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SPECIAL THEME ISSUE ON BELIZE:

Speleology in Belize: An Introduction

An Introduction to Cave Exploration in Belize

The Value of Small Expeditions to Regional Cave Research: A Reconnaissance to the Cayo District of Belize

Cave Archaeology of Belize

Geologic and Hydrologic Controls on Karst and Cave Development in Belize

Karstification on the Northern Vaca Plateau, Belize

Biology of the Chiquibul Cave System, Belize and Guatemala

Conservation of Karst in Belize

Bibliography of Belizean Caving

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Editor

Louise D. Hose

Environmental Studies Program
Westminster College
501 Westminster Avenue
Fulton, MO 65251-1299
(573) 642-3361
hosel@micro.wcmo.edu

Production Editor

James A. Pisarowicz

Wind Cave National Park
RR1 Box 190
Hot Springs, SD 57747
(605) 673-5582
pisarowi@rmii.com

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SPELEOLOGY IN BELIZE: AN INTRODUCTION

GEORGE VENI

Journal Guest Editor

George Veni and Associates, 11304 Candle Park, San Antonio, Texas 78249-4421, U.S.A.

Belize is a small, little known, and somewhat eccentric country; a pocket of Creole, Mayan, and British heritage surrounded by countries of predominantly Spanish origin. It measures only 300 km from its southern rainforests to the savannas of its northern border with Mexico. From the nation's eastern Caribbean coast, site of the world's second longest barrier reef, Belizeans look nervously 100 km westward to their border with Guatemala, which only in 1991 reluctantly relinquished its claim that Belize was in fact a Guatemalan state.

Despite its small size, Belize has world class caves, including some of the world's largest rooms and passages, perhaps the greatest concentration of archaeologically significant caves, and a diverse cavernicolous fauna that is still largely unstudied. The country's rich speleological potential has been explored with increasing frequency over the past 25 years. This theme issue was prepared to blend summaries of past work with reports of recent efforts to bring you up to date on caving and speleological research in Belize.

Formerly British Honduras, Belize received its independence from Great Britain in 1981. In its struggle to develop its economic independence, Belize has relied heavily on increasing tourism, which has also increased the notoriety of its caves and archaeological sites. Several caves are routinely visited by adventure tours, and new caves are being sought. As caves are discovered, many are quickly looted of ancient Mayan archaeological remains, which are sold on the black market. Consequently, another purpose of this issue is to help coordinate future caving in Belize by providing information on what caving and research has already been done, encouraging special caution and responsible behavior in the potentially sensitive caves, and offering the following tips on how to cave in Belize and minimize damage from looters:

Permission to cave or conduct cave research in Belize must be obtained from the Department of Archaeology (DOA), and, in some cases, the Forestry Department. Coordinate your efforts with them prior to arriving in Belize.

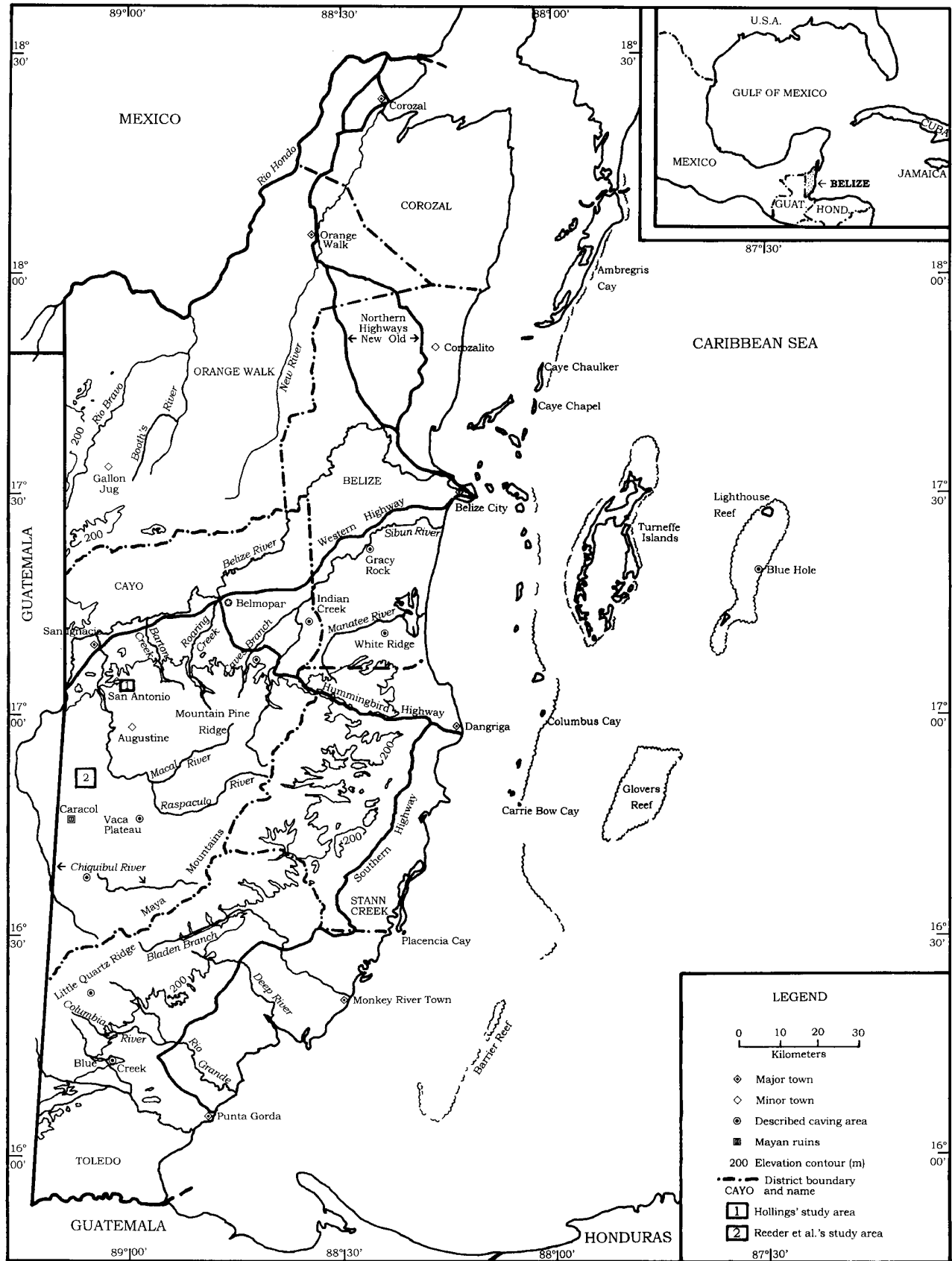
Survey and photograph archaeological materials in place. Do not handle the materials yourself! Provide the information to DOA as soon as possible, and, if feasible, accompany them to the site so they can properly handle, document, and remove the materials for safe study and storage.

Do not discuss the discovery of archaeological materials outside of your group and DOA. Belize is a small country where word travels fast—and often reaches looters.

Be patient and generous. Belize is a poor country with very limited resources. Officials will often be even more frustrated than you at their insufficient funding, personnel, time, and equipment to handle the many problems and opportunities that arise. Please provide them with copies of your notes or summaries of your findings, and don't forget to send copies of the final maps and reports you produce after arriving home. It makes their job of protecting the caves easier, and insures that you'll be welcome to go caving again in this friendly land.

The seven papers in this issue were prepared by some of the most knowledgeable people in Belize speleology. The papers refer to a "location map" which follows this introduction, or to Miller's Figure 4 of Belize karst areas. The location map provides general information on major physiographic and cultural features in Belize, plus the locations of major caving areas, research activities, or other sites discussed in the papers.

I'd like to thank the authors for their contributions to this first-ever compendium of Belize speleology, past *NSS Bulletin* editor Andy Flurkey for agreeing to publish this special issue, current editors Louise Hose and Jim Pizarowicz for guiding this effort to publication, the anonymous reviewers for their insightful comments, and again to the authors for reviewing each others' papers for Belize-specific glitches that other reviewers would miss. On behalf of all of the authors, I want to thank the government and people of Belize for hosting us in their wonderful country, supporting our research, and working hard to protect their priceless underground heritage.



Location Map of Physiographic, Cultural, and Speleological Features of Belize.

AN INTRODUCTION TO CAVE EXPLORATION IN BELIZE

NICK WILLIAMS

Wessex Cave Club Headquarters, Upper Pitts, Eastwater Lane, Priddy, Wells, Somerset, England BA5 3AX

Systematic speleological exploration has been taking place in Belize since about 1960. Such exploration tends to be characterized by long term involvement by a small number of individuals, principally from the USA, but with significant contributions from other countries, especially the UK. An estimated total of 250 km of passage have now been mapped, ranging from low dry grovels to large, active river passage, and two of the largest underground chambers in the world. The author assigns caves to eight geographical areas and describes the history of recent exploration in each. Future exploration problems and priorities are also discussed.

Belize is located in the southeastern section of the Yucatan Peninsula in Central America (see location map, page 68), bordered to the south and west by Guatemala, to the north by Mexico, and to the east by the Caribbean Sea. While the social geography and modern history of the country are very distinct from those of its neighbor countries, the physical geography is less of a contrast. The northern part of the country is flat and contains no known caves of significance, but the southern half of Belize has caves in great profusion throughout the limestone foothills and outliers of the Maya Mountain range.

CAVE EXPLORATION BEFORE MODERN TIMES

Caves are inextricably bound up with the history of Belize, having been fundamental to the religion of the Maya. Few do not already have some signs of human visitation. It rapidly becomes apparent to the modern cave explorer in Belize that, while virgin cave can still be discovered, evidence of the activities of the ancient Maya can be found almost everywhere, and often substantial distances inside the caves. Relics, principally in the form of smashed shards of pottery, are very common.

In more recent times, however, the caves have held little significance for the average Belizean, except as a source of income for a few unscrupulous individuals who loot the artifacts to sell them abroad. Only in the last few years, with the development of Belize as a major tourist destination, have the caves started to be valued as potential sources of income in their own right, and it is now common for local landowners and international travel companies to mention caves in their promotional information about the country and to provide cave tours as part of the "Belize experience" (Hollings, pers. comm., 1994; O'Regan, 1991; McNatt, pers. comm., 1993).

As a result of the looting problem, the Government of Belize has scheduled all caves as sites of archaeological interest and it is necessary for all visitors, be they explorers or tourists, to apply to the Department of Archaeology in Belmopan for a permit before going underground. Also, much of the cave-bearing land of Belize is located on private land

and owners, understandably, will not take kindly to trespassers. The importance of requesting permission cannot be over stressed since failure to observe this simple courtesy can not only land the visitor in jail, but will also eventually hasten the destruction of many of these beautiful and exciting caves.

In deference to the achievements of the Maya it has become standard practice among modern cavers in Belize to give the caves names taken from the Mayan language. Actun is the Mayan word for "cave" (ac- hollow, tun- stone). The choice of a noun to describe the cave is one of the more enjoyable aspects of the trip, and usually results in several interesting hours in the Department of Archaeology library in Belmopan leafing through their Mayan/Spanish dictionary. In common with cave culture everywhere in the world, names relating to life after death, sorcery, bats, and religious matters tend to predominate.

MODERN CAVE EXPLORATION

Modern caving in Belize can be traced back to about 1959 when W. Ford Young (who had been sent there by Gulf Oil to manage their oil explorations) visited caves in several areas (Young, 1961). Young was accompanied by Frank Norris, another American, with a ranch in the Cayo District. Explorations prior to the work of Young included A.H. Anderson, who was the Archaeological Commissioner (Pendergast, 1970), and others making archaeological investigations at specific sites, but systematic exploration and mapping for speleological purposes was pretty much unknown and as a result there is little relevant to be found in the speleological literature prior to 1960.

After Young, cave exploration grew mainly out of the work of archaeologists in Belize. A number of American workers were invited to participate in archaeological programs and because of the link between caves and the Maya civilization that the archaeologists were studying, it was inevitable that sooner or later cavers wishing to concentrate on cave exploration and mapping would visit the country. Among these,

workers such as Tom Miller, Logan McNatt, and more latterly Philip Reeder have all made considerable and long term commitments to exploration in Belize. Anyone researching cave exploration in the country rapidly comes to realize that the vast majority of work has been done by only a few dedicated individuals and the same names crop up again and again in the literature.

MAJOR CAVING REGIONS

For the purposes of description, the caves of Belize can be assigned to eight regions which correlate to karst areas or sub-areas shown on the location map on page 68 and Miller's figure 4 in this issue. The boundaries of these regions are inevitably blurred since the geology dictates that they are nearly all based on essentially the same limestone. The differences between the areas are significant, however, and probably the single most important factor is their position in relation to the main massif of the Maya Mountains because of the effect that this has on rainfall. The massif itself is of igneous origin and the sedimentary rocks comprising most of the other portions of the Maya Mountains are non-carbonates (Bateson & Hall, 1977) and contain no caves of significance. As a summary of significant caves in Belize, Table 1 lists the country's five longest and deepest.

CAVES BRANCH

By virtue of convenient location and long-term exploration, Caves Branch stands out as a distinct caving region, while actually a geological subregion of the Boundary Fault Karst Area. Caves Branch River rises in the northern foothills of the Maya Mountains and flows northeast to join the Sibun River about halfway between Belmopan and Belize City. The river gives its name to an area of land which is situated about 20 km

almost due south of Belmopan. Where the Hummingbird Highway crosses the river, a farm has existed for many years and access to the caves is relatively simple. In speleological terms this is certainly the most intensely studied area of the country.

The area was first explored by Young and Norris who visited St. Herman's Cave in the late 1950s. They were also aware of the Caves Branch River Cave and other caves in the area. Among the visitors to Belize they played host to were Americans Barbara MacLeod and Dave Albert (Albert & MacLeod, 1971) and probably the surveyor, Charles Wright (Wright et al., 1959). In an article for the National Geographic magazine in 1972, Louis de la Haba mentions visiting a cave somewhere on the Hummingbird Highway in the presence of Young, Norris, and Dan Bellini (de la Haba, 1972). Dan Bellini worked on the Caves Branch farm, and Department of Archaeology records indicate that the site visited was known as Pothunter's Cave.

Barbara MacLeod returned to Belize to work for the Department of Archaeology on a Smithsonian Institution/Peace Corps program (Bartholomew, 1973; Rushin-Bell, 1991). She was joined by Carol Jo Rushin, and between 1971 and 1974 they explored several caves in the Caves Branch area including Petroglyph Cave, a major river conduit linked to St. Herman's Cave. In 1978, she and other archaeologists engaged in an extensive study of Petroglyph, the results of which are still unpublished (MacLeod & Reents-Budet, 1995). This period could be considered the second phase of speleological exploration in Belize, involving a number of United States cavers, principally from the Sligo Grotto and Texas chapters of the National Speleological Society (NSS). Amongst these visitors was Tom Miller. He later centered the field work for his PhD thesis (Miller, 1981a) at Caves Branch where he was assisted by Mike Shawcross, Jerry Davis,

Table 1.

LONGEST CAVES IN BELIZE

CAVE NAME	KARST AREA	LENGTH
Cebada Cave	Chiquibul	17.2 km
Petroglyph-St Herman's Cave	Boundary Fault (Caves Branch subregion)	17.0 km
Actun Tun Kul	Chiquibul	12.2 km
Actun Chek	Boundary Fault (Caves Branch subregion)	8.1 km
Actun Tunichil Muknal	Boundary Fault	5.3 km

DEEPEST CAVES IN BELIZE

CAVE NAME	KARST AREA	DEPTH
Actun Box Ch'ii'ch	Boundary Fault	-183 m
Cebada Cave	Chiquibul	-155 m
Actun Zotziha	Boundary Fault	-152 m
Actun Tunichil Muknal	Boundary Fault	-127 m
Actun Lubul Ha	Boundary Fault	-120 m

and Logan McNatt, a speleo-archaeologist.

In his thesis, Miller concludes that all the caves in the Caves Branch area are hydrologically linked in some way or another. What is commonly referred to as the Caves Branch River system is found a few kilometers downstream from the Hummingbird Highway bridge. This system consists of sections of deep canal, where flotation aids are required, which occasionally break out into open jungle. A vehicle-negotiable track from the Western Highway to Frank's Eddy, about a kilometer downstream of the Caves Branch's confluence with the Sibun River, permits a party to be collected after a trip through the cave making this a perfect introduction to Belizean caving.

Another important segment of the system, St. Herman's Cave, is only five minutes' walk from the Hummingbird Highway. The cave consists of an active river passage and downstream from the entrance can be followed through several stretches of wading and swimming in deep water to a sump which eventually discharges into the Caves Branch River system. Upstream also leads to a sump eventually, but before this is reached it is possible to climb out of the water into a high level series leading to a second entrance. This whole area has been designated a nature reserve, and a nature trail leads from the second entrance back to the Hummingbird Highway at the Caves Branch Blue Hole. This is a popular public spot for swimming and is not to be confused with the Blue Hole at Lighthouse Reef off the coast.

McNatt also stayed in Belize on a more or less permanent basis until 1993, first attached to the Department of Archaeology through the Peace Corps and then latterly as an independent speleological consultant and researcher. He provided considerable assistance to the first serious British expedition to the country, undertaken by 18 members of Queen Mary College (QMC) (part of the University of London) from January to May 1988. The expedition spent three months based at Caves Branch and mapped caves throughout the area bound by the triangle formed between the Western Highway, the Hummingbird Highway and the Caribbean coast (Marochov & Williams, 1992). Many had not been explored or mapped before, but some had been the subject of work by previous expeditions (Miller, 1989a). Discoveries continue to be made at Caves Branch—in 1988 Miller re-discovered 1,600 meters of streamway which had been lost since 1977 (Miller, 1989b), and in 1993 he added a further 5 km to the system (Miller, pers. comm., 1994)

Caves Branch has also been the only focus of inland cave diving activity. The Petroglyph/St. Herman's connection was attempted by Miller in 1987, but he had to abandon the attempt because of regulator failure (Miller, 1987). The connection was finally proved, at the second attempt, by Jim Bowden with assistance from the QMC team in 1988 (Bowden, 1988). It is interesting to note that, despite considerable potential, relatively little cave diving has been attempted in Belize. This probably reflects the realities of lugging the necessary equipment to the most interesting (but most remote) sites.

INDIAN CREEK

The Indian Creek and Dry Creek basins lie in the area to the north of the Hummingbird Highway, northeast of Caves Branch. This area is not really part of the Maya Mountain range, being separated from it by the Caves Branch and Sibun Rivers, and is a subregion of the Sibun-Manatee Karst Area where the limestone hills are less pronounced than on the fringe of the mountains proper. Caves here tend to be short fragments, those at the water table being mostly river passage while above they are usually completely dry. The terrain is rugged and it is necessary to traverse considerable distances on foot through the bush in order to reach the caves, although the recent designation of Five Blues Lake as a National Park may assist somewhat in this regard (McNatt, pers. comm., 1991)

Ford Young mentions several caves in this area in his account (Young, 1961) including Ben Lomond (near the Northern Lagoon), Manatee Cave, and "a group of some forty caves in an area of limestone hills south of the Sibun River between Gracy Rock and Indian Creek." The disappearance of Indian Creek into a number of caves is noted on most maps of the country. This is probably accounted for by the work of a British Colonial Office survey team since Charles Wright recalled being taken through Indian Creek Cave in a canoe while working on a land use survey in the late 1950s (Wright, pers. comm., 1988).

Rushin and MacLeod visited caves in this area in 1972 during their work for the Department of Archaeology (Rushin-Bell, 1982). In 1979, Miller, in the company of Mark Gutchen, surveyed Darknight Cave which is marked on the 1:50,000 topographic maps (Miller, 1979). Miller was also aware of other caves close by, including Green Howards Cave which had first been investigated by British soldiers, but it was to be eleven years before he was able to return to map them (Miller, 1991). In the intervening years he investigated other caves in the area, notably K'op Kimen Cab, explored with Linda Gough in 1987 and 1988 (Miller, 1987), although a survey of this cave does not appear to have been published.

Surveys of other caves on Indian Creek were published by the 1988 QMC expedition (Marochov & Williams, 1992) which also investigated an area to the north which the team named "Gracy Rock." In terms of exploration this is a distinct area in its own right, being accessible via the Western Highway rather than from the Hummingbird, and having little previous record of exploration. However, the caves found were minor and the area is geologically a continuation of the Sibun-Manatee karst so it does not merit distinct status for this treatment.

WHITE RIDGE

White Ridge is the name of a farm company which cultivates a considerable amount of land on the flat coastal plain near Gales Point, about halfway along the coast from Belize City to Dangriga. Like the Indian Creek area to the northwest, White Ridge is a subregion of the Sibun-Manatee karst, but

contrasts as a caving area because its cave-bearing limestone is relatively easy to reach. The terrain is less rugged than further to the north and the farm's citrus plantations provide cleared land and tracks which give easy access to the edges of the low conical hills where the caves are found.

The biggest system is that of Darby Pat and White Ridge caves: basically a river passage with an abandoned top level which closely follows the line of the edge of a couple of the cones. The cave was first discovered by MacLeod and Rushin in 1973 and partly surveyed by Miller and colleagues in 1984 (Miller, 1989a). Miller also assisted the QMC team which extended the cave and produced the first published survey (Marochov & Williams, 1989). QMC explored a few other small caves in the area, including one they christened the Mines of Moria; a single dry trunk passage passing right through a single cone with entrances at each end (Marochov & Williams, 1992). Other caves in the area tend to be very limited in length, and the potential for vertical development is strictly limited since the area is very close to sea level and the cones are a maximum of about 40 m high.

BOUNDARY FAULT AREA

The Boundary Fault Area is the least distinct of all the Belizean caving areas, in the sense that where it ends and the adjacent Caves Branch subregion and Vaca Plateau karst area begin is not readily apparent in the field. For the purposes of this article, the Boundary Fault Area excludes the Caves Branch subregion and adjoining karst further east, and can be considered to include the ground extending west from the Caves Branch watershed up to and including the Barton Creek watershed. The principle rivers are Barton Creek and Roaring Creek.

The limestone of the Boundary Fault Area is some of the highest in Belize. Access to the most interesting caves is only possible by several hours of jungle bashing on steep, heavily vegetated slopes. However, the effort is well rewarded. Situated on the northern edge of the Mountain Pine Ridge, an area of non-carbonate rock, streams that drain onto the karst are chemically and hydrologically suited to form significant caves. The Boundary Fault Area is probably second only to the Chiquibul in its speleological potential and contains some of the most interesting caves in Belize.

Actun Zotziha is fairly typical and consists of a steeply descending entrance series which changes to a wide, high stream passage as the level of the resurgence is approached (Marochov & Williams, 1989). Actun Tunichil Muknal has a similar profile and is one of three through trips in this part of Belize, Actun Box Ch'ii'ch and Sunken Forest caves being the other two (Miller, 1990a; Marochov & Williams, 1992). There are several other caves in dolines along the top of the limestone, and resurgences can also be explored by following the tributaries to the major rivers in the valley bottoms.

Zotziha was originally discovered by Miller in 1985. In 1988, Miller gave directions to the area to the QMC team

which had, like himself, already noted the potential of the area obvious from the 1:50,000 survey. The QMC team explored and mapped the cave to a terminal sump in 1988, and a large Anglo-Canadian team continued the exploration of the area the following year (Frew, 1989; Marochov & Williams, 1992). Among other achievements, the expedition successfully completed a traverse of the Actun Tunichil Muknal system, but was the cause of some international tension (Miller, 1990a).

CHIQUIBUL

Undoubtedly the most spectacular caving area is the Chiquibul, on the western side of the Maya Mountains in close proximity to the Guatemalan border. The Chiquibul itself is one of the largest vanishing rivers in the Americas and explorations in this area have revealed many kilometers of enormous passage, some wet, some dry, much of it fabulously decorated, and all of it difficult to get to. Probably the most significant single cave is Cebada, but this is only part of a major system which extends across the border into Guatemala (Ganter, 1990).

The area had been known to be cavernous since early in the 20th century when it was important for mahogany and log-wood production. Ford Young notes the "Puente Natural" (natural bridge) spanning the Chiquibul River (Young, 1961). Wright also notes this feature and also that the average annual rainfall of the area is up to 4.1 m (Wright et al., 1959). The area is directly to the windward side of the Maya Mountains and this, combined with the proximity of the impermeable massif to concentrate rainwater runoff, and the ample, structurally strong but soluble Cretaceous limestone, leads to the formation of underground passages of considerable dimensions.

Mike Boon briefly visited the area in 1971 (Boon, 1971), but proper exploration did not take place for a decade. While completing work for his PhD, Miller realized that this was the main area of promise and so he spent eight days exploring it solo in 1982 (Miller, 1990b). This resulted in the organization of a major, inter-disciplinary expedition in 1984, funded by the National Geographic Society and the NSS. The cave system created by the sinking of the Chiquibul River was found to be divided by massive collapse and sumps into four main caves: Actun Kabal, Actun Tun Kul, Cebada Cave, and Xibalba. In 1984, exploration focused on Kabal and Tun Kul, the upper half of the system. The Chiquibul River no longer flows through these caves having been diverted to an impassable route beneath. Twenty-three kilometers of large passage were surveyed, including two of the largest rooms in the world: Belize Chamber and Chiquibul Chamber. Exploration ended at a deep sump at the downstream end of Tun Kul (Miller, 1984; Weintraub, 1984).

