BLUE HOLES: AN INAPPROPRIATE MONIKER FOR SCIENTIFIC DISCUSSION OF WATER-FILLED CAVES IN THE BAHAMAS

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ABSTRACT

By 1725, mariners from England had described submarine cave entrances in the Bahamas as "blue holes," and in 1843, the term "blue hole" first appears on sea charts from the Bahamas. As the term suggests, what sailors saw from the surface was a dark blue colour that is in sharp contrast to the white/aqua blue waters of the shallow banks. The term, "blue hole", signified safe anchorage for visiting ships, and was not intended to be a scientific description of what lies beneath the water surface. The first visual description of these flooded caves was given in 1950 using SCUBA. During the late 20th century numerous attempts were made to impose scientific meaning to the term "blue hole", without taking into account the varied morphologies and biogeochemistry of these features. This has resulted in an inappropriate definition for these caves. It is suggested here that caves in the Bahamas should be classified by the nature of their development as follows (1) horizontal caves, (2) fracture-guided caves, and (3) vertical caves. Horizontal caves include the currently subaerial flank margin caves and banana holes formed during past sea-level high stands, and horizontally extensive caves currently below sea level. Pit caves, and black holes fall within the vertical cave category. Black holes are flooded vertical caves with no known lateral passages that support a massive bacterial population giving them their black colour. Black holes form only in the interior stable regions of the larger Bahamian islands, which allows for the development of distinct geochemical environments enhanced by microbial activity. Fracture-guided caves develop along fractures that are sub-parallel to the bank-margins. Because of the non homogenous nature of the calcarenites exposed along the fracture, the walls of the fractures seem to have collapsed more extensively in localized areas to create separate small to large openings. These cave openings, although isolated from each other on the surface, are hydrologically connected.

Whilst the term blue hole has been in the literature for nearly three centuries, it is not being suggested that it be eliminated from the general literature, just from scientific discussion of these karst features that have been explored, and for which the mode of origin can be identified.

INTRODUCTION

Historically, caves in the Bahamas, both above and below sea level, were already described in literature dating as far back as 1725 by an English naturalist, Mark Catesby (Shaw, 1993). The underwater marine caves, "blue holes", were first recorded on sea charts at about 1843. Early on, water-filled cave openings on land were simply referred to as "caves" however, during the late 20th century the term, "blue holes" began to be applied broadly to many water-filled holes in the Bahamas.

For many years, ideas about the origin of blue holes have been mixed with local superstition and myth. Blue holes are sometimes referred to by native Bahamians as "blowing" or "boiling" holes, a phenomenon supposedly created by a mythical creature called "Lusca"; a belief still shared by many Bahamians today. The "blowing" and "sucking" phenomena are largely caused by differences in water surface elevation across Bahamian platforms generated by tides, local wave action, and ocean currents (Whitaker and Smart, 1997).

It is interesting that dry caves on land in the Bahamas have been described in recent literature in great detail and given descriptive names such as “flank margin caves”, “pit caves”, and “banana holes”. Yet, today, the non-cave-diving scientists studying Bahamian carbonate platforms still refer to all the openings of caves that are flooded or below sea level as “blue holes.” Few researchers have attempted to define the caves by width, depth, or passage morphology, because few have ventured into these subsurface terrains.

This practice of calling all water-filled cave entrances, and caves currently below sea level, “blue holes” is the equivalent of calling all the currently dry caves on land “air holes”. The reaction to calling dry caves “airholes” would fetch a smile for its absurdity. It would also be a fair assumption that sailors from three hundred years ago would have had the same response to the suggestion that the water-filled cave openings on land should be labelled “blue holes”. Although labelling land-based openings of flooded caves as “blue holes” is inappropriate, the idea that such caves have something in common with the offshore caves is not wrong.

