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BEDROCK GEOLOGY OF THE SCOTT HOLLOW CAVE, MONROE COUNTY, WEST VIRGINIA

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Introduction

Due to poor surface exposures, analysis of bedrock in cave passages can assist with mapping of the bedrock geology of an area, especially in understanding the 3-Dimensional structures. New tools make this endeavor more feasible than ever before. Digital cameras allow us to take pictures in the cave and bring them back into the lab for further analysis. The GoCad computer program allows us to visualize the 3-Dimensional aspect of the cave passages in relation to the surface and bedding orientation below the surface. The largest contribution to our work was the laser range finder. This device allows us to measure the distance between stations and the thickness of layers in unreachable areas.

In order to begin our research, we consulted the dissertations of Stacey B. Davis (1999), Sara A. Heller (1980), and Albert E. Ogden (1976) for their work in previous studies of geology in the Scott Hollow Cave area. To our knowledge, a 3-Dimensional map of both the surface and cave passages has not been previously attempted. A positive result of our work will hopefully be the completion of a very well detailed stratigraphic column of the lower Greenbrier Formation. Once compiled, the data we have collected will prove useful to all future studies of the area.

The Scott Hollow Cave is located in Monroe County, West Virginia at the transition between the Valley & Ridge and the Appalachian Plateau geomorphic provinces (Davis, 1999). At the surface, Mississippian aged shales, sandstones, and limestones crop out (Figure 1). The Mississippian Greenbrier Limestone is the dominant surface rock in this part of the Appalachian Plateau while the Valley & Ridge province contains many synclines and anticlines associated with the nearby Saint Clair Fault (Dasher, 2000). The Scott Hollow Cave lies on the western sloping limb of a mapped, unnamed anticline (Ogden, 1976).

The Greenbrier Limestone and the stratigraphically lower Maccrady Shale, are both Mississippian in age (Heller, 1980). The Greenbrier Limestone tends to carry a thickness of 275 meters in this area (Davis, 1999). This shallow-marine carbonate unit is usually a gray mudstone to grainstone, which may contain fossils. The older Maccrady Shale, on the other hand, is much thinner than the Greenbrier Limestone especially in the Scott Hollow Cave area (Ogden, 1976). For Monroe County, the shale reaches thicknesses of up to 106 meters. However, for our area of interest, the shale normally only reaches 15 meters in thickness. This shale is nonmarine and typically a bright red color (Davis, 1999).

Greenbrier limestone hosts the largest, deepest, and most complex caves, the largest karst basins, the largest number of caves, and the largest karst springs in West Virginia (Dasher, 2002). Scott Hollow Cave is the third longest cave in West Virginia with a length of 24.7 miles and many passages still undiscovered. Scott Hollow's main passage, Mystic River, accounts for over four miles of the cave and is one of the largest passages in West

Virginia.

We developed two objectives for the summer involving the study of Scott Hollow Cave. We wanted to create a 3-Dimensional model of the cave using six passages that have been discovered and surveyed. From the 3-Dimensional model, we wanted to add our own surveying points to represent the bedrock stratigraphy found in the cave. We wanted to build a surface for the green shale geologic unit within our 3-Dimensional model. To facilitate building of the model, we needed a detailed stratigraphic column of the units found in the Greenbrier Formation.

Stratigraphy Description

This section consists of a chert-rich limestone overlying a green shale, followed by a distinctive thinly bedded limestone. At the base of the section are fine-grained clastic units. This section is quite similar to the middle to low Hillsdale Formation of the Greenbrier Group described by Ogden (1976), and is consistent with Ogden's mapping of the area that indicated Hillsdale at the cave entrance. Thus we interpret the section described below as belonging to the middle to lower Hillsdale Formation.

Throughout the passages of the Scott Hollow Cave that were analyzed in the summer of 2002, a stratigraphic thickness of 13.45 meters of rock was measured and characterized (Figure 2). The highest stratigraphic member is a ubiquitous black chert set in a tan limestone matrix. We refer to this member as the Massive Chert (MC), and is easily identifiable by the finger-like chert formations (Figure 3), and broken "slab" formations protruding from the limestone walls (Figure 4). This member is a very resistant layer, and has a minimum thickness of 4.24 meters. Thin section analysis of this member (Appendix 2) shows the rock to be a microcrystalline chert with a quartz matrix. Brachiopod and crinoid fossils are common in the chert. The bottom 0.305 meters of limestone in this member lack the ever-present chert that is found throughout the rest of its thickness, but has a very high concentration of bivalve and crinoid fossils at its base.

The next member that is stratigraphically below the Massive Chert Member is referred to as the Double Chert (DC) (Figure 5). Its two horizontally parallel layers of chert clearly identify this member. The two chert layers are 0.30 meters apart, and form the resistant member that makes up the ceiling throughout most of the cave. Between the two layers of chert lies a light-tan limestone.

Immediately below the Double Chert member is a very thick tan limestone member. This 4.64 meter-thick rock member is referred to as the Massive Limestone (MALS). Thin section analysis indicates this limestone to be a micrite with numerous muscovite and calcite clasts within the sample. It lacks any real identifiable characteristics other than the fact that it is a wall-forming unit, and is more resistant than the member below it. A fresh surface of this limestone appears very dark grey in color, and effervesces when it comes in contact with hydrochloric acid. Within this MALS unit, there are three sub-members. The highest sub-member stratigraphically is the upper limestone, which is identified as being 4.34 meters thick, and has the same characteristics of the MALS member. Below the upper limestone is a 1-centimeter layer of bentonite clay. X-Ray Diffraction analysis identified this clay by determining the mineral composition of the clay we sampled. This light-grey clay is very sticky when wet, and seems to be a very unstable cementing agent between the upper and lower limestone units of the MALS member. This is obvious when observing the amount of erosion and breakdown that occurs below this sub-member in the cave. Below the bentonite lies the lower limestone, which is 0.29 meters thick, and is very similar to the upper limestone.

