Geology of the Caves in the Northern Cove 21

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Abstract
The structure plunges to the northeast, carrying the limestone below the Oriskany Sandstone and the Millboro Shale. There are three large caves in this region, Water Sinks Cave that marks the downstream termination of the Burnsville Cove Drainage, Helictite Cave just north of the contact, and Wishing Well Cave, completely beneath the caprock. Much of the drainage from the Cove converges to the Emerald Pool in the Water Sinks Subway and from there follows a major lineament eastward to Aqua Cave and discharges at Aqua Spring. Helictite Cave and Wishing Well Cave are an abandoned part of the Emory Spring drainage but developed deeper below the non-karstic sandstones and shales than might have been expected. Present day recharge along the flanks of Jack Mountain must flow at considerable depth and almost right angles to the structure to reach Emory Spring.

21.1 Introduction

At the northern end of Burnsville Cove, where it opens into the valley of the Bullpasture River, the carbonate rocks plunge beneath the Devonian sandstones and shales. In the early years of exploration, the water sinks depression, at the edge of the sandstone, marked the downstream end of the Sinking Creek Valley and the northern limit of cave development. The water sinks depression contained two small caves, known then as Siphon #1 and Siphon #2, and there was Aqua Cave, accessible through the Aqua Spring. Then Phil and Charlotte Lucas bought the Water Sinks property and spearheaded intensive exploration. First came the discovery of Helictite Cave, a complex maze cave apparently unrelated to the other drainage systems in the Cove. This was followed by the discovery of Water Sinks Subway and the caves of the water sinks depression suddenly became more significant. Finally, and most recently, there was the excavation into the Wishing Well. The discovery and exploration of these caves are described extensively in Chaps. 11, 12, and 13 and also in Phil Lucas' book (Lucas 2012). A description of Aqua Cave, known since the early exploration, is found in Chap. 4.

The northern caves add a whole new layer of complexity to the interpretation of cave development in Burnsville Cove. The objective of the present chapter is to describe the geologic setting of these caves and fit them into the overall pattern of cave development. Much of the geologic detail has already appeared in the description chapters. The present chapter draws heavily on the cave descriptions and on

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the revised Cove geology as given in Chap. 16. Mostly, it is an attempt to reconfigure the available information to highlight the geological story.

21.2 Geology of the Northern Cove

The northeastward plunging Sinking Creek Syncline carries the carbonate rocks deeper and exposes younger rocks at the land surface. The hilly upland north of the water sinks depression is underlain by the Oriskany Sandstone and the incised valley that descends into the main valley of the Bullpasture exposes the Needmore and Millboro Shales (Fig. 21.1). The entrance locations of the three caves are shown by the red dots; the location of Emory (along the river to the north) and Aqua (on Mill Run to the south) springs by green dots.

Important structural features are not well defined near the Bullpasture Gorge although the best available interpretation is shown in Fig. 21.1. The Sinking Creek Syncline continues to the northeast paralleling Jack Mountain. The plunge of the syncline takes the limestone beneath the sandstone and shale just north of the Highland County line. To the west, the only surface exposure of limestone is in a narrow band along the foot of Jack Mountain. Limestone is exposed along the Chestnut Ridge Anticline as far north as Water Sinks where the limestone is carried below the sandstone by the plunging structure. The Chestnut Ridge Anticline is shown with a jog near Water Sinks and then it appears to be lost near Wishing Well Cave. An extension of the trend of the Chestnut Ridge Anticline into the shale ridges to the northeast is shown as a syncline in Fig. 21.1. The White Oak Syncline veers more to the northeast leaving a wide region of poorly defined structure along the Bullpasture Gorge.

There is clearly a structural feature of different character and different orientation also present. A southeast-northwest line can be drawn across the northeastern end of Tower Hill Mountain, through a segment of the Bullpasture Gorge, up the valley of Mill Run past Aqua Spring and on to the Water Sinks. The nature of this structure is unclear except that it is almost at right angles to the anticlinal and synclinal fold axes of the basic Appalachian pattern. It may be a master lineament of the sort known elsewhere in the Appalachians,