More than 120 years ago, Agassiz (1884) described how marine blue holes might have formed. He assumed that the conditions for cave development in the aeolian strata were the same processes that formed potholes, boiling holes, banana holes, caverns, caves, sinks and other such openings on the shores of islands. He speculated that these features were formed by the action of rain percolating through the aeolian rocks and becoming charged with carbonic acid. He believed that ocean holes formed under very much the same conditions when the submerged bank was above the high water mark.

Today, after about twenty plus years of exploration and scientific study of these water-filled cave environments, results and observations appear to support, for the most part, Agassiz’s hypothesis that cave development in the Bahamian environment, is similar for both dry and flooded caves. The purpose of this paper is to bring together the science and observations generated from below the water level together with those made in dry caves, and properly describe these subsurface environments not just as “blue holes,” but with the same detail as has been applied to the caves currently above sea-level.

CLASSIFICATION OF CAVES

Many of the flooded cave openings found on the Bahamian platforms are entrances to some of the world’s most spectacular underwater cave systems. Their openings can be found on dry land, and among the shallow creeks, inland lakes, and the shallow banks of the Bahamas. The caves, which have developed within the Bahamian carbonate platforms, can be laterally and vertically very extensive. Lateral cave passages can extend to several kilometres, and may range in depth from ten metres to thousands of metres, particularly the fracture caves. Mylroie and Carew (1995, p. 60) stated that, “caves on carbonate platforms fall into three main categories: vadose, phreatic, and fracture caves.” Here we suggest that Bahamian caves can be broadly classified into three general types: (1) horizontal caves, (2) fracture-guided caves, and (3) vertical caves. Horizontal caves mostly begin as voids developed in the phreatic zone, especially in association with the fresh-water/salt-water mixing zone, and the water table surface. Vertical caves, generally referred to as pit caves (Mylroie and Carew, 1995), are developed primarily in the vadose zone, because of dissolutional processes associated with meteoric water descending to the water table. Over time, features formed by these processes may come to intersect one another to produce composite, or hybrid, cave morphologies. Categorization of such composite caves into one of the three proposed end-member cases may be difficult, but many caves are identifiable as predominantly one type or the other.

Horizontal Caves

Horizontal caves, such as the subaerially exposed flank margin caves and banana holes (Mylroie and Carew, 1990), are minimally developed horizontal caves. The currently flooded, predominantly horizontal caves initially formed as flank margin caves in association with the