Beneath the Massive Limestone is a Green Shale (GSH) with several sub-members. This Green Shale member measures 1.46 meters thick, and is easily identified by its pale green hue (Figure 6). Even under the bright yellow light emitted by our halogen bulbs, the color is easily seen. X-Ray Diffraction analysis (Appendix 3) determined that the mineral composition was best interpreted as a shale. It is composed of three sub-members of shale: two green and one red. The highest stratigraphic member of the GSH is the upper green shale. Thin section analysis identifies this shale as having a very fine brown clay matrix. Sporadic crystals of hematite, quartz, and muscovite are present in this sample. This shale is pale-green in color, with several red clay layers (between 0.5 and 3cm. thick) interspersed throughout the thicker green shale layers, and measures 0.29 meters thick. Below the upper green shale is a 0.88 meter-thick bed of red shale (Figure 7). This section analysis reveals more quartz and hematite (most likely responsible for the reddish-hue) in this sample of shale, but continues to have unorganized crystals of hematite and muscovite. This bed of red shale pinches out in several places in the cave, and is therefore not always visible throughout the cave passages. The red shale is more resistant that the green shale, and commonly protrudes further from the wall than either green shale layer does. Due to its solid composition and lack of fresh surfaces, it appears to be less weathered than either of the green shale layers. The lower green shale layer is 0.31 meters thick, and appears to have the same composition as the upper green shale layer.

Stratigraphically below the Green Shale Member lies the Dark Grey Dolomite Member (DGD). This member is 0.29 meters thick, but does not stand out at all in the cave as being identifiable. It is commonly covered with minerals growing on its surface, or clays and mud, rendering it virtually impossible to identify. When a fresh surface is created, we are able to see that the rock unit is a very dark grey color. Fresh surfaces of the rock barely effervesce when they come in contact with hydrochloric acid. Only a few bubbles can be seen, and these are thought to come from very thin calcite veins in the rock, not from the rock matrix itself. We are able to observe the presence of hematite and a number of calcite clasts, while the remainder of the sample was dominated by the presence of what we believe are dolomitic clasts. The matrix of the rock is calcite. We believe this sample is a dolomitic grainstone.

Immediately below the Dark Grey Dolomite Member lies a very identifiable limestone. This member is referred to as Bob's Limestone (after Bob Thren, the first member of our research team to find the rock). It is a very resistant limestone that often makes up the floor of the cave passages that we travel through. The rock is composed of very thinly bedded limestone beds, which often alternate between tan and dark brown clays (Figure 8). These beds range from 0.05mm. to 1mm. in thickness, and often display cross bedding. This is a member with very striking features, making it very easy to locate within the cave passages.

Below Bob's Limestone lies the lowest stratigraphic member that we were able to access this summer. This rock unit is referred to as the Calcareous Quartz Siltstone Member (CSS). It is a relatively difficult member to identify due to the amount of clay deposits on its surface, and its limited number of outcrops throughout the cave. Thin section analysis identifies this rock member as being a calcite-cemented quartz siltstone. The sample we observed was moderately well sorted and was dominated by the presence of angular quartz clasts with low sphereosity within the calcite matrix. This indicates that this member was deposited and covered quickly with clays of the Bob's Limestone. We also observed hematite, and minor amounts of biotite crystals within the sample. A fresh surface of the CSS Member reveals the true color of this rock to be light tan, with very small dark-brown clasts within its matrix.

Structure And Cave Passages In 2- And 3-Dimensions

In order to create the cave models we used the programs Compass for 2-Dimensional and GoCad for 3-Dimensional analysis. Thousands of surveyed points were required from the cave itself. These points were obtained by surveys contributed by Mike Dore and others over the last eighteen years of surveying Scott Hollow cave. The cave was modeled using a standard cave surveying procedure, involving distances, angles, and bearings between points. The first point of the entire cave lies at the opening to the tunnel leading down into the cave. This point is defined as 0, 0, 0 in an x, y, z coordinate system with all measurements taken from then until the end in relation to that point. All of the values used to define the spine and passage walls for the cave were taken from surveys performed by the cave owner, Mike Dore, and other experienced surveyors. These points were entered into large Excel spreadsheets in order to allow for easy data entry into Compass and GoCad for modeling (Appendices 4 & 5). With the spreadsheets in Compass, the x, y, z coordinate system for each station was converted to the Universal Transverse Mercator (UTM) coordinate system in order to enter the values into GoCad. With measurements for distance, bearing, and inclination between points, and the distances from the survey points to the walls in the left, right, up, and down directions, models for the cave passages were built in both 2-Dimensions and 3-Dimensions.

In order to create the planar surface depicting the location of the green shale layer, more data points were necessary from the cave. First, contact locations between the green shale and the massive limestone layer stratigraphically above were found. Once a contact was found, the original survey stations needed to be located based on the originally recorded data. From those survey points, measurements were taken of the exposed contact in order to later locate the contact in the model (Appendix 5). In addition to distance, bearing, and inclination, the thickness of the layer was also recorded with the use of a laser range finder.