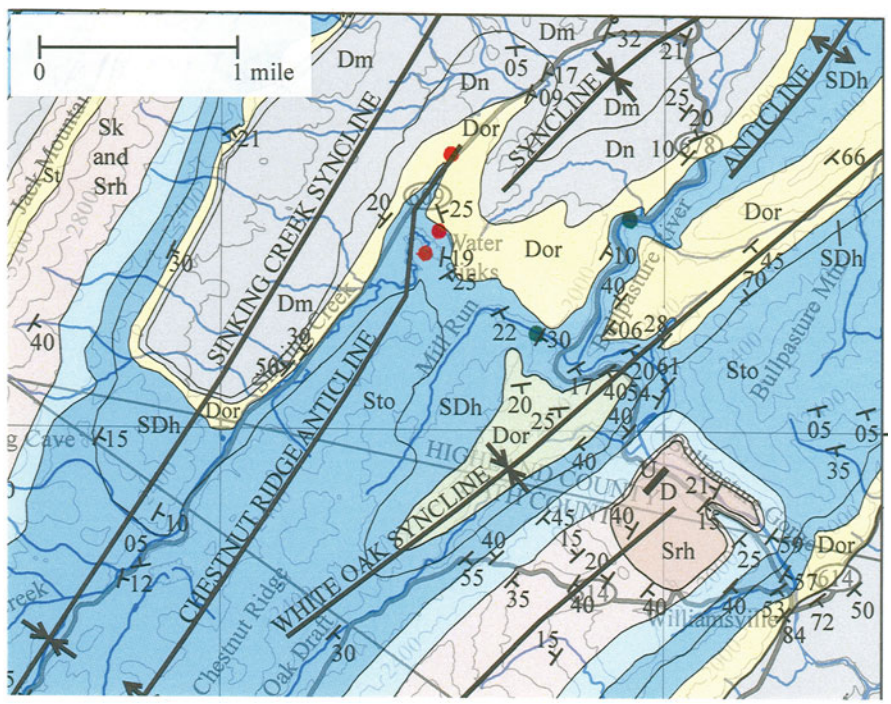

Fig. 21.1 Section of the geologic map of Burnsville Cove taken from Fig. 16.3 showing the location of the Water Sinks Caves, Helictite Cave, and Wishing Well Cave (*red dots*) and Emory and Aqua Springs (*green dots*)

for example the one through the Greenbrier Karst of Greenbrier and Monroe Counties West Virginia (Lessing 1979) and the one that guided the development of Simmons-Mingo Cave in Randolph County, West Virginia (Medville and Storage 1986). This structure is intimately connected to the drainage pathways that connect the Sinking Creek and Chestnut Ridge active drainage to Aqua Spring. Aqua Cave is developed along this feature with its main passage trends perpendicular to the regional strike. This feature will be referred to as the Water Sinks Lineament.

Many of John Haynes' stratigraphic studies were concentrated in and around the water sinks depression and as a result we have much better information on the stratigraphic setting of the northern caves than on many others in the Cove. Because of the plunge of the regional structure to the northeast, most of the caves are in the upper part of the section. The exposed section at the water sinks depression is shown in Fig. 21.2.

21.3 Geologic Setting of the Caves

21.3.1 The Water Sinks Caves

According to caver's conventions, Owl Cave is separate from upper Water Sinks Cave because the two have no known underground connection. Upper Water Sinks Cave and the Water Sinks Subway are part of one cave because one can traverse from one of the upper Water Sinks Cave's entrances to the entrance pipe of the Subway without getting outside the dripline. According to the hydrology and geomorphology of the system, it's the other way around.

Upper Water Sinks Cave and Owl Cave are fragments of network maze formed mostly in the Jersey Shore Member of the Keyser Limestone. The definitive stromatoporoid reef bed occurs immediately above the entrances to the two caves. See Figs. 16.19 and 16.20. Further extension of the caves is limited on three sides