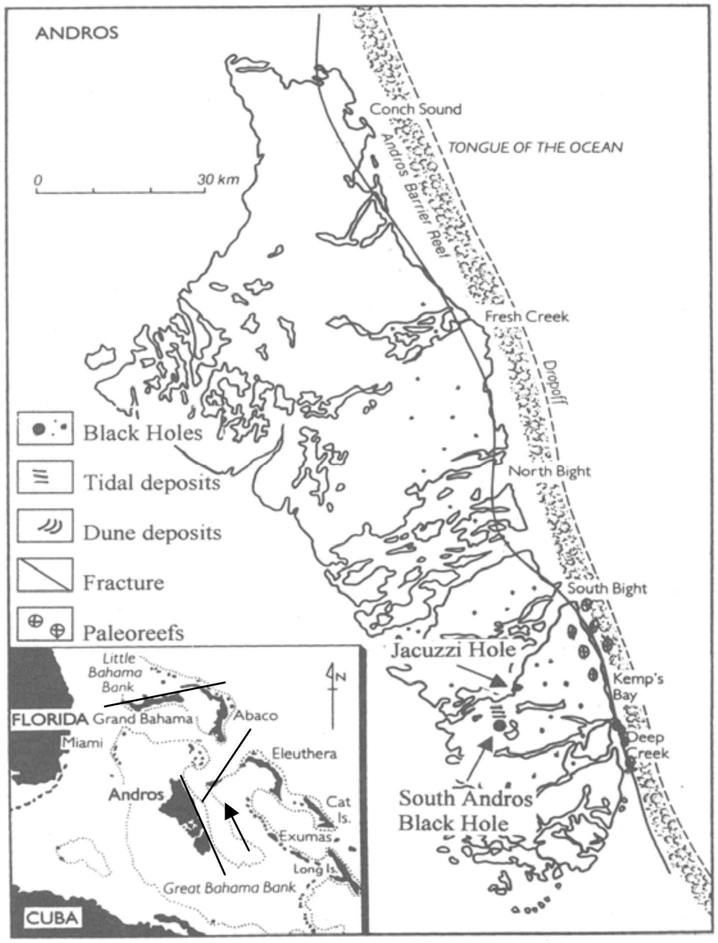

Figure 1. In the large diagram of Andros Island, on the east side of the island, it is possible to see that the cave openings(Paleoreef symbol) follow the fracture, as the fracture appears onshore and offshore. The smaller diagram in the lower left-hand corner is marked to generally show the direction of the fractures on Andros, Grand Bahama Island, and New Providence Island (arrow).

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boundaries between two water masses. However, they have been subsequently modified by additional dissolution during episodes of subaerial (vadose) exposure and renewed submergence in the phreatic environment.

The geological nature of the wall rock, (i.e., eolianites, coral deposits, and cement) also influences the form of passage development, the rate of passage development, and may also influence the sites at which the caves breach to the surface.

Fracture-Guided Caves

Fracture-guided caves have formed within fractures that are aligned sub-parallel to steep bank margins adjacent to very deep water, such as the Tongue of the Ocean (Fig.1), or Agassiz Canyon located immediately offshore of the north side of New Providence Island. Two other islands besides New Providence are known to have fracture-guided caves. Grand Bahama has a fracture that runs the length of the island from east to west just inland of the south shore. Andros Island has a north-south 150 km-long fracture along the eastern margin.

The circular cave openings (Paleoreef symbol) seen along the Andros fracture are the result of the non-homogenous nature of the rock exposed along the fracture. Because of the inhomogeneties the fracture has collapsed more extensively in localized areas to create separate small to large openings, which appear to be individual caves. At the surface these caves do not appear to connect, however, in some cases, where the passage is not blocked by boulders it is possible for a cave diver to enter in one opening and come out of another. Hydrologically, all the caves along the entire length of the fracture are connected.

Fracture cave openings can be located just offshore on the flooded platform, as well as high in the eolian ridges on dry land. The reason this occurs is that the fracture is not straight, and some segments occur offshore (Fig.2) and others are located on land (Fig.3). This makes these caves unusual in that these cave systems along the fracture link the terrestrial environment and the marine environment.

Flow rates of marine water through the land-based parts of the fracture are low, and the maximum tidal range can be measured via the elevation change of the water surface. In contrast, in marine sections of the fracture, water moves very rapidly and whirlpools (Fig.2) or domes of water are produced by tidal flood and ebb currents respectively.

Stalactites, indicating air-filled conditions, have been found as deep as –80 metres; however, in some fracture-guided caves it is a fair assumption that throughout their history the fracture caves have always had water in them. The reason for this is the extreme depth some of these fracture systems can reach. This is different from the horizontal caves and many of the vertical caves, in that once sea level drops below their passages, these caves are entirely in the vadose zone.

Because of the extreme depth of the fractures, the sections of the fractures that are on dry-land, always have at least a minor freshwater lens even at the lowest glacio-eustatic sea levels.