Not only were Scott Hollow Cave passages Patty Lane, Mastodon Avenue, Chris' Trunk, North-South, Root Canal, and Gypsum Way all modeled in 2-Dimensions under Compass, but modeling in the 3-Dimensional GoCad was also successful. The procedure of mapping the original survey points and searching for the green shale contact points worked in proving that GoCad can be used for cave modeling. Compass provided a thorough view of the passages in cross section with color coded depths (Figure 11) while GoCad also modeled the cross section and included the wall passages (Figure 12). A plan view of the passages with tetrahedra representing the contact points was created in GoCad (Figure 13). GoCad proved to be the most detailed and complete program for constructing and viewing the cave passages (Figure 14). This program allowed us to view the passages in relation to the topographic features at the surface (Figure 15), planes depicting certain rock formations (Figure 16), and the walls of the passages below the surface (Figure 17). GoCad also allows for views of the cave in all directions without limitation.

All but one passage that we mapped in our project follows either the strike or dip of the mapped, unnamed anticline in the area. The passages following the strike tend to not experience much change in elevation. Those passages that follow the dip do experience a decline to the west following the dip of the western limb of the anticline. According to Ogden's map (1976), the strike and dip measurement for the area of Scott Hollow Cave at the surface reads approximately N5E with a 30˚ dip to the NW which coincides with our work. North-South passage, the largest passage we mapped, runs north to south. This passage presently contains Mystic River, the dominant river used in the formation of the cave. Gypsum Way and the northern portion of Root Canal run relatively parallel to North-South. The Side Entrance off of Patty Lane and the crossover between Patty Lane and Mastodon Avenue run north to south as well. Mastodon Avenue, Patty Lane, and the southern portion of Root Canal all cross cut North-South and run east to west in direction following the dip of the anticline. Unlike the north to south running passages, these passages do experience a decrease in elevation. They dip to the west approximately 14-degrees. Chris' Trunk is the only passage we mapped not running directly north to south or east to west. This passage possesses a northeast to southwest orientation. The orientations of all passages but Chris' Trunk coincide with the western limb of the mapped, unnamed anticline in the Scott Hollow area. For the fact that the passages that follow the strike do not change in elevation and the passages that follow dip do decline in elevation, we believe Scott Hollow cave is under lithologic control.

The contact points between the green shale and massive limestone were found in many of the cave passages we mapped. The first contact point between the Hillsdale Formation and the Maccrady Shale lies in Mastodon

Avenue (Dore, 1995). Other wayward points were obtained further into Mastodon Avenue and North South. Most points, however, were taken from Gypsum Way and Root Canal. These points represent the green shale exposures within the most immediate passages of the cave.

Cave Formation Flow Description

In this section we give a narrative of walking through the Scott Hollow cave in order to help the reader visualize the cave. Entering the cave down through the 8.67-meter culvert pipe, the first member we drop down into is a very thick chert-rich limestone. Stratigraphic Site 1 is located at the base of the culvert pipe entrance (for details of all Stratigraphic Sites, see Appendix 1). This is the highest stratigraphic layer we were able to observe throughout the cave during our work in the summer of 2002. We refer to this unit as the Massive Chert Member (MC). The MC is a very thick layer of organic, finger-like chert formations that frequently protrude from the limestone walls (Figure 3). These "fingers" range anywhere from 5 to 25 cm. in length, and most are approximately 1.4 to 2.7 cm. in diameter. In this same layer, the chert forms many broken "slabs" that lay parallel to bedding, usually ranging from 7.6 to 36 cm. in length, and between 1.4 to 7.6 cm. in thickness (Figure 4). This MC unit is a very dark grey where a fresh surface can be found, and is at least 4.26 meters thick. We were not able to measure the entire thickness of the unit since MC extends above the ceiling of the cave at this point in the cave (Figure 9).

Immediately below the MC unit is a limestone unit with a double layer of thinly bedded chert. This unit is very distinctive in its appearance, and can be followed throughout most of the cave passages that we traveled through (Figure 5). We refer to this unit as the Double Chert Member (DC). In between the two chert layers, the limestone matrix is tan in color. It appears to weather more easily than the chert, and that is why we see the protruding chert "fingers" and "slabs". This DC member forms the stable ceiling unit throughout most of Mastodon Avenue, Patty Lane, Root Canal, and Gypsum Way. The double chert layers are approximately 20-26 cm. apart. Immediately below the DC unit is another important, easily distinguishable tan limestone unit with little visible bedding or protrusions. This is the Massive Limestone Member (MALS). At the entrance it is impossible to measure the entire thickness of this unit because there is a great deal of mud and rock debris that has been washed up against the base of the cave walls, however, it is the thickest unit we have observed to date, measuring approximately 4.57 meters thick at Stratigraphic Section Site 3. It is a wall-forming member, and it can be followed throughout most of the cave passages that we traveled this summer.

