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Geological Survey of Cueva Guhamra

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SIT Study Abroad

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Executive Summary (English Version)

As it has been said by many of the great scientists before us, “Geology Rocks.” While this may not be entirely scientific, the debatably of this statement as a whole truth is next to zero. But we mustn’t forget the latest contester in the battle of rocks- that is- Speleology. As the boundaries of science are continually being stretched to greater distances, we see the development of new branches of science to accommodate these boundary-breakthroughs. Speleology refers to the study of caves and is considered to be relatively new and unexplored. Generally, a cave survey (essentially a quantified and tangible map) is one of the preliminary steps to initiate further research. This study aims to do just that, in relation to the Caves of Lake Bayano, Panama, and more specifically, Cueva Guhamra in Del Teritorio de Maje Embera Dvua.

The cave survey was created by setting up line-of-sight stations, as well as measuring the distance in meters between, recording the angle of cardinal direction and floor inclination, measuring the width and height of each tunnel, and taking additional notes on cave formations of geological interest. After adapting the numbers with a few geometric equations, both a top view directional representation of the cave as well as a graph of vertical variance in inclination were generated. It was concluded that the cave is at least 67.39 meters long, and possibly up to twice long when considering inaccessible tunnels and unmeasured tunnels, the cave could potentially be 100+ meters in length. The vertical inclination had a variance of approximately ±12 meters.

In addition to the map of the cave, main geological cave formations, or speleothems were studies and analyzed. The cave was abundant in many classical speleothems, such as stalactites, stalagmites, columns, cave pearls, cave crystals, cave coral, flowstone, and drapery.

These formations are telling of the surrounding geological happenings and conditions because the formations of these substances require highly specific conditions. In order for speleothems to form the surrounding rock (thus the cave itself) must be composed of 80% calcium carbonate and the surrounding bedrock must be highly fractured to allow rain and groundwater to permeate through to the cave (3). Likewise the cave must be in an area of substantial rainfall (>500 mm) as well as relatively close to the surface to allow for rainwater seepage (3). Lastly, it is important for the above ground vegetation to supply the availability for acids for speleothem growth. All of these factors can help explain the chemical, physiological, and historical processes of the area.

However, though the basics of speleothem are known, there is dispute in the scientific community of the how and why details. Because cave formations are delicate and non-abundant, as well as chemically diverse, the continual discovery and exploration of the caves is a necessity to better understand these processes. The only way to study and understand speleothems is to explore and create useable works from discovery, like cave surveys, to pave the way for greater scientific interest, and ultimately, knowledge.

Resumen Ejecutivo (Español)

Estudié las cuevas de la región de Panamá. Mi objetive era crear un mapa de la Cueva Guhamra. Las medidas que debía tomar era la longitud, el ángulo de inclinación, túnel de anchura y altura y notas adicionales. No hay una gran cantidad de información sobre las cuevas porque nadie los ha estudiado y no son populares. Después de tomar las mediciones, llegue a la conclusión de que la cueva es de 59.77 metros de largo. También, la cueva tiene un cambio vertical de ±12 metros.

Hice un mapa, pero también estudie las principales características geológicas de la cueva. La cueva tenía muchas características geológicas importantes. Estas características geológicas son referidas como espelotemos. Algunos de los espelotemos en la cueva son las estalactitas, estalagmitas, 'drapery', cristales, y 'coral cueva.' Estos espeleotemas son importantes porque tienen información sobre la geología y la química de la zona de Bayano. Los espeleotemas necesitan condiciones específicas para formarse. Algunas de estas condiciones incluyen minerales, las lluvias, y las grietas de la roca.

A pesar de espeleotemas puede ser cómos en las cuevas, no todos los científicos saben cómo crecer espeleotemas. Por eso es importante que las cuevas que es estudiara. Hay muchas cuevas en Panamá que no han sido investigados. Un buen para comenzar con el estudio es hacer un mapa. Este proyecto está dirigido a lograr eso.

Introduction

As collective scientific knowledge is continually compounding at a rapid pace, researchers often begin to recognize different branches of science due specialization and discovery. One new branch of science which applies to this concept is the branch Speleology. Speleology, defined, is the study of caves. According to the National Speleological Society, traditionally the studying of caves has been largely grouped into the three branches of geology, archeology, and geography (4). However, caves have become a recognized and esteemed study in the scientific community and in the last two centuries, Speleology has come a long way (4). Taking that into consideration, a large amount of caves has yet to be properly explored and documented, let alone discovered. The Alto Bayano region in the Eastern half of Panama, on Lake Bayano in Panama, is composed of a primary example of this.