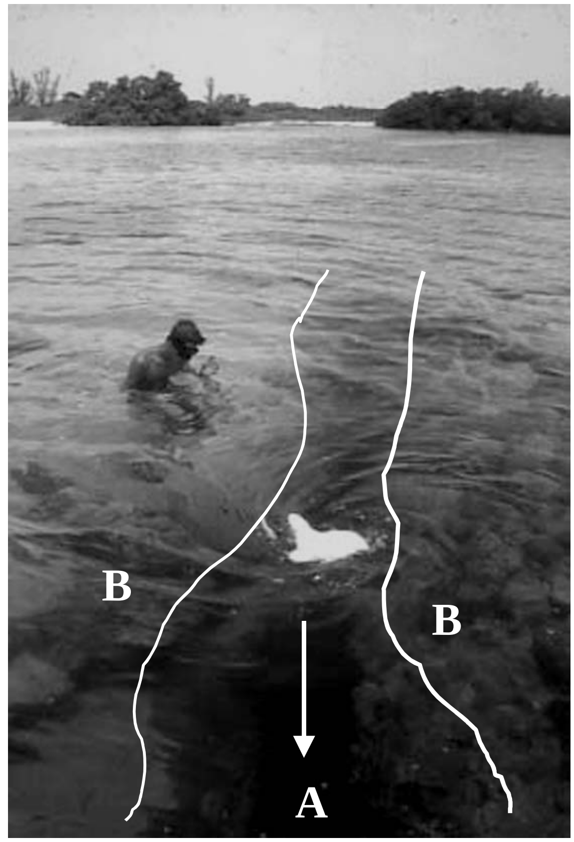

Figure 2. The lines marked as 'B' are outlining the Andros fracture walls beneath the water. The arrow marked 'A' is indicating the way into the cave. The whirlpool in the middle indicates that water is being drawn into the cave.

Vertical Caves

Vertical caves penetrate more or less vertically into the subsurface and have no known lateral passages. These Bahamian caves are different from traditional cenotes in that they do not form by stopping upward from a previously existing void that was formed at greater depth below the surface. Vertical caves in the Bahamas have been dubbed pit caves (Pace et al., 1993; Mylroie and Carew, 1995). Their genesis in the host rock can be a result of fracturing, preferred vadose flow routes, mechanical and chemical weathering downward via the roots of vegetation, and by enhanced dissolution resulting from organics that accumulate in surface depressions (Smart and Whittaker, 1988). Because the surfaces of the Bahamian Islands

