).

Of the various sumps, only Last Hope Siphon has a cross-section large enough to admit a diver. Diving this sump produced some additional passage and then another sump. The other sumps are choked with gravel.

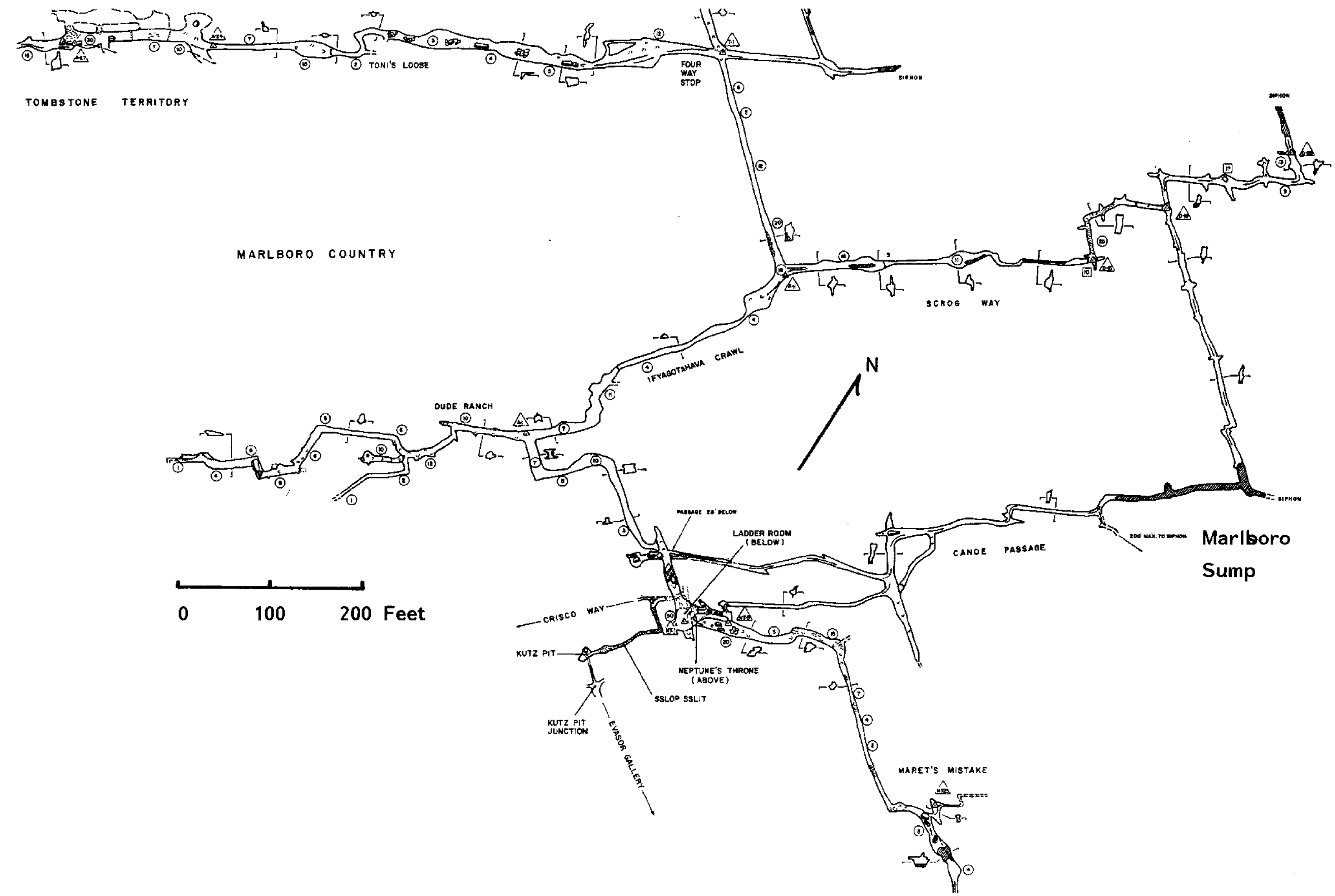


Fig. 19.20 Map of part of Marlboro Country showing the drainage leading to the Marlboro Sump