Miller returned with another expedition in 1986, regaining the Chiquibul River in Cebada and Xibalba (the downstream half of the system) and added a further 27 km to the system. Xibalba was followed right through into Guatemala to the

Chiquibul River's resurgence, an entrance measuring 200 m wide by 80 m high (Miller, 1986). In May 1988 Miller returned again to try to complete the work in the Chiquibul by joining Cebada to Tun Kul. Due to a number of problems this was not achieved (Miller, 1988). Cebada Cave still retains the title as the longest in Belize at 17.2 km. A comprehensive survey was published by Steve Grundy and Olivia Whitwell in 1990.

VACA PLATEAU

The Vaca Plateau is immediately north of the Chiquibul and forms the western boundary of the Mountain Pine Ridge. For this paper the Plateau is considered to include the Pine Ridge's isolated erosional remnants of limestone located atop some hills and ridges. Certainly the earliest properly recorded cave in this area is Rio Frio Cave, a site of significance in the development of archaeological study in Belize (Pendergast, 1970), and visited frequently by cavers (Young, 1961; Albert & MacLeod, 1971). Caves in this area are mentioned by Ford Young (Young, 1961) but apparently were not investigated in detail. The 1988 QMC expedition looked briefly at this area but concluded that easier rewards were available elsewhere, so it was not until 1990 that systematic exploration commenced with the first of a series of expeditions led by Philip Reeder.

Reeder's interest followed from a long series of investigations into aspects of the human and physical geography of Belize by members of the Department of Geography at the University of Wisconsin-Milwaukee. Prior to 1990, Dr. Mick Day from the University had often visited Belize and, on occasions, engaged in karst research (e.g. Day, 1983), but Reeder's painstaking investigation of a large number of small caves, many with important archaeological remains, was the first large scale effort at serious speleological work by cavers from the Department. Reeder, now affiliated to the University of Nebraska at Omaha, and his team returned again in the six following years and to the end of the 1995 field season had explored about 100 caves ranging from short horizontal stoops to caves with vertical shafts of over 100 m depth (Reeder, 1993, 1995).

During the preparatory phase of an expedition to the Little Quartz Ridge in 1991, British cavers David Arveschoug and Ern Hardy mapped two caves to the southwest of the village of San Antonio (not to be confused with the village of the same name in Toledo District) (Williams, 1992a). Then, in April 1994, Pete Hollings and three other members of the UK's Mendip Caving Group discovered a total of 20 caves, up to 800 m in length (Hollings, 1994 and this issue). Being very close to the area studied by Reeder, it comes as no surprise that the caves are similar.

TOLEDO DISTRICT

South of the Maya Mountains, there are two major areas of interest. The first of these is centered on the village of Blue Creek, about 25 km northwest of Punta Gorda, in the K-T Fault

Ridges Karst Area in the southern portion of the Toledo district. Here Blue Creek Cave is an exhilarating, wet trip and other caves in the area have long been known for their archaeological significance. The second area is the Little Quartz Ridge, 15 km north of Blue Creek and considerably more difficult to get to.

Ford Young mentions the explorations of Donald Owen-Lewis in the Toledo district, who stated that most of the caves in the area were quite wet and had active streams in the lower reaches (Young, 1961). Unfortunately, neither Ford Young nor Owen-Lewis documented discoveries in this area. This had to wait until the second phase of exploration in Belize, pioneered by MacLeod and Rushin in 1971-74.

With work in the Caves Branch area essentially completed by 1979, Miller turned his attention south and, with a group from McMaster University, explored and mapped about 4 km of cave in the Toledo District, including Blue Creek Cave (Miller, 1981b). On another occasion he and McNatt nearly drowned during a flash flood (McNatt, 1982). In the company of John Wyeth and others, Miller completed a traverse of Blue Creek Cave to the Rio Blanco in 1984.

Miller found himself back in Blue Creek Cave ten years later. As part of the multi-disciplinary Jason Project, led by deep-sea explorer Robert Ballard, Miller lectured live via satellite from within the cave to school children at receiving sites in England and the USA (Musgrave, 1993). During the project, Miller, Wyeth and others were also able to map further into the cave, bringing the total surveyed length to 9 km (Miller, 1995).

British Forces stationed in Belize have had a somewhat mixed relationship with the caves. As a result of the protectorate status of Belize which pertained until the beginning of 1994, the Royal Engineers were responsible for mapping in the country. Undoubtedly some of the caves appearing on the 1:50,000 survey of the country were initially reported by military patrols (Miller, 1991), and caves at Caves Branch were used for "adventurous training" if an officer with caving experience was stationed in Belize at the time (e.g. Sims, 1988). However, few British Soldiers stationed in the country undertook any systematic exploration and very little speleological mapping was ever done. About the only soldier who has produced any records of original research in the caves is Sgt. Chris Jackson, who was stationed at Salamanca Camp in 1987 and made notes on a series of trips into Blue Creek Cave (Jackson, pers. comm., 1991). In early 1994, having been diverted from his original intention to visit the Chiapas area of Mexico by impending civil war, Jackson returned to Blue Creek and was able to complete a traverse from sink to resurgence, unaware that this had already been completed by Miller ten years previously (Jackson, 1994).

Fifteen kilometers north of San Antonio is the Little Quartz Ridge, an igneous intrusion pushed up through the surrounding limestone. In mid-1985 Percy Dougherty and crew from Kutztown University explored the Rio Grande on the north-eastern end of the ridge (Dougherty, 1985), working in large

passages with lots of water. The main finds were Tiger and Mucbe caves which had already been discovered and partially explored by MacLeod, Rushin, and Harriot Topsey. Dougherty returned subsequently (Turner, 1991) but has published little on the results of his research.

Work at the southwestern end of the ridge has been decidedly less successful, and it would appear that most of the drainage is deeply subterranean. The first officially sanctioned British Forces caving expedition to the country was part of a joint civilian/military trip led by Nick Williams (a veteran of the 1988 QMC expedition). It attempted to explore the caves at the southwestern end of the ridge. Despite some serious logistical problems (Frew, 1991), the expedition managed to reach the target sinks marked on the map, but was disappointed to discover only a few hundred meters of enterable cave passage throughout the area (Williams, 1992b). Some small caves do exist, particularly to the south of the ridge, and some of these contain archaeological artifacts (Matola, 1990).

OFFSHORE

None of the cayes which form Belize's barrier reef rise more than a few meters above sea level so caves out on the reef are inevitably totally submerged. Many large, submerged sinkholes also occur in the reef and are known as "blue holes." The most famous is the Blue Hole at Lighthouse Reef, which is some 300 m in diameter by 120 m deep. The first recorded exploration was made by Jacques Cousteau in 1967. Observations of the shaft were made visually and by using a miniature submarine, and various specimens, including a large detached stalagmite, were recovered to the surface (Cousteau, 1973; Mathews, 1991). In subsequent years this Blue Hole became a popular destination for tourist divers.

Underwater caves have been explored under the cayes closer to the mainland. The most significant discovery was Giant Cave at Caye Caulker. Descriptions of the cave differ. Mapping led by Sheck Exley in 1982 shows the cave as a group of 5- to 20-m-wide conduits radiating from a 50-m-diameter room. While not completely explored, the cave's 3116 m surveyed length ranks it as the world's longest underwater saltwater cave (Exley, 1994). However, between 1985 and 1988, survey and exploration by Jim Coke and his colleagues found problems with the original survey and describe the cave as a large chamber, possibly as large as 600 m in diameter (Coke, 1986, 1987, 1988). If these dimensions prove to be accurate, the room would be the largest known in the world by a significant margin.

Later explorations at other sites of interest on the reef have revealed Double Hole Cave off Caye Chapel, and Rio Hondo off Ambergris Caye (Coke, pers. comm., 1989). In 1989, an expedition led by Tom Iliffe examined the biology of the blue holes, and mapped caves under Caye Chapel and Columbus Caye (Sarbu, pers. comm., 1990). Iliffe reported a new species of *calanoid*, a type of *copepod*, from Giant Cave (Fosshagen & Iliffe, 1991).

SUMMARY

In conclusion it may be said that there are few areas of Belize likely to contain underground development which have not been subject to at least cursory examination, and in some areas work of considerable detail has been performed. The obvious major leads are taken but there is much detailed systematic investigation still required. There is also a great need for diligent publication by cavers visiting Belize for while an increasing number of cavers are returning to places which have been previously explored and mapped, even minor discoveries should be documented properly. Even now in Belize there are some significant known systems whose surveys have yet to appear in the literature.

This, of course, poses particular problems for persons wishing to undertake new research in Belize. Much of the work which has been published on cave exploration has appeared in relatively obscure caving journals, and the poor cross fertilization between academic researchers (especially archaeologists) and amateur speleologists has exacerbated the problem. It is notable that the most successful explorers to date have been those who are able to straddle this divide.

New explorers wishing to start projects in Belize are advised to take great care in their background research. While the Department of Archaeology in Belmopan maintains a library with as much material on caving as it can obtain, the record is far from complete. Information about the detail of what has been done in the country is often only available by directly contacting the researchers responsible. It is hoped that this paper may provide some assistance in that regard.

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THE VALUE OF SMALL EXPEDITIONS TO REGIONAL CAVE RESEARCH: A RECONNAISSANCE TO THE CAYO DISTRICT OF BELIZE

PETE HOLLINGS

Department of Geological Sciences, 114 Science Place, University of Saskatchewan, Saskatoon, Saskatchewan, S7N 5E2, Canada

During a five week period, 19 caves were explored by a team of four cavers comprising the 1994 Mendip Caving Group (MCG) expedition to Belize. Six sizable caves were identified in the Cretaceous limestone, west of the Maya Mountains, and surveyed a total length of 2.5 km. Time spent in the field is broken down so as to show both the advantages and disadvantages of a small-scale expedition. Suggestions are made as to how future groups could benefit from the experiences of the expedition with regard to conducting significant research with a small team. The MCG expedition is compared to other larger expeditions, with the results showing that lightweight expeditions are more easily financed and organized than larger expeditions; however, they may not be suitable if detailed scientific studies are intended.

There has over recent years been a trend toward smaller, lightweight expeditions in the caving world, with groups commonly taking only the equipment they can carry on the aircraft, rather than shipping large quantities of equipment out in advance. This paper is intended to provide a detailed analysis of both a lightweight and large scale expedition in order to demonstrate the significant contribution that can be made by the former to regional research, and to help others planning similar expeditions to avoid the mistakes we made. The results and logistics of the Mendip Caving Group (MCG) expedition to Belize will be discussed in order to provide a basis for comparison. The two larger expeditions examined in detail were also based in the United Kingdom (UK) and, consequently, were faced by similar obstacles and expenses.

During March and April 1994, four members of the MCG conducted a cave reconnaissance expedition to Belize. The intention was to investigate the area around San Antonio, Cayo District (see location map, page 68) with a view to mounting a larger expedition should the area warrant it. This was the first expedition for all of the team members and proved to be a considerable learning experience.

The team spent five weeks in the field and in that time investigated 19 sites. While 13 of these proved to be small fossil caves or shallow choked pits, six sizable caves were also found. Descriptions and surveys of these caves have been published elsewhere (Francis et al., 1995; Hesketh, 1995; Hollings, 1994). In total 2.5 km of passage were surveyed, the longest single cave being the 840-m-long Cool Spot Cave (Figure 1). Perhaps the most interesting area was the Valley of the Caves where Actun Mai was connected to Tzonot, with further potential for connecting Actun Hoyanko and Cueva del Indio Perdido into the system (Figure 2). As far as the team was aware, we were the first to map any caves in this area, although archaeological evidence proved that we were by no means the first to enter the caves. On returning to the UK we learned that Cocohil Cave (also known as Gibnut Cave) had

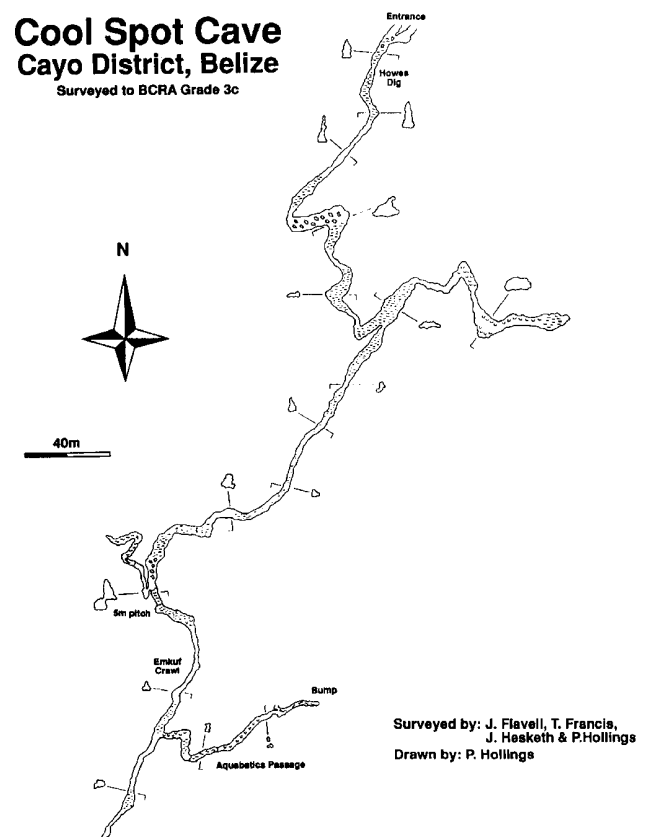


Figure 1. Cool Spot Cave.

been previously mapped both by Tom Miller in 1970 and Carol Vesely and Bill Farr in 1986 (Miller, pers. comm., 1995). Some of the smaller caves were shown to the team by local farmers who provide this service to tourists as a means of supplementing their income. The seven caves surveyed had not been used in this way and represent 95% of the cave passage the expedition explored in the region.

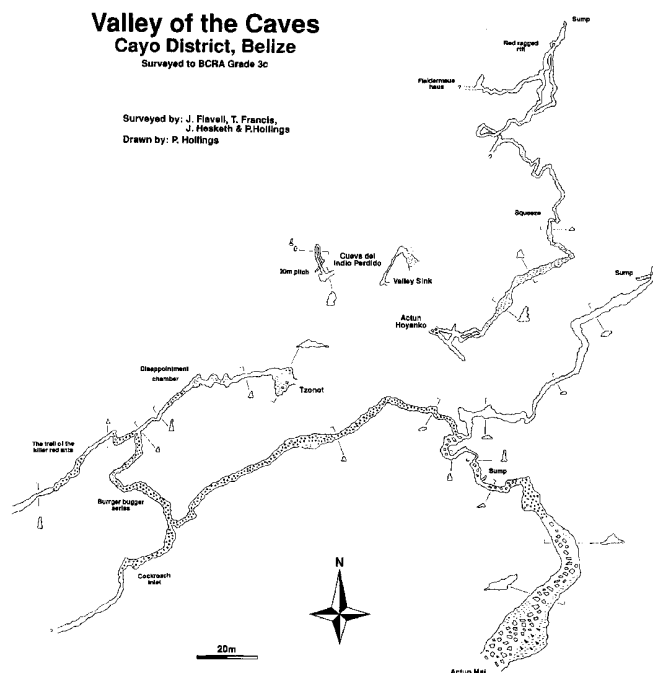


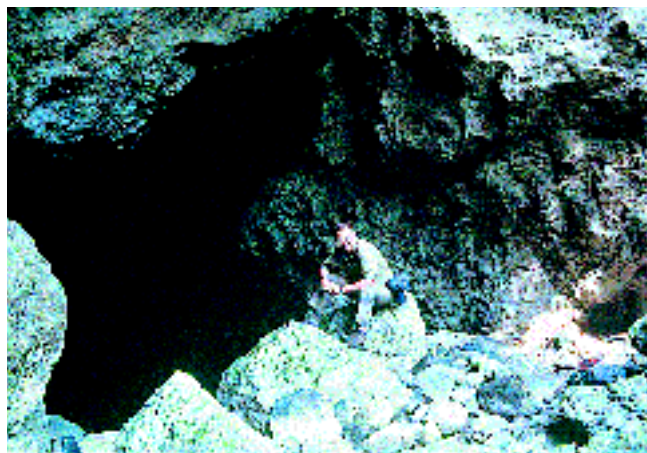
Figure 2. Valley of the Caves.

ANALYSIS OF LOGISTICS AND FIELD RESULTS

The expedition was intended as a reconnaissance which, as defined by White (1986), would imply only superficial examination of the area and rough surveys. However, the nature of the area and the assistance of local hunters meant that far more was achieved than was originally hoped, with six caves being fully explored and surveyed. The area around San Antonio was thoroughly investigated, but many leads were left unexplored due to a lack of time. This highlights one of the principal problems of an expedition of this scale, that the expedition had limited manpower and we were unable to do everything we would have liked. The expedition log book shows that 122 person-days were spent in Belize; of these 46% were spent caving, 23% as rest days, 21% in administration, and 10% for illness. This is comparable to the 1992 Caves of Thunder expedition to Irian Jaya, which spent 27% of its time on administration, 25% accessing the area and caving, and lost 6% to illness (Boothroyd et al., 1993). Our general lack of experience meant that we carried out most activities as a group. By splitting the team into smaller groups we could have reduced the number of days spent on administration. Also the contacts we made would reduce the time a follow-up expedition would be required to spend in this way. With a small team rest days were unavoidable, as after five days of exploration and surveying it was difficult to summon up the energy or enthusiasm to continue, particularly toward the end of the expedition. The days lost to illness were generally caused by stomach problems. One member had arrived via Mexico and



Typical terrain within the field area. Photo by Pete Hollings.



Pete Hollings at the entrance to Mai's Cave. Photo by Julian Flavel.

was afflicted throughout the expedition by diarrhea he acquired there. The rest of the team were all struck down with diarrhea at some point; however, the one person using an iodine-based water purification tablets ("Aqua Pura") suffered less than those using a chlorine-based product ("Puritabs"). This individual only accounted for one sick day and experienced less severe symptoms. The days lost through illness tended to increase the work load for the others by magnifying the fatigue factor, but there was little else that could have been done to avoid these problems.

While the members of the expedition were either geographers or geologists, the scientific observations were limited. This was partially due to how the group perceived the expedition, as we had no particular scientific goals other than to explore and map caves. However, it is also all that can reasonably be expected of a group without the necessary training to become involved in detailed scientific projects, such as those involved with an archaeological excavation. Instead the MCG expedition concentrated on providing a basic descriptive record of the area through surveys, photographs and published reports, as recommended by Smart (1986). For example the surveys revealed a conjugate northeast/southwest and northwest/southeast trend to the cave passages, similar to that mapped in the Chiquibul River drainage basin of the northern Vaca Plateau (Reeder, 1992, 1993). However, observations as to the general nature of the caves differ from those of Reeder (1993); longer horizontal caves were located in the valley bottoms, while caves higher on the valley sides were characterized by shafts as deep as 20 m.

Five sites of archaeological significance were also identified, the small fossil caves high in the valley sides commonly containing pot and bone fragments. The inclusion of an archaeologist within the team would have allowed a more detailed study of these items; however, it would also have meant that the cave reconnaissance of the area would have been less thorough, as time would have been spent investigating the archaeology rather than locating caves. Future expeditions may wish to investigate the possibility of a closer liaison with the staff of the Department of Archaeology in Belmopan. With the increasing interest in ecotourism in Belize as well as the large number of groups conducting archaeological studies in the area, perhaps this will be possible in the future. Given the limited time available to the expedition, the team concentrated on surveying the larger active caves. The presence of pot sherds, some nearly intact polychrome vessels, and bone fragments found in the fossil cave was reported to the Department of Archaeology, hopefully insuring the preservation of these sites for future study.

The caves that were mapped contained a varied fauna including bats, fish, crabs, and numerous insects. The team did not have the necessary training to identify the biota; however, this is one area where, with a little more planning, some research could easily have been conducted. It is relatively straight forward to collect specimens for later identification.

Simple notes were recorded in survey and log books and this information was passed on to cave biologist James Reddell at the Texas Memorial Museum.

So far I have highlighted the problems faced by a small expedition, yet it is my belief that these are far outweighed by the benefits. To demonstrate this point, I have chosen to examine two other UK-based expeditions, partly because they offer a good base for comparison due to the similar costs involved, and also because they are the only expeditions for which sufficiently detailed statistics were available. The amount of passage surveyed has been chosen as an indicator of the level of success simply because cave exploration was the principal goal of the three expeditions. The Queen Mary's College (QMC) Below Belize '88 expedition represents a large scale expedition, with 18 members and a budget of £35,000, while Below Belize '91 falls somewhere between a large scale and lightweight trip, due mainly to the fact that it was a joint expedition organized with the British Army (which was stationed in Belize), and thus received extensive logistic support.

One of the advantages of a lightweight expedition is shown by the fact that the MCG expedition was organized in under four months, while the QMC Below Belize '88 and Below Belize '91 expeditions took almost two years of planning (Williams, 1990, 1992). There seem to be two main reasons for this: our expedition had no need to raise large sums of money, nor did we have to worry about shipping large volumes of equipment to Belize in advance. Table 1 provides a more detailed comparison of the expeditions. Data from North American expeditions also supports this view; the Chiquibul 1984 expedition, which raised \$13,000 from outside the expedition members, took three months to organize, while the trip to the Indian Creek area took one month and was self-funding (Miller, 1984, 1991).

The majority of UK-based expeditions to Belize, prior to that of the MCG, received some level of assistance from the British Army. Below Belize '91 was a joint expedition that included army personnel and consequently had access to extensive logistic support that included helicopter flights into the field area (Williams, 1992). A small expedition has no need of this level of support, although the knowledge that the support was there in case of emergency was comforting. This support was also not available to U.S.-based cavers who have worked extensively in Belize for many years (Williams, this issue); thus, comparisons with North American-based expeditions are not really useful in this context because of the different logistics involved. For example it is possible for North Americans to drive their own vehicles into Belize thus reducing shipping and transport costs while increasing the flexibility of the expedition. This flexibility was possible for the 1988 and 1991 British expeditions because the former shipped two vehicles to Belize while the latter had access to military support. The high cost of vehicle hire in Belize, combined with the poor reliability of these vehicles (Williams, pers. comm., 1995), meant that this was not an option for the MCG expedi-

Table 1. Comparison of the Mendip Caving Group, Queen Mary's College (Williams, 1990) and Below Belize '91 (Williams, 1992) expeditions.

Mendip Caving Group, 1994	Queen Mary's College, 1988	Below Belize, 1991
Four month planning period.	Two year planning period.	Two year planning period.
One month spent in the field.	Four months spent in the field.	Two months spent in the field.
2.5km of cave passage surveyed.	20km of cave passage mapped.	900 m of cave passage mapped
A budget of £3,275 of which all but £700 was contributed by expedition members.	A budget of £35,000 of which £18,000 was contributed by expedition members.	A budget of £7,800 of which £6270 was contributed by expedition members.
No shipping of equipment.	Shipped 8 tonnes of equipment, including two Landrovers	No shipping of equipment
No need for logistical support in the field.	Received support from the British Army, including transport of equipment and personnel and the loan of radios. Were also able to arrange helicopter reconnaissance flights.	Joint expedition with the British Army so were able to arrange transport, accommodation and the loan of radios. RAF Puma helicopters were used to transport personnel to the field area.
Four man team with no medical or scientific background.	Eighteen member team with medical experience and the ability to mount two biological projects as well as a number of geographical ones.	Sixteen member team including trained medical personnel.
Relied on local transport which was not always convenient and could have been a problem had an accident occurred.	Supported by two Landrovers shipped from the UK.	Trucks, Landrovers and helicopter support all provided by the British army

tion. In general, the costs incurred by expeditions from North America are lower than from the UK: ~£180-200/person/ expedition month (Miller, pers. comm., 1995), compared to about £500/person/month for Below Belize '88 (Williams, 1990) and £820/person/month for the MCG expedition (Francis et al., 1995).

A small expedition also has the advantage that it can more easily adapt to the community around it. We found that we were quickly accepted by the people of San Antonio, who were at first curious and then enthusiastic about the aims of the expedition. As a result we were informed of more leads than we had time to investigate.

CONCLUSIONS

The MCG expedition was able to achieve results comparable, and in some cases superior, to those of much larger efforts (Table 2), with the quantity of cave surveyed being also a reflection of the nature of the caves in the area. This is demonstrated by the Chiquibul 1984 expedition which mapped 23 km in 45 days (Miller, 1984), and is particularly true in the case of

the Below Belize '91 expedition which only surveyed 28 m/person/month, emphasizing the value of small, lightweight expeditions in a reconnaissance role. Had the team been increased to six, possibly by the inclusion of a photographer and an archaeologist, the expedition could probably have achieved even more with little loss of efficiency. As it stands, data were collected that should be of use to others working in the area, as well as increasing the database on Belizean caves and locating an area for further exploration.

ACKNOWLEDGMENTS

I would like to thank my fellow expedition members J. Hesketh, T. Francis, and J. Flavell for their hard work and perseverance, without which the expedition would not have happened. In Belize we are grateful to the staff of the Department of Archaeology and the residents of San Antonio, particularly Javier Mai and Fidencio Bol. The expedition is also grateful for financial support from the Sports Council of Great Britain through a grant administered by the National Caving Association, and to the Ghar Parau Foundation.

Table 2. Comparison of the results of the Mendip Caving Group, Queen Mary's College (Williams, 1990) and Below Belize '91 (Williams, 1992) expeditions.