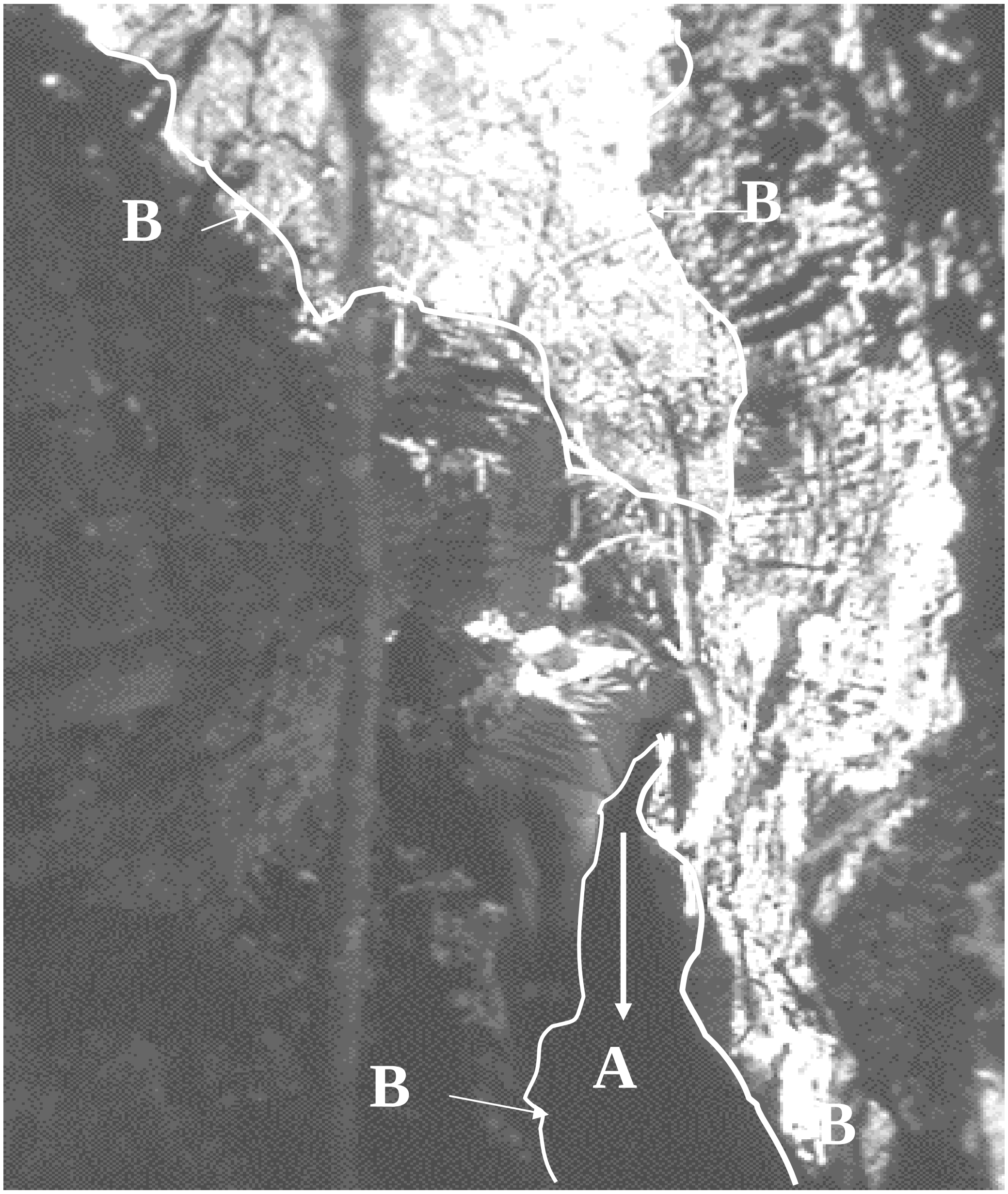

Figure 3. An on-land section of the same fracture as seen in Figure 2. Note the individual (arrow) standing on the left wall next to the tree trunk for scale.

are not flat, the slightly acidic rainwater collects in the depressions and any water that does not evaporate eventually migrates downward following root paths, or other inhomogeneties. As the water descends toward the water table, it dissolves the host rock along the way.

A unique class of vertical caves has also formed in the interior stable regions of the larger Bahamian Islands. They are found where the transitional environment between submerged and dry land, is nearly flat (Schwabe and Herbert, 2004). Most of these vertical caves have formed in the central to western side of South Andros Island. Another has been identified on the northern transitional shore of Grand Bahama Island. These particular caves, known as black holes, are flooded at current sea level. The descriptive term black hole is used here because they appear black in colour due to the presence of a 1-metre-thick microbial layer located at the boundary between the oxic low-salinity upper water mass, and the denser anoxic saline water layer directly beneath. The microbial mass in the largest of these caves is estimated to be as much as 5 tons dry weight (Schwabe and Herbert, 2004).

DISCUSSION

When the term 'blue hole' was applied nearly 300 years ago to the deep blue coloured holes on the carbonate banks of the Bahamas, where ships often dropped their anchors, it can be said with certainty that that term was not intended to describe what may or may not have existed at depth beyond the entrance. At that time, diving into these subsurface worlds to study and better understand them was not an option. It made perfect sense to identify them according to the dark blue colour that can be observed from the surface.

In 1950 however, Dr. George Benjamin and his son George Jr. donned SCUBA, made waterproof housings for their cameras and lights, and descended into these flooded karst features. They were the first to bring back images of what lies beyond the blue entrances (Benjamin, 1970). From their images (Fig. 4), one could easily see that these caves had a likeness to caves that had been explored on land.