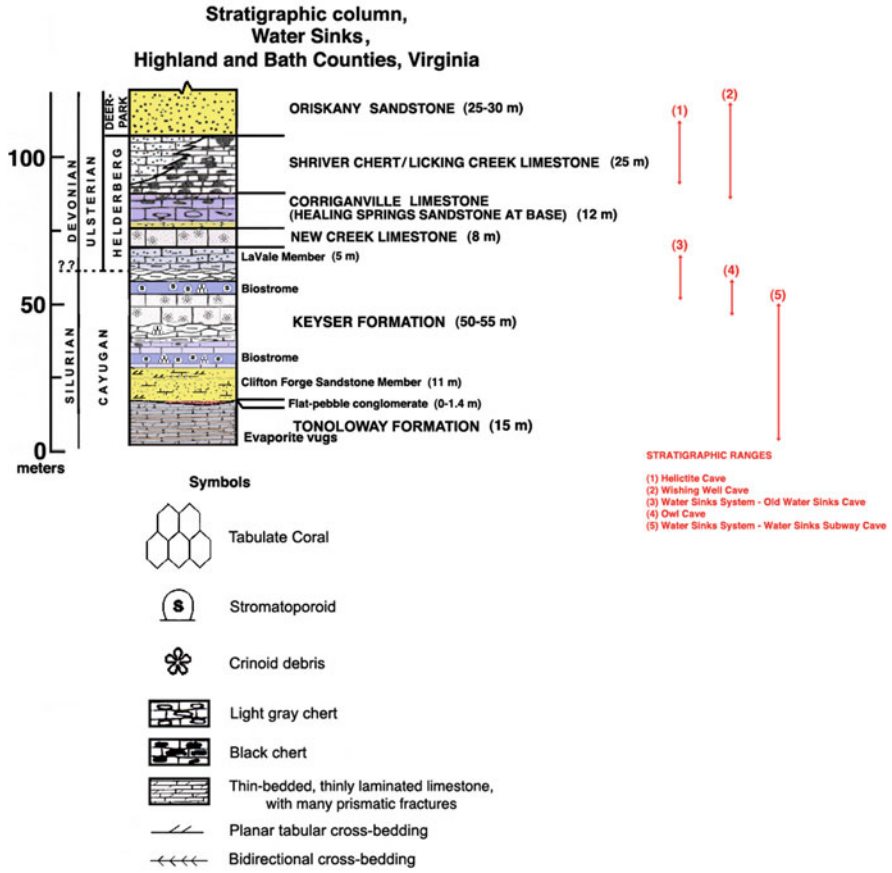

Fig. 21.2 Stratigraphic section for the water sinks depression as measured by John Haynes and his students

by the edges of Cave Hill, an erosional remnant formed by the dissection of Chestnut Ridge. Whether there is a further extension of Owl Cave into Chestnut Ridge at the talus cone dig remains to be seen.

The Water Sinks Subway, presently located below the level of the clastic sediment that forms the bottom of Water Sinks, is also a maze cave but has a somewhat different morphology than the upper caves. The main subway passage begins at the collapse at the edge of Water Sinks and continues southwest as a very large cross-section trunk (see Figs. 11.12, 11.13 and 11.14) which splits into multiple smaller passages. The other passages that make up the maze are even smaller. The subway section has all of the characteristics of a floodwater maze as described by Palmer (1975). As Phil Lucas points out in his description of the cave, prior to the sediment infilling of the water sinks depression, the main subway passage may have been an open insurgence cave, taking the flow of Water Sinks Creek. When the creek was in flood, the entire system would back up, creating a high hydrostatic head that would force water into every available joint and bedding plane parting. The result is a master passage with many auxiliary maze passages. The Brush Creek Caves in the Uinta Mountains of Utah show a similar development (White 1979).

The subway section breaks through the Clifton Forge Sandstone so that many of the passages are in the thin-bedded upper Tonoloway Limestone (Fig. 11.19). Dips are very low throughout the Water Sinks Caves so that the terminal sump, 155 feet below the entrance should be in the middle Tonoloway beds.

That the Water Sinks Caves are formed in tiers is apparent from the profile shown in Fig. 21.3. The upper maze caves–Upper Water Sinks Cave and Owl Cave–form what appears to be a double tier with passages 50–60 feet above the zero datum and at 10–20 feet above the zero datum. The subway section has two tiers, one sharply defined at 20 feet below datum and the other 44 feet below datum. The upper tier has a pronounced dip to the northeast, presumably following the structural plunge. A third possible tier is represented by Roaring River which rises from Emerald Pool at 140 feet below datum and disappears at the terminal sump at 155 feet below datum.