Mendip Caving Group, 1994	Queen Mary's College, 1988	Below Belize, 1991
Cost of expedition per kilometer of survey.		
<i>£1310 per kilometer.</i>	<i>£1750 per kilometer.</i>	<i>£8670 per kilometer.</i>
Quantity of survey.		
<i>625m/person/month.</i>	<i>277m/person/month.</i>	<i>28m/person/month</i>
Time spent in planning versus time in the field.		
<i>4:1</i>	<i>6:1</i>	<i>12:1</i>
Number of scientific projects.		
<i>Zero</i>	<i>Four</i>	<i>Zero</i>

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CAVE ARCHAEOLOGY OF BELIZE

LOGAN MCNATT

1101 West 22 ½ Street, Austin, Texas 78705, U.S.A.

Approximately 300 caves have been documented in Belize in the past 100 years. These include 198 registered archaeological sites. Ethnohistoric, ethnographic, iconographic, and archaeological sources indicate the importance of caves in Maya culture over a period spanning at least 1,500 years. The few analyses of ceramics from Belize caves indicate use predominantly during the Late/Terminal Classic and Early Postclassic (A.D. 600-1100). A wide array of archaeological evidence such as ceremonial dumps, burials, art, and artificial construction support the idea that caves were used primarily for ceremonial activities. Looting is a major problem, and lack of funding seriously compromises not only the protection of cave sites, but also the preservation of materials and publication of the information recovered by archaeological research.

Our understanding of the importance of caves within Maya culture comes from three major sources: ethnohistoric accounts, ethnographic studies, and archaeological reports. The ethnohistoric and ethnographic sources address almost exclusively the Maya of Guatemala and Mexico. However, many aspects of Maya culture were sufficiently similar throughout the region that these sources can also be applied to Belize. They have been summarized extensively by various authors (Thompson, 1959, 1970, 1975; Pohl & Pohl, 1983; Schele & Miller, 1986; Bonor, 1986, 1989; Bassie-Sweet, 1991; Brady, 1989). In addition, recent advances have been made in interpreting cave and underworld themes in Maya art, iconography, and epigraphy (Coe, 1978; Schele & Miller, 1986; Bassie-Sweet, 1991).

In general, the Maya believed that caves, as well as standing bodies of water, were entrances to the underworld known as Xibalba. This is a watery place inhabited by numerous unpleasant deities representing death, disease, old age, sacrifice, decay, and foul smells. Souls of the dead are required to journey through the nine levels of Xibalba, suffering numerous tests of wisdom and courage. The Sun himself successfully completes this journey each night, taking the form of the Jaguar God of the Underworld. Caves also have a very contrasting and positive aspect as the source of clouds, rain, thunder and lightning, and are thus associated with life, fertility, and rebirth. In the Maya world, caves were not simply inanimate physical features, but rather living manifestations of spiritual power. Associated with the important cycles of both life and death, caves were logical places for rituals and ceremonies. One cannot help but respect the courage of the Maya who ventured far into these realms of darkness, perhaps in small groups guided only by the light of their torches, and burdened not only with their physical offerings but also with the considerable weight of their religious beliefs.

Archaeological investigations have great potential to further increase our understanding of the Maya by studying the physical evidence left in caves. In 1983, the number of recorded archaeological sites in the Belize Department of Archaeology files was 403, of which 86 (21.3%) are caves

(Gutchen 1983). By August 1995, the number of registered cave sites had increased to 198 (Bonor, pers. comm., 1995), and ongoing projects are constantly adding new discoveries. The exact total is uncertain, because some caves have been recorded under different names, and multiple entrances to one cave system have often been recorded as separate sites. An additional problem is distinguishing between rockshelters and caves, since that distinction is sometimes not clear in the Department of Archaeology site files or in published reports. Unless noted otherwise, this paper deals exclusively with Belize caves extending beyond the daylight zone, rather than rockshelters. Unfortunately, very few of these sites have been intensively investigated, and only a handful of thorough cave archaeological studies in Belize have been completed or published. In this report, I provide a selective review of the available archaeological information regarding Belize caves. Note that some information—particularly regarding burials—is presented in general terms because of the threat of looting. Many caves in Belize are located on government or private land, and permission to visit them should first be obtained from the appropriate authorities, such as the Department of Archaeology, Forestry Department, and/or private landowner.

HISTORY OF ARCHAEOLOGICAL RESEARCH

1884-1954

The earliest published reference to archeological materials from a cave in Belize is by Lefroy (1884), who describes pottery from a cave near Garbutt's Falls on the Belize River, in the Cayo District. In an unpublished 1897 letter, Cayo District Commissioner F.L. Davis refers to approximately 44 vessels that he removed from a cave near Benque Viejo (Thompson, 1975). From 1894 to 1930, however, virtually all of the published information about Belize cave archaeology was written by Thomas Gann, a British Colonial Medical Officer. He was not an archaeologist, but had a strong interest in the ancient Maya, including their use of caves. Because his work required travel throughout the country, Gann was able to investigate caves near San Ignacio, Benque Viejo, and Arenal in the west-

ern Cayo District (1894-95, 1925, 1929), near Sarteneja and Blue Creek in the Orange Walk District (1896-97, 1918), near Churchyard in western Belize District (1929), on Indian Creek which marks the boundary between the Belize and Cayo Districts (1929), and near San Antonio and Laguna in the Toledo District (1925, 1929). (The “caves” he describes at Sarteneja and Blue Creek may have been artificially dug rather than natural.)

Gann also participated in the first formal institutional work in Belize cave archaeology, as part of the 1928 to 1930 British Museum Expedition to the Pusilha ruins and caves in the Toledo District (Gann, 1928, 1930; Joyce et al., 1928; Joyce, 1929; Gruning, 1930; Gann and Thompson, 1937). Because of his extensive pioneering contributions, Gann probably deserves the informal title of “grandfather” of Belize cave archaeology.

During this early period, only one other institution was involved in Belize caves. In 1928, the Museum of the American Indian funded Gregory Mason’s investigations in Rio Frio Caves A, B, and C, and Chikin Ac Tun in the Mountain Pine Ridge of the Cayo District (Mason, 1928, 1940).

The years from 1931 through 1954 represent a hiatus in cave research, other than a one day visit in 1938 by British civil servant Alexander Hamilton Anderson to Awe Caves (now known as Las Cuevas) in the Chiquibul area (Anderson, 1952, 1962). It is important to realize, however, that caves were being discovered and at least partially explored during this period by the few people going “back-a-bush”—the game hunters, chicleros, loggers, surveyors, geologists, and Forestry Department personnel. Modern cavers have often followed old overgrown logging roads to “discover” caves, only to find nearby sapodilla trees (*Achras sapota*) marked by the chicleros and stumps of large mahogany trees (*Swietenia macrophylla king*) removed by the loggers. Caves with names such as Awe, Casconil, and Eduardo Quiroz are tributes to the forest guards and others who first found them.

1955-1970

The Department of Archaeology was established in 1955 with A.H. Anderson as the first Archaeological Commissioner (hereafter referred to as A.C.) from 1957 to 1967. Like Gann, he was not a trained archaeologist, but his keen interest in caves proved to be a powerful force for cave archaeology in the country. Anderson was aided in his work by two American spelunkers living in Belize, W. Ford Young and Frank Norris, who discovered and explored many caves with archaeological remains, primarily in the Cayo District. During this same period, British Liaison Officer Don Owen Lewis was locating numerous caves in the Toledo District (Young, 1961).

In 1957, with Anderson’s assistance, the British Museum excavated Las Cuevas/Awe Caves (Digby, 1958a, 1958b). From 1957 to 1961, Anderson also conducted limited collections and excavations in Cubeta Caves, Eduardo Quiroz Cave,

and Rio Frio Cave E (Anderson, 1962). Sadly, many of his notes and collections were damaged or destroyed by Hurricane Hattie in 1961, and he was not able to publish his findings before his retirement and death in 1967.

Fortunately much of Anderson’s work was published and carried on by David M. Pendergast, an American who became the primary figure in Belize cave archaeology throughout the 1960’s. In 1961 he was taken to several caves in the Cayo District by Anderson (Pendergast, 1962). This trip resulted in his 1963 excavations at Eduardo Quiroz Cave (Pendergast, 1964, 1971). In 1964 he conducted excavations in Actun Balam (Pendergast, 1966, 1969) and in 1967 became Acting A.C. when Anderson retired. Subsequent publications include a general summary of Anderson’s work (Pendergast, 1968a), the description of a vessel recovered from Cubeta Cave (Pendergast, 1968b), the results of Anderson’s work in Rio Frio Cave E (Pendergast, 1970), and an account of his own 1970 investigations of Actun Polbilche (Malone, 1971; Pendergast, 1974).

Continuing the tradition of Anderson and Pendergast, the German archaeologist Peter Schmidt (A.C. 1968-1971) reported on his 1970 excavations in the small but important cave of Uchentzub in the Cayo District (Schmidt, 1978). Schmidt also made a lasting contribution by beginning a formal cataloging system of sites and artifacts within the Department of Archaeology. He recorded many cave sites by reviewing Anderson’s notes and letters as well as the published literature.

1971-1979

Two significant events occurred in 1971 and 1972. Joe Palacio became the first Belizean-born A.C. (1971-1976), and the Department of Archaeology hired two American cavers, Barbara MacLeod and Carol Jo Rushin, as Peace Corps volunteers (1972-1975). Together with Archaeological Assistant Harriott Topsey and Wildlife Conservation Officer Lucilo Sosa, they documented numerous archaeological finds in caves throughout Belize (MacLeod, 1974, 1978; Rushin, 1974, Rushin-Bell, 1982). One of the more spectacular discoveries during this period was made by a non-caver Peace Corps volunteer, Kim Kennedy, who in 1973 found 24 complete or nearly complete vessels placed in front of an altar in Hokeb Ha in the Toledo District (anon., 1973; Palacio, 1977a, 1977b).

The presence of MacLeod and Rushin had a significant long-term impact in that it attracted visits from other foreign cavers, primarily from the United States. Tom Miller made his first cave archaeology discovery in Blancaneaux Cave on his first visit in 1973 (Halliday, 1973). Miller returned to conduct his doctoral research on the karst hydrology and morphology of the Caves Branch area from 1976 to 1979 (Miller, 1981). An important result of his research was the discovery of numerous large caves with important archaeological sites that were reported to the Department of Archaeology. MacLeod returned to Belize in 1978 with Dorie Reents to co-direct the Petroglyph Cave and Caves Branch Valley Project (Reents,

1980a, 1980b; Reents-Budet & MacLeod, 1986). Elizabeth Graham, an archaeologist from the United States (Acting A.C. 1977-1979), organized excavations in Actun Chek in 1979 (Graham, McNatt & Gutchen, 1980).

1980-1989

As a result of the groundwork laid in the 1970s, and the continuing cooperation between the Department of Archaeology and foreign cavers, the 1980's saw an explosion of caving expeditions to Belize. Harriott Topsey, the second Belizean-born A.C. (1979-1995), and several Acting A.C.'s supported and occasionally conducted cave archaeology work. The Department also requested my services as a caver-archaeologist through the Peace Corps from 1983 through 1986. One of the projects that included cave archaeology as a primary research goal was the series of Chiquibul expeditions in 1984, 1986, and 1988, partially funded by the National Geographic Society and directed by Tom Miller. Cavers located numerous archaeological remains inside Actun Kabal and Cebada Cave, two of the longest and largest caves in Belize (anon., 1986a, 1986b, 1987; Crittenden, 1987; McNatt, 1984; Miller, 1984, 1986b, 1986c, 1988; Stone, 1984; Weintraub, 1984).

Another project was the 1988-92 Maya Ceremonial Caves Project, funded by Earthwatch in conjunction with the NSS Maya Caves Project (Schaeffer & Cobb, 1988). Based at Laguna Village in the Toledo District, it located approximately 60 caves, 44 of which had archaeological remains (Walters, n.d., 1988a, 1988b, 1989). Other major projects that found archaeological remains as a byproduct of cave exploration include the 1984 to 1988 Rio Grande Project in the Toledo District (Dougherty, 1985, 1986; Miller, 1986a), the 1988 Queen Mary College Speleological Expedition, and the 1989 British Speleological Expedition (Marochov & Williams, 1992).

Two additional discoveries were made in the Cayo District during the 1980s and deserve mention. In 1986, a burial chamber was found in Actun Tunichil Muknal (Miller, 1989a, 1989b, 1989c, 1989d, 1990; Roberts, 1990). Another important cave, Chechem Ha, found by a hunter ca. 1989, contains 64 complete vessels and several ceremonial features (anon., 1990; Hun, 1992; Kirk, 1993; Williams, 1992a, 1992b).

1990-PRESENT

The Department of Archaeology continues to be active in cave research. Belizean archaeologist Paul Francisco documented several caves in the Toledo District as part of the 1990 Columbia River Forest Reserve Expedition (Matola, 1991). Jaime Awe of Belize (A.C. 1976-1977) was the archaeologist in "Journey Through The Underworld," a 30 minute television documentary film on Belize cave archaeology/biology (National Geographic Society, 1995). Juan L. Bonor, a cave archaeologist from Spain, is currently working for the Department and excavating caves in the Caves Branch area (Bonor, 1994, 1995, pers. comm., 1995; Bonor & Martinez,

1995).

Two current projects from the U.S. have included cave archaeology as part of their objectives. Philip Reeder has directed speleological and geomorphic investigations in the northern Vaca Plateau of the Cayo District since 1990. His teams have located over 100 caves, many of which contain significant remains of the ancient Maya (Reeder, 1990, 1991, 1993, 1995, pers. comm., 1995). In the Toledo District, the Maya Mountains Archaeological Project began in 1992 under the direction of Peter Dunham, and has also made very important discoveries in caves (Dunham, 1995, pers. comm., 1995; Pruffer, 1995, pers. comm., 1995, 1996).

Judging from the first 100 years of archaeological investigations in the caves of Belize, it can be stated with certainty that many more important discoveries will be made in the future. Every piece of evidence, when properly documented, adds to our knowledge of the ancient Maya and their use of caves.

CHRONOLOGY

One of the most important questions to answer about cave sites is determining the dates when they were used. Ancient Maya culture has been divided into three major periods: Preclassic, Classic and Postclassic (Table 1).

Dating of cave sites presents some unique problems. Stratified deposits are often not present because the underground environment is not subject to the usual above-ground processes of weathering and natural deposition that can separate cultural layers. Despite public perception, rockfalls in caves are geologic events that are sporadic rather than common, and of little relevance to most cave sites. Major floods in active river caves tumble and break artifacts rather than preserve them under a layer of sediment. The most obvious form of natural deposition in many cave sites is the calcite deposited by dripping water. Artifacts are often covered in a calcite crust, and may even have stalagmites growing on top of them. No isotopic dating of speleothems on artifacts has yet been conducted, but the rate of calcite deposition varies tremendously in both space and time, so the results probably could not be generalized.

Table 1. Chronology of Maya Cultural Periods.

Modern:	1841 - Present
Historic:	1541 - 1841
Postclassic:	900 - 1541
Late Classic:	600 - 900
Early Classic:	250/350 - 600
Protoclassic	A.D. 100 - 250/350
Late Preclassic:	300 B.C. - A.D. 100
Middle Preclassic:	900 - 300 B.C.
Early Preclassic:	1800/1400 - 900 B.C.
Archaic:	pre-1800/1400 B.C.

To give a hypothetical example, imagine finding two complete ceramic vessels placed next to each other on a ledge. One was placed under an active drip, which has deposited a one meter tall stalagmite on top of the vessel; the other was not placed under a drip and does not have any calcite deposition. Because of their close association, one might at first assume that the vessels were put in place at the same time. However, the styles of the vessels indicate that one of them was made in Early Classic times, ca. A.D. 200, while the other was made in early Postclassic times, ca. A.D. 1,000, although the date of manufacture does not necessarily indicate the date of placement. Fortunately, both vessels contain charcoal and other organic material that can be radiocarbon dated. The radiocarbon dates closely approximate the dates of manufacture, strongly suggesting that the vessels were placed on the ledge at two discrete times, separated by about 800 years.

The above example refers to the two means by which cultural remains in Maya cave sites are dated. By far the most common technique is relative dating of pottery based on changes in styles of manufacture, form, and decoration. This method depends on comparisons with ceramics excavated from stratified deposits at surface sites, but there are limitations to this approach. For example, the most common form of vessel found in most caves is the olla or storage jar. Although this particular form has a wide range of sizes, only minor variations occur in shape and decoration, and the basic style remains consistent throughout a very long time span. Assigning dates to such vessels is often problematic. Other limitations of this method include the local variation in styles from region to region, and the frequent lack of comparative material from nearby surface sites that may be linked to use of the caves.

Radiocarbon dating of organic cultural remains can provide more absolute dates than comparative dating of ceramic styles. Although wooden artifacts and cultural vegetal remains such as maize or seeds are rare, human bone is relatively common, and charcoal from torches (generally recognized by archaeologists as pitchpine) and hearths is plentiful in many cave sites. Surprisingly, only two radiocarbon dates could be found in the published reports on Belize caves (Pendergast 1970, 1974). Processing radiocarbon samples is expensive because of the special facilities needed. The analysis of ceramics and other artifacts is also expensive because of the time involved and specialized knowledge required.

PRECLASSIC (1800 B.C. - A.D. 200)

One probable Late Preclassic sherd was found in Eduardo Quiroz Cave (Pendergast, 1964, 1971), and several sherds from the same period were recovered from Caves Branch Rock Shelter (Bonor, 1994, 1995, Bonor & Martinez, 1995). Preclassic ceramics have been found in caves in all of the areas adjacent to Belize: Yucatan, Mexico (e.g. Brainerd, 1958), Guatemala (e.g. Brady, 1989, 1991), and Honduras (e.g. Healy, 1974). The small number of Preclassic ceramics known from

Belize caves is probably a result of the incomplete nature of archaeological investigations, rather than the lack of cave use during this period (Brady, 1995, pers. comm.).

EARLY CLASSIC (A.D. 200 -600)

Ceramics from this period have been found in Eduardo Quiroz Cave (Pendergast, 1964, 1971), Caves Branch River Cave (MacLeod, 1974, Reents, 1980b), and Caves Branch Rock Shelter (Bonor, 1994, 1995; Bonor & Martinez, 1995). They make up 38.1% of the vessels represented in Petroglyph Cave (Reents, 1980a), perhaps indicating that this was the main period of use for this cave. In the Toledo District, Walters (1988b, 1989) mentions Early Classic ceramics from caves in the Actun Dzib, Blue Creek, and Deep River areas, but no detailed descriptions have been published. Prufer (1995, pers. comm., 1995) reports finding a cache of Early Classic vessels in a cave in the Toledo District.

LATE CLASSIC (A.D. 600 - C.A. 800)

Several of the most beautifully painted and unique vessels found in Belize caves date from this period, including two that have appeared on Belize postage stamps. The polychrome "Hokeb Ha vase" was one of twenty-four complete or nearly complete vessels found as an offering in the Toledo District (Palacio, 1977a, 1977b). The polychrome "Actun Balam vase" was partially reconstructed from a looted ceremonial cave deposit in the Chiquibul area (Pendergast, 1966, 1969). These are exceptional examples of apparent elite items not commonly found in Belize caves. Only "sparse" Late Classic evidence was found in the 44 cave sites documented by the Maya Ceremonial Caves Project in the Toledo District (Walters, 1988a, 1988b, 1989). Late Classic materials were also reported from Uchentzib (Schmidt, 1978), and may represent the main period of use in Eduardo Quiroz Cave (Pendergast, 1964, 1971) and Rio Frio Cave E (Pendergast, 1970). The one radiocarbon date from Rio Frio Cave E is only slightly later, at A.D. 830. One partial vessel was recovered in Batty's Cave (Pendergast, 1974) and another in Actun Polbilche, as well as a radiocarbon date of A.D. 625 from Actun Polbilche (Pendergast, 1974). In Petroglyph Cave, 32.9% of the ceramic collection was Late Classic, a slight decrease from the Early Classic (Reents, 1980a). Late Classic ceramics have also been found in Caves Branch Rock Shelter (Bonor, 1994, 1995; Bonor & Martinez, 1995).

TERMINAL CLASSIC/EARLY POSTCLASSIC (CA. A.D. 800 - 1100)

Ceramics from this transitional period are dominant in Actun Balam (Pendergast, 1966, 1969), Actun Chek (Graham, McNatt, and Gutchen, 1980), Actun Polbilche (Pendergast, 1974), and Las Cuevas (Digby, 1958a, 1958b). The latest ceramics in Eduardo Quiroz Cave (Pendergast, 1964, 1971) and a vessel from Cubeta Cave (Pendergast, 1968b) also date to this time. Schmidt (1978) places major use of Uchentzib in

the Postclassic, although contradictory data from major surface sites made it difficult for him to be sure which subdivision of the Postclassic was indicated. Several forms of vessels from unspecified caves in the Toledo District are also tentatively dated to this period (Walters, 1989). Petroglyph Cave continues to show a slight decrease in the number of vessels represented through time, but the Terminal Classic is still significant at 29% of the total collection (Reents, 1980a).

HISTORIC (A.D. 1541-1841)

No cultural remains, Mayan or other, from this period have been documented in Belize caves, which is surprising given the complex history of the country during the colonial era. However, occasional first-hand accounts persist of finding Spanish gold and weapons in caves (Pedro Reyes, pers. comm., 1992).

USES OF CAVES

Thompson (1959, 1975) lists the following major uses of caves by the Maya: 1) sources of drinking water, 2) sources of "virgin water" for religious rites, 3) religious rites, 4) burials, ossuaries, and cremations, 5) art galleries, 6) ceremonial dumps, 7) places of refuge, and 8) other uses. This list has proven to be effective in interpreting most cave sites, and is used here as a general basis for evaluating the archaeological evidence from caves in Belize.

MINOR USES

Thompson mentions the historic use of caves as temporary places of refuge, for example during the War of the Castes in Yucatan, and of walls in caves being used as hunting blinds, but neither of these has been documented in Belize. Former Belize A.C. Harriot Topsey suggested that bat and/or bird guano may have been extracted from caves for use as fertilizer (Marachov & Williams, 1992). Although not mentioned by Thompson, this is an intriguing idea since the Maya practiced large-scale agriculture in areas of very low soil fertility. Thompson does mention the use of caves as a minor source of minerals, but this activity is discussed in a following section on clay mines.

SOURCES OF DRINKING WATER

Any cave with easily accessible water could have been used for this purpose, even in places with plentiful surface water. However, in several karst areas of Belize this activity would have been a necessity rather than a convenience, particularly during the dry season. Large portions of the Vaca Plateau, Chiquibul Forest, and southern Maya Mountains around Little Quartz Ridge do not have perennial streams. In recent times, permanent water sources such as Las Cuevas and Cebada Cave were used as camps by chicleros, hunters, and/or loggers. Actun Kabal and Cebada Cave were also primary camps for cavers on the Chiquibul Caves expeditions because

of the water supply. The surface site of Las Cuevas may have been established because of the permanent spring inside the cave, a practice common in most of the Mayan karst areas (Veni, 1990). Specific use of caves for drinking water is difficult if not impossible to discern in the archaeological record, and would likely be obscured by other more obvious ceremonial activities.

RELIGIOUS RITES

As mentioned in the introduction, a wide array of deities is associated with caves in traditional Maya belief. The numerous ethnohistoric and ethnographic accounts have already been adequately summarized by authors including Thompson (1959, 1970, 1975), Pohl and Pohl (1983), Bonor (1986, 1989), and Bassie-Sweet (1991). Because caves were associated with such basic ideas as life (in the form of rain) and death (the journey through the underworld), the list of deities and associated reasons for conducting rituals in caves is very long. It includes but is not limited to rain, fertility, birth, agriculture, hunting, jaguars, deer, frogs, serpents, disease, aging, death, ancestors, calendrical period endings, and rebirth. MacLeod and Puleston (1978) theorize that the isolation and total darkness of the cave environment would have been ideal for spiritual vision quests by individuals, and perhaps further enhanced by auto-sacrifice in the form of ritual bloodletting. The burning of copal incense likely accompanied every ritual, and human sacrifice was occasionally required. Based on the archaeological evidence, ritual offerings could include every example of Maya material culture such as items of pottery, stone, bone, shell, and wood, as well as incense, maize, and other more perishable items. However, the evidence is heavily biased toward those materials that have been preserved. Missing from the archaeological record are the droning chants of priests; the music from flutes, whistles, and drums, including perhaps the pounding of "stone drums"—speleothems that resonate sound when struck; the pungent smoke from copal incense and torches; the dark and mysterious environment of the cave. The combined effect on any person involved with these ceremonies must have been overwhelming.

Unfortunately the archaeological evidence does not usually provide answers about which specific ritual(s) took place. Some caves appear to have been used for one primary activity, but others were used for a variety of ceremonial functions. Some of these uses are identifiable and are discussed below within the context of Thompson's list.

SOURCES OF VIRGIN WATER (ZUHUY HA)

Traditional Maya ceremonies required new/pure/virgin offerings, including water. Spring water and dripping water found in cenotes and caves fulfilled this need, and was usually collected in ollas. Sherds of these vessels represent the most common type of pottery found in most caves. In some instances the vessels are still complete and in place under dripping speleothems. A classic example was found in Actun



Figure 1. Bowl placed under drip in Actun Kabal to collect *zuhuy ha* (virgin water), now covered by a 1-m-tall stalagmite. Photo courtesy of George Veni.