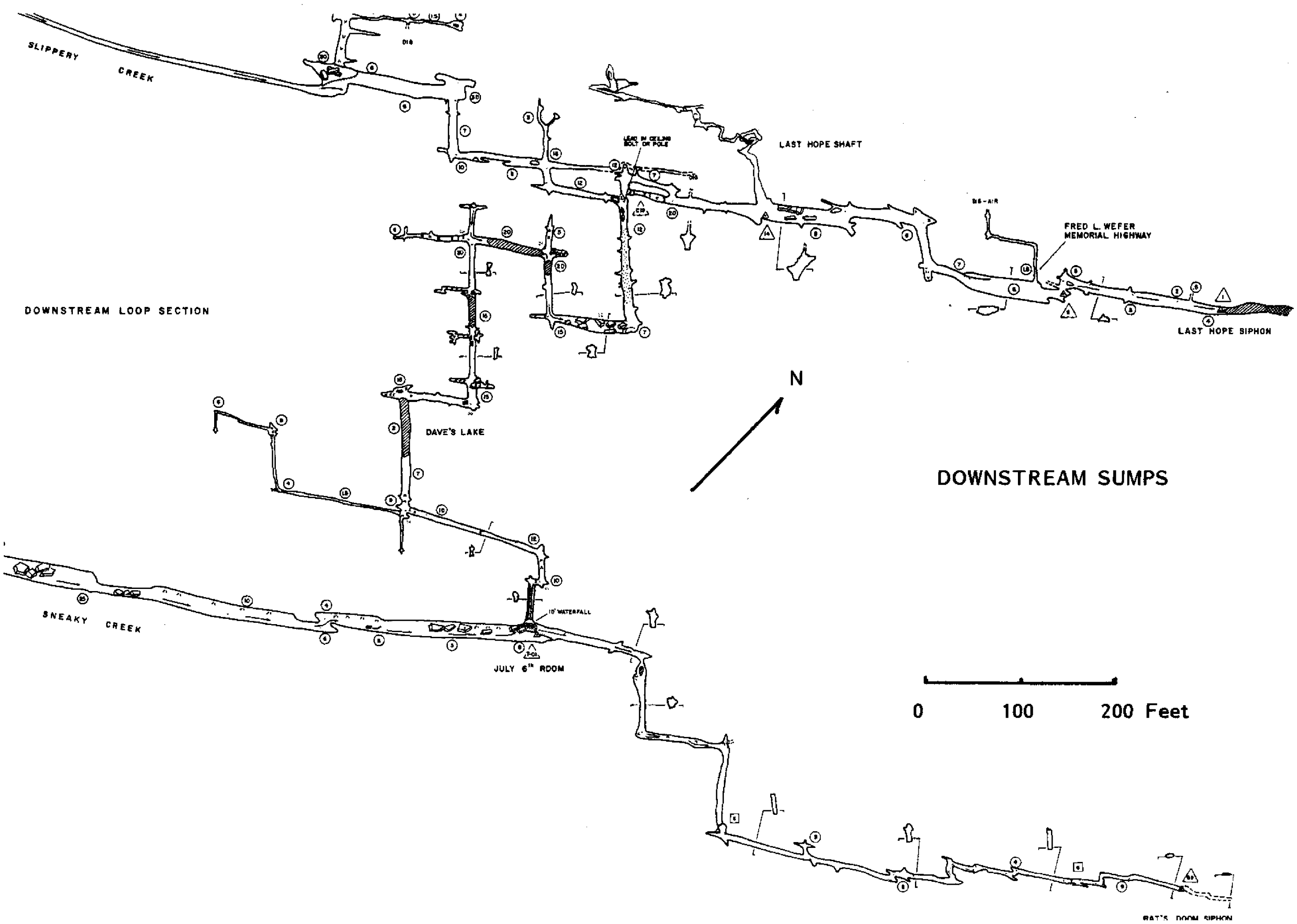


Fig. 19.21 Map segment showing the downstream sumps at Rat’s Doom and Last Hope Siphons