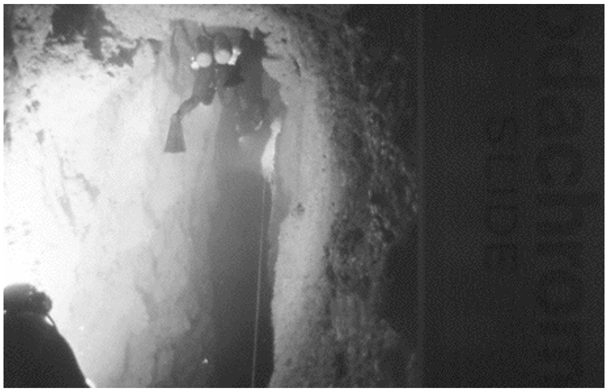

Figure 4. One of George Benjamin's first photos taken from inside a cave that Cousteau later named, Benjamin's Cave. This cave is part of the Andros fracture system in South Bight. (Photo provided by George Benjamin)

The appearance of these submerged caves seems to provide documentation that Agassiz's (1884) conclusion that the same processes that produced the caves on land also formed those caves currently flooded with marine-water out on the platform, was correct.

With the knowledge that we currently have concerning the history of sea-level fluctuations, and the vertical and horizontal extent of flooded Bahamian caves (Table 1), it is no longer reasonable to apply scientific meaning to the term 'blue hole'. Yet, all currently flooded caves within the Bahamian carbonate platforms, which are generally inaccessible to most scientists, continue to be referred to only as blue holes.

Table 1. Flooded Caves (Blue Holes)

Cave Name and Location	**Cave type**
Stargate Blue Hole; South Andros	Fracture-guided
Watlings Blue Hole; San Salvador	Vertical
Lucayan Caverns; Grand Bahama	Horizontal
Black Hole; South Andros	Vertical
Aussie's Black Hole; South Andros	Vertical
School House Blue Hole; South Andros	Fracture-guided
Zodiac Caverns; Grand Bahama	Horizontal
Lothlorein Blue Hole; Grand Bahama	Fracture-guided
Mermaid's Lair and Owl's Hole; Grand Bahama	Horizontal
Evelyn Greens Blue Hole; South Andros	Fracture-guided
Luska's Blue Hole; South Andros	Fracture-guided
Eduardo Blue Hole; South Andros	Fracture-guided
Elvenholme Blue Hole; South Andros	Fracture-guided
Atlantis Blue Hole; South Andros	Fracture-guided

According to Mylroie et al. (1995 p.225), in a paper titled "Blue Holes: Definition and Genesis", the initial description given for blue holes is that they are "…vertical openings in the carbonate rock that exhibit complex morphologies, ecologies, and water chemistries." They further state that their deep blue colour, which they explain is why they were given their name, is the result of their great depth, and they may lead to cave systems below sea level.

This description of “blue holes” is inappropriate for several reasons. First, cave openings on land that contain water are rarely dark blue in colour. Their colour as seen from the air ranges from light green/aqua to black, and the flooded cave entrances that lead steeply down to great depth tend to appear black, not blue.

Secondly, many caves whose openings are below water are not vertical and do not penetrate to great depth. If being vertical or deep is a requirement for being labelled a “blue hole”, then many features commonly called blue holes do not qualify. In addition many flooded caves whose openings are directly below the water surface, can have light blue entrances that open on the sides of submerged eolianites. These flooded caves are morphologically similar to the subaerial horizontal caves known as flank margin caves. Examples of currently submerged horizontal caves are Mermaid’s Lair and Lucayan Caverns on Grand Bahama Island, which have the afore-mentioned type of openings.

Thirdly, the entrance waters of caves in the marine environment do not harbour complex ecologies and water chemistries. On the other hand, land-based flooded-cave openings such as Lucayan Caverns do.