Kabal in the Chiquibul, where one vessel that still caught water from an active drip was also partially covered by a one-meter-tall stalagmite (Figure 1). Any cave with dripping and/or flowing water was a potential source, so there are literally scores if not hundreds of caves in Belize that may have been used for the collection of *zuhuy ha*. Areas of dripping speleothems with large numbers of olla sherds can be observed in some of the more frequently visited caves in Belize, for example St. Herman's, Actun Tzimin, and Caves Branch River Cave. However, the available literature provides only a short list of caves with actual documented archaeological evidence for this specific activity: Actun Kabal (McNatt, 1984; Stone, 1984), Eduardo Quiroz Cave (Pendergast, 1964, 1971), Las Cuevas (Digby, 1958a, 1958b), an unnamed cave near Benque Viejo (Gann, 1925, 1929), and probably Rio Frio Cave A (Mason, 1928, 1940).

Certain caves such as Actun Kabal, Cebada Cave, and Las Cuevas very likely served dual purposes as sources of both

zuhuy ha and drinking water. Easily accessible permanently flowing streams just inside the entrance could have provided drinking water, while less accessible interior chambers with dripping speleothems would have been more suited for the collection of *zuhuy ha*. Long dry seasons or periods of drought would reduce the amount of water available from both sources. The Maya might have prepared for this situation by storing sufficient quantities of water in ollas.

CEREMONIAL DUMPS/OFFERINGS

Substantial deposits of cultural debris have been found in several caves, occurring as piles at the bottom of vertical shafts. These deposits do not represent occupation middens but rather materials that were obviously thrown into the caves. They usually contain large amounts of broken pottery of all kinds, plus items of flint, obsidian, bone, and shell, fragments of metates and manos, a variety of faunal remains, and sometimes even human bones. The piles include not only domestic pieces such as undecorated utilitarian pottery and simple grinding stones, but also elite objects such as obsidian blades and elaborate polychrome pottery.

Thompson interpreted these types of deposits as ceremonial "dumps." The custom of ceremonially discarding both secular and religious items was common throughout the Maya area. This activity was an important part of rituals, in particular the renewal ceremonies at the end of Maya calendrical cycles which included 260 day, 360 day, 20 year, 52 year, and even 400 year intervals.

Actun Balam contained such a deposit at the bottom of a 4-m shaft just inside the entrance. The pile measured over 5 m in diameter and 1.5 m high and held over 22,000 sherds, plus a variety of other remains (Pendergast, 1969). A deposit over 1 m thick was found under an entrance shaft in Pusilha Cave No. 1 (Joyce et al., 1928, Joyce, 1929). Brady and Rodas (1995) compare the assemblage of artifacts from these caves with that from a similar dump in Cueva de los Quetzales in Guatemala. The number of elite artifacts in these deposits apparently reflects the social setting of the cave. Actun Balam is not located near a major center and did not have many elite items, the "Pottery Cave" at Pusilha is located near the ceremonial center of the same name and contained a greater proportion of elite objects, while Los Quetzales is directly associated with a surface center and yielded a large number of elite goods.

Two recently discovered caves in the northern Vaca Plateau offer an excellent opportunity to test this hypothesis further. Macal Chasm is a large 53-m-deep vertical shaft with an 8-m-high pile of cultural debris on the bottom. It is located only 100 m from the central plaza of a ceremonial center, Ix Chel. Pottery Hill Cave is located 1500 m from the central plaza but is directly associated with an outlying structure. It is a small cave but contains thousands of sherds, including many polychromes, at the bottom of a 2-m entrance slope. These two caves have not yet been excavated (Reeder, 1993, 1995, pers.

comm. 1995).

Pendergast (1969) proposed that at least some of these piles were more than just ceremonial rubbish heaps, and were specifically intended as offerings to cave deities. For example, Actun Balam is not near any known surface site, so people would have had to make a special pilgrimage to throw the materials down the shaft. Discarding such a significant item as the Actun Balam vase would likely carry more importance as a ritual offering than any other purpose. Thompson's and Pendergast's ideas are not mutually exclusive and actually complement each other. Artifacts and other remains thrown into caves could have been intended for both ceremonial destruction and as offerings. This action would have fulfilled two needs of the Maya, to discard the pieces ceremonially, and at the same time to make offerings to the cave gods.

All of the examples given above involve artifacts apparently used outside the caves and thrown down vertical shafts, which is the basic definition of a ceremonial dump. However, one probable exception to this rule must be mentioned. About 50 m inside one of the Actun Kabal entrances is a large room (40 m long by 20 m wide and, 10 m high) christened the "Ledge of Offerings" because of the thousands of artifacts found there (Figure 2). The entrance is located at the bottom of a large sinkhole, and the room is illuminated by indirect sunlight. At the highest end of the room a 10 m vertical climb leads to a passage where *zuhuy ha* was collected. The lowest end of the room overlooks a nearly vertical shaft that drops approximately 25 m to an underground river, appearing very much like an underground cenote. Access to the ledge is possible from only one place along the edge of this shaft. A detailed description of the artifacts cannot be given here. Suffice it to say that the great quantity and variety of artifacts represent all the characteristics of a classic ceremonial dump, except that these objects were carried rather than thrown into



Figure 2. A sampling of artifacts found at the Ledge of Offerings, Actun Kabal: ceramic whistle, two incensarios, and obsidian blade. Photo courtesy of George Veni.

the cave. The nature of the assemblage together with the physical setting of the room strongly suggest the idea of ceremonial discards deposited in the cave as offerings.

The large quantities of olla sherds and complete ollas found in caves most likely represent vessels used there, and another form of ceremonial discarding. As part of the cycle of renewal and the need for pure containers for the pure water, the vessels were periodically smashed or ceremonially "killed" by punching one or more holes in them. In many cases, the sherds and/or complete vessels were then placed in niches, under rocks, or on ledges in areas where no dripping water occurs, thus fulfilling their final role as offerings. Complete ollas (some without kill holes) and olla sherds are also found in dry caves with no speleothems or other sign of *zuhuy ha* collection. In these instances the vessels were either used for some purpose other than *zuhuy ha* and/or were placed as offerings.

BURIALS

Human burials have been found in at least 23 caves in Belize, and represent approximately 200 individuals. The exact number of individuals is difficult to determine, because the mixing of bones by both cultural and natural processes often obscures the remains of individuals in a particular burial or cave. For example, even in ancient times earlier burials were inadvertently disturbed and mixed by the digging of later ones, and in recent times the actions of looters have had the same result. Burials in caves are susceptible to natural events ranging from short-term floods, which can wash them away in a single moment, to the slow but steady drips of water, which can conceal them with calcite (Figure 3).

A further complication is the wide range of burial practices used by the Maya in Belize caves: primary and secondary, single and multiple, extended and flexed, formal interments and shaft burials, ossuaries and cremations, elite and commoners, with grave goods and without, with orientation to a primary direction or not, male and female, young and old, natural causes versus possible sacrifices. Although the presence of human remains is mentioned in many reports, very few detailed descriptions have been published (Pendergast, 1971; Roberts, 1990). Therefore my discussion is limited to general aspects such as (1) major burial caves, (2) probable elite burials, and (3) the possibility of sacrifice.

Major burial caves are defined as those that contain a large number of burials and/or appear to have been used primarily for the purpose of burials. In sheer numbers, one cave in the northern Vaca Plateau is significant with an estimated 40 individuals, while another recently discovered cave in the same area has at least 12. In the northern Mountain Pine Ridge, one cave contained approximately 20 individuals, but unfortunately most of these have apparently been removed or disturbed by casual visitors. Three other caves in this area held totals of seven, six, and six burials. A large cave in the Caves Branch area contains at least 26 burials, whereas a recently discovered small cave in the same area yielded the somewhat surprising



Figure 3. Human skull covered by calcite. Photo by Logan McNatt.

total of at least nine individuals. One cave in the Toledo District is reported to have more than 23 burials and another held five. These ten caves contain approximately 154 individuals, representing the vast majority of known burials in Belize caves. At least four of the caves appear to have functioned primarily as burial sites; there are not enough data from the other six to enable any conclusions about their major use.

Elite burials are defined here by two traits. First, skulls with artificially flattened foreheads, and teeth inlaid with jade, obsidian, and/or iron pyrite indicate people of high status. Second, certain items such as slate-backed iron pyrite mosaic mirrors and elaborate personal adornments made from jadeite, bone, and/or shell were usually possessed by the elite rather than lower status individuals. Although one or two such items might be found with a low-status individual, an assemblage of such artifacts as associated grave goods strongly suggests an elite burial. Cave burials with one or both traits are not common in Belize, and flattened skulls are reported from only three cave sites. One of these contained 26 burials of which at

least one had a flattened skull but no grave goods. A second cave held six individuals, three of whom had flattened skulls, but again no associated grave goods. In the third cave, which contained an estimated 40 burials, a minimum of five had flattened skulls. Several of these had mandibles with inlaid teeth. Associated artifacts included a slate/pyrite mirror, jade beads, an alabaster bead, and a decorated bone pin. At least one dozen skulls had been removed from the main burials and placed in a separate walled chamber.

Two additional caves contain apparent elite burials based on associated grave goods, but information on the presence/absence of flattened skulls is not available. One of these caves held a multiple shaft burial with a least six individuals and a large quantity of associated artifacts including a slate/pyrite mirror, four drilled jaguar canines, a deer antler, 5 to 10 obsidian blades, and approximately 600 shell beads. The second cave has at least 12 burials, some of which are associated with polychrome pottery, obsidian blades, and jade, shell, and turquoise jewelry.

Additional elite burials may have been found but not recognized or reported. The grave goods sometimes associated with such burials are prime targets of looters, so some data may have been removed. However, the available information backs up the general consensus among archaeologists that caves were most often used as burial sites by the “common folk” rather than the elite.

Human sacrifice in caves is very difficult to demonstrate based on the archaeological evidence alone. As Roberts (1990) states regarding Maya burial practices in general: “Skeletal mutilation after death has been observed (Welsh, 1988) including, apparently, decapitations, hand and foot removal and intentionally smashed or drilled skulls and long bones.” Pendergast (1971) comments that “the difficulty of distinguishing between sacrifice and honorific burial of a naturally-deceased individual is such that no identification of sacrifices can be made in the absence of clear signs of violent death.” Given these limitations, absolute proof of human sacrifice in caves may depend on finding an obsidian or chert sacrificial knife protruding from the skull or chest of a burial. Therefore the following comments are offered as speculative inquiry rather than scientific fact.

The possibility that some of the human remains found in Belize caves may be the result of sacrifice is worth considering. The association of caves with rain ceremonies, and the association of rain ceremonies with occasional human sacrifice, particularly of children, is documented in various ethno-historic and ethnographic accounts (Thompson, 1975; Bonor, 1986, 1989). One possible example of this association in Belize is a large river cave in the Caves Branch area which contains 26 burials, of which 16 are infant/child. The predominance of infant/child remains in what is clearly a ceremonial setting suggests that they were special offerings. In traditional Maya belief, the value of such offerings to the gods would be greatly enhanced if they were sacrifices.

Assuming that sacrificial victims do represent some of the human remains found in caves, there exists the question of where they were sacrificed—outside the cave or within? Many caves with burials are easily accessible, the burials are found within a short distance of the entrance, and there is no indication of possible sacrifice. However, at least two of the major burial caves contain large burial chambers that can be reached only by traversing difficult climbs and/or long stretches of water. It is this type of setting that I think would be most likely for possible sacrifice, for both ceremonial and practical reasons. The darkness, isolation, and acoustics of the cave environment would provide an ideal location for a solemn ritual, particularly one regarding sacrifice. For practical matters, as one modern visitor observed after experiencing the difficulty of traversing the climbs and water, it would be much more logical and dignified to escort a live sacrifice (at least in the case of an adult) to the final destination than to struggle with hauling the body of a deceased one. Both the ancient Maya and their gods might have had a similar perspective.

ART

Petroglyphs (carvings in rock) are rare in Belize caves. Perhaps the best known example is Petroglyph Cave, so named because of etchings on large rimstone dams just inside the entrance (Reents, 1980a). These glyphs include “step-frets in series of seven, cloud symbols, and the Union Jack—a possible variant of the day sign Akbal” (Figure 4; MacLeod & Puleston, 1978). Also cut into the faces of the rimstone dams are numerous holes of unknown function, ranging in size from 2-18 cm wide and 0.5-10 cm deep. Some of them are large enough to serve as handholds and footholds, but many of them are not. They may have served as small niches for the burning of copal incense and/or other offerings, or perhaps as torch holders, but this is merely speculation since natural erosion and desiccation of the dams has obliterated all evidence. Bonor (1995) describes the recent discovery of petroglyphs in



Figure 4. Petroglyphs carved in a rimstone dam in Petroglyph Cave. Photo by Logan McNatt.

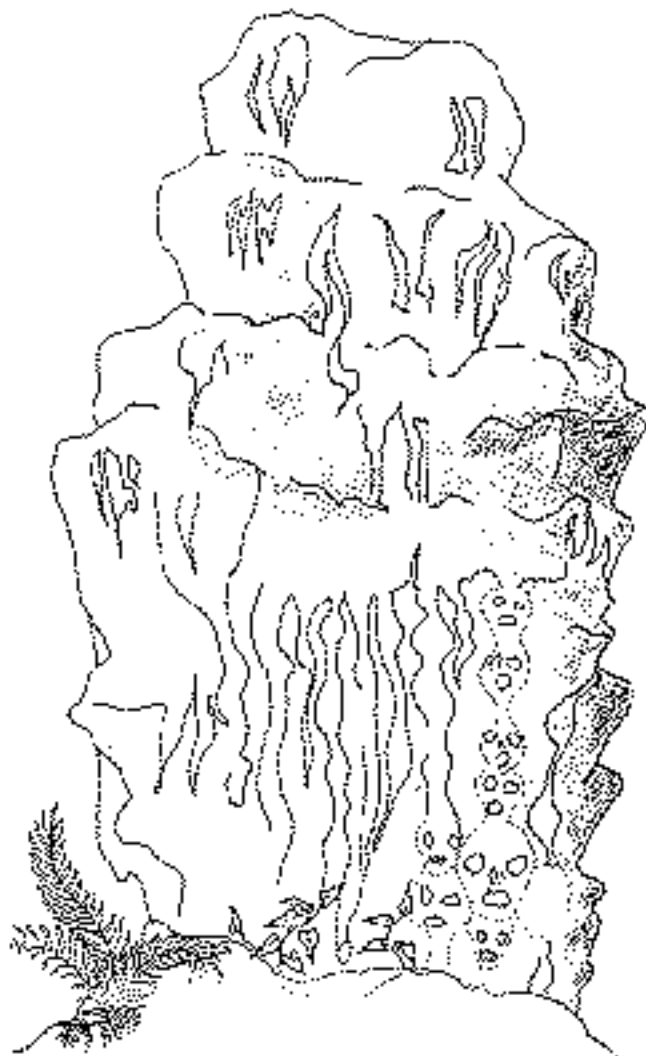


Figure 5. Faces carved in 4-m-tall stalagmite in the Caves Branch area. Drawing courtesy of Marit Brook-Kothlow.

a small cave next to the Caves Branch Rockshelter, including one “Quincunx” glyph, and others that he believes are definitely associated with water. Also in the Caves Branch area is a large interior cave room with flat rocks naturally embedded in the wall. Irregular lines circling outward from a central point are etched into these rocks.

Another style of petroglyph has been found in two caves. Eight simple human-like faces are carved into a stalagmite approximately 20 meters inside a large entrance in the Caves Branch area (Figure 5). A similar face appears on a rock outside a large cave entrance in the Toledo District. Bonor (1995) discusses the association of such faces in caves with water, so perhaps it is more than coincidence that both of the above examples involve major river caves.

Pictographs (paintings on rock) are equally rare in Belize caves, with all three known sites located in the Toledo District

(Stone, 1995). Actun Dzib (originally recorded as Actun Tz'uib) has three panels of charcoal drawings on smooth cave walls approximately 25 meters inside the entrance (Figure 6; Walters, 1988a, 1988b, 1989). The majority of these drawings are geometric designs and stick figures of humans and animals, which Stone describes as "the finest schematic paintings in the corpus of Maya cave art." Only one human figure, set apart from the rest, is drawn in a more typical Maya style. The cave contains Maya ceramics and burials, but it is virtually impossible to prove any association between these remains and the drawings. Sadly, some of the pictographs in Actun Dzib have been vandalized by modern graffiti, and the burials have been severely disturbed by looters.

The other two pictograph caves are only about 30 m in length, and contain few drawings. Roberto's Cave, near Laguna Village, has six (Walters, 1988b). Bladen 2 Cave, on the Bladen Branch of the Monkey River, has four, two of which are deity heads. When these drawings were made and why these particular caves were chosen is not known. A thorough discussion and analysis of these three Belize cave sites and all other known Maya cave pictograph sites is presented by Stone (1995).

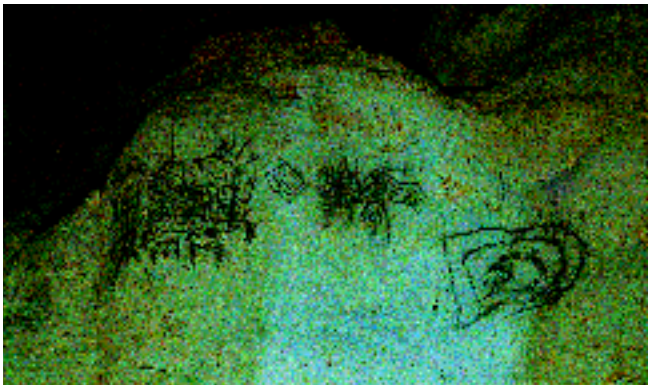


Figure 6. Pictographs in Actun Dzib. Photo by Logan McNatt.

ALTARS, IDOLS AND STELAE

These features are reported from only eleven caves in Belize. A formal altar was found in Hokeb Ha, consisting of a flattened platform 1.65 m by 1.27 m with a 0.3-m-high retaining wall of river cobbles. Immediately in front of it were 24 complete or nearly complete vessels (Palacio, 1977a, 1977b). In an unnamed cave near Benque Viejo, Gann (1929) found a "table-like altar" approximately 2.5 m long, with an associated platform and two ollas in front, and carved steps leading up to the recess containing the altar. In Rio Frio Cave C, Mason (1928) refers to "a structure which I have called an altar, although I am uncertain as to its use." From his description and the dimensions (9.1 m long by 2.7 m wide by 1.2 m high), this structure is simply a large platform rather than an altar. In a cave along the Deep River, Toledo District, Walters (1988b)

depicts an altar of four flat stones, roughly 1.5 m square, but does not provide a verbal description.

A very different type of altar was found in Actun Kabal, consisting of two upright stones about 0.5 m tall and 0.2 m apart, supported by rock rubble. One of these stones was a broken stalagmite. Immediately in front of the uprights was a meter-square area of flat stones. The entire feature was coated by dried silt from a flood, which may have washed away or covered any associated artifacts or other remains such as charcoal (McNatt, 1984; Stone, 1984, 1995: Figure 5-48). A similar style of altar, consisting of three vertical stalagmites, is reported from a cave in the Bladen Branch area (Prufer, 1995).

In some cases the attributes of "altar" and "idol" are combined. For example, in an unnamed cave near Benque Viejo, Gann (1925) observed "the top of one of the stalagmites in the great chamber had been rudely carved to represent a human head, and that in front of it was placed a more or less cubical block of stone, which may have served as an altar."

Features which are best described as idols are known from only three caves in Belize. One is the carved stalagmite described above by Gann. Another altered stalagmite is located at the back of Rio Frio Cave E, approximately 150 m from the entrance. This imposing speleothem is 2.25 m wide, 2.5 m thick, and 2.75 m tall, and resembles a seated human figure. Despite its substantial weight, the figure appears to have been moved an unknown distance to its present location at the back center of the cave. A series of eight small circular depressions were cut into the front of the figure. A.H. Anderson recovered olla sherds, burnt wood, and possible copal charcoal from a depression in front of the "head," indicating use as an altar. Pendergast (1970) discusses the figure and its possible relationship to other activities in the cave. Although the figure likely represents some Maya cave deity, neither its identity nor the ceremonies associated with it can be determined with any certainty.

A head carved out of a clay bank in Actun Chek (Figure 7) poses similar problems. This feature measures 0.3 m high by 0.25 m wide, and is located in a clay mine 450 m inside the cave. A black stain on the ceiling immediately above indicates that some substance, possibly copal, was burned on top of the head. This evidence, and a small complete olla placed immediately below together with other associated artifacts, indicate that the idol also served as an altar. For a thorough description and discussion of this feature, see Graham, McNatt, and Gutchen (1980).

Three caves in Belize contain stones placed in upright positions resembling a crude form of stela. In the entrance of Petroglyph Cave, a 1.6-m-tall broken stalagmite was held in place by rock rubble (Reents, 1980a; Reents-Budet & MacLeod, 1986). Another broken stalagmite about one meter tall was obviously placed on a dirt floor in a cathedral-like room at the end of Chechem Ha, about 200 m from the entrance (anon., 1990). The most intriguing example is a slate slab, also about one meter tall, found in a small chamber over-



Figure 7. Face carved in a clay bank, height 0.3 m, Actun Chek. Drawing courtesy of Kathy Bareiss-Roemer.

looking an active stream passage in Actun Tunichil Muknal (Miller, 1989b, 1989c, 1989d, 1990). A primitive face is carved on one side, and the edges of the slab have been scalloped in such a way as to remind one observer of a stingray spine. As with so many features found in caves, the exact purpose of these stones and the ceremonies associated with them may never be known. However, it may be significant that two of the three sites containing stelae are major burial caves.

CLAY MINES

Although the extraction of clay and other minerals is known from several caves in the Yucatan, this activity is known from only one cave in Belize. Actun Chek (Footprint Cave) has three areas of red clay deposits that contain obvious digging marks. The clay appears white because of a thin coating of calcite. All of these areas are located within the dark zone of the cave, from 100-450 m inside the entrance. Reaching them requires traversing a river that flows through the cave. In one locale, a finely chipped chert knife was found, similar to the sacrificial knives used by the Maya. At the most interior mine site, a grotesque clay face had been sculpted out of the clay bank, and a complete small olla was placed immediately below

it. Sherds, charcoal, and other signs of cultural activity were associated with this mine (Graham, McNatt, & Gutchen, 1980).

MacLeod and Puleston (1978) argue that these mines were a type of ritual activity. The location in dark and relatively inaccessible places, and the association of ceremonial features such as the clay face and chert knife strongly support this view. The authors also suggest that the clay may have been used for the specific purpose of making ceremonial vessels painted with underworld scenes to be placed in tombs. Although logical, this hypothesis could be tested only by matching a chemical analysis of these clay sources with clay from specific vessels.

ARTIFICIAL CONSTRUCTION IN CAVES

The Maya artificially modified the natural setting in so many caves in Belize and elsewhere that this subject requires separate discussion. Some features in the dark interior such as narrowed passages, walls separating chambers, and sealed chambers have no practical purpose other than ceremonial. Other features such as terraces, walls, platforms and steps in the daylight zone of large entrances could have been used for habitation rather than strictly ceremonial purposes. However, the overwhelming importance and use of caves as sacred areas is a strong argument against such domestic use (Brady et al., 1992; Brady, pers. comm., 1995).

Only five caves in Belize have received intensive investigations of artificial construction in the entrance areas, and only one of these contained evidence of long-term use. Excavations in Eduardo Quiroz Cave (Pendergast, 1971) revealed a refuse midden 0.5-0.9 m thick in Chamber 1, 10-20 m inside the entrance. The chamber also contained walls, terraces or steps, a plaster floor, and five burials including two children. A wall of dry-laid stones separates the rear of the chamber from the rest of the cave. Because the interior of the cave beyond the chamber was obviously used for ceremonial purposes, it is difficult to imagine a strictly secular use of the cave entrance by a family or other small group of residents. Pendergast concludes that Chamber 1 was occupied for considerable lengths of time, and that the occupants perhaps served as caretakers for the cave. Their duties might have included supervision of the collection of *zuhuy ha* in the interior, the cyclic destruction and replacement of *zuhuy ha* vessels, and other ceremonies for which there is less definite archaeological evidence. Whether the caretakers lived in the cave throughout the year or only periodically during ceremonies is open to question, although Pendergast thinks that the midden and burials suggest continuous occupation in Eduardo Quiroz Cave.

Las Cuevas (Digby, 1958a, 1958b) is located below and adjacent to a minor ceremonial center of the same name. A permanently flowing stream immediately inside the entrance probably provided drinking water for the surface site, while dripping speleothems in the cave interior were obviously used for the collection of *zuhuy ha*. The large entrance room is illu-

minated by daylight during part of each day, and has three platforms, several walls, and traces of plaster floors. Digby excavated these features but does not mention finding an occupation midden similar to the one in Eduardo Quiroz Cave. Few artifacts were uncovered in the entrance area, including fragments of several incensarios and one vessel that may have held a cremation.

Rio Frio Cave C is a large tunnel-like cave, cut by the Rio Frio through a limestone hill. It is approximately 150 m long, 50 m wide and 25 m high, with large entrances at either end. Indirect sunlight illuminates the entire cave, except for several small side passages and recesses. Mason (1928, 1940) removed a large platform approximately 9 m long by 3 m wide by 1 m high. He found a deposit of ashes and several pieces of jadeite, but no occupation midden.