As we travel down Mastodon Avenue, we walk down a consistently dipping 14-degree bedding that we interpret as the western limb of the Sinks Grove Anticline. Throughout Mastodon Avenue, the ceiling is intermittently peppered with the bottom chert layer of the DC member. There is also a visible fault, or joint, that runs down the middle of the ceiling unit, so when the chert disappears from the base of the ceiling, we are usually able to see it through the crack formed by the fault. The walls are composed of the MALS unit, and are very thick, extending down below the mud and rock that has been washed up against the walls by runoff and flooding in the cave. Most of the streams that run through Mastodon Avenue have washed away any clay or rock debris, and therefore expose the stable rock member that forms the cave's floor. This floor member is referred to as Bob's Limestone (BLS) and is a very weather-resistant layer. Its beautiful alternating dark brown and tan crossbedding patters makes it easy to identify (Figure 8). These layers within the BLS unit are extremely thin, usually measuring between 0.05mm. and 1.0mm. Although we cannot see most of the rock beneath the MALS and above the BLS at this point in the cave, we know that there are a few members between the two. These were discovered at Stratigraphic Section Site 2, and will be described later. Once we reach the Crossover leading from Mastodon Ave. to Patty Lane, we crawl up into the DC layer. Here it forms the passage ceiling and extends down into the cave walls. We can see the distinctive brachiopod and crinoid fossils immediately below the DC member.

Upon entering Patty Lane, we quickly recognize the walls to be the MALS member, and the ceiling to be the base of the DC member. After a short travel downstream, we walk into what is referred to as the "Green Room". This is where we find a new very distinctive rock member. We refer to this unit as the Green Shale Member (GSH), and it is very easy to identify (Figure 6). True to its name, this shale unit is a pale-green (even in the bright yellow light emitted by our halogen headlamps), and is very easy to spot because it is so different from the carbonate units (the details of this unit will be discussed further at Stratigraphic Section Site 2). The walls and ceiling remain the same throughout Patty Lane, and the floor is thought to be BLS, however it is difficult to identify due to the amount of breakdown covering it. When Patty Lane meets up with Mastodon Avenue coming in from the left (survey site P48), at cave left there is a very good example of the GSH, and it is here where we can see several new units. This is where the data for Stratigraphic Site 2 was recorded.

This site is located at survey station point S2-2 (our own survey point shot from Mike Dore's Scott Hollow survey station P48). The ceiling at this point is composed of DC. There is a fault that divides the ceiling in half, allowing us to spot the obvious bottom layer of the black DC unit. The wall is composed of MALS, and this member forms a large overhang about 1.8 meters off of the ground. Directly below the MALS member, we notice extremely sticky clay that seems to be a very unstable cementing material. X-Ray Diffraction analysis identifies this clay layer to most likely be bentonite. This clay layer is most likely responsible for the formation of the overhanging shape of the cave at this point. The clay unit itself is approximately 1cm. thick, and once weathered away it no longer supports the rock beneath it, allowing for much more severe erosion to take place in the form of wall collapse and massive breakdown. The rock below the Bentonite is more limestone, and it makes up the bottom 0.26 to 0.30 meters of the MALS member. Below the MALS, lies the GSH. At this point in the cave we find a red shale layer in between two green shale layers. This is not uncommon. The GSH member varies in composition throughout the cave. At times it has one 0.91 to 1.22 meter thick green layer. And at other times it has three sub-members: a 0.31-meter layer of green shale, a 0.91-meter layer of red shale, and a 0.31-meter layer of green shale (Figure 7). Below the GSH is a 0.31-meter layer of the Dark Grey Dolomite Member (DGD). A fresh surface reveals a very dark grey coloration, and only faintly effervesces when in contact with acid. This reaction to the acid only occurs in the cracks of the rock. This leads us to believe that the cracks are calcitic veins inside the dolomite, and that the calcite is the only portion of the rock that is reacting. Below this DGD member is the BLS from before (Figure 8). Again, we can see at the base of the stream running through Mastodon Avenue that the BLS makes up the stable floor member. At this point in the cave we cannot see the base of the member, but there is approximately 0.66 meters of BLS exposed.

As we move further down Patty Lane, we follow the same units in the ceiling, walls, and floor until we climb up into the Junction Room. Here we crawl stratigraphically up into the upper MALS, DC, and MC layers, and pop out into a fairly large opening with a number of caves branching out in different directions. After heading straight for approximately 10 meters, take a left turn toward a tall, yet skinny passageway. This portion of the cave is the beginning of the North/South passage. It is recognizable by the flowstone and "bacon grease" formations on the left as you enter the passage. In this part of the cave it is difficult to identify rock types in the walls, but in a few places we are able to follow the MALS and GSH members in the wall. The GSH member can be found in several locations at cave right, usually beneath a large overhang approximately 1.21 meters off of the cave floor. At Scott Hollow survey station NS11 there will be a sharp left hand turn into Root Canal as North/South continues straight.

Root Canal is a very fragile section of the cave sporting thousands of "soda straw" stalactites and stalagmites. We do not run into these formations until after a decent climb above the stream at the base of the cave. The rock members that form the wall in this section of the cave are hard to identify due to the amount of clay and gypsum crystals that have been deposited or are in the process of growing on the walls. By paying attention earlier in North/South, and by watching the rock in the cave ceiling, we know that we are not up in the chert formations yet, therefore it is safe to say that the walls are MALS, GSH, and DGD. Soon after entering Root Canal the lower section of the cave chokes out, so we are forced to climb up shelves in the wall in order to be able to continue further into the cave. After dropping down on the far side of the high climb, the cave trail takes us through some massive breakdown and thousands of "soda straw" formations. After all of the breakdown and friction climbs, the cave opens up and shows some good exposure of MALS, GSH, DGD, BLS, and a new rock member, the Calcareous Siltstone Member (CSS). This occurs immediately after the floor becomes a very smooth clay trail. Approximately 3 meters to the right of survey station NSA38, on the wall at cave right there is a white growth of calcite or gypsum. This is the location of where we took data for Stratigraphic Site 3.