Much of the low flow drainage is concealed. Sinking Creek and its confluences with the various in-feeder streams generally occupy small inaccessible passages beneath the trunk channel. During flood flow, the small passages spill over and flood waters flow down the trunk channel. The drainage system raises a question: Are the diversion routes of the trunk channel drainage a recent development or did these low lying passage exist earlier but are nearly choked with sediment so that they only have the capacity to carry low flows?

It is apparent from mud-coatings that the stream passages at the downstream end of the cave fill completely during flood flow. However, little is known of possible diversion and overflow routes during flood flow. Of the hydrologic behavior of Marlboro Country during flood flow, nothing is known.

19.5.2 Elevations and Gradients

There is a great deal of vertical relief both in the Butler Cave-Sinking Creek System and in other caves in the Cove. Interpretation of the development of the cave systems will depend as much on vertical relations of the caves as on the horizontal relations. Cave surveyors usually set their vertical control datum to zero at the cave entrance. There is need for a more useful reference point for inter-cave comparisons. However, elevations above sea level are not as useful as elevations above some local benchmark. The chosen benchmark is the junction of the Bullpasture and Cowpasture Rivers near Williamsville. The wide, flat floodplain of the Cowpasture suggests that this has been a stable base level for a long time. This is also the ultimate low point for Burnsville Cove and vicinity. The benchmark elevation has been set at 1595 feet = zero datum. Elevations of features within the cave are then calculated with respect to this datum.

Table 19.1 lists some locations within the cave giving their elevations with respect to sea level, with respect to the river confluence benchmark, and with respect to the elevation of Aqua Spring. The elevation of Aqua Spring is 1770 feet, 175 feet above the river confluence benchmark. The in-cave elevations are those tabulated on the Butler Cave-Sinking Creek System map folio compiled by Lester Good in 1985. The vertical accuracy of the survey data is not known so that these values should be used with some caution.

The highest point in the cave is the Nicholson Entrance. The Butler Cave section descends steeply to

Table 19.1 Selected elevations within the Butler Cave-Sinking Creek System

Station	Location	Sea level	Benchmark	Spring
	Butler Cave			
A-01	Nicholson Entrance	2536	941	766
B-36	Window Room	2380	785	610
B–H	Dave's Gallery, below SOFA Entrance	2366	771	596
B-24	Cross Canyon	2307	712	537
10	Lower Bean Room	2179	584	409
B-13	Rimstone Pools	2269	674	499
B-01	Sand Canyon	2240	645	470
	Trunk Channel			
CP-1	Rise of Sinking Creek	2200	605	430
J-22	Pat's Section junction	2156	561	386
L-22	Near Sinking Creek Sump	2129	534	359
I-22	Below Dry Sumps	2096	501	326
E-01	Pool Room	2073	478	303
T-01	July 6 Room	2017	422	247
D-19	Feeder to Marlboro Sump at Scrog Way	1981	386	211
69	Rats Doom Siphon	1912	317	142
1	Last Hope Siphon	1976	381	206

Sand Canyon, roughly 300 feet below the entrance. According to the survey data, the lower Bean Room and also the passages downstream from the Tobacco Room lie at lower elevations than the rise of Sinking Creek into the Trunk Channel. This arrangement seems unlikely; the elevation discrepancy is more likely error in the elevation data.

The ultimate sink of Sinking Creek at the Marlboro Sump is at about the same elevation as the Last Hope Siphon. Although Last Hope Siphon is above the lower sandstone and the Marlboro Sump is below the lower sandstone, the Marlboro Sump lies farther upstream along the Trunk Channel and so is higher in the stratigraphic section. If the elevation data are to be believed, the lowest point in the cave is the Rats Doom Siphon which would be more than 60 feet lower than the other two sumps.