Petroglyph Cave has one of the most spectacular entrances known in Belize. It is located at the bottom of a 150-m-wide sinkhole with vertical walls 10-30 m high. Only one place affords "easy" access, and even this requires artificial aid such as ropes or a log ladder. The entrance itself is approximately 70 m wide by 30 m high, opening into a room about 220 m long. The floor drops precipitously to a permanently flowing stream 40 m below, accessible by only one precarious route, which shows signs of use by the ancient Maya. The ceiling of this immense void is 40-60 m above the stream, and the entire area is illuminated by daylight. The trail to the stream passes beside a huge rock (ca. 15 m long by 10 m wide by 10 m high) that fell from the ceiling before the Maya used the cave. At the base of this rock was a series of 5-6 wide steps which have been destroyed by looters. On a breakdown/talus slope above the steps are eight terraces with low retaining walls of dry laid stones. From any viewpoint, even the most jaded modern visitor is impressed by the cathedral aspects of this vast chamber.

MacLeod and Reents conducted investigations in the cave in 1978, including some excavations in the entrance chamber (Reents, 1980a; Reents-Budet & MacLeod, 1986). Although numerous sherds, pieces of obsidian, modified and unmodified shell, ash and charcoal from hearths, and other remains were found scattered around the room, there was no midden or other sign of continuous occupation. This negative evidence of occupation is reinforced by positive evidence of ceremonial use such as petroglyphs, a stalagmite "stela," and major use of the cave for burials. In practical terms alone, the difficulty of moving in and out of the cave makes it an unlikely residence.

A final example of major artificial construction is found in the Chiquibul Chamber, the largest entrance of Actun Kabal in the Chiquibul Cave system (McNatt, 1984; Miller, 1984; Stone, 1984). At the time of its discovery, it was the fifth largest cave room known in the world, with an 80-m-wide entrance opening into a room approximately 150 m wide by 250 m long by 45 m high. Like the entrance of Petroglyph Cave, it is at the bottom of a huge sinkhole, but access is comparatively easy and does not require any artificial aids. There is a permanent spring at the rear of the chamber, and the entire



Figure 8. Colluvium-covered terraces on talus slope into Chiquibul Chamber, Actun Kabal; note people and tent in foreground for scale. Photo courtesy of George Veni.

room is illuminated by daylight during part of each day. A massive breakdown pile on one side of the chamber concealed numerous complete vessels, including large ollas and several polychrome dishes and plates. On the other side of the chamber, a large talus slope extends from ceiling to floor. A total of 31 terraces and platforms were mapped in the entrance, with most of them found on the talus slope (Figure 8). Some of these features are contiguous and up to 25 m long, while others are isolated. The size and surface area of the terraces varies greatly, but all are held by retaining walls of dry-laid stones from 0.25-1.5 m in height. It is possible that the entire slope was terraced and that many of the surfaces and retaining walls have been covered with colluvial debris. The series of terraces descend the slope to a large colluvial fan, that has been leveled and outlined with rocks, on the edge of a 20-m-wide rocky streambed that carries water only during floods. On one side of the fan is a massive 10-m-tall stalagmite which has natural features resembling a human figure. The overall visual effect is of a grand amphitheater, with the terraces serving as viewing platforms and the colluvial fan as "center stage." One unmortared stone wall 20 m long by 1 m thick by 1.5 m high is located between two large breakdown blocks. The calcite-covered remnant of another wall is found at the rear of the chamber between two speleothems. These walls are easily avoided, and appear to have no other purpose than to restrict or direct access to the spring at the back of the chamber.

The spring provides a major source of permanent water during the dry season. For such an important resource located within the sacred setting of a cave, the presence of part-time or full-time caretakers is a possibility. Other areas of the cave were used for various ritual purposes such as *zuhuy ha* collection and ceremonial dumping. During the 1984 and 1986 Chiquibul Cave expeditions, a thorough surface examination of the terraces was conducted, which yielded only a thin scat-

ter of sherds and a few other artifacts. Although no excavations were undertaken, the surficial nature of these terraces on the talus slope does not indicate the presence of a deeper midden deposit.

In the examples cited above, there is no evidence to suggest that the platforms and terraces supported perishable structures. However, three caves do contain tantalizing evidence of such structures. In another major entrance of Actun Kabal, a 3-m-square outline of flat stones has all the appearances of a building foundation. About 50 m inside one of the large entrances of the Caves Branch River Cave, approximately 30 postholes were found (MacLeod, pers. comm., 1995). In Actun Balam, Pendergast (1974) found "39 fragments of unburnt clay daub, with impressions of poles, leaves, and what appears to be grass." The pieces of daub were small, dissolved easily in water, and were recovered only because conditions in the cave were relatively dry and unusually conducive to preservation. They were located in a high alcove containing numerous vessels and other remains including a wooden spear. Pendergast interprets them as the probable remains of a pole screen or framework enclosure of the artifacts, rather than as the remains of a dwelling. Such small clues provide intriguing hints of the possibility of perishable structures in other caves, where more typical wet conditions have eliminated such fragile remains from the archaeological record.

In conclusion, the available evidence indicates that artificial construction in the daylight zones of large entrances in Belize caves was intended for ceremonial purposes rather than domestic habitation. First, these entrances provide access to significant ceremonial areas within the dark zone. Second, they do not usually contain refuse middens indicative of long-term occupation. Although such a midden was found in Eduardo Quiroz Cave, Pendergast interprets it as a result of ceremonial "caretaker" activities rather than a purely secular use. Many caves with artificial construction in Belize offer the opportunity for excavations to determine the presence/absence of middens and perhaps perishable structures.

PROBLEMS

LOOTING

The most obvious and critical problem confronting cave archaeology in Belize is looting. The theft of antiquities for sale on the black market is a worldwide problem, and Mayan artifacts are increasingly popular among collectors. One reason for this may be the international publicity that any major discovery receives, often in glamorous terms of "lost treasure" rather than a more educational or scientific approach. Other reasons include the relative poverty of many people in less developed countries, the ease of transporting artifacts through already established networks such as drug-smuggling, the low risk of prosecution, and the low fines compared to the financial rewards.

Since 1971, Belize has had strong laws protecting its

archaeological resources (anon., 1971; Government of Belize 1971; Gutchen, 1983), but enforcing those laws is very difficult. Caves are particularly vulnerable to looting. There are many of them, the entrances are often naturally concealed far from roads and habitations, and they contain artifacts that are usually not buried and can thus be easily collected with minimal effort and time.

The extent of the problem is widely recognized but difficult to measure. Occasional publications have mentioned the looting of caves (anon., 1982, 1984; Rushin-Bell, 1982). The only systematic study of looting in Belize was made by Mark Gutchen (1983), a former Peace Corps volunteer for the Department of Archaeology from 1978 to 1980. Of the 86 registered cave sites in his study, 37 or 43% had documented damage from looting. The actual damage may be much greater, as Gutchen states:

Determining the extent of looting in cave sites is often quite difficult because it is possible to remove artifacts without leaving any trace. The only ways to determine if artifacts were removed, therefore, are 1) to have information as to their presence before the looting took place; 2) to have data from reliable informants that the items were removed; or 3) to seize artifacts illegally removed and have the thief report the location to investigators.

In 1976, Tom Miller and I took Acting A.C. Jaime Awe into a large cave in the Caves Branch area to show him several complete vessels and a human skeleton that had been found during our initial exploration. We took photographs but did not remove the artifacts because the cave was known only to our small group of five people. Unfortunately, one of this group (neither a caver nor archaeologist) told others, and word eventually spread. When we returned to the cave nine months later, we found that the vessels had been stolen, the skeleton trampled on, and the skull removed. Although the culprits were known by several witnesses, they were not prosecuted due to a lack of direct evidence.

In 1978, a beautiful calcite-encrusted human skull was chipped out of its sacred resting place by persons unknown. Until then, the skull had been respectfully viewed by dozens of modern explorers over a ten year period. As recently as 1992, a series of steps in Petroglyph Cave was dismantled and discarded as rubble, apparently by some looter futilely searching for "treasure." The vessels, skeletons, and steps in these caves had been sitting undisturbed for over 1,000 years, but were removed/destroyed in a few brief moments of greed. All we have to offer future generations are photographs.

The causes of looting are complex and not easily resolved. Matsuda (1994, 1995) provides an interesting discussion from the looter's perspective. He argues rather convincingly that until basic social and economic disparities that create poverty are resolved, then looting will continue to be a viable source of income for some people. Griffin (1986) defended the collec-

tor's viewpoint in a National Geographic article, which surprised and angered many archaeologists. Their rebuttal is given by Chase, Chase, and Topsey (1988). The onus of the problem ultimately rests upon the buyers and collectors, most of whom live in foreign countries. As long as there is a demand, there will be a supply.

FUNDING

A second more subtle but equally critical problem affecting cave archaeology in Belize and many other countries is best described as the lack of funding. The Department of Archaeology (DOA) is the primary governmental agency in charge of archaeology throughout Belize. Major responsibilities include documentation of all known archaeological sites (including many non-Maya historic ruins), curation of antiquities, maintenance of several Maya ruins open to the public, and administrative duties involving the many foreign projects working in Belize. In addition, the DOA provides lectures, exhibits, and other public education and information services.

In spite of these many responsibilities, the DOA has consistently been underfunded and understaffed, and there has been a significant turnover in personnel over the years. Understandably, archaeology is a low priority compared to building roads, schools, and other basic infrastructure. The lack of funding affects cave archaeology in three important ways: protection, preservation, and publication.

Protection of cave sites is a daunting task. Employment of full-time guards and/or the installation of cave gates are costly and impractical measures in most cases. Protection will more likely result from serious efforts by archaeologists, cavers, government agencies and others to increase public awareness and reduce the basic causes of looting. The problem appears much larger than any practical solution.

However, several cave sites in Belize have been protected. Chechem Ha in the Vaca Plateau was gated with funds and labor provided by Chaa Creek, a nearby tourist resort owned by Mick and Lucy Fleming. The Antonio Morales family serves as guardians of the cave, offering lodging, meals, and guided tours for visitors. In the Caves Branch area, Ian Anderson operates a similar service to several different caves, providing an opportunity for people to visit the caves while restricting access by unauthorized persons. Las Cuevas in the Chiquibul Forest Reserve has recently become the location of a research station, which allows self-guided tours of the cave by visitors. Other than the gate at Chechem Ha, these caves have been preserved in their natural state with no artificial development such as lights or trails. Artifacts and other archaeological remains can be observed and photographed by visitors but are not disturbed. The combination of efforts by private "ecotourism/adventure" entrepreneurs and/or non-profit research organizations in cooperation with governmental agencies such as the DOA and Forestry Department may provide future protection for other important cave sites throughout the country.

Preservation as used here regards both the physical remains and written information gleaned from cave archaeology. Although a Department of Museums was established in 1990, Belize does not yet have a National Museum. There is an appalling lack of storage space for artifacts, requiring the DOA to use offices, a dirt-floored basement, and for several years even unused jail cells for storage. Threats from termites, silverfish, heat, dust, and humidity are constant. Lack of security is also a problem; in 1983 the DOA was broken into and ten irreplaceable artifacts were stolen, including two from caves (anon., 1983).

Hundreds of artifacts from caves are present in the collections, ranging from dozens of large ceramic vessels to many small fragile items of bone, shell, and wood. Although some of the items are stored on shelves, many are packed away in cardboard boxes, which, by necessity, are piled on top of each other. Misplacement and mixing of artifacts is an inevitable result. For example, while working for the DOA in 1984, I found a box with large ceramic sherds and several historic bottles. In the box was a silverfish-eaten scrap of paper with a barely legible handwritten note: "Found by two white men in a cave in the Toledo District." It is doubtful that the bottles came from a cave or were originally associated with the potsherds. Without a date or other information the artifacts were necessarily labeled PNK, meaning Provenience Not Known.

In addition to the potential for damage, accessibility for cataloging, analysis, photography, and further study is a problem. The lack of adequate storage space combined with a shortage of laboratory and office space is a severe hindrance to both DOA personnel and foreign researchers wishing to conduct studies of archaeological materials, whether from caves or other sites.

Preservation of written information about cave sites is also a problem. Within the DOA, much of the data are buried in letters, memos, and reports of trips, which are filed by date rather than subject. Many of the files are yellowed and brittle from age, and have suffered damage from silverfish. For example, A.H. Anderson typed many lengthy letters on onion-skin paper, which include information about his work in caves. I found one of his letters explaining how Casconil Cave got its name, from combining the last names of the discoverers "Castillo, Cocum, and Cunil." This information had not been previously recorded on the card catalog for this site.

Outside of Belize, a great deal of information about Belize cave sites also exists in both published and unpublished form: articles, journals, trip reports, maps, and photographs, by cavers, archaeologists, tourists, and other visitors. DOA policy requires copies of such information from all officially permitted projects, but obviously cannot keep track of information acquired by casual visitors. Actun Polbilche is an example of how important this information can be. The cave was discovered by non-archaeologists from the United States, who removed some artifacts and casually reported their findings in a non-archaeological publication (Malone, 1971). Fortunately

the report came to the attention of archaeologist David Pendergast; the cave contained rarely preserved perishable items—a wooden spear and wooden box—as well as numerous complete ceramic vessels and other cultural material (Pendergast, 1974).

Publication, or rather the lack of publications about cave sites despite the hundreds of reported discoveries, is the final result of the lack of funding. It is much easier and less expensive to find the sites than it is to conduct an extensive evaluation and interpretation of them. Many serendipitous discoveries have been made by both Belizeans and foreigners who visited caves and unintentionally found archaeological remains. The DOA itself has conducted numerous investigations in caves—essentially salvage operations to recover artifacts because of the threat of looting—which have never been published. Even major caving and archaeological projects that expect to find cave sites cannot usually include the costs of archaeological excavations, analysis, and write-up. With the growing population, development, and research in Belize, the rate of archaeological discoveries in caves has increased, but unfortunately so has the information gap.

Obviously, funding of archaeological research in caves is not the primary responsibility of any particular country, government agency, archaeological or caving organization, or individual. Ironically, the lack of funding is less of a problem for looters and their buyers/collectors than for archaeologists and governments. As long as “finding” surpasses “funding,” efforts to protect, preserve, and publish will be severely limited, and cave sites will continue to be an increasingly endangered heritage.

THE FUTURE OF THE PAST: SUGGESTIONS FOR FUTURE RESEARCH

This paper offers only a broad overview of cave archaeology in Belize. Each of the major topics could be and should be discussed in much greater detail. Certain subjects such as perishable remains, exotic trade goods, and the relationship of cave sites to surface sites, are mentioned only briefly or not at all. I accept full responsibility for these and other omissions and for any errors, and have the audacity to offer the following suggestions for future work.

LABORATORY ANALYSIS

A tremendous amount of material has been collected from caves in Belize, but much of it has never been analyzed. (Examples include several projects in which the author participated such as the Footprint Cave and the Chiquibul Caves expeditions) These artifacts represent a significant component of the DOA's collections, and an invaluable resource for current and future cave studies. The following analyses should be completed:

A. Ceramics, Lithics, and Faunal (non-human) Materials: Ceramics are the most common cultural remains found in

caves, and are the major source for not only dating the use of caves but also interpreting the meaning of use. Studies of ground stone and chipped stone artifacts can include typology, use-wear, and residue analyses. Animal teeth and bones, as well as marine and freshwater shells, have been found as both modified artifacts and as unmodified naturally occurring remains. Analyses of the faunal remains can identify which animals may have been exploited for food and/or ceremonial use, and provide clues to the micro-climate of the cave in which they were found.

B. Burials: Human skulls and other skeletal remains can often provide answers to questions such as age, sex, diet, disease, social status, and cause of death.

C. Exotics: Although jadeite and obsidian have been found in numerous caves in Belize, the only known sources are outside the country. Species of marine shells have been found from both the Atlantic and Pacific. Lithics such as chert, basalt, and granite occur only in certain places within Belize but are found in caves throughout the country. Chemical and/or biological analyses can often pinpoint the sources of these materials, and provide important information on trade routes and the relationship between sites.

D. Perishables: Although preservation of items such as wood is rare in Belize caves, the DOA collections include several wooden artifacts that have never been analyzed for identification of the material used, or submitted for radiocarbon dating. Outside the lab, other unique perishable remains such as the human footprints and clay mask in Actun Chek are susceptible to damage from both floods and casual visitors. They have been photographed, but should be further documented with latex or plaster molds. Vegetal remains, such as a reported corn husk in an olla in Chechem Ha (anon., 1990), also should be preserved and analyzed.

E. Archival: A wealth of information about caves is buried in trip reports, letters, and memos within the DOA files. In particular, much of A.H. Anderson's work in caves is recorded in his letters and memos typed on thin onion-skin paper. The letters include memorable comments on not only the caves, but also on Belize in general. “The Letters of A.H. Anderson” would make a fascinating volume.

FIELD WORK

Despite the hundreds of cave sites known in Belize, basic information is still lacking for many of them:

A. Location: Until recently, the lack of adequate topographic maps prevented precise location of most caves, especially those found far from roads or other recognizable landmarks. Satellites and GPS systems now make it possible to locate caves precisely, but considerable time and effort is needed to relocate many caves. Of course, information about locations of cave sites would have to be controlled by the DOA and other responsible agencies to prevent looting and disturbance by casual visitors.

B. Maps: Many cave sites have not been mapped. Cave

surveys in Belize have generally been accomplished by caver volunteers, and the maps are often not published or available to other researchers. The maps do not usually include archaeological remains, and at least in the case of large caves do not provide enough detail for an archaeologist to precisely locate such remains. Even well-known and frequently visited caves such as St. Herman's and Rio Frio Cave C do not have adequate maps, although both caves are tourist sites and have been surveyed. In most cases, distribution of cave maps should be restricted for the same reasons as those involving locational information. Surveying or in some instances resurveying the known cave sites in Belize would be an expensive but highly productive undertaking, and might be accomplished by using the skills of the many experienced caver volunteers who visit Belize each year.

C. Collections and Excavations: Most cave sites in Belize have not been adequately sampled from an archaeological standpoint. Even a small controlled surface collection and one or two test pits in each cave could provide important data regarding such basic questions as stratigraphy, chronology, and use. Charcoal samples could easily be collected in numerous caves for radiocarbon dating.

PUBLICATION

The lack of detailed archaeological publications on cave sites in Belize has already been mentioned, and was a major difficulty in writing this paper. Even if field work and laboratory analyses have been conducted, the information is virtually useless unless it is communicated and shared. As Chase, Chase, and Topsey (1988) state: "Not writing up and not publishing findings is irresponsible. However, non-archaeologists need to understand that for every day spent in the field, at minimum seven days are required for processing, analyzing, and writing." The few published reports, particularly those by David Pendergast, cast a luminous glow in the otherwise stygian darkness of cave archaeology in Belize.

As a final thought, perhaps Alexander Hamilton Anderson's statement is just as true today as when he made it: "The more I see of caves with Maya remains the stronger I feel that they merit, almost demand, far deeper probing than the very shallow scratching that has been done to date" (Anderson, 1962).

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GEOLOGIC AND HYDROLOGIC CONTROLS ON KARST AND CAVE DEVELOPMENT IN BELIZE

THOMAS E. MILLER

Department of Geology, Eastern Washington University, Cheney, Washington 99004, U.S.A.

0.1 Nearly 3000 km² of Belize display well-developed karst that occurs dominantly on Cretaceous limestones distributed on the periphery of the Maya Mountains. Other exposed carbonates in Belize, sharing the same tropical climate and heavy rainfall, are not karsted. The Mayas represent a horst structure raised by movement of the Caribbean-North American plate boundary. In excess of 150 km of large cave passage has been mapped, often exhibiting multi-level development likely related to this regional tectonic motion. Passages are dominantly trunk conduits solutionally bored through the lower-lying limestones by integrated allogenic streams from the Mayas. Other large, independent caves and collapse chambers are also known. Limited U-series dating of speleothem gives minimum ages of 176 KaBP for cave development. The karst surfaces are dominated by disaggregated remnants of previous fluvial networks, but also contain spectacular collapse dolines. The karst aquifers appear to be solutionally "open" systems of relatively high porosity (>1%). Boosting of carbon dioxide levels above surface soil CO₂ occurs within aquifers, perhaps due to decay of washed-in vegetation. Mean solutional erosion is estimated at 0.10-0.13 m/Ka for these karsts.

Belize consists of the ancient, escarpment-bounded Maya Mountains, which rise to 1,100 m and are encircled by lower and younger sedimentary rocks, chiefly carbonates. Of primary importance to karst and cave development is the broad belt of Cretaceous limestones and dolomites which routes all but the largest highland streams underground. The remainder of Belize is mostly a seasonally swampy plain (0-80 m elevation) of soft Tertiary and Quaternary carbonates. The coastline is bordered by a 250-km-long barrier reef. Of the country's 23,000 km², about 3,000 km² has well-developed karst.

Knowledge of the Belizean karst has come chiefly from sporadic but often intense cave exploration within the past 40 years. More than 150 km of cave passages have been surveyed by various groups. Investigations of the development of the karst surface and the carbonate water chemistry have been considerably briefer and areally-confined.

Some information in this report has appeared in scattered international caving or cave-science publications, often only as abstracts accompanying presentations. The majority of the karst information is from unpublished monographs submitted as reports to funding agencies, and is published here for the first time. Substantial data remain unpublished and unanalyzed.

The following is intended to be a general review of the range of these karst-related studies in Belize, rather than an in-depth discussion of the enormous subject of karst and cave genesis in that country. However, much that is presented or collated here appears together, also for the first time. The regional geology contributing to the presence of karst in Belize is emphasized in more detail than has been presented elsewhere, as are the details of cave morphology and, to a lesser extent, surface karst development.

REGIONAL CLIMATE AND HYDROLOGY

Belize is divided by the boundary between the tropical savanna climate of its northern half (very similar to that of the Mexican Yucatan) and tropical rainforest to the south (Hartshorn et al., 1984). Annual rainfall in Belize increases with elevation and more southerly latitude, affected by the large topographic bulk of the Maya Mountains in the southern half of the country (Figure 1). Walker (1973) cites mean annual rainfall of 130 cm near Corozal, in the north, to more than 450 cm at Punta Gorda, in the south. Prevailing winds are easterly from the Caribbean, and deposit sodium and chloride ions in decreasing amounts landward.

Density fronts, common in temperate latitudes, are rare in the tropics due to the uniform temperatures. Although occasional outbreaks of polar air, called "northers," can produce heavy rains; thunderstorms and other convergences of similar, high-temperature saturated air masses are the primary causes of precipitation. Hurricanes can create heavy rain but hit Belize infrequently, with seven landfalls from 1931-1978 (Hartshorn et al., 1984), and most recently in 1995.

Daily temperature variations are due primarily to changes in cloud cover; only 63% of the possible solar insolation is received at the ground due to cloud interception, a major inhibitor of high temperatures. The northers sometimes lower temperatures to less than 10°C during the winter months. Temperature spans monthly minima of 16°C to monthly maxima of 33°C in the lowlands. Higher elevations are cooler, but freezing temperatures have never been recorded in Belize (Walker, 1973).

Figure 2 shows monthly temperature and rainfall for three representative sites in central Belize that range from sea level to 560 m elevation. The highest, Cooma Cairn, is located in the

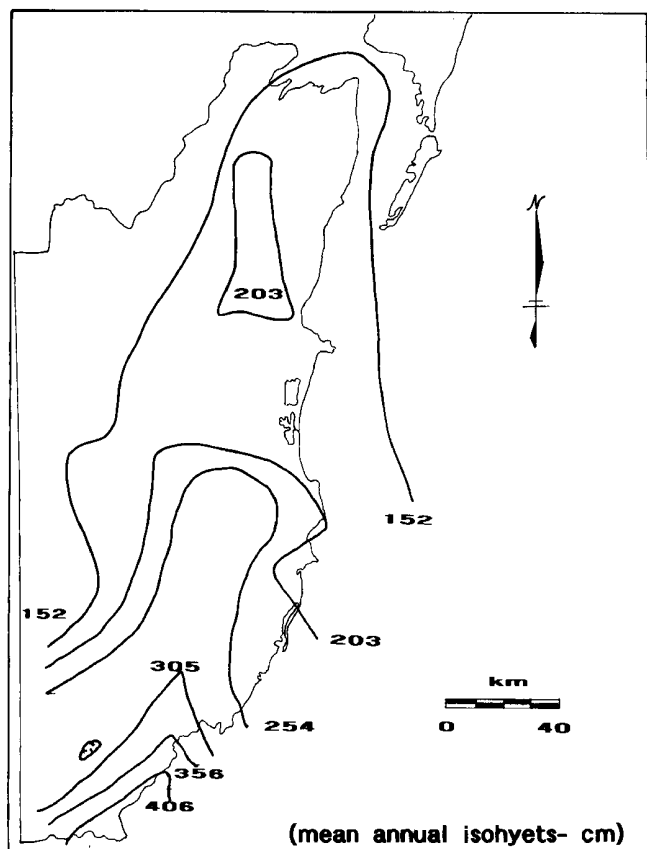


Figure 1. Rainfall isohyets, Belize (after Hartshorn et al., 1984).

northern Maya Mountains above the Boundary Fault Karst. All have precipitation greater than 100 cm/yr and mean temperatures above 20°C. March and April are the driest months at all three sites, with May being the month with the most variable rainfall pattern. The wet season occurs from June through December. Because of the abundant precipitation and vegetation, evapotranspiration operates nearly at maximum rates all year except for the short dry season.

A stream-gauging network has been established in Belize, but few streamflow data have been published (Government of Belize, 1982). For the water year 1981-1982, the mean annual flow of the Belize River, the largest in the country, was calculated at 155 m³/sec (Hartshorn et al., 1984). Unit catchment sizes needed to produce 10 m³/sec mean annual discharges ranged from 160-525 km², generally with the smaller areas in the higher rainfall regions of the south.