It is little known to the majority of the inhabitants of the country and moreover the scientific community that there are a large number of untouched, unstudied caves in the Bayano area. Upon initial exploration, it is evident that the caves are full of diverse geological forms (known as speleothems), but because there is no documentation or baseline knowledge of the caves, there is no incentive for in depth research. This preliminary research was conducted to lay the foundation of that baseline knowledge in hopes to not only spark a scientific interest in the Bayano tunnel systems, but also to map and analyze more specifically, Cueva Guhamra.

Research Question

What is the topography and main geological features of Cueva Guhamra in the Lake Bayano region of Panamá?

Objectives

1. Analyze the caves main topographical, bathymetrical, and geological features and the processes by which they were formed.
2. Measure and quantify tunnel length, direction, inclination, and shape into a useable cave survey.

Justification

Caves are very important biological, geological, geographical, and ecological formations. Speleology is a relatively young science and a large portion of caves across the world have yet to be explored and discovered. There is virtually no research on the caves of Bayano, which gives added purpose to the study. In addition to mapping a cave, studying the basic geological features and processes is the first step towards learning more. By quantifying the size of the cave and cataloguing the main features of the cave, the chances of further research increases. Caves won't be studied if only a handful of people know of their existence. Having access to the location map as well as a broad idea of what is in it gives researchers an open door to study further. It facilitates the hunger for learning more. Opening doors for exploration also opens the door for more discoveries. If scientists are surprised to know that the cave is much bigger than previously assumed, then they could also make the assumption that there is more study in the cave. Cueva Guhamra proved to be no exception to this idea, as it had many speleothems highly regarded in the scientific community as still not fully understood, yet continually of interest and under study.

Historical Background

There is relatively little known about the caves of Lake Bayano. Though the caves are given a general location on the country map, there are no specific locations. There are no publicly available surveys of any documented locations of the interior of the caves of the Bayano region, nor a known number of caves and/or tunnel systems. The Maje of the West Rio Bayano have a word-of-mouth history of the caves as well as a general knowledge (though unspecific and un-quantified) of locations. There are many disputes amoungst the community over the details and number of these caves, and little to no scientific information on the cave. Beyond the locals, the large majority of the existence of the caves is unknown. According to the Maje word of mouth history, the caves were first acknowledged in approximately 1960 while former leader Edwardo Mecha set out to map El Territotio de Maje Embera Dvua Alto Bayano. Mecha did not actively place the location of these caves on his map, he took note of the general location on the map he made of the Maje area. Though the Maje people knew of the existence of the cave, their superstitions of spirits and danger prevented any type of exploration. It is reported that it has only been within the last 50 or less years that any of the members have been into the depths of the caves. The current leader of the Union Embera in Maje reports that this survey is the first scientific research ever conducted on the caves of Bayano in the Maje area.

Methods

The Bayano area is a host to many different caves. The first step of the study was to choose which cave should be studied. In order to do this, the five main caves that are easily accessible in the area were explored- Guhamra, Sokerre, Cueva Misteriosa, and 2 unnamed caves. This was done by taking a boat off of the main river of southern Lake Bayano into smaller rivers with a guide that is familiar with the area and knows the relative location of all accessible caves. These caves were accessed and explored on foot, as well as minor climbing and crawling when the tunnel was elevated or very small, respectively. After all caves were looked at while making noted observations, the cave that was essentially the largest with the most visibly diverse geology and topography was selected (Cueva Guhamra). Over a course of the next two weeks of November 14, 2012 to November 28, 2012, the site was visited first by boat and then a 15 minute walk, where the cave of the mouth is likewise accessible by foot. The survey was the conducted in the manner below.