21.3.2 Aqua Cave

Aqua Spring at the head of Mill Run is about 50 feet above the elevation of the Bullpasture River at this location. The stream passage that feeds Aqua Spring, described in some detail in Chap. 4, can be followed upstream from the spring to the Siphon Lake. The average passage trend is N 50°W, close to the trend of the Water Sinks lineament. The stream passage is developed in the Keyser Limestone. The Clifton Forge Sandstone has been identified in the upstream stream passage by John Haynes and his students, suggesting that the cave is perched on the Clifton Forge Sandstone and this may account for the location of the spring, perched above the river. The deep submerged passages below the sumps must cross the Clifton Forge Sandstone so that the lowest points reached by

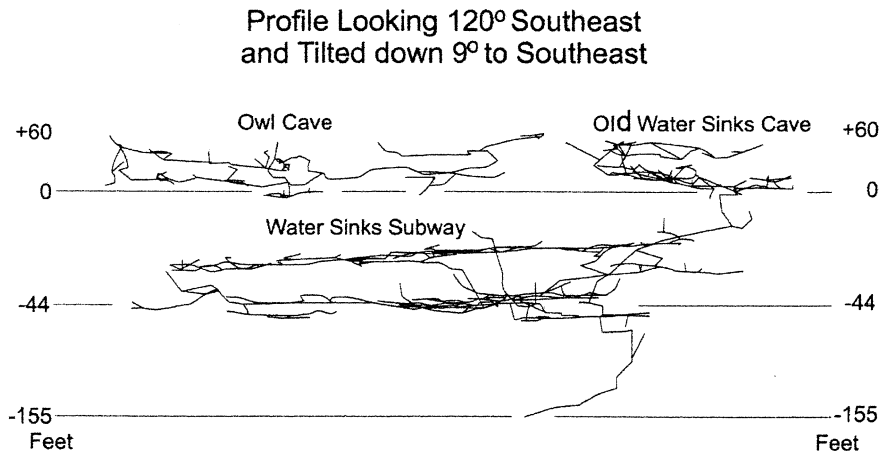

Fig. 21.3 Profiles of the Water Sinks Caves. Extracted from the Water Sinks map by Philip C. Lucas

divers in Siphon Lake and French Lake must be well down into the Tonoloway Limestone.

21.3.3 Helictite Cave

Helictite Cave has three components (Fig. 21.4). The Entrance Series is a tangle of tightly-spaced passages on multiple levels that descend to the Streamway, a well developed but short length of elliptical conduit (Fig. 12.16). The Streamway trends almost due north-south. The third, and most extensive component, is the Canyon Maze. The cave is developed in the cherty Licking Creek Limestone and the chert beds have a strong controlling influence on passage morphology. Except for the area immediately around the entrance, the cave lies beneath the Oriskany Sandstone that forms the caprock on Helictite Hill.

The orientations of the joints that provided the primary ground water pathways for the development of Helictite Cave were determined by measuring passage trends rather than by constructing a detailed passage rosette. The main passage trends are N 37°E and N 46°W (or S 134°E). The northeast joint set is more or less along the orientation of the Appalachian folding and may be called strike joints. The northwest joint set is roughly perpendicular to the regional folding and may be called dip joints. The joint set that controlled the Canyon Maze may be compared with the joint set that guided the development of the Butler Cave-Sinking Creek System (Fig. 19.8). The dip joints in Breathing Cave, and upstream and downstream Butler Cave have a mean orientation of 129°, close to the 134° of Helictite Cave. The strike joints in upstream Butler Cave are oriented at 63° but with a much wider distribution of values than the dip joints. The downstream passages in Butler have strike orientations of 52°. At Helictite Cave, the strike orientation has shifted to 36°. This distinct shift in the strike-joint orientation may represent a different structural pattern northeast of the water sinks lineament or may represent the different orientations of the Sinking Creek Syncline and the Chestnut Ridge Anticline.

The horizontal extension of Helictite Cave is to some extent limited by the limits of Helictite Hill. However, it is curious that no passage has been discovered east of the Streamway. The southwestern side of the maze is cut off abruptly. A line drawn along the ends of these southwest passage terminations has an orientation of N 42°W, roughly parallel to the orientation of the dip joints. This cutoff may represent the influence of the Water Sinks Lineament, a hypothesis supported by the extensive faulting observed in the Entrance Series part of the cave.

21.3.4 Wishing Well Cave

The discovery of Wishing Well Cave is a triumph of caver's intuition and persistence over logical geological deduction. It had been understood for a long time that the water sinks depression marked the northern limit of cave development. Underground drainage flowing northeast down Burnsville Cove reached the Water Sinks Lineament, made a right turn, and flowed to Aqua Spring. Searching for new caves farther to the northeast, well out onto the Oriskany Sandstone caprock, would seem a complete waste of time. But there it was, a persistent airflow from a sandstone rubble-filled sinkhole. At the end of an incredible exercise in excavation, documented in Chap. 13, the master cave was discovered, completely beneath the sandstone caprock.