At Stratigraphic Site 3, the ceiling is approximately 8.2 meters above the cave floor. It is fairly easy to see the bottom DC chert layer through the crack in the roof here. The upper walls are made up of 4.87 meters of MALS, 1.52 meters of GSH (0.31 meters of upper green shale layer, 0.91 meters of red shale, and 0.31 meters of green shale), 0.31 meters of DGD, 1.32 meters of BLS, and 0.20 meters of CSS.

After rounding the corner there is a large pile of small breakdown in the right "elbow" of the cave before it changes direction back to the left. It is here at cave right, after the pile of small breakdown and immediately before the large blocks of breakdown that we took our last data in the cave (between survey stations NSA39 and NSA40). This is Stratigraphic Site 4.

Stratigraphic Site 4 is the lowest stratigraphic layer of the cave that we were able to access in the summer of 2002. The cave ceiling is approximately 9.6 meters above the cave floor. The stable bottom layer of the DC chert layer forms the roof. There are approximately 4.83 meters of MALS exposed below the DC layer. Below the MALS, we are able to measure 1.56 meters of GSH (0.32 meters of upper green shale layer, 0.94 meters of red shale, and 0.31 meters of green shale). Below the GSH member is the DGD member that measured 0.31 meters thick. Beneath the DGD layer lies approximately 1.32 meters of BLS. At the very base of everything is the CSS member. This is a minimum thickness of this member since clay covers the rock on the ground, and the fact that the cave trail climbs in stratigraphic height after this point in the cave. However, at this point, we were able to measure 1.35 meters of the exposed CSS member.

Conclusion

We accomplished all objectives we set for ourselves. First, we used all survey points for passages Patty Lane, Mastodon Avenue, Chris' Trunk, North South, Root Canal, and Gypsum Way in Scott Hollow Cave to create a 3-Dimensional model of them. These passages are placed correctly within zone 17 of the 1983 Universal Transverse Mercator (UTM) coordinate system. Placing them in the UTM coordinate system allowed other geologic formations to be placed accurately in relation to the cave spatially. The air photograph of the surface above the cave was draped into a topographically correct surface with the use of contour lines in GoCad. This allows the passages to be directly associated with the surface. In addition to the data points provided by Mike Dore, we collected points of the green shale contact with the massive limestone. We used these points to construct a possible representation of the green shale layer throughout the cave passages. We also removed and analyzed all formations found within the cave. These formations were then shaped into hand samples and thin sections in order to determine the rock composition and type and corresponding formation. While in the cave we also measured the thickness of each layer in order to accurately represent the formations in the stratigraphy column. We did not bias our research by viewing other geologists' stratigraphy columns of this area. Instead, we broke down what is the Greenbrier Group into rock types that we identified. As a result, the stratigraphy column is quite distinct and can be tracked throughout the passages and correlated with the middle to lower Hillsdale.

We hope that our work can be used to further map the Scott Hollow Cave of Monroe County, West Virginia. We feel we may have opened doors in the use of GoCad for modeling of caves in addition to its current use within the Petroleum Industry. We hope that our stratigraphy column will allow other cavers in the area to find their position stratigraphically. We hope our modeling of the green shale has provided a brief glimpse into the structure of the subsurface and an understanding of the surrounding formations. More contact points between the green shale and massive limestone could be collected in Chris' Trunk and North South leading down to Mystic River in order to more accurately model the green shale layer throughout the cave. Other layers could be modeled throughout the cave in addition to the fault (Davis, 1999) that could lead to a more complete stratigraphy column. With the new formations and their measurements, a 3-Dimensional model could be created in GoCad showing all structure that occurs below the surface and offer a direct view in relation to the topography at the surface and the cave passages found below. Ultimately, it would be wonderful to match the subsurface structure with the formations found at the surface. Eventually, continued work on Scott Hollow cave will prove or disprove its connection to Windy Cave and the possibility of an even larger cave.

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Appendix 1: Detailed Description of Stratigraphic Sites 1-4

Stratigraphic Site 1

This site is located at the base of the entrance culvert pipe. Before we crawl through the triangular opening in the Massive Chert Member walls in order to get into the main section of the cave, there is a passage off to the right that leads towards Patty Lane. One meter into this passage and on the right is where we took our data for Stratigraphic Site 1.

The walls are entirely composed of chert "slabs" and "fingers". The distance from the passage floor to the ceiling was measured to be 4.57 meters. The chert in this Massive Chert Member (MC) is held in a limestone matrix. The limestone is dark grey in color when a fresh surface is created, but weathers a light tan color in the cave. The chert is a very dark grey to almost black color, and remains black on the surface of the cave walls unless covered with clay. This member contains many brachiopod and crinoid fossils at the very base of the member where there is no chert. The thickness of this member was measured to be 4.26 meters thick (although we were probably not able to measure the entire member due the fact that it seemed to continue past where the ceiling allowed us to measure). Below the MC is the Double Chert Member (DC). The DC member is a very visible unit throughout most of the cave due to its highly weather resistant characteristic, and its continuous two parallel layers of broken "slab" chert. From the top of the highest stratigraphic layer to the bottom of the lowest stratigraphic layer, this DC unit measured 0.305 meters in thickness.

Stratigraphic Site 2

This site is located at the confluence of Patty Lane and Mastodon Avenue. From survey station P48, we shot our own point to survey station S2-2. This new station lies 7.49 meters away from P48 at a 223-degree angle (when using an azimuthal compass). There is a white spot on the left wall above the Green Shale Member, and it is at this point where we took our data for Stratigraphic Site 2.