The traditional cave mapping technique contains seven major aspects. A comprehensive representation of all seven of these categories in a data table can be found in Appendix 2.1. The first step is to mark 'stations', or specified measuring points in which line-of-sight measurements can be made. Line-of-sight measurements mean that the distance between each station will be as far as away as one can directly see. So, if the cave tunnel being flagged for stations takes a sudden turn to the left or right, a new station will be marked right before the turn that is clearly visible from the station directly before it. The overall technique for flagging is very simple. In this study, yellow tape marked with permanent marker stating 'Station One', 'Station Two', ect., were attached to various parts of the cave wall (see appendix 1.1). This cave was very porous, as well as the fact that it contained numerous stalactites and stalagmites, all of which create sufficient and numerous places in which the tags in be attached.

After all the stations are marked with numbered flagging tape, the distance between them was then measured, one station a time. The technique used for measuring the distance of the cave floor required two people: one person to hold the zero end of the measuring tape on the ground at the base of the flag for the specified station, and one to read the distance on the tape at the next station. The second person walks with the tape measure towards the next respective station and records the distance with the end of the measuring tape on the floor at the base of that station. If the distance in between the two stations is on a steep grade, the tape is not pulled taught to have tension in it (causing it to lift off the ground), it is instead set on the ground, only pulled tight to be sure there is no slack or hang-ups on the tape. Person number two then records the measurement on the data table, and the process is repeated between every single station.

The third measurement is the angle of direction that the cave follows. The most effective tool for this measurement is a compass. The cardinal angle (and thus direction) of the cave can be determined by standing at station one and pointing the compass directly towards station two down the line-of-sight measurement. While standing at station one and facing station two, using basic compass technique of holding the compass flat in the palm of the hand and lining the red needle into the red shed and adjusting the bezel, one can derive the angle of direction. This angle was recorded into the data table and was done in this matter between every single station. One extra precaution that proved to be necessary was that the person using the compass should not also be holding or close to other gear. Other tools used in the study had metal with a magnetic quality that would influence the needle of the compass if it were too close.

The fourth measurement is the incline of the cave floor in between all stations. Because the cave floor is not perfectly flat, the incline must be measured in order to calculate the true distance between station to station (See appendix Sect 3.1), as well as to create a graph of the vertical topography of the cave (See appendix Sect 3.3). The incline measurement is taken in a similar manner as the angle measurement. The measurer would stand at station one, holding an inclinometer and measure directly towards the station at station two. An inclinometer is a device in which the user holds the device in his or her hand and angles the inclinometer either up or down (up for positive incline, down for negative incline) and aligns a notch at the top of the device with a point the at the next station that is at the same vertical distance as his or her eye-level. This means that because my eye level (the measurer) is approximately 1.6 meters, that I would then be aligning the notch at the top of the inclinometer at a fixed point that is also 1.6 above the cave floor at the station being measured. There is a gauged meter on the side of the inclinometer that then shows the angle of incline/decline. One technique that I found helpful to ensure accurate measurements with the inclinometer is to use sticks to maintain a constant vertical measuring point. Before entering the cave, I found a long stick, and had it cut to exactly my eye level. While I stood at station one, a second person held this stick at the base of station two. I then lined the notch on the inclinometer to the top of the stick at station two, which helped to ensure that I was taking measurements from equal heights above the ground.

The fifth and sixth measurements were to approximate tunnel width and height. These measurements were taken in a similar manner as the tunnel length measurements were recorded. There were some variations in how these measurements were taken, depending on the circumstance. Some areas of the cave are a small crawl space, so only to one person was used to measure the width of the tunnel. Another instance, in which the height of the tunnel exceeded 8 meters, estimation was used. The measurements of height and width are not essential to the cave survey; they are solely for the purpose of additional detail of the final survey. In the interest of time, estimation was used when it wasn't pertinent to the exactness of the skeleton of the survey.

The last section of the data table was used for other various notes. If a large stalactite was observed, or at small 3 meter tunnel was observed, extra measurements could be taken and recorded there. The larger stalactites were measured as they can be used date the age of the cave. Also, when including topographic and esthetic features to the skeleton of the preliminary map, documented notes are necessary. It is not uncommon to see in traditional and modern cave surveys that certain areas or tunnels in the cave that are known for extreme beauty of crystalline features, or great volume, for example, are given a specific name. Additional notes were made for accomplishing all of those objectives. Along with notes, a digital camera was used for documenting speleothems that I was unable to identify in the field. These pictures were then compared with pictures from other published geological surveys, scholarly articles, or sent by e-mail to Geologist Liz Wagar for her expertise in geological classification.