The Trunk Channel drops 270 feet over the roughly one mile between Sand Canyon and the downstream sumps, giving a gradient much higher than the 10–50 feet/mile typical of karst aquifers with open conduit permeability. If this gradient were to continue over the roughly two miles between the downstream sumps and Aqua Cave, the water would need to descend more than 500 feet and would have to rise more than 300 feet to reach the spring. Given the deep sumps at the back of Aqua Cave, this rough extrapolation may not be impossible. It would require strong geological controls to force the water into deep phreatic circulation because karst aquifers usually develop a shallow pathway to local base level streams.

19.6 Geochemistry of Cave Waters

19.6.1 Bulk Chemistry

There is a limited amount of information on the chemistry of the waters of the Butler Cave-Sinking Creek System. Table 19.2 give a set of cation analyses (Chess 1987). The karst waters in the Butler Cave-Sinking Creek system are of very high quality. Toxic heavy metals such as Co, Cu, Ni, Pb and Zn are all below limits of detection.

The cation analyses were based on a single set of samples collected in August, 1984. As part of his thesis work, Dan Chess collected samples for anion analysis at different times of the year. Values given in Table 19.3 are based on from three to eight samples. Again, all concentrations are very low. The species of concern is nitrate which might be expected as a contaminant in a rural farming area such as Burnsville Cove. Although nitrate values tend to fluctuate throughout the year, all values are well below the drinking water standard of 45 mg/L.

19.6.2 Carbonate Chemistry

The investigation by Harmon and Hess (1982) provides the only source of information on the geochemistry of carbonate dissolution and precipitation. The tables that follow are extracted from or calculated from the data in the appendix to their paper. Harmon

Table 19.2 Cation analyses of selected streams and springs (mg/L)

Cation	Butler farm Springhouse	Dave's Gallery	Moon Room Passage	Huntley's Cave	Aqua Spring
Al	<0.02	0.03	<0.02	<0.02	0.04
Ca	2.63	17.2	40	21.3	34
Co	<0.02	<0.02	<0.02	<0.02	<0.02
Cu	<0.02	<0.02	<0.02	<0.02	<0.02
Fe	<0.02	0.03	<0.02	<0.02	0.02
K	0.37	0.76	0.65	0.60	0.75
Mg	0.52	0.70	3.41	0.89	3.21
Mn	<0.02	<0.02	<0.02	<0.02	<0.02
Na	0.30	0.39	0.48	0.35	0.36
Ni	<0.02	<0.02	<0.02	<0.02	<0.02
Pb	<0.02	<0.02	0.03	<0.02	<0.02
Sr	<0.02	0.03	0.10	0.06	0.08
Zn	<0.02	<0.02	<0.02	<0.02	<0.02

Table 19.3 Anion analyses of selected surface and cave streams

Location	Cl^-	σ	NO_3^-	σ	SO_4^{2-}	σ
Surface streams						
Butler Farmhouse Spring	0.61	0.08	0.21	0.19	0.96	0.14
White Rock Mountain Stream	0.46	0.08	0.05	0.02	1.83	0/17
Sink of Sinking Creek	1.11	0.32	0.20	0.17	2.43	0.59
Cave streams						
Dave's Gallery	0.73	0.21	1.72	1.14	2.41	0.28
Moon Room	0.95	0.08	6.28	0.04	4.85	0.45
Huntley's Cave	0.65	0.16	1.22	0.81	3.31	0.38
Sinking Creek Resurgence	1.22	0.60	2.25	1.06	3.92	0.26
Sinking Creek Siphon	1.26	0.13	3.08	0.23	4.11	0.02
Sneaky Creek—Pool Room	1.60	0.17	2.76	1.53	3.45	1.76
Springs						
Aqua Spring	0.72	0.20	0.69	0.51	4.74	0.32

Analyses are given in mg/L. σ standard deviation

and Hess measured Ca-ion, Mg-ion, and bicarbonate ion concentrations as well as pH, temperature, and specific conductivity at the springs, and in Butler Cave at a number of sites. Sites were visited from one to five times as indicated by the dates. The temporal data are too sparse for more than a hint at the chemical variability at the sites; certainly no comparisons of chemistry with flow hydrographs can be made. However, the data are adequate to provide a rough idea of the present day chemical behavior of the cave system. Emphasis must be placed on the phase "present day".