REGIONAL GEOLOGY AND ORIGIN OF THE MAJOR KARSTED ROCKS

All known caves and karst in Belize are developed in carbonate rocks, primarily Cretaceous limestone. Much less frequently, Tertiary dolomites and Quaternary carbonates contain solutional features. Most prior geologic attention has concen-

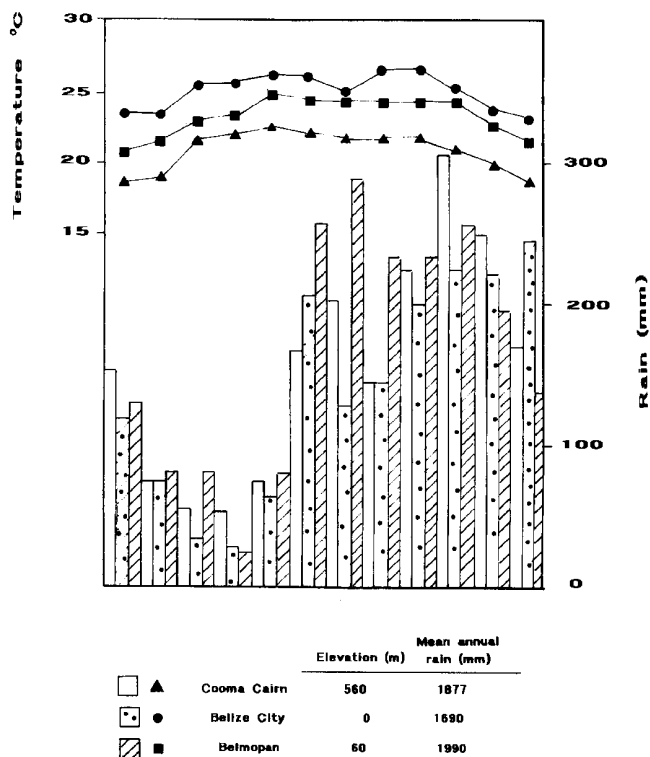


Figure 2. Climate data, Belize: three selected sites (from Miller, 1981a).

trated on the mineral potential of the Maya Mountains, the petrocarbons of the deeply-buried Cretaceous carbonates of northern Belize, or the ecologically-interesting barrier reef. Consequently, basic stratigraphic knowledge of the Cretaceous limestones has scarcely advanced beyond Ower's (1928) fossil collecting, and most is of peripheral value to karst investigations. The several units of Cretaceous carbonates continue to remain undifferentiated on most geologic maps (Figure 3).

Although preliminary geologic work was begun in Belize near the turn of the twentieth century, the first detailed studies were by Ower (1928). These were followed by Flores (1952) and numerous reports beginning in the late 1960s. The total number of geologic studies increased dramatically in the 1970s, and in the 1980s the Office of Geology and Petroleum (Ministry of Natural Resources) was established by the government of Belize.

TECTONIC HISTORY

The geologic structure of Belize is dominated by the Maya Mountains (or *Mayas*). Although underlain chiefly by essentially non-soluble metasediments and igneous intrusives, the evolution of the range played a major role in the location of later carbonate rocks, as well as the topographic situations most favorable to cavern development in Belize.

The Mayas are an uplifted block of Paleozoic metasedi-

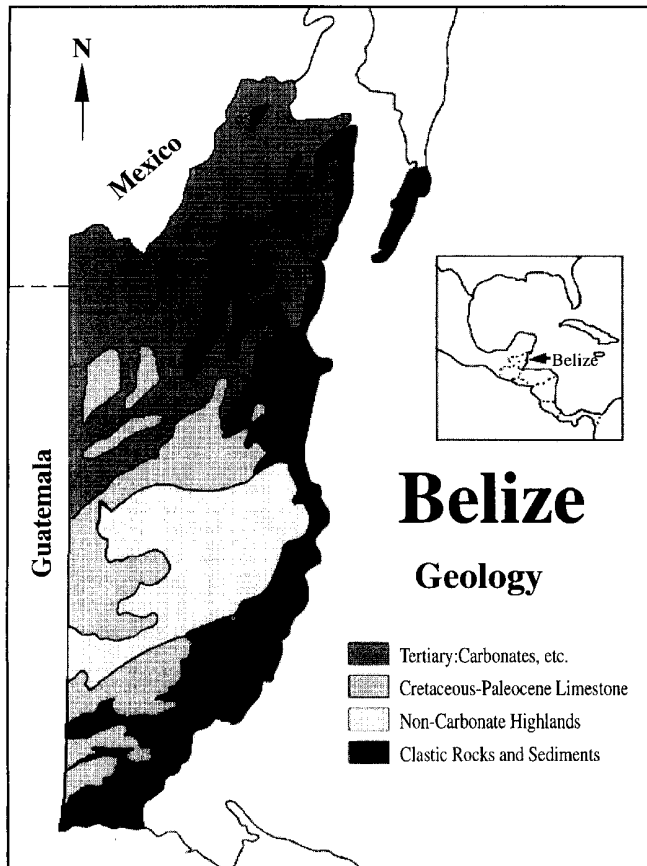


Figure 3. Generalized geology of Belize, detailing the carbonates most important for karst.

ments and Triassic intrusives that is bounded on the north and south by major faults striking east-west (Dixon, 1955). The eastern boundary is also probably a major fault. The underlying structure of the sloping western edge of the mountains is obscured by Cretaceous and Tertiary carbonates. The Mayas are the eastern terminus of the anticlinal La Libertad Arch, which extends into Guatemala. The present horst structure of the Mayas dates from the mid-Cretaceous, influenced by Paleozoic age lineaments apparently related to initiation of the La Libertad Arch. The block was affected by periodic relative uplift until the mid-Tertiary (Bateson & Hall, 1971).

Fewer than 25 km from the southern end of the Mayas, and paralleling the La Libertad Arch, is the Cayman Trench and the extensive complex of the Motagua Fault Zone. This 2,200-km-long complex is the boundary between the North American and Caribbean plates, a transform fault with left-lateral motion. It was probably initiated in the Permian, when north-south compression in the Mayas forcefully intruded granites with associated volcanism and basalt outflow. This episode lasted until the late Triassic (Dillon & Vedder, 1973) and included the initiation of block faulting. Major fault development also occurred in the Cretaceous (Meyerhoff, 1966; Dengo &

Bohnenberger, 1969; Malfait & Dinkelman, 1972; Dengo 1975; Newcomb, 1977).

The La Libertad Arch and the Maya Mountains parallel the plate boundary for 200 km and share a history of Paleozoic origin and major Mesozoic fault activity. They almost certainly have a causal relation to activity along the Cayman-Motagua Complex, but with a greater uplift. Quaternary movement along the Motagua Fault has been estimated at 0.5 cm/yr (Kupfer & Godoy, 1967; Schwartz, 1977).

CRETACEOUS CARBONATE DEPOSITION

Although limited Jurassic sedimentation occurred, the local event of greatest karst significance began with massive deposition of Cretaceous evaporites and marine carbonates throughout the Caribbean. These grade upward into reef facies in Guatemala and Belize that surrounded the then-extant islands of the Maya Mountains (Dillon & Vedder, 1973). The Cretaceous deposition is as much as 3,200 m thick westward from the Maya Mountains in the Peten of Guatemala, yet thins to only 900 m at the mountain fringes (Viniegra O., 1971). At the close of the Cretaceous, the west end of the Mayas was submerged and covered by limestone and dolomite (Bateson, 1972). Viniegra O. (1971) identified three major divisions of the Cretaceous carbonates in Guatemala, which he also applied to Belize. The oldest unit, the Coban Limestone, has been reported in outcrops north of the Mayas, possibly in the Yalbac Hills (Hartshorn et al., 1984). Most of the rest of the Cretaceous outcrops, including the Caves Branch area, the Vaca Plateau, and in southern Belize, were identified as the middle unit, the Campur Limestone.

RECENT GEOLOGIC HISTORY

Intense folding and thrusting occurred in Guatemala and Mexico during and after the late Cretaceous. Only minor tectonic activity affected Belize in the Tertiary, and shales, siltstone and limestones were deposited over much of the area (Dillon & Vedder, 1973). Northern Belize has since been characterized by slow subsidence and attendant carbonate deposition through most of the Tertiary. The primary deposition episode was in the late Paleocene to Eocene (Pusey, 1975; Dillon & Vedder, 1973). Late Cenozoic uplift in the Mayas has raised Oligocene carbonates to 50 m above sea level, and further recent uplift is demonstrated by numerous river terraces, cave levels, and modern marine faunal remains in inland sediments (Jean Cornec, Office of Geology and Petroleum, personal communication, 1986). "Tilted" stalactites in the Blue Hole, a drowned doline on Belize's barrier reef, have been cited as evidence of recent and continued tectonic activity (Dillon & Vedder, 1973). However, such features are common in large inland cave entrances, apparently due to differential calcite precipitation. Most recently, Quaternary alluvium from the Maya Mountains filled in an arm of the ocean that had

extended into central Belize.

In summary, the events of chief geological significance to karst development in Belize are:

1. deposition of clastic sediments, and subsequent uplift and intrusions by granites;
2. massive Cretaceous carbonate deposition, around and on the Maya Mountains; and
3. the uplift, faulting, and fracturing related to the nearby plate tectonic boundary.

Sizable volumes of runoff from highlands of poorly soluble metasediments and crystalline rocks entered large areas of lower-lying soluble rocks. Large caves formed as these streams sank underground. Extensive areas of carbonate rock that are not peripheral to the Mayas, primarily in northern Belize, do not display pronounced karst.

KARST REGIONS OF BELIZE

Eight karst regions have been identified in Belize and cover about half of its area (Miller, 1986a). The regions are shown in Figure 4 and a summary of their characteristics is given in Table 1. Although all eight regions share similarities in climate and geology, only five are dramatically karsted; these cover about 3,000 km² of a total land area of 23,000 km². In the following brief individual discussions of these regions, it is evident that the most dramatic expressions of karst topography and cave development occur in those Cretaceous carbonates downslope of catchments integrated on the intrusive and metamorphic highlands of the Maya Mountains. Other hydrogeologic factors particular to each region have played relatively minor roles in their development.

The two karsts most examined in Belize are those centered on the southern Vaca Plateau and on the Caves Branch section of the Boundary Fault Karst. These areas will be discussed in more detail as type examples of the surface formation of karst in Belize. Caves Branch best demonstrates subsurface development.

Several features are common to most Belize karsts. Large areas contain sinking allogenic streams (Figure 5), integrated dry valley networks of fluvial origin, "hanging valleys," and poljes with through-flowing allogenic rivers. Other areas contain thousands of closed depressions of seemingly chaotic distribution.

Those areas in Belize dominated by closed depressions of at least 30 m relief, surrounded by residual hills, are similar in appearance to areas elsewhere called kegelkarst, or cone karst. Because the *depressions* are the dynamic foci of surface erosion, and are termed "cockpits" in Jamaica, these areas are here referred to as "cockpit karsts" in keeping with the terminology of their nearby analogues.

Scores of vertical-walled depressions scattered throughout Belize are sited over and near known cave networks, and are likely collapse features (Figure 6). They are impressive, but of minor total area. The densest grouping is in the Chiquibul area

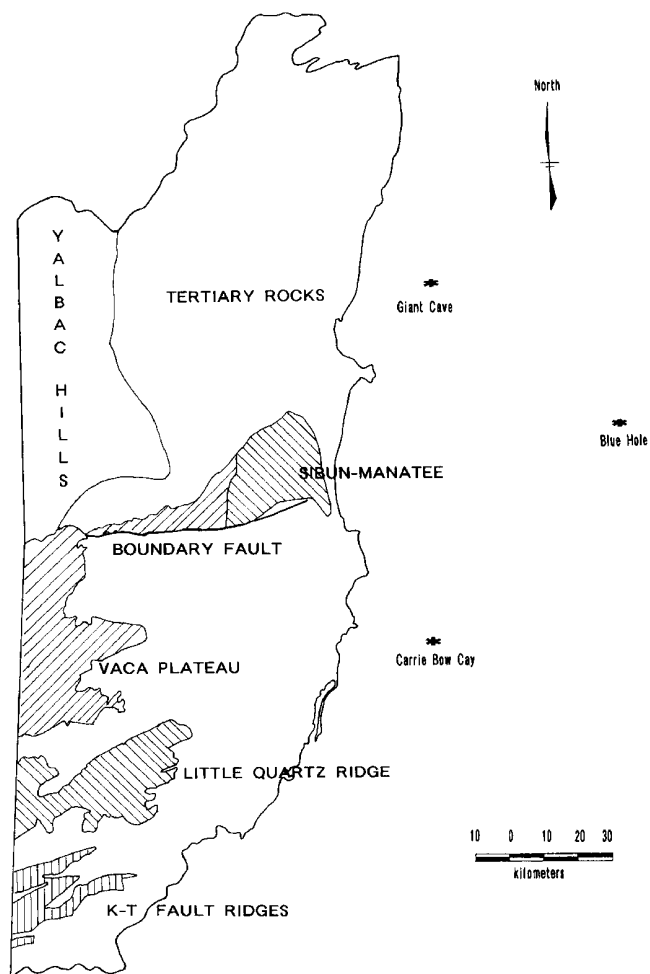


Figure 4. The major inland karst areas of Belize. Three of the Offshore Karst sites are shown.



Figure 5. The ponor of the Caves Branch River at the north end of its polje. The hills are about 50 meters high.

Table 1. Characteristics of Major Karsts of Belize.

Location	Area (km ²)	Relief (m)	Erosion	Features
1. Boundary Fault	300	350	100	C,P,F
2. Vaca Plateau	1000	400	130	C,F
3. Sibun-Manatee	550	200	—	P,T
4. Little Quartz Ridge	750	600	—	C,F
5. K-T Fault Ridges	300	250	120	C,F
6. Cayes/Barrier Reef	—	150?	—	—
7. Yalbac Hills	1950	200	—	—
8. Tertiary Rocks	7000	70	—	—

where: area is in km² within Belize, maximum areal relief is in meters, erosion is the rate of solutional removal of CaCO₃ (m²/km³/yr), and C (cockpits), P (poljes), F (fluviokarst), and T (towers) are landform features common to the surfaces of these karsts.

of the Vaca Plateau, where 20 known collapses cover only 2% of the 30 km² in which they occur.

The large allogenic streams that enter the carbonates frequently bore through at local base level to emerge on the plains near sea level. They flow through large cave passages—*trunk conduits*—that developed independently of internal runoff from the karst surfaces. None of the allogenic streams merge below ground.

1. BOUNDARY FAULT KARST

The Boundary Fault Karst is sharply delineated. It is bounded on the south at 200-300 m elevation by the Northern Boundary Fault. This east-west trending fault spans the width of the country, has a downward throw to the north of at least 900 m (Dixon, 1955), and forms a 700- to 800-m-high escarpment. The region's northern margin is a relatively abrupt termination at the contact with younger, chiefly carbonate, Paleocene-Eocene formations that continue northward as rolling plains. The Cretaceous limestone ends in hills 30 m or more in height at an elevation of 40 m a.s.l. A few isolated towers extend into the alluvium-covered plains.

The Boundary Fault region is lithologically and structurally almost identical to the Sibun-Manatee Karst, but is distinguished morphologically from the latter. The difference results chiefly from the Boundary Fault Karst's higher elevation and steeper slope due to its closer proximity to the highest and most pronounced portion of the Northern Boundary Fault. Structurally, the area is a northward-dipping shelf of Cretaceous Campur Formation carbonates, marked by north- or northeast-trending faults. The Northern Boundary Fault disappears northward beneath the Cretaceous carbonates, and is believed by Cuche and Glaus (1967) to pre-date them.

Major valleys aligned along the north-trending faults are cut by small rivers descending onto the carbonates from dendritic catchments on the granites and metasediments of the Mountain Pine Ridge to the south. Smaller valleys are also cut by lesser streams that enter the karst. These streams penetrate distances proportional to their catchment areas and discharge (Miller, 1981a), before disappearing into poljes and trunk conduits. The larger rivers, Barton, Roaring, and Sibun, are all

through-flowing to the sea; the Caves Branch is pirated underground, but a wide flat opening in the hills at the northern end of its polje suggests this river was also through-flowing in the past.

The geologic conditions of the Boundary Fault region are conducive to the formation of trunk conduits. Well-integrated streams discharge large volumes of solutionally-aggressive water from the Mountain Pine Ridge onto the limestone. At present, perhaps 70 km of active and abandoned trunk passages have been mapped in this karst (Miller, 1990a; Marochov & Williams, 1992; Hollings, 1994).

Although Day (1979, 1987) has examined surface depression development further west, currently the Caves Branch section of the Boundary Fault Karst has been studied in the greatest detail (Miller, 1977, 1981a). An overview of its hydrology, hydrochemistry, and geomorphology follows as a summary of the common conditions that prevail throughout the karst region.

CAVES BRANCH GEOLOGY AND MORPHOLOGY

The Caves Branch River originates in the Mountain Pine Ridge in the center of Belize, with a noncarbonate catchment area of 64 km². Two other allogenic streams flow from these highlands through major trunk conduits to the Caves Branch, with respective catchments of 20.3 and 3.3 km². The remaining area of the river's karst catchment is vaguely defined as ~100 km² because its drainage is internal. The Caves Branch disappears into the Cretaceous limestone at a large ponor, or open conduit sinkpoint, after flowing 10 km through a prominent polje floored with clay, sand, and cobbles derived from the highlands (Figure 7).

The limestone of the Caves Branch has a restricted fauna typical of lagoonal to back-reef deposition (Flores, 1952). The majority of exposures are 2-15 cm (often larger) gray or cream-colored limestone breccias cemented in a red calcite matrix. Anderson et al. (1973) described a similarly-appearing breccia of lower Cretaceous age in Guatemala that he identified as "clearly depositional." In Caves Branch, bedding is rarely encountered, and is infrequently more than 40 meters thick. The rock is well-fractured. Slickensides give evidence of faulting, which is difficult to observe because brecciation



Figure 6. The collapse doline of Nohoch Ch'en (Great Well), on the Vaca Plateau, possibly overlying a segment of the Chiquibul System. The doline is 300 meters in diameter and about 50 meters deep.

obscures relative movement and the amount of displacement. Where bedding is present, it usually dips 5° or less, most frequently to the northeast. Of three local samples of Cretaceous limestone (Table 2, Miller, 1981a), two were micritic clasts in the breccia which resembled rock exposed in bedded areas and one was a mixture of clast and matrix. All were very pure calcitic rock.

Table 2. Analysis of Three Rocks from the Caves Branch Valley.

General Description	CO ₂	MgO	CaO
Micritic Clast	41.70	0.24	57.32
Micritic Clast	43.16	0.36	58.09
Breccia	41.80	0.92	57.08

all values given in %, (from Miller, 1981a)

SURFACE MORPHOLOGY

Hundreds of cockpits in the Caves Branch area, most surrounded by hills, have been outlined from airphotos (Miller, 1981a). Smaller dolines frequently nest within the larger depressions. Visible differences in texture separate groups; large dolines are common, but depressions may occur as numerous, smaller, densely-packed clusters.

Beneath heavy vegetation, the hilltop ground surfaces are often bare rock, deeply fissured to several meters along joints. The cockpit floors contain clayey soils reaching depths of tens of centimeters. Many cockpits, but not all, contain simple integrated drainages terminating in vertical bedrock swallets (sink-points which may or may not be open cave entrances).

Nearest neighbor analyses were performed on 210 dolines identified from aerial photographs (40-m contour intervals on topographic maps were too large for adequate interpretation) in the Caves Branch area. In a similar section of the southern Vaca Plateau, 160 dolines were analyzed (identified from topographic maps because contour intervals were a useable 20 m and aerial photographs could not be obtained). The patterns in both areas differed significantly from a purely random distribution, with a trend towards uniform patterns of dispersion (Miller, 1981a).

In the Caves Branch, a 20-km²-area was chosen to identify influences of major joints and faults upon cockpit siting, as interpreted from photo-lineations. The 255 depressions within this area highly correlated with the lineations (Miller, 1981a). The cockpit karst appears to be the likely result of non-random processes of fluvial dissection centered by points of lithologic weakness; it has presumably advanced in dissection until past evidence of fluvial networks was largely obscured.

HYDROLOGY AND CARBONATE WATER CHEMISTRY

Data collected from 1976-1979 by Miller (1981a), com-

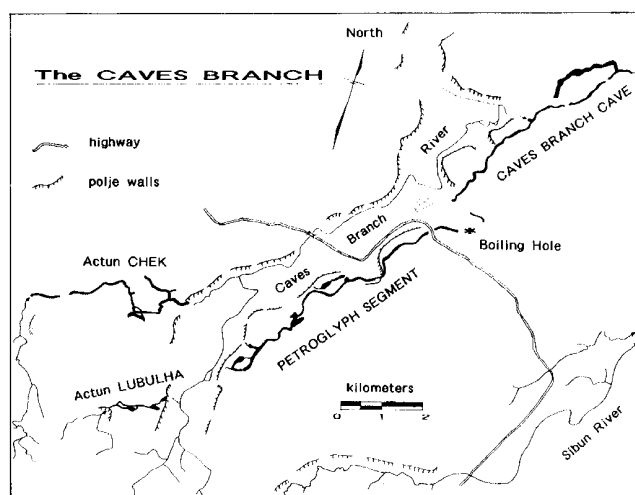


Figure 7. Major caves of the Caves Branch Valley (after Miller, 1981a).

prise most of the hydrology information about the Caves Branch area. Daily rainfall records were also kept during most of the 1950s to the 1970s at three sites along the Hummingbird Highway: Roaring Creek, Caves Branch River, and Sibun River (Walker, 1973). Mean annual precipitation was 207, 236, and 264 cm respectively, with wet season conditions dominating from June to November. Mean annual temperature, as estimated from caves, is 24°C. Precipitation in the Caves Branch drainage basin is concentrated in a slightly longer June-December wet season with convective storms producing rainfalls >5 cm/hr. Dry season discharge of the Caves Branch River was stable at 0.5 m³/sec, with wet season floods exceeding 100 m³/sec.

Scores of tributaries and uncounted stalactite drips feed the trunk conduits. Their sources are autogenic water derived from rainfall onto the karst hills bordering the polje. The combined allogenic and autogenic recharge of the area resurges 5 km to the northeast at the termination of the karst.

Surface flow on the karst is infrequent, even though most large cockpits contain stream channels integrated on the clay floors. The permeability of the karst is such that flow occurs only when rainfall exceeds 12 mm per day. The range of hardness of these streams was a low 10-40 mg/L (as CaCO₃), as was PCO₂ at 0.05-0.35%, and they were undersaturated with respect to calcite (SIc -2.54 to -1.05) and dolomite (SI_d -2.86 to -1.77).

The autogenic streams and drips display a pronounced, delayed response in discharge at the start of each wet season (Figure 8 and Miller, 1983). The mass volume of early wet season rain, falling prior to hydrograph response, closely approximates calculated losses from aquifer storage due to unreplenished base flow during the dry season. A deterministic computer model was able to correlate volumes and temporal

responses of discharge to rainfall, and enable calculations of a minimum effective porosity of 2-3% for the Caves Branch karst. A mean residence time of up to seven months was indicated (Miller, 1981a).

The amount of limestone solution by allogenic highland water was obscured by mixing with autogenic waters in the trunk conduits. These allogenic streams all had hardnesses of less than 35 mg/L (as CaCO₃) prior to contacting the carbonates, pH <7.0, and were undersaturated with respect to calcite (SIc -3.79 to -0.82) and dolomite (SI_d -3.64 to -0.87).

Most waters entering the trunk conduits were supersaturated and depositing travertine, with markedly higher hardnesses (means of 187 mg/L as CaCO₃, and PCO₂ 1.1%) than either the cockpit source runoff ranges noted above, or mean measured local soil CO₂ of 0.7%. A subsurface enrichment of PCO₂ is indicated, possibly through decay of vegetation washed into the aquifer. Combining these data with open-system carbonate solution (per Langmuir, 1971) as indicated by the high internal porosity, led to a calculation of a relatively high denudation rate of ~100 m³/km²/yr (Miller, 1986b).

CAVE MORPHOLOGY

Extensive cave exploration and mapping has occurred in the Caves Branch River valley and its environs. At least 60 caves are known, totaling about 50 km explored with about 45 km of these mapped. Because the Caves Branch area is well-studied and contains numerous features common to other karst areas of Belize, the characteristics of its caves are examined below in detail. Much of this discussion is from Miller (1981a).

Morphologic and hydrologic criteria were used to establish cavern categories for the Caves Branch area, largely based on phreatic versus vadose features of individual passages. Relevant characteristics are outlined for each cave and respective group in Table 3. Because the trunk conduits are so extensive, they often intersect other cave types, forming aggregates or systems (Figure 9). These merging cave passages have been treated as separate caves in Table 3.

PHREATIC CAVES

Four cave types of chiefly phreatic origin can be distinguished. Two are inactive or fossil. The other two are only seasonally active, but owe most of their features to solution under phreatic conditions.

Isolated Phreatic Caves. This group is composed of fossil chambers scattered at moderate to high elevations of 50-150 m above local base level. They are generally three-dimensionally complex and consist primarily of rooms rather than passages. No scalloping or fluvial sediments are present to identify localized stream flow, and the solutional pocketing, discordant elevations, and elevationally nongraded floors all indicate an isolated, nonintegrated phreatic origin. Joint control appears predominant with only minor bedding effects. Any collapse and/or sedimentation present is due to breaching and invasion related to surface erosion, rather than to phases of cavern formation.