After leaving the field, all of seven aspects of the data had to be synthesized together to hand draw the survey. All calculations and adaptions of numbers to do so are shown in the second section of the appendix. After the numbers were adjusted, the first step was to choose a scale. I did this by taking the total length of the cave and dividing it by the length of one piece of paper. This scale is approximately 0.4 centimeters for every meter measured. All cave measurements between stations must be multiplied by 0.4 before they are drawn with a straight edge. The angle measured in the cave with a compass is then drawn in between the stations using a protractor. The initial drawing process is mostly trial and error, because the drawer cannot tell where the cave is going to go on the paper, so it often takes a few attempts and adjustments to format the cave to the paper. After the skeleton of the map is drawn, the details can be added, like the wall width, tunnel names, and areas of geological interest.

Results

Section One: Mathematical Results

Cave Guhamra was determined to have a walking length of 67.28 meters (Leg C of hypotenuse in Appendix 3.1), and true length of 59.77 (Leg A of hypotenuse in Appendix 3.1). The vertical incline varied by about ±12 meters (See Appendix 3.7). To note, not all areas of the cave were mapped and quantified. Station 13 (refer to Appendix 4.2) continued on into a split level tunnel, which further connected to one room with a 2 dead end tunnels. One tunnel was approximately 6 or 7 meters, and the other larger tunnel was up to 30 meters. These numbers were determined by noting number of steps taken in larger areas as well as visual notes when in crawl spaces. These tunnels were not measured because they were difficult to navigate a team of more than one person into as many of the tunnels were crawl spaces, but also due to lack of time. Also, near station 12 (Appendix 4.2), there was an additional tunnel that was too small to be accessed. The length of this tunnel was estimated to be about 7.5 meters long, but that was all that was able to be seen. It is uncertain how much further the tunnel expands. The known length of 59.77 meters combined with the estimated length of 45 meters, gives a total of 104.27+ meters.

Section Two: Topographical/Bathymetrical Results

Cave Guhamra had a complex topographical and bathymetrical aspect, some of which cannot be exactly translated onto a 2-D cave survey. The first major complexity occurs at Station 11 (appendix 4.2). In this area the crawlspace opens up into a larger cavern on the undocumented side. The cave has many levels, at some points it is three levels. This happened at this station. The tunnel ended with a 7 meter drop to a separate area, but also about 2 meters up was station 9. It wasn't fully connected but on a 2-D map I would compare to be a giant loop. While it is a loop, it is not connected in a way that is continuous. Station 5 was contained flowstone covered in crystallized minerals that looked similar to a long-flat waterfall system (Appendix 1.2 and 4.2). Station 6 to 8 was the largest room in the cave, measuring at approximately 5 meters wide and 4 meters tall. It contained an abundance of columns and stalagmites and stalactites. Also at Station 12, as noted earlier, there was a smaller tunnel that was not able to be accessed due to the tunnel entrance size. In order to map this, the area would have to be widened using either explosives or a rock chipping device. This was not conducted due to lack of time but also to uphold the integrity and natural formation of the cave. The cave had large variances in tunnel height and width, as seen from the crawl-space at Stations 3, and 10-12 but also the skinny crack which branches off the main path of the cave at Station 6 with a 1 meter width and 10 meter ceiling height. The cave walls vary from dry and muddy, to crystallized flowstone, to wet stalactites. Areas of notable variance are marked and named accordingly on the official survey (Appendix 4.2). The area of the cave not documented in the official survey was similar the mapped areas. The only noted differences were little crystallization, but an increase in larger ceiling drapery.

Not only was a top view directional representation of the cave created from the data collection (Appendix 4.2), but also a graph of vertical variance in inclination was generated (see Appendix 3.7). This graph shows all the slopes of the cave. It is as if a cross section of the length of the cave was taken. The x-axis represents the distance into the cave, starting at the mouth on the left at zero, and ending at the dead end at station 12 at 53.61 meters. The y-axis is vertical height in meters. All parts of the blue line that is below the horizontal axis at 0, is lower than the entrance at the mouth, and all areas of the blue line that are above the horizontal axis at 0, is elevated above the mouth of the cave. In the beginning, the cave drops steeply upon entering the mouth of the cave (70 degrees). After the initial drop, however, the cave continues to have a positive incline all the way to the back. The total variation in vertical height is ±12 meters.