The cave appears to be formed mainly in the Licking Creek Limestone. Chert beds are prominent in the passage walls. The excavated entrance shaft is entirely in a rubble zone of Oriskany Sandstone as is the excavated crawlway connecting the base of the shaft to the Doodlebug Room. The contact between the Oriskany and the Licking Creek Limestone is in the crawlway leading from the base of the Doodlebug Hole to the top of Companion Canyon. The contact is roughly 100 feet below datum. There are ledges of Oriskany Sandstone along Route 609 showing that some sandstone was eroded to form the shallow valley where the entrance is located. Nonetheless, the combined pit excavation and the descent through the Doodlebug Hole must span much of the thickness of the Oriskany Sandstone. It seems likely that a large cave chamber existed in the limestone below the entrance. Collapse and upward stoping through the sandstone produced the rubble zone that allowed escape of the air that called attention to the site and also permitted excavation without mining through solid rock.

Wishing Well Cave is mainly a set of conduit fragments—fragments of a drainage system entirely

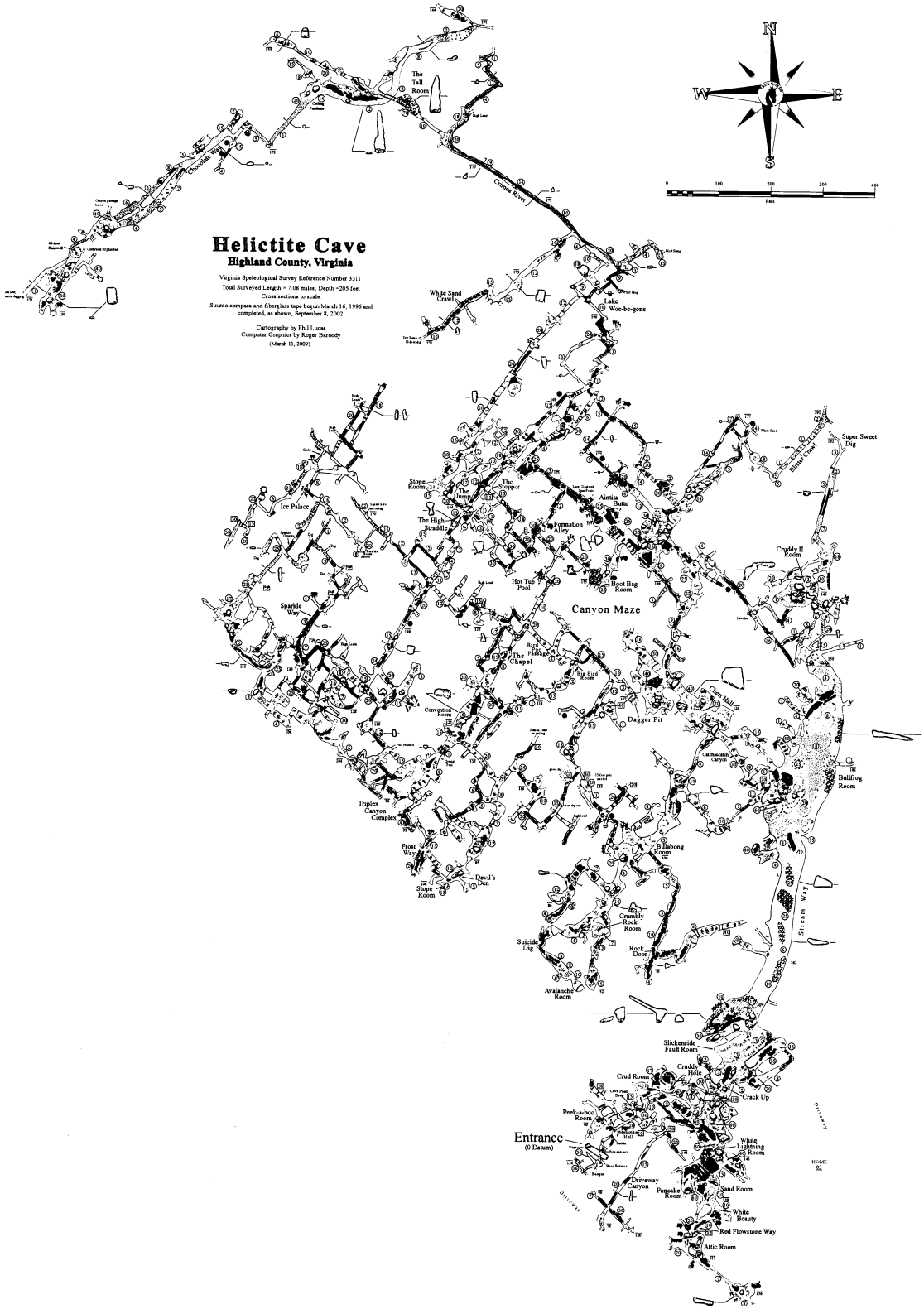

Fig. 21.4 The Lucas map for Helictite Cave in outline. An expandable copy of this map is in the electronic file