The ceiling at this point is the bottom layer of the DC unit. The Massive Limestone Member (MALS) makes up the upper 4.57 meters of the walls, ending approximately 1.8 meters from the floor. There are a few sub-members of the MALS unit. Immediately below the upper 4.57 meters of limestone, lies a 1 cm.-thick layer of bentonite. Below this bentonite sub-member is a second layer of limestone, which like the thicker layer, effervesces when it comes in contact with hydrochloric acid. This sub-member measures 0.305 meters in thickness. Beneath this MALS unit, we find the Green Shale Member (GSH). This member measures 1.52 meters thick. This unit also has several easily identifiable sub-members. The GSH unit is composed of three sub-members: an upper layer of pale-green shale measuring 0.305 meters thick; a middle layer of red shale measuring 0.914 meters thick; and a lower layer of pale-green shale measuring 0.305 meters thick. Beneath the GSH is the Dark Grey Dolomite Member (DGD). It measures 0.305 meters thick, and has very few attributes that set it aside from other members in the cave. It fresh surface is dark grey in color, and slightly effervesces with hydrochloric acid. Stratigraphically below the DGD unit lies the Bob's Limestone Member (BLS). Its thin cross-bedded layers of light-tan and dark-brown limestone easily identify this unit. These layers vary from 0.05 mm. to 1.0 mm. At this point in the cave, the BLS unit can only be measured to be 0.66 meters thick because it continues to make up the floor of the cave passage.

Stratigraphic Site 3

This site is located in Root Canal, 3 meters to the right of the NSS survey station NSA38. On the opposite wall of NSA38 there is a white growth on the wall, most likely formed from calcite or gypsum crystal growth. This is where we gathered our data for Stratigraphic Site 3.

At Stratigraphic Site 3, the ceiling is approximately 8.2 meters above the cave floor. It is fairly easy to see the bottom of the DC chert layer through the crack in the ceiling. The upper walls are made up of 4.87 meters of MALS (4.56 meters of upper limestone, 1 cm. of bentonite, and 0.305 meters of lower limestone), 1.52 meters of GSH (0.305 meters of upper green shale layer, 0.914 meters of red shale, and 0.305 meters of green shale), 0.305 meters of DGD, 1.32 meters of BLS, and 0.204 meters of Calcareous Siltstone (CSS). If a fresh surface can be found/made in this member, it will reveal a much different composition than any of the other rock members found so far. The CSS member is tan in color, and under a microscope we can see that it is a quartz-rich siltstone within a calcite matrix. This CSS member cannot be measured to its deepest depths because it composed the floor of the cave.

Stratigraphic Site 4

This site is located just around the bend from Stratigraphic Site 3. After rounding the corner there is a large pile of small breakdown in the right "elbow" of the cave before it changes direction back to the left. It is here at cave right, after the pile of small breakdown and immediately before the large blocks of breakdown that we took our last data in the cave (between survey stations NSA39 and NSA40). This is Stratigraphic Site 4.

Stratigraphic Site 4 is stratigraphically the lowest point of the cave that we were able to access in the summer of 2002. The cave ceiling is 9.6 meters above the cave floor. The stable bottom layer of the DC chert layer forms the roof. There are 4.83 meters of MALS exposed below the DC layer (4.50 meters of upper limestone, 1 cm. of bentonite, and 0.305 meters of lower limestone). Below the MALS, we are able to measure 1.56 meters of GSH (0.315 meters of upper green shale layer, 0.942 meters of red shale, and 0.305 meters of green shale). Below the GSH member is the DGD member that measured 0.305 meters thick. Beneath the DGD layer lies 1.32 meters of BLS. At the very base of everything is the CSS member. We do not think that the entire thickness of this member has been measured due to the clay covering the rock on the ground, and the fact that the cave trail climbs in stratigraphic height after this point in the cave. However, at this point, we were able to measure 1.35 meters of the exposed CSS member.

Appendix 2: Descriptions of Thin Section Samples

All thin sections but slide SH1-5 were viewed under plane polarized and cross-polarized light with a magnification of 10/0.25, which gives an actual view of 1.1 millimeters. The Fossiliferous Chert of slide SH1-5 was viewed with a magnification of 4/0.10, which gives an actual view of 3 millimeters.

Slide SH1-5: Fossiliferous Chert

The Fossiliferous Chert has a microcrystalline matrix with multiple vein sequences. Both calcite and quartz veins are present in different orientations and do not appear to be deformed. Brachiopods are also found within the matrix.

Slide SH1-7: Micrite

This limestone has a microcrystalline calcite matrix with an assortment of grain sizes all falling below 0.10 millimeters. Minor amounts of quartz lie within the calcite grains. The quartz grains are sub-angular. No deformation or fossils were found.

Slide SH1-4L: Shale

This shale has a microcrystalline matrix of clay minerals. Quartz grains are sub-angular and larger than the matrix grains. There is no apparent alignment of minerals. Hematite and muscovite mica contribute as accessory minerals to the shale. All grain sizes fell below 0.10 millimeters.

Slide SH1-2A: Shale

This shale has a microcrystalline matrix of clay minerals. Quartz grains are sub-angular, are larger than the matrix grains, and account for approximately 5% of the composition. This sample is also porous. Hematite grains serve as an accessory mineral. All grain sizes fell below 0.10 millimeters. No deformation or fossils were found.