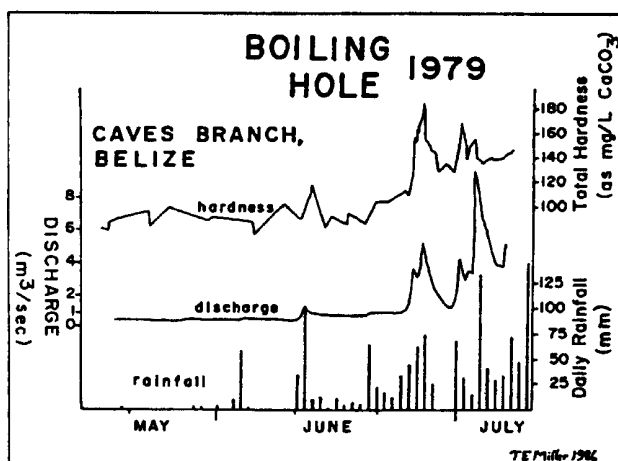


Figure 8. Hydrograph and total hardness as related to valley rainfall of the Boiling Hole trunk conduit stream, located midway on the east side of the Caves Branch polje (from Miller, 1986a)

Table 3. **Some Type Examples of Cavern Morphologic Classes, Caves Branch**

Class	Name	ID	UTM Location	1 Phreatic	2 Vadose	3 Plan Type	4 Size	5 Collapse	6 Speleothem Development	7 Sediments
Zuhuyha	Toh	Z-4	997218	Cs	s	H	60	-	-	-
	5% Solution	Z-7	971187	C	?	?	?	-	-	-
	Crooked Bend	Z-31	943184	Cs		2	150+			au
Isolated Phreatic	Swiss Cheese	0-3	004227	Cf		3	200?			
	Candlestick	0-12	947193	If		3	1-200	M1	M3	
	Cave-Around-The-Bend	0-17	912146	If		3	150?	M1	M2	
Swallet	-	S-1	997225		s	V	20			
	Swallowet Hole	S-4	955194		s	V	40			au
	VICEG	S-5	956191		s	V	100?			
Pirate	Thunder Road	P-4	007221	Cs	s	2	200+			al
	Buccaneer Alley	P-5	004218	Cs	s	2	500			al
	Zephyr Zig-Zag	P-8	956185	Cf,s(?)	f,s(?)	2	300			al
Margin Swallet	-	M-2	001217	Cs	?	?	?			
	-	M-7	965197		s	V?	?			
	-	M-11		f?		2	40		M1	
Trunk Conduit	Tuxmanu Yocmac, Chek		940152	Cs	s	2	1100		M2	al
	High Levels, Lubul Ha		915150	Cf	f	2	300	M1		al
	Petroglyph			C	P	2	3000+	M1	M2	
Collapse Chamber	Cantziñal Caan, Lubul Ha		918157	If		2	200	M3	M3	
	Burial Chamber, Petroglyph		983175	If		2	300	M3	M2	
	Mtn. Cow		958188	If		2	1000	M3	M3	

1 Phreatic
2 Vadose
3 Plan Type
4 Size
5 Collapse
6 Speleothem Development
7 Sediments

C - conduit; I - isolated; f - fossil, s - seasonally active
P - permanent stream; s - seasonally active, f - fossil
H - linear horizontal; V - linear vertical; 2 - two dimensional (horizontal) 3 - three (dimensional)
(known passage length, in meters)
M - 3,2,1 major, moderate, minor
M - 3,2,1 major, moderate, minor a - active f - fossil
Co - cobble fill; D - dirt; al - allogenic source, au - authigenic

Speleothem development is variable in extent and activity, though generally common.

Chamber Stratum Caves. Many massive collapse areas exist underground that share similarities in their general alignment with the trunk conduits. In most instances, the collapses consist of rubble-floored chambers with extensive active and inactive speleothems (Figure 10). With rare exception, ceilings occur at elevations of 50 m or less above neighboring trunk conduits. It is not possible to determine the elevations of the bottoms of the collapses, but they appear to be no lower than, and sometimes above, the floors of the trunk conduits. Nearly all these rooms are parts of cave systems that include trunk conduits. Sizes of the chambers range up to 300 m in length, with ceiling heights often reaching 20 m. Because of widespread collapse, undisturbed sections of bedrock are almost entirely absent. High portions of these caves sometimes show undisturbed phreatic tubes and chambers with little or no evidence (e.g. scalloping) of localized conduit flow. The collapse material nearly always lacks markings from any solutional activity subsequent to collapse. Clastic sediment accumula-

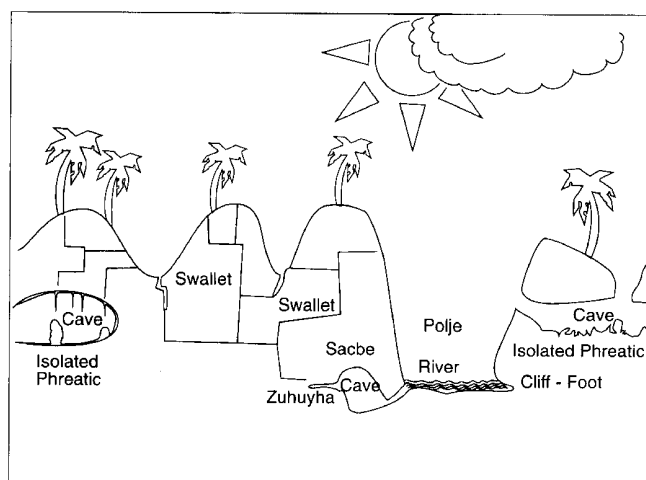


Figure 9. Generalized relations of cave and passage types in the Caves Branch.



Figure 10. A collapse chamber intersected by the trunk conduit of Petroglyph Cave.

tions are absent except where bordered by a trunk conduit.

Generally, the collapsed chambers clearly predate the trunk conduit channels. For example, the modern, hydrologically active trunk conduit at the Petroglyph Cave entrance flows briefly in a symmetrical tunnel, 15-20 m in diameter, with a roof composed of breakdown blocks in the sink above, and a floor cut in bedrock. In most other chamber/trunk conduit intersections the conduit has cut into bedrock slightly below the apparent base of the collapse. Widespread collapse on a massive scale obscures bedrock clues concerning their development.

Some examples exist of collapse after trunk conduit formation and intersection. In the Dead Room of Actun Lubul Ha

(Figure 11), collapse has filled a former stream passage and presumably forced its abandonment as an active channel. Streams have cut smaller channels on both sides of the blockage upstream, but failed to link up again with the former downstream segment. No clastic sediments or remnants, buried by collapse or otherwise, have been found in collapse chambers except directly alongside active trunk conduits. Huge speleothems are additional evidence of the great age and relative stability of most collapse chambers.

Zuhuyhas ("zu-hu-e-ha," from Yucatec Maya for "virgin water"). These are chemically diffuse flows that have the hydrological character of trunk conduits. They are active conduits of autogenic flow generally found at the lowest levels of the explorable karst. Most discharge into the trunk conduits, where they often deposit travertine (Figure 12), but several emerge as surface springs. Internal speleothem or calcite deposition is rare. No clastic sediments of obvious allogenic origin are ever present. *Zuhuyhas* are probably dendritic collectors of long residence karst water from the overlying karst surface, and are subject to runoff pulse transmission and expulsion during the wet season. They undergo seasonal to continuous modification, and, when active, consist of flooded segments (sumps) with intervening air-filled sections, except in highest flow. These passages are occasionally anastomosing, frequently tubular in form, scalloped, irregularly pocketed, joint-guided, and lack graded profiles. Travertine deposition (into trunk conduits for example) is common at their termini, but other calcite precipitation is rare. At present only one *zuhuyha* has been penetrated during the dry season to these predicted inner regions. Most are enterable no more than 50 to 100 m.

Figure 11. Western end of Actun Lubul Ha showing multi-level character of trunk conduit, collapse chamber, entrenchment, and piracy (from Miller, 1981a)

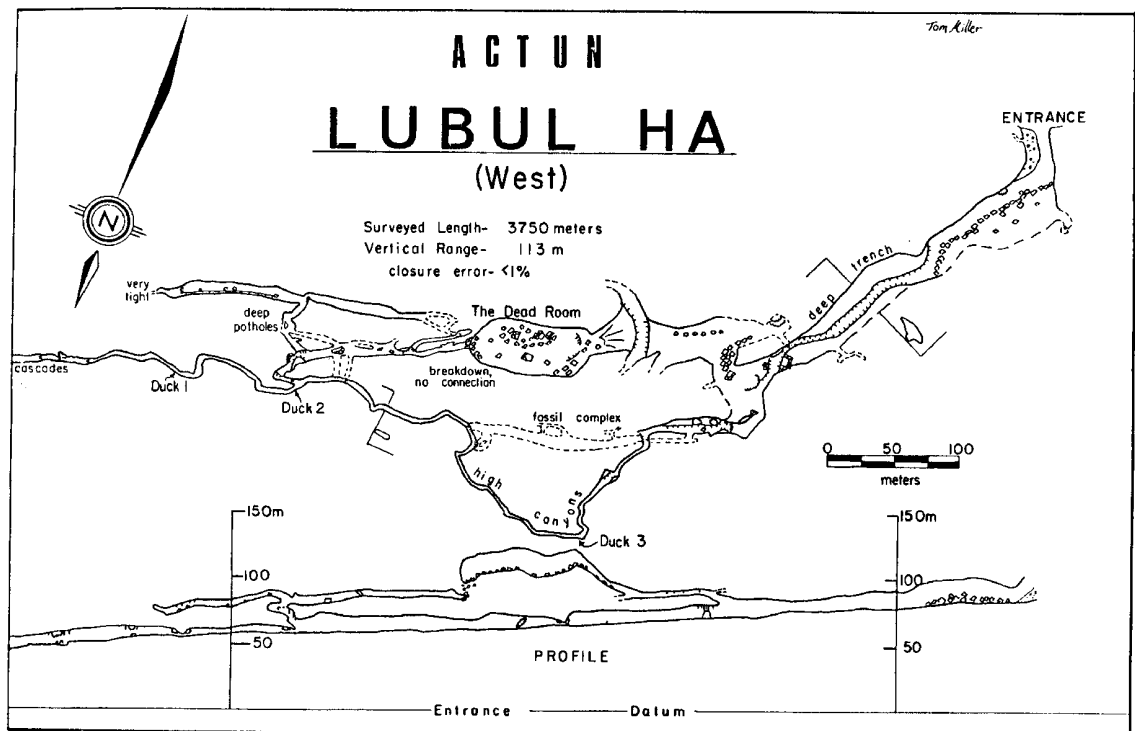




Figure 12. A wet season *zuhuyha* depositing travertine where it enters above the floor of the trunk conduit of Saint Herman's Cave in the Caves Branch area.

Karst Margin Swallets. These caves are found at or near local base levels, and function as intake conduits into the limestone for solutionally aggressive runoff from valley clays and clastics. They are commonly phreatic and anastomotic in plan, and rapidly lead to sumps with seasonally fluctuating levels.

EPIPHREATIC/VADOSE CHANNELS

These cave passages form the majority of the passages known in Belize because of their attractive size and ease of exploration. Though they may contain sumps, they generally have ample airspace except during seasonal flooding. Three passage types are known: trunk conduits, swallets, and piratic conduits.

Trunk conduits. The bulk of the known Caves Branch area cave passages belong to this category (Figure 13). Trunk conduits are the allogenic counterpart of the *zuhuyhas*, functioning to transport water and sediment from the highlands through the karst. Because of the large areal coverage provided by these lengthy conduit networks, much autogenic water is intercepted by them.

By far the largest trunk conduit in the Caves Branch area is within the 30-km-long Caves Branch Cave System, but the trunk conduits of Actun Chek (~9 km) and Actun Lubulha (~4 km) are also major karst throughways.

In Caves Branch, trunk conduits parallel photo-lineations, are similarly oriented to the regional fault trends, and also parallel the local topographic dip, which is generally to the north-east. In the brecciated bedrock there are no aquitards and bedding planes to encourage lateral development and truncate vertical fractures. However, Lubulha and Chek near the Northern Boundary Fault show examples of offset multi-level development, as opposed to the entrenchment in the trunk conduits of the main Caves Branch Cave System. In both caves, the fossil channels lie up-dip and topographically higher than the present active channels, and down-dip migration appears to have

occurred.

Swallets. These shaft caves function as transport channels for runoff from the karst's surface to its subsurface drainage system. They are almost exclusively vadose in morphology, with vertical, fluted walls and minor clastic deposits. Those presently known are located at or near cockpit bottoms, frequently at the end of a gully cut into the floor. Streams flow in the gullies only during prolonged or very intense rainfall. Passage orientation in the swallets is exclusively controlled by joints in the bedrock. Collapse occurs in solutionally-"rotted" limestone, but is not common. In contrast to the other cave types, swallets diminish in size along their courses. They end either in sediment chokes or impassably narrow fissures. Those known are all less than 30 m deep.

Piratic Conduits. The extent and function of these conduits in Belize are largely unique to the Caves Branch area. They are distinguished from the trunk conduits chiefly by smaller size, location, relative age, and the transport of predominantly allogenic water. They exist only where the Caves Branch River parallels a major cave conduit, and feed extracted river water

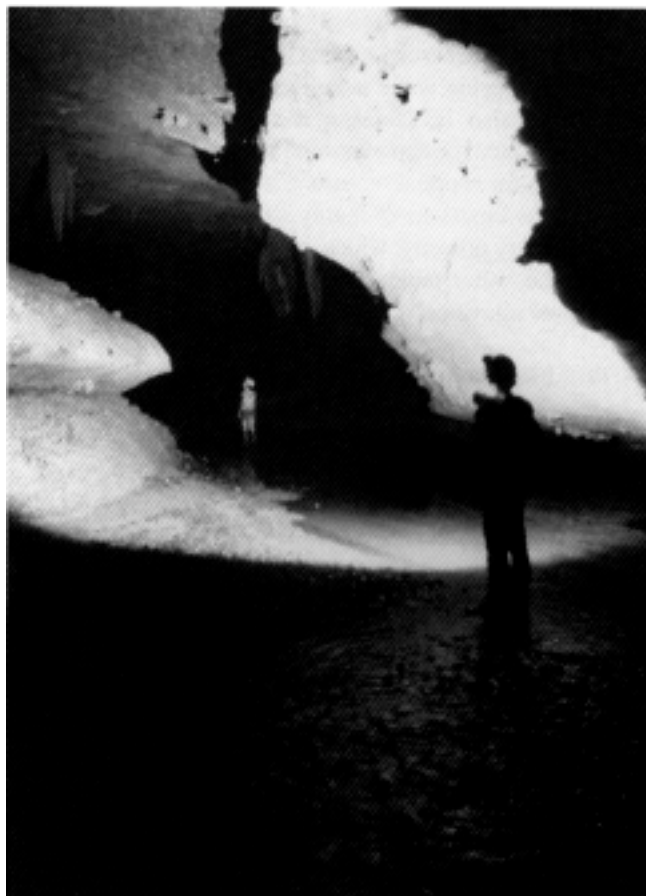


Figure 13. The main passage of Petroglyph Cave. Note the allogenic clastic sediments on the floor and the incised wall niches. The lowest 1.5-m-high niche is common to all trunk conduits of the valley.

to the neighboring trunk conduit. All have joint-controlled courses and sizes averaging 2-3 m high by 1-2 m wide. They are always located on the polje-ward side of the trunk conduit into which they empty, have sediments of Mountain Pine Ridge origin, low solute loads of less than 100 mg/L total hardness (as CaCO₃), and comparatively high water temperatures of about 25°C. Finally, the mean solute content of each piratic conduit stream increases with distance downstream in the polje and mimics that of the nearby Caves Branch River. Except for short sump sections, all are presently in states of active vadose entrenchment and all but one enter flush with the trunk conduit floor. These last four characteristics are opposite those of *zuhuyhas* off the same trunk channels.

The major cave network change presently occurring in the upper Caves Branch Cave System (e.g. Petroglyph Segment) is the growing complexity of the network through growth of piratic conduits. The main trunk conduit is laterally offset and lower than the surface river channel that it parallels, giving it a hydraulically advantageous position relative to the independent surface stream. This is likely due to insoluble sediments armor-ing the polje floor. This appears to be common elsewhere. LeGrand and Stringfield (1963) have noted that the lower course of the Río Cobres, in Jamaica, lies on alluvium higher than the neighboring water table in the limestone. Brown and Ford (1973), also in Jamaica, and McDonald (1976a), in Belize, have noted the apparent affinity of many polje and open polje streams for residual limestone masses. McDonald postulates that "the limestone is highly soluble and has developed much secondary porosity, which allows for freer movement of runoff to the water tables than the relatively insoluble and impermeable alluvium."

CAVES BRANCH SUMMARY

In the Caves Branch area, the high caves are isolated and unintegrated in the top 70-150 m of the aquifer. They are abruptly replaced in the bottom 20-30 m by the well-integrated present network, where the function and relationships of all conduits types are known. There is no apparent evidence of headward integration of the various components, or gradual evolution of the aquifer to the present low-gradient state.

The initial siting of the surface river channel was followed by:

1. development of large allogenic phreatic or epiphreatic trunk conduits
2. *zuhuyha* integration with the trunk conduits
3. vadose entrenchment and/or development of lateral cut-off
4. formation and integration of piratic conduits in the upper Caves Branch Cave system, followed by a phase of sedimentary infilling

The surface depressions have demonstrated a significantly greater occurrence near photo-lineations and the northeast-southwest trending fracture system, and are presumably located at favorable sites for the movement and penetration of

groundwater. However, there appears to be little correlation between surface and subsurface features. Observed photo-lineations seldom correlate with cave passages, and except for rare instances where massive collapse occurs to the surface, most breakdown chambers in the caves have no surface expression.

While some *zuhuyhas* demonstrate a tendency to occur at sites where a large doline was located near a conduit, trunk conduits rarely pass beneath surface dolines, and never follow surface valleys. Surprisingly, much of the course of the upper Caves Branch Cave System strongly correlates with surface ridges, in spite of a limestone thickness exceeding 100 m. Brown and Ford (1973) described a similar situation in Jamaica where conduits tended to locate beneath hills rather than depressions. It is unclear why the obviously joint-guided cave passages have an affinity with surface ridges, rather than beneath the dolines which are demonstrably favorable locations for water movement.

2. VACA PLATEAU KARST

The Vaca Plateau, containing the Chiquibul area, is the largest of Belize's five major karsts (1,000 km²) and is the eastward end of a broad platform of Cretaceous carbonates extending from central Guatemala. It spreads 10 km west into Guatemala, to the gorge of the Chiquibul River, and extends south and east to the Maya Mountains. To the north, it is defined as ending at the Northern Boundary Fault where it indistinctly merges into non-Cretaceous carbonates and clastic sediments in the plain of the Belize River. This limestone plateau has relatively uniform summit elevations, but its intervening areas are quite rugged with steep local reliefs of 100-150 m. It increases in general elevation from about 400 m in the north to about 700 m in the south, near the contact with the noncarbonates of the Maya Mountains.

VACA PLATEAU GEOLOGY

No in-depth studies exist of the limestone. (*Editors note: See Reeder, Brinkmann, and Alt in this issue for recent petrologic analyses.*) Previous geologic work has concentrated upon the mineralogy of the surrounding Maya Mountain's Paleozoic metasediments and Triassic granites (Flanders, 1978). The limestone Campur Formation dips gently westward, lying unconformably over these older noncarbonate units.

The Vaca Plateau is crossed by several major faults striking southwest-northeast. Aerial photographs of the Chiquibul section, in the southern plateau, show numerous linear features. Flanders (1978) stated that the streams on the noncarbonates to the south are fully structurally controlled by joints, faults, and bedding planes. Faults and major joints are likely the causes of linear features noted in the limestone. Identification of faults in the field, and verification of their influence, are hampered by the thick vegetation, and in the caves, by the ubiquitous brecciated bedrock, inaccessibility of many walls and ceilings by

Table 4. Rock, Soil, and Sediment Analyses from the Chiquibul, Belize, 1984.

Class/Type	n	SiO ₂	Al ₂ O ₃	Fe-oxides	CaO	MgO	Na ₂ O
Cockpit sediments	5	61.1	24.1	9.5	1.5	0.8	0.3
Bedrock	3	0.0	0.0	0.0	68.2	25.7	5.9
Cavern sediments	3	85.4	6.9	3.1	0.3	<0.1	0.5
Highlands soil	1	68.7	16.7	9.7	1.7	0.5	0.3

n = number of samples; figures are %, only 6 variables analyzed (after Miller, 1987).

large passage dimensions, and the massive deposition of sediment and speleothem on exposed surfaces.

The Chiquibul expeditions (Miller, 1984, 1986c; Miller, McNatt & Veni, 1987) identified two common lithologic units. The first is that of a dense, micritic, often-crystallized bedded limestone of dark gray to white hue. The second is a highly brecciated, usually recrystallized rock composed apparently of clasts derived from the bedded limestone, set in a matrix of orange-brown calcite. This second unit was the most commonly encountered in the area, perhaps because it was also the unit in which all of the major cave exploration occurred. Table 4 (Miller, 1987) lists several analyses of the bedrock from the southern Vaca Plateau, showing the bedrock is a high-magnesian limestone.

SURFACE MORPHOLOGY

The Vaca Plateau can be separated into two distinct areas (Figure 14). The northern two-thirds is a fluvio-karst in which integrated, dendritic valley networks are clearly visible from aerial photos. These valleys are fossil; the local gradients of their former thalwegs now contain closed depressions, though remaining graded overall.

Most of the southern area is a cockpit karst, with considerably less evidence of a fluvial past. Remnant limestone hills rising above alluviated plains run up the eastern margin of the southern karst in a several-kilometer-wide strip. The cockpits contain short (<100 m) channels, ending in swallets and short caves that likely direct surface runoff into the underlying trunk conduits.

The present distinction between the two karst surfaces of the plateau may simply be the result of their fluvial history — the southern area receives discharge from several integrated allogenic streams from higher-elevation noncarbonates to the east. Table 4 demonstrates the similarity in composition between soils on the noncarbonate highlands, soils in the cockpits, and sediments in the Chiquibul caves. Sediments from the highlands have clearly been carried onto the eastern strip of the karst and deposited into Chiquibul cockpits. Soils in the southern section of the plateau display a very strong similarity with soils and sediments developed in-situ on neighboring noncarbonate rocks, and a strong dissimilarity to insoluble residues of the local limestone bedrock. Initially, this area likely hosted a

fluvial network until the allogenic streams were pirated underground and induced the development of cockpit topography and drainage.

In this scenario, the northern area of the Vaca Plateau remains in a far less dissected state because the substantial 200-300 m incisions of the Macal and Raspaculo Rivers buffered the limestone from incursions of aggressive allogenic runoff. Well-integrated internal drainage focusing on trunk conduits would not have occurred, which is consistent with the

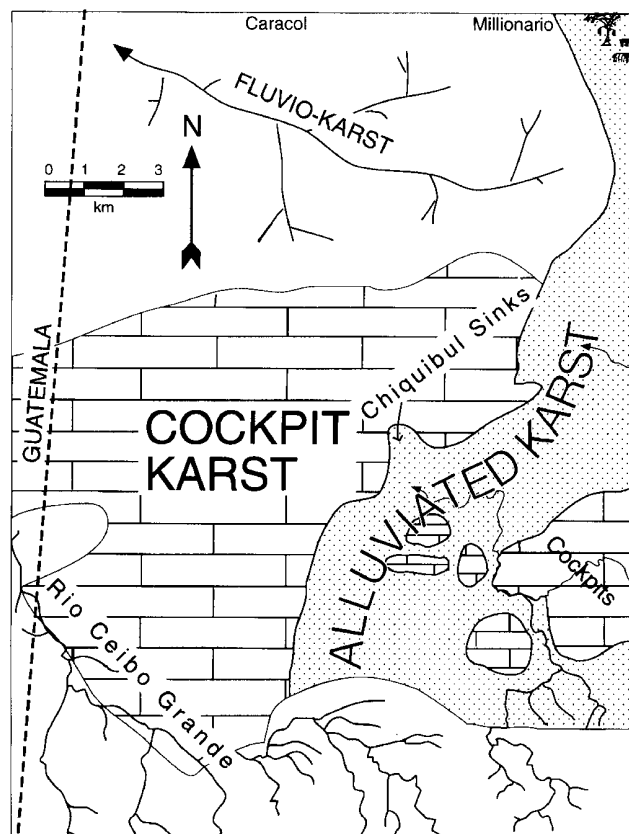


Figure 14. Boundaries of different sub-areas of the karst in the Chiquibul area, in the southern Vaca Plateau (from Miller, 1984a).

results of explorations in the area that have found few and relatively small caves (Reeder, 1993).

CAVE GEOMORPHOLOGY

At over 55 km in length and with a vertical relief of 300 m through its four major caves, the Chiquibul System is the largest hydrologically-linked cave network in Central America (Figure 15). The passages in the western half of the system are hydrologically active portions of the underground Chiquibul River; most known passages in the eastern half are abandoned channels. The river's ponor has moved upstream with time, regressing 5 km to its present position, and largely bypassing the eastern passages.

The eastern section of the system is the most complex, the result of vertical and lateral migration of the river. Various sections of the system display at least four levels that can be correlated from cave to cave. The western section has the greatest vertical development and the largest diameter passages—occasionally exceeding 100 m in width. Only a few kilometers of the total mapped passages are independent tributaries. These usually enter at or slightly above the floor of the trunk conduits.