separate from the systems farther south in Burnsville Cove. It has several oddities. For one, the general orientation of the cave is north-south which cuts across the structural grain much like the North-South Trunk in the Chestnut Ridge System. A second oddity is the profile of Sugar Run, the master trunk passage of the system. The cave system, reduced to passage outline, is shown with some key elevations in Fig. 21.5. According to the interpretation of the explorers (Chap. 13) Sugar Run originates from the complex of passages at Echo Junction at the extreme southern end of the system at an elevation of about 180 feet below the entrance. At the Declivity the passage rises 40 feet as a lift tube to an elevation of about 135 feet at which it remains to the Angel Wing Room and the intersection with the Northwest Passage. Sugar Run then drops back to about 180 feet and continues downward to what was interpreted as the downstream end in the sump at 228 feet below the entrance. The Northwest Passage can be regarded as a south-flowing tributary, nearly horizontal, at an elevation of about 170 feet except at the downstream junction where the Hourglass lift tube segment is necessary to bring the passage up to the level of Sugar Run. These undulations in the vertical plane provide strong evidence that the cave system developed deep below local base levels as they existed at the time of passage development.

The main conduit is oriented more or less northeast-southwest following the crest of what should be the extension of the Chestnut Ridge Anticline. The Northwest Passage cuts almost at right angles to the regional structure and, because the passage is very nearly horizontal must also cut across the bedding. The presence of stream cobbles in Sugar Run demonstrates that the passage functioned as a master drain carrying water at velocities high enough to move the cobbles. It is less obvious where the water was coming from and where it was going. The geologic map (Fig. 21.1) illustrates the problem. The source for the Northwest Passage has been suspected to be the band of limestone exposed along the base of Jack Mountain. Recharge from Jack Mountain would have to pass down and under the Sinking Creek Syncline in order to reach the Northwest Passage. If the Sugar Run sump does indeed represent the downstream end of the system, the passage is trending to the northeast, following the anticline but there is no outlet in that direction. The plunging structure is taking the limestone deeper beneath the sandstone and shale. To reach the obvious outlet, Emory Spring, the drainage must turn eastward and pass under the unnamed syncline shown on the geologic map. Discovering more segments of the cave would definitely be helpful.

21.4 Karst Drainage in the Northern Cove

For the most part, the discoveries of major new caves in the northern Cove created more problems than they solved. To quote former Defense Secretary Donald Rumsfeld, there are known knowns, there are known unknowns, and—most importantly—there are unknown unknowns. The known knowns make up the substance of this book in the form of maps, photographs, and written text. With regard to the northern Cove, the known unknowns are discussed in the following sections. But it is more than likely that there are important unknown unknowns that will force major revisions of everything that has been said.

Elevations for important components of the northern Cove caves were calculated with respect to the established base level at 1595 feet, the confluence of the Bullpasture and Cowpasture Rivers (Table 21.1).

21.4.1 The Mysterious Feeder System for Aqua Spring

The underground drainage in Burnsville Cove is mostly southwest to northeast following the trend of the geologic structure. Because of the fold axes and more importantly because of the interbedded sandstones in the Tonoloway Limestone, the drainage takes the form of more or less parallel drainage lines, the various streams in the Butler-Sinking Creek System being good examples. What is observed are segments of streams, rising from sumps and ending in sumps, so that it is difficult to string together any complete drainage line.