Slide SH1-3B: Shale

This shale has a microcrystalline matrix of clay minerals. Both the quartz and hematite grains are sub-angular and accessory minerals to the matrix. All grain sizes fell below 0.10 millimeters. No deformation or fossils were found.

Slide SH1-4S: Shale

This shale has a microcrystalline matrix of clay minerals. Small amounts of quartz, calcite, and hematite grains contribute as accessory minerals. Grains are sub-angular and are smaller than 0.10 millimeters. No deformation or fossils were found.

Slide SH2-2A: Dolomitic Grainstone

This dolomite has a poorly sorted, microcrystalline matrix of different grain sizes. Hematite provides as an accessory mineral while calcite and biotite constitute approximately 2-4% of the sample. Quartz provides approximately 10% of the sample. Grains appear sub-angular and smaller than 0.10 millimeters. No deformation or fossils were seen.

Slide SH2-1A: Calcite Cemented Quartz Siltstone

This siltstone contains good porosity and angular grains with calcite acting as the cement. Quartz grains are clearly visible and compose most of the sample (approximately 40-50%) with hematite serving as an accessory mineral and biotite providing approximately 5%. No deformation, fossils, or quartz overgrowth were noted.

Appendix 4: Creating Channels in GoCad from Cave Survey Data

Enter all survey data into Microsoft Excel including: station names, the distance, azimuth, and inclination between the stations, and the distance from the station to the passage walls in the left, right, up, and down directions. With this information, open Compass. Within Compass, name the project the County of your research; the file the name of the cave; and designate each passage with a letter representing the full name. For example, our project was "Monroe" (Monroe County), file name was "Scott Hollow", and one passage would be "M" for Mastodon. Once the structure of the project is set, begin inputting the data from the excel spreadsheet for the respective passages. With all the passage data within the Scott Hollow file, "close all" the passages. The program will automatically change the survey values in order to correct for holes or errors within the values. In order to visually check the passages for accuracy plot the values. Compass provides a 2-Dimensional model representing the direction of the cave with its turns and the lengths. With the cave passages "closed" go to the "Cave Stats" option under the "View" file. Select "Station Coords" and "process" in meters. When given the opportunity to "close" the cave, do so. Save the newly displayed values (northing, easting, and vertical) for future use in GoCad.

A new, larger Excel Spreadsheet needs to be created. This spreadsheet will include the station names, distance, azimuth, and inclination from the original data as well as the northing, easting, and vertical values from Compass. The northing, easting, and vertical values allow you to transfer the points of the cave from Compass (based on a 0, 0, 0 coordinate system with 0, 0, 0 being the entrance of the cave) to the Universal Transverse Mercator (UTM) coordinate system. The left, right, up, and down values from Compass for the locations of the passage walls also need to be transferred to a 3-Dimensional system using equations. These numbers are also included in the spreadsheet. This information will now be separated based on the specific passages and segments within those passages.

For each segment of passage, an excel file needs to contain all its individual information in a specific format that will be read in GoCad. Each passage segment is defined as a channel and will follow the format specific to this object. At the top of the spreadsheet, there must be a proper header. Directly under the header, the information from the master spreadsheet is pasted. The next portion of the spreadsheet will list the stations for that segment of passage and define those stations as vertices (VRTX). Each vertex is listed in ascending order with the station's northing, easting, and vertical values. Below the vertices, the format calls for the connection of the vertices into segments (SEG). Because the segments will match up in ascension, the vertices must be listed in the proper order of how they occur within the cave passage. Below the segments, a line containing "NBRIB 4" is included to let the GoCad program know there are four directions the passage is extending from the station. Now the coordinates for the walls need to be entered. These values are taken from the master spreadsheet's Excel format and pasted into Microsoft Word. The format needs to be changed from that of horizontal cells to vertical. With the transformation, the values are placed into the new Excel file and numbered in ascension. To finalize the excel spreadsheet for this segment of passage, enter "END" below the last section value to signify the end of the equation. See end of Appendix 3 (Mastodon_1.gs)

Note that when a passage is divided up into more than one segment, the values for the station and walls through which the tributary is connecting must also be included in the spreadsheet. Otherwise, the tributary will have no station through which to join the main passage. All files need to be saved with the ".gs" extension and not ".xls". This extension is readable by GoCad.

To view the cave passages, first open GoCad. Select "Load Object" from the File column and select the desired channel in ".gs" format. Choose "Compute" from the toolbar and then "On Object". Within the new window, select the desired channel and "load" the formula entered earlier to place the Compass values in the correct location under the UTM coordinate system. Apply this command. Then, right click on the desired channel under the list of channels and choose, "set orthogonal". Finally, go to the 3-Dimensional model itself and right click on the backbone of the channel. This will place all cross sections of the passage in right angles with the spine. Once all channels have been imported into the model and have been set properly within the UTM coordinate system and the orthogonal set, change the attributes of the channels to the preferred settings.