The analytical quantities measured by Harmon and Hess permitted the calculation of other parameters that are more helpful in interpreting cave processes. For a more complete derivation and justification of these parameters, see any of several textbooks such as White (1988) and Langmuir (1997).

Hardness: Hardness is a measure of the amount of dissolved carbonate in the water. It is defined in terms of the measured Ca^{2+} and Mg^{2+} concentration and recalculated in units of mg/L as $CaCO_3$. It is a somewhat phony parameter in that both calcium and magnesium are treated as $CaCO_3$ but it does provide a useful measure of total dissolved carbonate.

$$Hd = 100.09\left(\frac{C_{Ca}}{40.08} + \frac{C_{Mg}}{24.31}\right)$$

The C's are concentrations of Ca and Mg in units of mg/L; the numerical values are atomic and molecular weights. Hardness is expressed in units of mg/L as $CaCO_3$.

Saturation Index: A question for any karst water: Is the water at chemical equilibrium with the limestone (or dolomite) bedrock? Is the water undersaturated, meaning that it is capable of dissolving more limestone? Is the water supersaturated, meaning that calcite (speleothems) should be precipitated. Saturation index is calculated from the measured Ca^{2+} and bicarbonate concentrations, the pH, the specific conductance, and the temperature. The saturation index is the logarithm of the ratio of the ions actually in solution to what the solution could hold if it were at equilibrium. Water at equilibrium has a saturation index of zero, positive values indicate supersaturation and negative values indicate undersaturation.

Carbon Dioxide Partial Pressure: Karst waters contain various concentrations of dissolved CO_2 which provides the weak acid that allows the water to dissolve limestone. Thick, organic-rich soils tend to produce high CO_2 concentrations (usually expressed as a partial pressure rather than a concentration) while water infiltrating from bare bedrock usually has a CO_2 pressure equal to or only slightly higher than the atmosphere. The amount of CO_2 in the water can be calculated from the bicarbonate ion concentration, the pH, the specific conductance, and the temperature. CO_2 concentrations in the atmosphere are actually rather low, 0.033 volume percent (330 ppmv) in the 1970s when these data were collected. Rather than giving the results of the calculation as CO_2 pressures,

Table 19.4 Carbonate parameters for streams within the Butler Cave-Sinking Creek System

Location	Date	Hardness	SI_C	$P_{CO_2}/\text{Atm } CO_2$
Rise of Sinking Creek	10/24/70	110	−0.55	8.8
	12/19/70	70	−1.08	11.6
	10/3/70	120	−0.66	15.3
	2/20/71	52	−1.15	3.3
	5/8/71	76	−0.58	3.5
Sinking Creek Sump	10/24/70	141	−0.53	13.0
	12/19/70	81	−0.93	10.8
	10/3/70	132	−0.43	11.4
	2/20/71	55	−1.07	3.2
	5/8/71	86	−0.45	3.3
Slippery Creek	10/24/70	116	−0.78	10.3
	10/3/70	116	−0.77	10.6
Moon Room Stream	12/19/70	117	−0.44	7.3
Rise of Sneaky Creek	12/19/70	124	−0.81	13.0
	12/19/70	133	−0.64	10.8
	10/3/70	186	−0.35	24.9
Huntley's Cave Stream	*2/20/71*	29	−1.66	2.7
Natural Bridge Stream	*2/20/71*	34	−1.39	3.1
Sand Canyon Stream	*2/20/71*	41	−1.28	3.0

Italicized data were collected under high flow conditions

it is convenient to calculate a CO_2 enhancement factor, defined as the ratio of the calculated CO_2 pressure to the CO_2 pressure in the atmosphere and it is this parameter that is listed in the tables.