The larger sources draining to Aqua Spring include the Butler-Sinking Creek streams, last seen at their sumps, the steam in Better Forgotten Cave, the Black Canyon stream in the Chestnut Ridge System, last seen at the 622 Sump, the surface overflow route of Sinking Creek at the Sinking Creek Swallet, and Water Sinks Creek which sinks at several points near Twisting Sister and Castle Rock with its final swallet in the water sinks

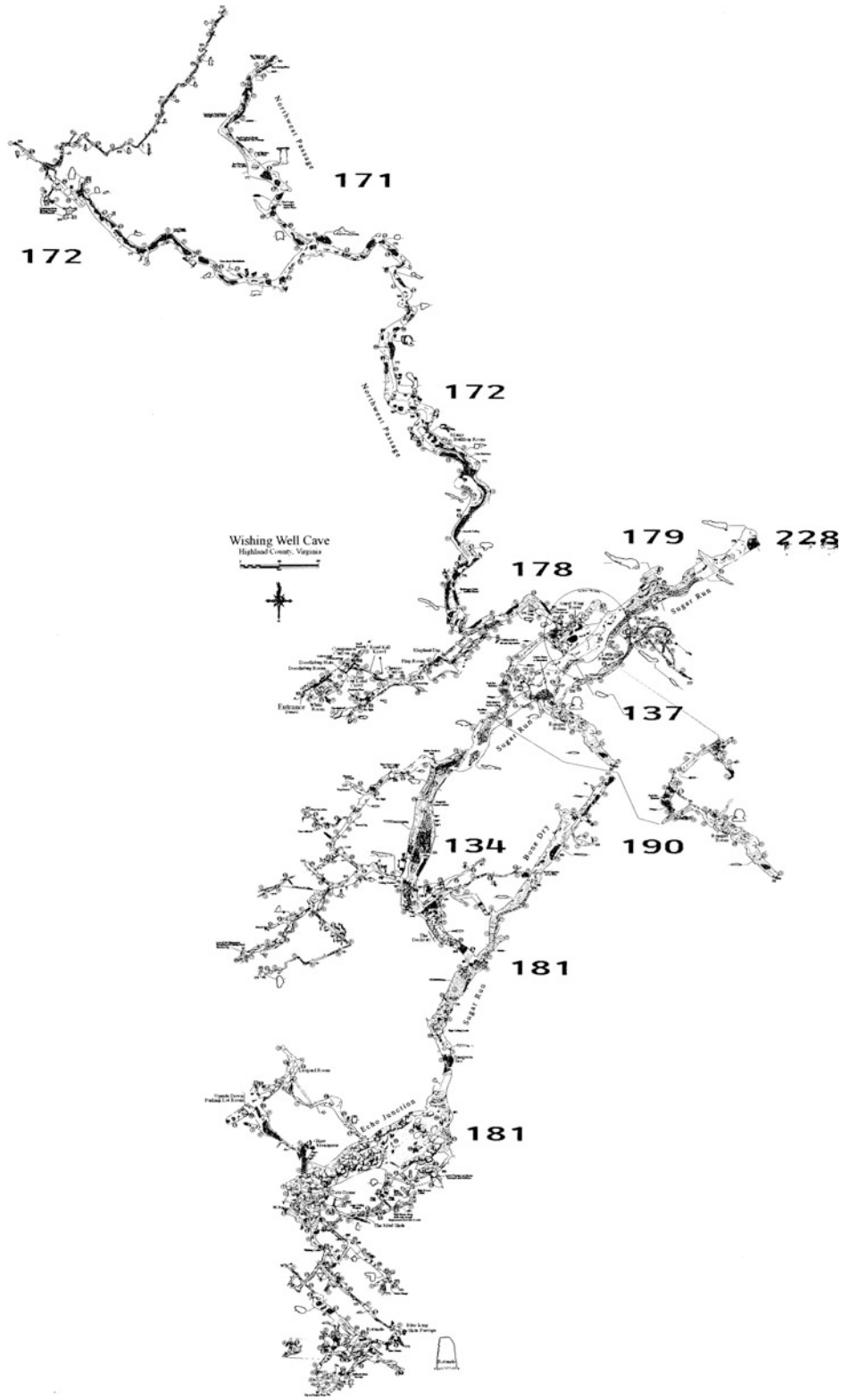

Fig. 21.5 Outline of the Lucas map of Wishing Well Cave. An expandable map is given in the electronic file. Passage elevations are given as depth below the zero datum at the cave entrance