Example ".gs" File for Modeling the Cave Passages in GoCad

```
GOCAD GShapeBundle 1
HEADER {name:Mastodon_1}
ILINE
VRTX 1 -5.494 0.345 -12.032
VRTX 2 -8.863 -6.879 -16.45
VRTX 3 -3.85 -15.562 -11.56
VRTX 4 -20.763 -5.797 -25.749
VRTX 5 -31.925 0.138 -26.19
VRTX 6 -32.346 1.083 -24.324
VRTX 7 -31.723 8.201 -24.824
VRTX 8 -22.698 3.603 -24.47
VRTX 9 -20.112 -1.063 -24.47
SEG 1 2
SEG 2 3
SEG 3 4
SEG 4 5
SEG 5 6
SEG 6 7
SEG 7 8
SEG 8 9
NBRIB 4
SEC 1
0 0 -2
-1 0 0
0 0 2
2 0 0
SEC 2
0 0 -1
-1 0 0
0 0 2
1 0 0
SEC 3
0 0 -1
-1 0 0
0 0 2
1 0 0
SEC 4
0 0 -1
-1 0 0
0 0 2
1 0 0
SEC 5
0 0 -1
-1 0 0
0 0 2
1 0 0
SEC 6
0 0 -1
-1 0 0
0 0 2
1 0 0
SEC 7
0 0 -1
-1 0 0
0 0 2
1 0 0
```

```
SEC 8
0 0 -1
-2 0 0
0 0 2
1 0 0
SEC 9
0 0 -1
-2 0 0
0 0 2
1 0 0
END
```

Appendix 5: Creating Point Sets from Contacts Surveyed from Cave Survey Data

Create a Microsoft Excel spreadsheet containing the x, y, and z values of the last point of the contact (in our case, of the green shale). These points are going to become a point set and follow a certain format to be read by Gocad just as was done with the channels. Below the point set's specific header, all the points will be listed as vertices (VRTX) and again will receive numbers in ascending order. Beside the vertex number, the easting, northing, and vertical values of each point, based on the 0, 0, 0 coordinate system will also be listed. This file must be saved as a ".vs" extension, not ".xls" in order for GoCad to acknowledge it.

In GoCad, load the object just as was done with the channels except under the different file extension. View in "plan view." From the scroll down list of all the objects permitted in GoCad, choose "Curve." This will cause the toolbar to adjust to the function keys associated with this object. Select the key with a square and create a box around all of the points. A window will pop up for you to name your new surface. Next, press the list with "General Mode" at the top and scroll down to "Curve". Again, GoCad will change the options at the top to accommodate this object. Under the "Edit" file, select densify, highlight your new surface as the "curve" in question and select a value for the "maximum length." Now, change the options at the top of the window by altering the "Curve Mode" to "Surface Mode". From the list entitled "New" select "closed curve." Again, name the new surface and select "homogenous triangles" as the "densification type." Before going any further, make copies of both the surface and curve in order to allow for experimenting at a later point. Right click on the object's name and select "copy". Choose whatever you would like to call the new objects, but also make sure that the boxes for copying "properties, regions, style, and points" are all selected.

At this time, more settings must be programmed. From the scroll lists within the "Surface Mode," select "Constraint" followed by "Control Nodes," and choose "Everywhere" from under "Unset." This will allow the surface to move and not remained fixed to the control nodes at the edges. Then, return back to the same "Constraint," list and select "Set," and "All Borders." For a third time, return to "Constraints," select "Control Points" and choose "Set Control Points." Set the "control points" to whatever the name is of the point sets file loaded from Excel. Save this new surface and make sure that the "copy constraints" box is also checked in addition to the ones mentioned earlier.

To obtain a realistic model of where the surface may lie, it will probably need to be moved somewhere in space. For our project, the surface needed to be lowered in order to fit to all the points and still make a realistic surface. You can alter the x, y, or z values by going to "Compute" list while in the "Surface Mode" and selecting "On Object." This allows you to manipulate the coordinate values. For example, we entered {Z = Z-50;} to make our desired adjustments. In the same "Surface Mode" select the "Interpolation" file and highlight "On Entire Surface" from under "Geometry." Set the interval for the number of iterations you would like to occur with each command to calculate. Our project used intervals of two so that we could have better control and observation of the manipulation.

Example ".vs" File for Modeling the Contact Layer in GoCad

```
GOCAD Vset 1.0
HEADER {name: contact_points_two}
VRTX 1 -289.142 85.90159 -101.41
VRTX 2 -147.422 43.43453 -41.8812
VRTX 3 -357.357 47.30377 -117.031
VRTX 4 -287.135 -50.0774 -85.7556
VRTX 5 -171.91 -269.88 -29.1897
VRTX 6 -156.805 -272.407 -40.4204
VRTX 7 -158.378 -273.786 -42.8639
VRTX 8 -158.247 -274.974 -42.936
VRTX 9 -157.481 -275.199 -42.8713
VRTX 10 -155.922 -275.769 -42.4363
VRTX 11 -154.169 -275.966 -41.0045
VRTX 12 -157.423 -273.152 -40.3472
VRTX 13 -155.757 -272.848 -42.6276
VRTX 14 -153.681 -273.593 -42.3457
VRTX 15 -111.364 -341.762 -33.0013
VRTX 16 -113.321 -341.783 -30.5013
VRTX 17 -111.98 -343.97 -33.9699
VRTX 18 -110.809 -344.609 -29.7147
VRTX 19 -110.329 -345.068 -23.9427
VRTX 20 -110.109 -346.387 -21.4075
VRTX 21 -105.534 -346.532 -34.6063
VRTX 22 -103.448 -343.387 -34.161
VRTX 23 -104.24 -340.479 -34.3258
VRTX 24 -108.267 -339.187 -35.2006
VRTX 25 -110.301 -341.353 -27.6593
VRTX 26 -116.015 -356.906 -36.239
VRTX 27 -113.387 -358.245 -24.0161
VRTX 28 -115.33 -357.249 -25.5556
VRTX 29 -114.529 -357.577 -22.7073
END
```