Section Three: Geological Observations

The cave was situated in an area that has a large amount of rainfall and is near a body of water. The cave is in a ridge that is formed of porous limestone. I visually identified the cave as being limestone, but to ensure accuracy of this assumption a sample of the rock was gathered and a few drops of vinegar were added. Limestone contains basic minerals and vinegar contains acetic acid, so when the two are introduced, an acid-base neutralization occurs which is visually evident on the rock (much like adding vinegar to baking soda). The floor of the cave was generally a mud and clay mixture, or rock. Guhamra exemplified many types of know geological cave features. The cave had stalactites, stalagmites, columns, flowstone, and crystallization (Appendix 1.2). The stalactites varied in growth- some were only a few centimeters, but some were up to 20 centimeters. The cave had specific areas of high and active stalactite growth (denoted by water drops at the tips of the stalactites) but also areas in which the stalactites and stalagmites appeared to be dead (broken, brown and dry). The cave had a small area of cave coral as well as a few areas of crystallization, commonly in cracks or on flowstone.

Discussion

Section One: Mathematics

Mathematics is the bones of the cave survey. Taking measurements is what sets apart reliable and accurate maps from amateur and unusable maps. However, the accuracy of these measurements relies on multiple variables- proper tools, knowledgeable and appropriate sized crew, time on the site and environmental variable. This study used the traditional mapping tools of a compass, tape measure, inclinometer, and hand-written map. These tools are becoming obscure because of more accurate options like GPS and laser measurements. This is not to say that the traditional method is inaccurate, but it is less precise. Another necessity is a large enough team that has knowledge of the tools and procedures. Because this study was independently designed, I did not have a scientific team to aid me in my measurements. While I did have a guide, my guide was not familiar with the equipment, and therefore many measurements were done alone when two people would have increased the accuracy. A third variable is the cave conditions. Some areas of the caves were so low that it was near impossible to get an accurate incline reading. Also, the cave is full of rocks as well as other equipment that has a magnetic pull, which can give skewed compass readings. Lastly, time in the cave, but also around the cave is important.

No matter how thorough notes are taken, there is always a possibility for confusion after the fact and disorientation during. If a measurement does not make sense, but the report is being finished in an area that the researcher can go back, and then accuracy is increased. These are all hurdles that researchers encounter in the field and a lot of the equipment and methods have been modified to account for. Ultimately, the Geological Survey of Guhamra is intended to serve as an accurate and useable map for scientists and cavers alike. This was executed by taking as precise of measures as possible using the appropriate and necessary tools.

Section Two: Topography/Bathymetry

The interior of the cave is one of the key elements for understanding what previously happened to form this cave. The contour of the walls as well as the shapes and sizes of the tunnel are all affected by water movement, both actively and many years before. These contours and shapes are key to understanding details of the caves history. Cave Guhamra had low and flat crawl spaces, tall narrow passes, and a circular-type passage as well. According to the Speleological Society of Ireland, each one of these formations is from separate geological and hydrological events (8). The low, flat areas of the cave, like a crawlspace, see at station 3 for example (Appendix 4.2) is situated on a bedding crack in the layers between sheets of limestone (8). Tall and narrow passages, like the crack near station 6, are usually formed on vertical cracks also known as ‘joints’ in the limestone, but could also have been formed by a single stream (8). In the case of this cave, it is believed that the crack was formed most likely due to being on a fault because of the tunnel length and location in the cave. Lastly, the circular passage, at stations 6-8 could be formed due to having been completely filled at one point in time with water, as all sides were evenly dissolved (8).

All of these shapes and contours tell a story. It is almost impossible to be certain that each of these hydrological events took place, but the shapes of the tunnels are small clues left behind for scientists to study and make deductive statements. From my research, it cannot be definitely determined when or how, or certainly if, these events transpired thousands of years ago, but it does point out evidence and consistencies which have been researched previously.