Table 21.1 Elevation data for major features in the Northern Cove Caves

Location	Below datum	Above sea level	Above base level
Aqua Spring		1770	175
Siphon Lake	−25	1795	200
French Lake	−29	1799	204
French Lake Dive	256	1543	−52
Emory Spring		1754	159
Pancake Fields		2030	435
Water Sinks		1946	351
Subway passage	20	1926	331
Emerald Pool	155	1799	204
Owl Cave		1986	391
Helictite Cave		2068	473
Streamway	165	1903	308
Wishing Well		2005	410
Northwest Passage	170	1835	240
Angel Wing Junction	135	1870	275
Sugar Run	180	1825	230
Sugar Run Sump	228	1777	182

depression. Where and how these tributaries merge to form the aqua stream is not known. Water Sinks Creek, the Sinking Creek swallet, and the Butler streams appear at Emerald Pool but the upstream insurgences do not. In the 1600 feet separating the Roaring River Sump from the Siphon Lake and French Lake rise pools in Aqua Cave, the stream must pick up the other tributaries, descend to at least the depth reached in the Aqua Cave dives, rise stratigraphically from the middle Tonoloway Limestone to breach the Clifton Forge Sandstone at the base of the Keyser Limestone, and finally become the Aqua stream.

Down-loops in conduits usually form in response to structural constraints. What these structures might be along the water sinks lineament are unknown. It is possible that Roaring River is perched on the Upper Breathing Cave Sandstone and that the Emerald Pool rise is a break through the sandstone.

One way to probe the system would be to make careful flow rate measurements on the input streams during a dry period when water levels are low and stable. A water balance calculation would then show if the discharge at Aqua Spring does indeed account for all of the infeeders. The perching of Aqua Spring at the head of Mill Run is curious. If the water feeding the spring rises through lift tubes beneath the lakes, the lakes would provide a substantial hydrostatic head tending to force a new pathway closer to river level. Springs near river level or under the river might already exist, fed by leakage from the perched underground lakes in Aqua Cave.

21.4.2 The Equally Mysterious Drainage Basin of Emory Spring

According to the dye traces described in Chap. 17, Emory Spring has a large catchment area that extends several miles north up the Bullpasture Valley. The storm response of the spring (see Figs. 17.2 and 17.3) clearly indicates that the spring is fed by a conduit system in the Licking Creek Limestone. The few geochemical data available for the spring (Table 21.2) (Harmon and Hess 1982) support the hypothesis of a conduit system extending from the only available catchment along Jack Mountain to the spring on the Bullpasture River in spite of stratigraphic and structural barriers.

The concentration of dissolved limestone (hardness) is low compared with typical carbonate waters. The saturation index is strongly negative, showing that the water is far below equilibrium and has moved along the flow path from recharge area to the spring without coming into equilibrium with the limestone

Table 21.2 Geochemical data for Emory Spring

Date	Temperature	Hardness	SI-Calcite	p_{co_2} enhancement
October 4, 1970	10.2	96	−0.85	12.2
October 24, 1970	11.0	94	−0.39	5.2
May 8, 1971	10.5	73	−0.50	3.2
May 2, 1972	11.2	81	−1.06	12.8

Temperature is in °C and hardness is in mg/L as $CaCO_3$. p_{co_2} enhancement is the ratio of the CO_2 concentration calculated for the spring water to the atmospheric CO_2 concentration which, in 1972, was 326 parts per million

walls of the conduit. The concentration of carbon dioxide is enhanced by at most a factor of ten above the atmospheric background. The CO_2 concentrations are supportive of the hypothesis that the recharge is mountain runoff from the sandstone slopes of Jack Mountain sinking at the limestone contact. The geochemical data imply that there is indeed a conduit system and moreover that it is an open and highly efficient conduit system. This is consistent with the observation of stream cobbles in the Sugar Run Passage of Wishing Well Cave.

For streams sinking along Jack Mountain, the flow path to Emory Spring is at right angles to the structure. It must cross under the Sinking Creek Syncline, over the Chestnut Ridge Anticline, and under the unnamed Syncline shown on the geologic map just west of Emory Spring. The dye traces (Chap. 17) show that this flow path is indeed possible. A dye trace in the Clover Creek Basin, the next drainage basin to the north, reached Clover Creek Spring by a path which required flow beneath the Bullpasture River.

It seems reasonable that the Streamway in Helictite Cave and the Northwest Passage and Sugar Run in Wishing Well Cave are fragments of paleodrainage trunks that were part of the Emory Spring drainage basin. The active drain—the long-sought Emory River—must be down there somewhere. Exploration from Wishing Well Cave, on the crest of the anticline, has the best possibility of finding an air-filled segment of what is otherwise likely to be completely submerged passages.

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