Calculated carbonate parameters for flowing waters sampled in the cave at various places and times are given in Table 19.4. The data collected on February 20, 1971 were noted as being under "high flow conditions" although no quantitative measure of "high flow" was given.

As representatives of the input waters to the system, the chemical data on the flowing streams are remarkably consistent. All waters are highly undersaturated, meaning that they have been in contact with the limestone for too short a time for the chemical reactions to go to equilibrium. Carbon dioxide pressures are mostly in the range of 3–10 times the atmospheric background which is rather low. This also indicates the cave streams are derived primarily from surface runoff that has not had lengthy contact with organic-rich soils. Much of the water in the cave is mountain runoff. Soils are thin, sandy, and throughput times are rapid. Storm flow further dilutes the already dilute water.

The chemistry of the output waters was investigated by sampling the springs (Table 19.5).

The geochemical parameters for the spring waters are not greatly different from those measured for the streams in the cave. At first glance, this would seem to be entirely reasonable. In reality, these results raise some very difficult questions. All of the cave streams ultimately drain into sumps. The sumps are about two miles from Aqua Spring. The water feeding Aqua Spring rises from deep sumps at the back of Aqua Cave. There is no known source of additional CO_2 at depth in the ground water system so the CO_2 pressure should remain characteristic of surface runoff as it does. However, the deep flow system should be slow moving and provide plenty of time for the water to reach chemical equilibrium. Obviously, that didn't happen. The spring waters are undersaturated at about the same values as the cave streams. The transport of water through the entire system, including the unknown passages between the cave and the spring, must be very rapid and could contain air-filled segments.

A similar situation applies to Emory, Cathedral, and Blue Springs. There is a single measurement at

Table 19.5 Carbonate parameters for the Burnsville Cove springs

Location	Date	Hardness	SI_C	P_{CO_2}/Atm CO_2
Emory Spring	10/24/70	94	−0.39	5.2
	10/4/70	96	−0.85	12.2
	5/8/71	73	−0.50	3.2
	5/2/72	81	−1.06	12.8
Aqua Spring	10/24/70	106	−0.28	4.5
	10/4/70	111	−0.48	19.3
	2/20/71	67	−0.64	2.1
	5/81/71	78	−0.44	3.4
	5/2/72	71	−0.91	7.9
Cathedral Spring	10/24/70	105	−0.48	7.0
	10/4/70	102	−1.16	33.5
	5/8/71	90	−0.35	3.0
Blue Spring	10/4/70	142	−0.40	15.3
	5/8/71	131	−0.12	4.7

Blue Spring where the water approaches equilibrium. From the perspective of the cave explorer, this is good news. The unknown system that feeds Emory Spring must consist mostly of open conduits because the water chemistry is not distinguishably different from that of the other springs.

19.7 Concluding Thoughts

A full interpretation of the geologic history of the Butler Cave-Sinking Creek System must be woven into a broader and more comprehensive picture of the geologic and geomorphic history of entire Burnsville Cove (Chap. 24). There are clearly three, or perhaps four, major epochs in the development of the cave system.

1. The development of the "Old Cave"—the large passages of Butler Cave and certainly the southern portion of the Trunk Channel.
2. A massive sedimentation event that filled many of the passages of the "Old Cave" with sand, gravel and cobbles. Paleomagnetic reversals show that this event took place at least 990,000 years ago, mid-Pleistocene or older.
3. The development of the "New Cave", the removal of much of the earlier fill and the downcutting of much more passage such as the Bean Room and the canyon upstream from Sand Canyon.
4. The invasion of the pre-existing cave by present day drainage and perhaps the development of the present-day drainage pathways beneath the trunk channel. The use of the cave as a pathway carrying runoff from mountain streams to the springs seems an opportunistic use of existing cave passages, possibly with the development of new and immature passages beneath the present system.

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