Section Three: Geology

First and foremost, it is important to understand how caves are formed. The environments and circumstance in how the cave came to be dictates all other things that follow- growth, variation in speleothems, life forms, and more. The presence of a cave in and of itself is telling of the history and geological attributes of an area. Specific conditions, minerals, rocks, and historical events are all necessary in order for a cave to exist. The first condition necessary for cave formation is soluble bedrock, usually carbonate rock (most commonly limestone, in which this cave is composed of) (3). Usually when these bedrocks are introduced to rainwater, a karst formation is created (5). The chemical process in which rain water reacts chemically with the air and soil upon permeating into the cave is responsible for the dissolution of the carbonate rock, leading to karst formation (see Appendix 3.6). Karst is a geological feature formed by dissolved bedrock. As this bedrock is then washed away with additional rain and water flow into the karst, a cave is formed. It must be noted that this is a very slow process. Every cave will take a different amount of time to form depending on size, water availability, carbon content of soil, and other variables.

Once a cave is formed, the interior begins to evolve and grow. Cave Guhamra had numerous speleothems, including but not limited to stalactites, stalagmites, columns, flowstone, crystallization and cave coral. In order for speleothems to form, the surrounding rock (thus the cave itself) must be composed of 80% calcium carbonate and the surrounding bedrock must be highly fractured to allow rain and groundwater to permeate through to the cave (3). Likewise the cave must be in an area of substantial rainfall (>500 mm) as well as relatively close to the surface to allow for rainwater seepage (3). Lastly, it is important for the above ground vegetation to supply the availability for acids for speleothem growth.

One of the more common speleothems found in the cave was stalactites and stalagmites. The existence of stalactites and stalagmites tells scientists a few things about caves. According to Science daily, "Stalactites grow when water laden with carbon dioxide and calcium carbonate drips from cracks or holes in the cave's ceiling. As a water droplet hangs from the crack, the carbon dioxide escapes, much as a bottle of sparkling water fizzes when opened. As a result, the calcium carbonate comes out of solution and is left behind as a tiny bit of solid calcium carbonate. As each successive drip flows over the minute mineral deposit, the sequence repeats, ultimately forming a stalactite" (1). All of that information is telling of the general chemistry and mineralogy of the area. This is important because when looking for ground to build on, searching for materials to build with, needing fertile land to grow food on, and other things of similar nature, it is necessary to understand what the land contains beyond what is visible to the naked eye. Beyond the existence of stalactites, the details of the stalactites themselves are important as well. Stalactites are one tool used to date a cave. The average stalactite has a growth rate of 0.13 mm a year (6). In the cave I observed that some of the stalactites were about 200 mm. When dividing 200 mm by the growth rate of 0.13 mm per year, the age is about 1563 years old. Of course, it is difficult to be completely certain of the accuracy of this figure; it does give at least of an idea of how long this cave has been forming.

Conclusion

Let’s digress to that initial thought- Geology Rocks. Perhaps it would be more appropriate to say Speleology Rocks, but that just doesn’t quite have the ring to it. Geology rocks because it integrates multiple aspects of study and synthesizes them together to build deductive relationships and useable tools for further study. This survey used the seven classic methods of measurement, which integrates cartography and geometry. The survey also observes the speleothems of the caves adds biology, chemistry, geology and hydrology to the equation. Cave Guhamra exemplified a cave worthy of further research due to its diverse geological features.

The stalactites and stalagmites of the cave are important because their formation relies on the minerals of the area, likewise they can be used to date the cave to a degree. Cave Guhamra has many other aspects of interest to the scientific community such as extensive and diverse tunnel systems, cave coral, drapery, crystallization and more throughout all 59.77 meters . Though the community in whole is understudied, this survey which makes public knowledge of the scientific significance is designed to spark further exploration and discovery.

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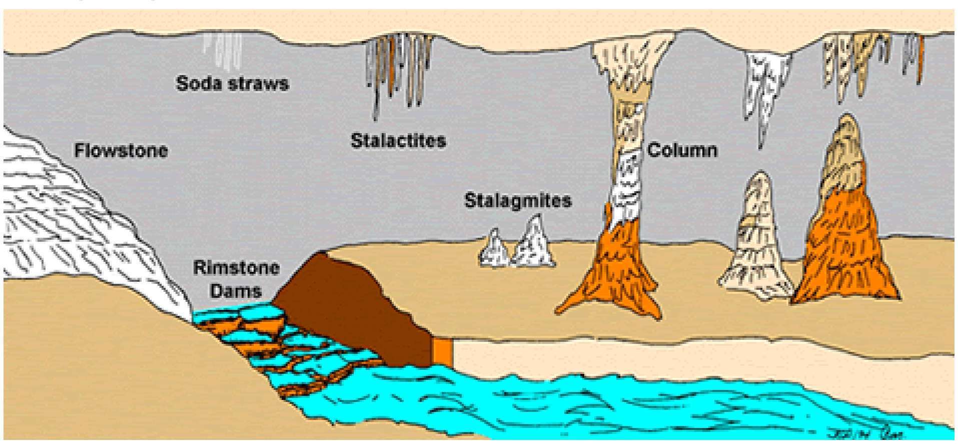
Appendix