Mylroie et al. (1995, p.225) also stated that inland blue holes are isolated by present topography from surface marine conditions. This statement comes into direct conflict with current knowledge of fracture-guided caves. The fracture-guided cave system of Andros and Grand Bahama extends from the sea onto land and is connected at the surface and at depth (Fig. 5). Mylroie et al. (1995) further suggested that the caves with their openings on land should be separately categorised as blue holes, whereas those with openings on the submerged platform, should be referred to as ocean holes. Again, using the fracture-guided system as an example (Fig. 5), this is not possible. It is one system that exists both on land and in the marine environment at the same time.

CONCLUSION

So, the question is, ‘what is a blue hole’? The answer to that question is that it still is what it originally was meant to be: a depression or hole on the flooded carbonate platform that is darker blue in colour because of the depth of the water, and where ships or boats can safely anchor. According to some Bahamians, blue holes are also the home of the mythical Lusca. “Blue hole” is not a term that is useful for describing flooded karst features. Instead, a scientific description of caves found in the Bahamas should be based on the nature of

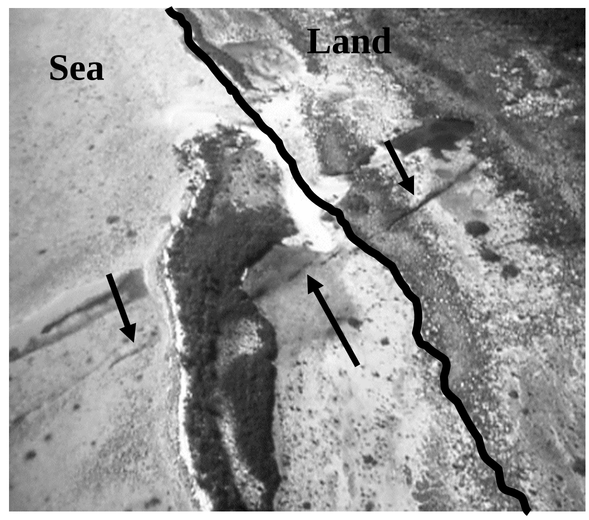

Figure 5. The arrows are pointing to the fracture that in this picture crosses two environments: the sea to the lower left corner and land on the upper right hand corner of this photo.

their development. We suggest that Bahamian caves should be divided into three categories: (1) horizontal (phreatic) caves, (2) fracture-guided caves, and (3) vertical (vadose) caves. Horizontal caves form in the interior of a limestone mass when the surface above is above sea level and exposed to air. This is crucial in that it allows meteoric waters that harbour bacteria and organic matter to migrate to depth and settle on the denser sea-water that also carries organic and inorganic particles that support micro-and macro-faunal populations. The dissolution front, which is concentrated at the water table density interface and the mixing zone, dissolves the limestone to form primarily horizontal voids that are associated with sea level. Glacio-eustatic changes in sea level over the past few million years has continuously moved these density boundaries up or down more than a hundred metres.

Fracture-guided caves form on the edges of some islands that are closely situated next to very deep water. Three islands are known to have these types of caves. They are Andros, Grand Bahama, and New Providence. The fractures form when the buoyant support of the water is gone during intervals of low sea level, and where the rock has been weakened by deep-water currents undercutting the edge of the platforms. These caves have been modified by the same dissolutional processes as all other caves. Vertical caves form from dissolution from descending meteoric water primarily in the vadose zone. They tend to develop from the surface downward. They may intersect with phreatic horizontal caves.

There is no scientifically useful division of caves based on whether they are currently dry or flooded, or whether their openings are found on dry land or on the flooded carbonate platform. Cave development in the Bahamas, whether these caves are currently above sea level or below, require the same ingredients. All the caves result from the interplay of acidic fresh-water, marine-water, and microbial activity. What we see today in the Bahamas are the variabilities of the same recipe and "cooking time" if you will. Some caves are relatively young, and have experienced only one phase of development. Others are much older and positioned deeper, and they have experienced several episodes of development as sea level has oscillated up and down during the Pleistocene and Holocene. The sites of cave development have changed, not the ingredients nature provides to make caves in carbonate platforms.

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