Section One- Photos

1.1 Flagging techniques

1.2 Main geological features



(7)

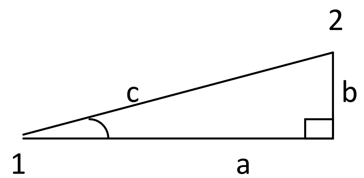
Section Two- Gathering Data

2.1 Sample Data Table Used in Field

Station Number	Distance Bt Stations	Angle of Direction	Degree of Incline	Tunnel Width	Tunnel Height	Notes
1-2						
2-3						
3-4						

Section Three- Calculations

3.1 True Distance Calculations



The right triangle above is a representation of a cave measurement up a positive incline. Number one represents station one, likewise 2 represents station two. A is the true distance, B is the vertical incline, and C is the cave floor, as well as the measurement that would be recorded between station one and two. The arc is the angle of incline, denoted by the inclinometer. As we can see from the visual, the distance value for letter C would be greater than that of station A. This is due to the rise of the incline, or letter B. Essentially, C is the distance that one has to walk, but it is not the actual distance of that section of the cave. In order to correct for this, a cosine function must be calculated to derive the true distance. That is:

$\mathrm{Cos}\theta = \frac{\mathrm{Adjacent}}{\mathrm{Hypotenuse}}$ where Adjacent = Side a and Hypotenuse = Side c and θ = measure of incline

We know both theta, as well as hypotenuse length so the derived equation would be:

$\mathrm{Adjacent} = \mathrm{Cos}\ \theta(\mathrm{Hypotenuse})$, or a = Cos(incline) x c

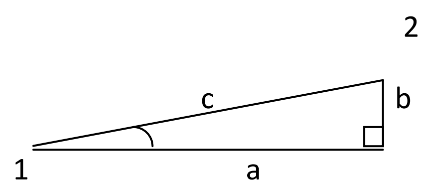
3.2 Actual Measurements and Calculations of 3.1

Station Number	Measured Distance (in meters)	Angle of Incline (in degrees)	True Length (in meters)
1	6.22	-70	2.13
2	6.73	-5	6.70
3	5.18	+5	5.16
4	5.18	+5	5.16
5	5.20	+10	5.12
6	7.25	+10	7.14

7	2.59	+25	2.35
8	8.29	+5	8.26
9	5.20	+40	3.98
10	3.11	+53	1.87
11	2.08	+40	1.59
12	4.15	0	4.15
13	6.10	+7	6.05

Total Walking Distance	Total 'True' Distance
67.28 meters	59.77 meters

3.3 Vertical Distance Calculations



In order to create a map of the vertical topography of the cave floor, it is necessary to know the quantified vertical height in meters. In the field, it was not possible to make such a measurement, but using the numbers that were gathered for the cave floor as well as the angle of incline, this number can be derived using a geometric equation using the same model triangle found above. All lettered and numerical values are identical to the values used for the triangle representation in Appendix Section 3.1.

The difference in this case is that the value we are solving for is b, the vertical height. This number can be derived from the equation:

$\text{Sin}\ \theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$, where Opposite= b, Hypotenuse= c, and θ= Inclination

We know both theta, as well as hypotenuse length so the derived equation would be:

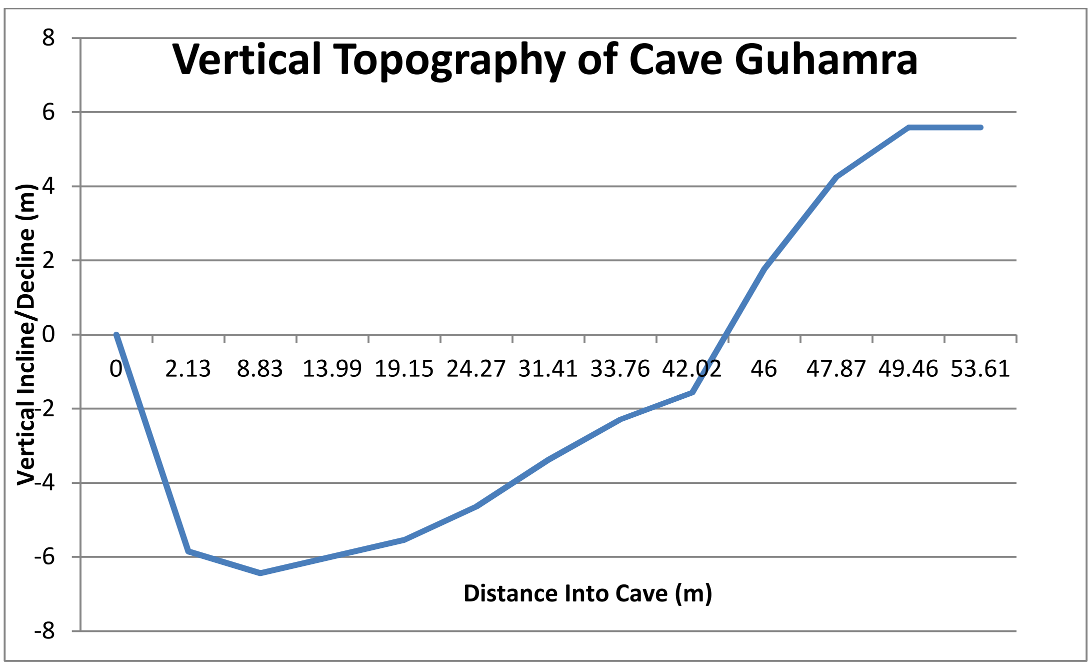
Opposite = Sin θ(Hypotenuse), or b = Sin(incline) x c

3.4 Actual Measurements and Calculations of Section 3.3

Station Number	Measured Length (leg C of Triangle)	Angle of Inclination	Vertical Height (in meters)
1	6.22	-70	-5.85
2	6.73	-5	-0.59
3	5.18	+5	+0.45
4	5.18	+5	+0.45
5	5.20	+10	+0.90
6	7.25	+10	+1.26
7	2.59	+25	+1.09
8	8.29	+5	+0.72
9	5.20	+40	+3.34
10	3.11	+53	+2.48
11	2.08	+40	+1.34
12	4.15	0	0
13	6.10	+7	+0.74

Total Vertical Incline= 12 meters

3.7 Graphic Representation of Vertical Variance



3.6 Chemical Equations for Karst Formation

a. $H_2O + CO_2 \rightarrow H_2CO_3$

In equation ‘a’ we see water (rain/runoff) mixing with atmospheric carbon dioxide as well as carbon in the soil to yield carbonic acid.

b. $CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2$

In equation ‘b’ calcium carbonate (limestone) reacts with the carbonic acid formed by the mixing of rain and atmospheric carbon dioxide to yield calcium bicarbonate. The limestone is essentially dissolved by carbonic acid into calcium bicarbonate which is soluble and ultimately washed away when more ground water enters the cave. This is the basic chemical process in which caves are created.

Section Four- Cave Map

4.1 Relative location

see folded map in pocket

4.2 Official Cave Survey (final page, 22)

Geological Survey of Cave Guhamra del Territorio de Maje Embera Duva Alto Bayano

Key

Station

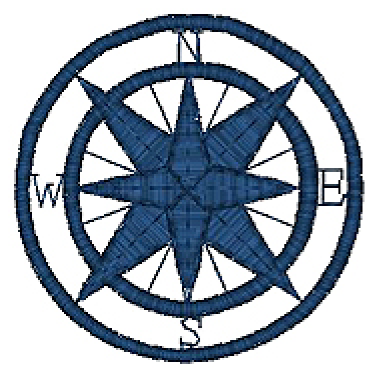
Line of sight measurement

Tunnel of unknown length

High accumulation of Stalactites

High acc. of crystallization

Cave Coral



Scale

0.4 cm = 1 m