Except in some of the large rooms, there is surprisingly little bedrock collapse for the size of the passages. Most breakdown is the result of massive stalagmites undermined by repeated floods in the trunk conduits (Figure 16). The active channels of the trunk passages are floored with sand and pebbles derived from the highlands. Most of the trunks are occu-

piated by large, lengthy clay banks tens of meters high and wide.

Isolated caves occur in the area, some of large size, but they form only a small percentage of the known total. Only one is an old high level river cave, the others being of isolated phreatic origin.

CLIMATE AND HYDROLOGY

The Vaca Plateau is largely uninhabited, and long-term climate data are few. Data collected from 1956-1959 at Millionario (Johnson and Chaffey, 1973) indicate a mean precipitation of only 148 cm/yr, and a wet season that begins in May and lasts into December. Because these years were slightly drier than average along the Hummingbird Highway, and assuming a proportional relationship with the Millionario data, which probably reflect a slight rainshadow from the Maya Mountains, 200 cm/yr may be slightly closer to the long-term mean rainfall of the Vaca Plateau as a whole. At the slightly cooler elevations at the southern part of the plateau, annual runoff is estimated at 110 cm of the 200 cm total. Mean annual temperature, as estimated from caves, is 22-22.5°C.

During the dry season, baseflow of the Chiquibul River was measured at 2 m³/sec. Perhaps another 400-500 L/sec was contributed by stalactite drips and the short tributaries carrying autogenic water. Surface runoff was of short duration after heavy rainfall.

All waters analyzed in the Chiquibul were alkaline. The Chiquibul River, both before and after sinking, was the lowest in bicarbonate at 90-107 mg/L (as CaCO₃), and undersaturated

Figure 15. The meandering course of the Chiquibul System, longest (55 km) and deepest (300 m) in Central America (after Miller, 1986c).

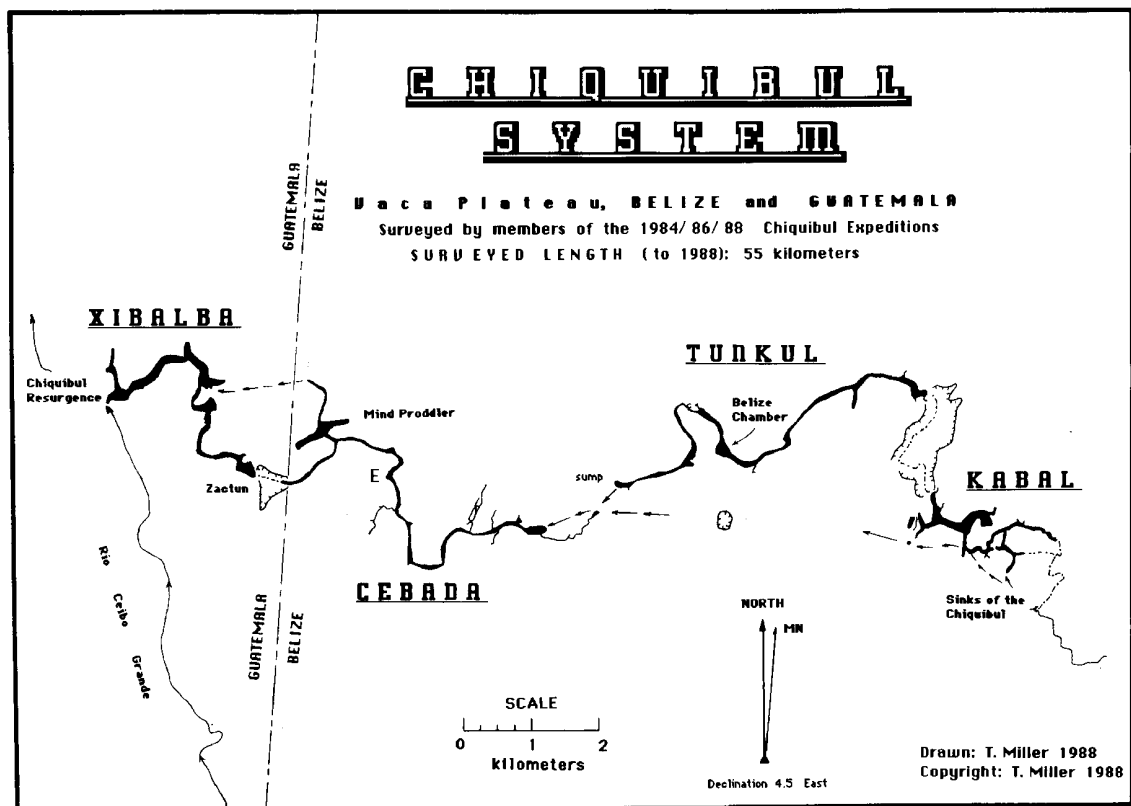




Figure 16. An undermined and fallen stalagmite typical of the Chiquibul System, as well as in many other trunk conduits in Belize. Sumps and low ceilings in this cave are located in synclinal areas.

for both calcite (SIc -0.68 to -0.19) and dolomite (SI_d -0.71 to -0.24). The autogenic waters, however, were often in the 300-400 mg/L range for bicarbonate, and PCO₂ frequently exceeded 1%. These waters contained substantial amounts of magnesium, and were always oversaturated for calcite (SIc 0.18 to 0.98) and dolomite (SI_d ranging to 0.88). A combination of degassing in the trunk atmospheres, and incongruent dissolution of calcite and dolomite may be indicated. Nearly always, these streams were depositing calcite where they entered the main passages (Miller, 1984). Using a mean total hardness of 300 mg/L and mean runoff of 110 cm/yr, an approximation of mean annual surface solutional removal of about 130 m³/km²/yr can be calculated :

$$E = [QA(H/d)]/100 \quad [\text{Eq. 1}]$$

where

E = erosion rate (solute mass removed per year), m³/km²/yr, inserting the absolute values of the following units:

QA = mean surface discharge, cm (precipitation - evapotranspiration),

H = mean hardness of local discharges, as mg/L CaCO₃, and

d = 2.5 (assumed 2.5 g/cm³ density of the dissolved rock).

3. SIBUN-MANATEE KARST

The Sibun-Manatee is in many ways simply the eastern extension of the Boundary Fault Karst. It does differ in two important respects: rocks in its northeast corner are regarded to be Tertiary dolomites (Cornec, 1986), and in surface appearance most of it is tower karst. The region is bounded on the west by the north-south line between Dry Creek and the Sibun River, and by the contact with the noncarbonate highland to the south. The tower karst summits rise to 200 m above flat valley

floors that descend to sea level from less than 40 m inland.

SIBUN-MANATEE GEOLOGY

The southern half of the Sibun-Manatee region is in the Cretaceous limestone of the Campur Formation that forms most of the karst in Belize. If Cornec's (1986) identification of the northern half as Tertiary dolomite is true, it would be a rare example in Belize of significant karst development on non-Cretaceous rock. Several major faults in the area may be responsible for uplifting the rock to the elevation of the Cretaceous outcrops. However, a rock sample from the Gracy Rock area, in this northern section, showed an almost pure calcite rather than dolomite, where CaO = 55.64%, MgO = 0.14%, and CO₂ = 43.6% (Miller, 1981a).

CLIMATE AND HYDROLOGY

Rainfall is variable in this karst, declining from 210 cm/yr at the southeastern corner to about 170 cm/yr near the coast. This is among the driest of the major Belize karsts.

The majority of this area, unlike the Boundary Fault Karst, is relatively remote from the noncarbonate highlands. Major streams do entirely traverse the area, from Indian Creek on the west, to the Manatee River, Bayman, Big, and Quamina creeks on the east. These allogenic streams carry a high sand bedload, and are associated with nearly all the large caves known in this karst, although most of the runoff is likely of autogenic origin.

SURFACE MORPHOLOGY

The area consists of thousands of hills, a mixture of cockpits, small classical towers rising from flat floors, and skeins of hills surrounding flat-floored depressions. The mixture may result from tectonic juxtaposition of differing Cretaceous rock units. Several north-south faults have been identified, and numerous dominantly east-west linear features traverse the hills. The lineaments separate tracts of hills with differing textures, either "smooth" with relatively similar summit elevations, or with rough and broken cockpit topography.

Neighboring flat areas share similar elevations, and are floored with insoluble clays. The clay source of those near the through-flowing streams is presumably deposited material from the highlands. The few interior valleys visited may contain in-situ residuum from the carbonates, or deposits from base level conduits that connect with the rivers. A few valleys appear to have the integration associated with fluviokarst.

CAVE MORPHOLOGY

The major caves of the Sibun-Manatee region are dominantly trunk conduits entered by allogenic highland streams. Examples are Actun Kimin Cab, Manatee River Cave, the White Ridges System (Darby Pat), and the five caves traversed by Indian Creek. Caves abandoned by the allogenic streams occur as far as several hundred meters from the present river courses. The largest of these caves are multi-level, such as Actun Kimin Cab and Gargantuan Cave (Miller, 1991) and the

White Ridges System (Marochov & Williams, 1992), and are reminiscent of the Caves Branch caves.

Other caves have formed where the major streams abut bedrock, but do not use it as a throughway. These passages tend to be smaller, of phreatic origin, and parallel the cliff face. They may also be multi-level, such as The Lost World (Miller, 1991), indicating a long period of development and adjustment to incising base level streams.

Flat-floored depressions, surrounded by towers and floored by insoluble clays, are often drained through small caves to the major river caves. They may also drain to what appear to be small conduits developed within the karst hills that are independent of the allogenic streams.

Isolated higher level caves have also been mapped to 600 m long and 30 m high. They are located as much as a kilometer or more from present river courses, do not contain river sediments, and their walls and ceilings are of obvious phreatic origin. They may represent an eastward extent of the large isolated phreatic cavities of the Boundary Fault Karst.

McDonald (1976a, 1976b) described ponded depressions in the northern Sibun-Manatee Karst and cave streams in Sulawesi, Indonesia, that appeared to preferentially enlarge cavernous openings in limestone bordering alluviated valleys. He believed that the limestone presented hydraulically more efficient pathways to streams perched on non-soluble alluvium. The caves on Manatee River, Mahogany Creek, and the three caves of upper Indian Creek are likely examples of this phenomenon. In all of these cases, the through-flowing stream should have experienced little difficulty in flowing around the isolated hills in which they occur.

4. LITTLE QUARTZ RIDGE KARST

Covering an expanse of ~750 km², this karst is the second-largest in Belize, and extends westward into Guatemala. Although only the interior of its western half is dominated by the non-soluble rocks of the Little Quartz Ridge, this name has been extended to the whole region.

LITTLE QUARTZ RIDGE KARST GEOLOGY

The surface is presumably underlain by the same group of Cretaceous limestones of the Campur Formation that form major karst elsewhere in Belize. Faulting plays an obvious role in some areas, particularly along the Bladen Branch, whose course, and many of its tributaries, is largely fault-controlled. The sinkpoint of the Central River, draining the Little Quartz Ridge, is at one end of a fault that extends 40 km southwest into Guatemala. The two major fault orientations in the area are at approximate right angles (southwest to northeast and northwest to southeast), although airphotos show other lineations running east-west.

SURFACE MORPHOLOGY

There are three main elements of the Little Quartz Ridge

karst. The western half is dominated by the Little Quartz Ridge, a faulted ridge of upper Paleozoic metasediments and volcanics. The streams formed on its relatively high summits (>1,000 m) flow into the surrounding carbonates 300 m below and at most penetrate a few kilometers before sinking. South and west of the ridge the carbonates form a fluviokarst; other areas are broad expanses with little relief. Many large vertically-walled dolines are scattered south and east of the ridge.

Eastward, the Bladen Branch river and its fault-controlled tributaries drain a mixed surface of fluviokarst and cockpit. Valley bottoms are at about 80 m msl, with karst summits to 400 m. A few large collapse dolines are present. South of the Bladen is a little-explored region of several hundred square kilometers, also a fluviokarst with some linear features.

CLIMATE AND HYDROLOGY

The climate in the Little Quartz Ridge region is likely similar to that of the K-T Fault-Ridges Karst to the south, with a longer and considerably more humid wet season than the Vaca Plateau to the north. Estimations of mean rainfall as high as 500 cm/yr have been made for these mountainous areas.

With such precipitation, large volumes of runoff enter the karst, and four substantial rivers drain it, beginning in the west with the Machaquila which continues into Guatemala. In Belize, the Bladen Branch, Rio Grande, and Columbia Branch are fed by numerous resurgences, and rise and sink throughout their courses. The fluviokarst south of the Bladen is likely drained by Deep River and Golden Stream.

CAVE MORPHOLOGY

Presently, the largest caves in the Little Quartz Ridge Karst are associated with the Rio Grande River. These include Tiger Cave, the longest surveyed at 4 km. Tiger Cave is described as a lengthy fossil trunk of the Rio Grande, with lower connections to the active river (Dougherty, 1985). Several small stream tributaries were noted in the cave.

The entire Rio Grande valley begins 8-10 km upstream, at the mouth of an abandoned resurgence. The valley is normally dry, but is fed during floods by short surface streams and by large overflow shafts, from which groundwater rises and discharges.

This Rio Grande source cave is apparently the end of the trunk that leads from the downstream sump of Yax Ta' Ha, a complex multi-level, 3-km-long cave (Figure 17). Dry season flow in both caves is from local autogenic karst drainage. Yax Ta' Ha is remarkable in Belize because it occurs entirely in bedded limestone. Folds in the bedrock control changes in passage elevation, and the present sump terminations at either end of the cave are due to local down-dipping strata. The cave formed under phreatic conditions, and was later invaded by downcutting surface streams in the partial fluviokarst overhead. Further up-valley toward the Little Quartz Ridge is Dead Gibnut Cave, also formed under phreatic conditions. It serves as an overflow for large wet-season discharges that likely feed

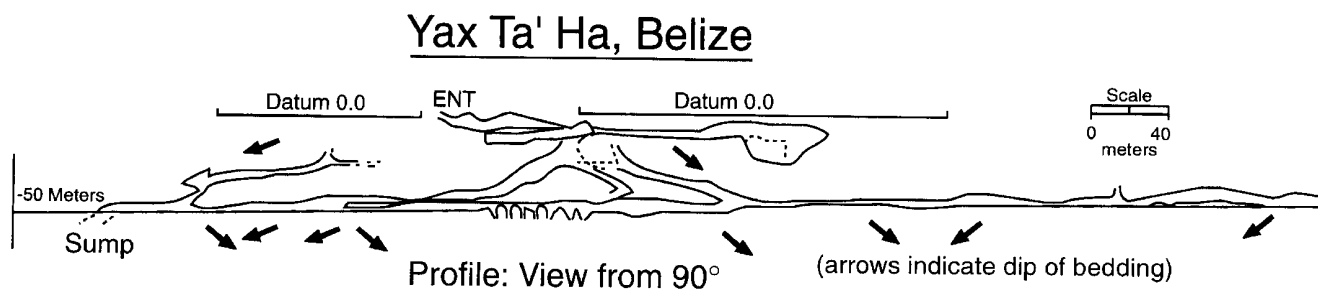


Figure 17. Profile of the multi-level trunk conduit passages of Yax Ta'Ha, the largest cave (3 km) in bedded limestones in Belize. Sumps and low ceilings in this cave are located in synclinal areas.

the sump at the upper end of Yax Ta' Ha.

Several massive vertical-walled dolines exist between Dead Gibnut Cave and the sinks of the Central River. No ponor was located at the sinks, which is an alluviated blind valley. Given the characteristics of the Rio Grande's caves and resurgences between the Central River Sinks (at 500 m elevation) and Tiger Cave (~15 m msl), and the size of its discharge from Tiger Cave (10-15 m³/sec), the presence of a large, active integrated conduit system is implied. This may be as much as 100 m below the surface. The present passages are insufficient to channel flood flow, which emerges either into higher fossil channels, or onto the surface up vertical shafts. The resurgence flow suggests it integrates the sinking Central River, scores of kilometers of autogenic drainage, and perhaps some of the other sinking Little Quartz Ridge runoff in the 14-km-distance that it traverses to the plains. While only relatively minor caves have been explored in the Little Quartz Ridge karst, the deeper, unexplored conduit system of the Rio Grande may be comparable to that of the Chiquibul in size and complexity.

The observed lack of cave development immediately surrounding the Little Quartz Ridge is anomalous in Belize. In spite of high rainfall on the non-carbonate ridge, and substantial runoff into the surrounding soluble limestones, only a few hundred meters of enterable cave passage was found by the 1990 Queen Mary Expedition (Williams, 1992). Although these potential ponors may simply be plugged by alluvial debris, the smallness of such apertures is a surprise in Belize.

The Bladen is an area difficult to access. Visits by the author in 1988, 1994, and 1996 (Miller, 1996), and more detailed explorations by the Maya Mountains Archeological Project (Dunham et al., 1995) have revealed complex systems potentially rivaling those of the Rio Grande River. With the completion of the 1996 field season, several caves now exceed 2 km in surveyed length, with the longest approaching 4 km. Several independent systems currently occupy the disaggregated Snake Creek-Bladen catchment; the largest known parallels the course of the Bladen River. The bedrock hosting the caves is a mixture of brecciated and bedded carbonates.

In the Bladen area, runoff from the non-carbonate Maya Mountains enters the lower limestone hills on armored alluvial

beds before sinking in swallets or caves, then combines with autogenic tributaries underground. Analyses by the author show total dissolved loads ranging from about 40-80 mg/L (as CaCO₃) for allogenic waters, to 300 mg/L for cave waters. All were moderately alkaline (pH 7.5-8.0), with the cave waters approximating saturation with respect to calcite. Cave water temperatures were 23-25°C.

5. K-T FAULT RIDGES KARST

K-T FAULT RIDGES GEOLOGY

The carbonates of the K-T Fault Ridges differ significantly from the other karsts of Belize in both age and structural setting. Cornec (1986) assigns these primarily to the La Cumbre Formation of Late Cretaceous to Tertiary Paleocene age, thus the name "K-T." They consist of long, isolated, block-fault ridges, trending southwest to northeast, the largest being 20 km long. The ridges total about 300 km² and rise above plains of the Toledo Series, a suite of Quaternary shales, mudstones and sandstones.

Most knowledge of the karst and caves of this area is the result of visits to the longest ridge, which contains Blue Creek Cave (also known by its Mayan name *Hokeb Ha*). Walters (1988) has described small caves of unknown genesis (possibly isolated phreatic caves) from the ridges south from Blue Creek.

SURFACE MORPHOLOGY

The Toledo Series plains are generally less than 100 m in elevation, with the intervening limestone ridges at 220-380 m. The ridges exhibit cockpit topography, with some cross-cutting valleys suggesting former fluvio-karst. Only one surface stream presently crosses through any ridge, that of Jalacte Creek at the southwest end of the ridge containing Blue Creek Cave.

The streams of the area all appear to originate on the Toledo Series, some to the west in Guatemala. The largest catchments with the most direct downstream course to limestone are those in the Pueblo Viejo-San Antonio valley, and they may be fed by outflow from the Little Quartz Ridge Karst. These streams plunge into ponors and flow in classic trunk

conduit fashion to emerge at resurgence caves such as Ochochpec and Blue Creek.

CAVE MORPHOLOGY

Two small blocks of Cretaceous limestone have been faulted into the longest ridge, outlined by the villages of Pueblo Viejo, Aguacate, Blue Creek, and San Antonio. The ridge is traversed by at least two large caves. Ochochpec, and the large ponor that appears to feed it, are simple huge trunk conduits. Blue Creek Cave, however, is among the most complicated in Belize with 9 km of mapped passages. It developed as the White River abandoned flow through a limestone gorge in the ridge above the cave, to dissolve open a subsurface route and emerge as Blue Creek (Miller, 1981b, 1995). At least four progressively-abandoned levels developed in the brecciated limestone, three of which are periodically flooded by waters exceeding 30 m in depth.

HYDROLOGY AND CARBONATE WATER CHEMISTRY

The wet season in the southern Toledo District is long and pronounced. Mean rainfalls of 200-450 cm/yr, and their consequently greater runoffs, substantially exceed the 100-150 cm/yr of the northern karst regions. Estimations of mean rainfall as high as 500 cm/yr have been made for the mountainous areas northwest of Punta Gorda.

Waters from Blue Creek Cave were analyzed as part of the Jason Project (Miller, 1995). The waters were generally bicarbonate, calcite-saturated with pH of 7.5-8.2, and dissolved solids of 160-260 mg/L. Nutrients (orthophosphate and nitrate) each averaged 0.2 mg/L, except for two pools containing guano, which exceeded 1 mg/L. Traces of dissolved sulfate, iron, and copper were found.

A large, ~300 L/sec, autogenic resurgence known as Cliff Source is located near the resurgence of Blue Creek Cave. Its water was saturated with respect to calcite, and had a high PCO_2 of ~1.5%. Its mean temperature was 25.5°C, likely reflecting the mean annual temperature of its low elevation and latitude. Given its size, the spring is probably a reasonable gauge of local solution rates. At a total hardness of 220 mg/L ($CaCO_3$), and local runoff of perhaps 150 cm/yr, the K-T Fault Ridges Karst would have a mean surface solution rate of ~1.20 $m^3/km^2/yr$, comparable to other Belizean karsts (as per Equation 1).

6. CAYES AND BARRIER REEF

The low-lying islands (cayes) and 250-km-long barrier reef fronting Belize form a significant shelf of soluble Pleistocene to Holocene carbonates. To date, few caves have been reported, probably because of the difficulty attendant to underwater cave exploration. Some caves on the cayes of Belize seem to represent development during lower sea level stands, while others may still be developing at the fresh/salt water interface.

CAYES AND BARRIER REEF GEOLOGY

The underlying reef foundation appears to be Cretaceous carbonates similar to the mainland. For example, nearly 1,800 m of the Coban Formation were exposed in a well drilled on Ambergris Cay (Dillon & Vedder, 1973).

There are two main views of the recent development of the cayes and reef. Purdy (1974) described the relief on the Belize shelf as influenced by an inherited, pre-Holocene limestone surface that eroded when the entire shelf was exposed during lower sea-level stands. Purdy stated that a pre-existing karst surface has been "accentuated... through an accelerated ... carbonate deposition on the highs."

Choi and Holmes (1982) cited a few drilling cores to support their contention that the Quaternary reef pattern was located on topographic highs of deltas, bars, river levees, and other siliciclastic depositional highs spread over the previously exposed shelf. Some mixed carbonate-siliciclastic deposition, supplied by rivers, occurs today off Placentia Cay (Wiedemeier, 1989).

CAVE MORPHOLOGY

The Blue Hole of Lighthouse Reef is a major example of a drowned offshore karst feature (Dill, 1971; Mathews, 1991). It is approximately 120 m deep, and a circular 300 m in diameter. "Tilted" stalactites beneath the overhanging lip have been cited as evidence for Holocene tectonic activity (Dillon & Vedder, 1973), although in many mainland cave entrances tilting is due to local factors of speleothem growth. The large size of this cavity and its speleothem development supports the idea of subaerial cavern development on the cayes.

Caye Caulker contains a large underwater cave on the east side of the island. Exley (1994) described the cave as over 3 km long, with several large conduits extending from a 50-m-diameter room. Later work by Coke found problems with the survey and described the cave as a room that could be as much as 600 m in diameter (Coke, 1986, 1987, 1988). The cave was subaerially exposed by low sea levels during the Pleistocene glaciations, as indicated by its abundant speleothems. Although the cave covers a large area and exceeds depths of 30 m, it has a relatively low average ceiling height of 10-13 m.

Giant Cave, small reported depressions, and some other known but minor caves of the cayes are of unknown origin. They could be the result of subaerial development on an exposed karst surface, or due to subaqueous solution at the freshwater/seawater interface. Freshwater lenses described on many cayes have been in long use as water supplies (e.g. Carrie Bow Caye [Urish, 1987]).

7. YALBAC HILLS

The surface of the northern third of Belize is formed on rocks that are generally progressively younger in age with increasing distance north from the Maya Mountains. Most of the topography is <100 m msl, with local relief on the order of

10 m or less; the surface is often swampy. The exceptions are the Yalbac Hills and the area north of Gallon Jug along the Guatemalan border west of the Booth River escarpment.

The Yalbac Hills rise to elevations of 200-250 m, with most drainage on the surface. Hartshorn et al. (1984) have reported outcrops of the Coban Formation (Cretaceous), perhaps covering about 300 km² of a total 2,000 km². In spite of their lithologic similarities to the Cretaceous carbonates further south, a cockpit karst has not developed to any degree. North of San Ignacio near the Guatemalan border a line of several vertical-walled dolines in Paleocene-Eocene carbonates have been explored. They exceed 100 m in depth but no caves were found in the vicinity (Albert & MacLeod, 1971). Areas to the north are about 100 m lower, with a "modest karst topography" developed on the early Eocene Santa Amelia Formation (Hartshorn et al., 1984).

8. TERTIARY ROCKS

All epochs of the Tertiary and Quaternary, from Paleocene to Holocene, are exposed somewhere in the rocks and sediments of northern Belize. They are largely carbonates, including marls, but bentonitic clays and poorly consolidated sands are found as a terrigenous clastic cover over much of this area. The basement rocks underlying the carbonates of northern Belize vary from Paleozoic metasediments to granites (Deguen & Schact, 1975), and are at progressively greater depths of 800 m to 3,000 m from Belmopan north to the Mexican border (Anschutz Mineral Corporation, 1976).

Most of the surface drainage (e.g. Rio Hondo, New River, and Freshwater Creek) has a distinctly northeast orientation, due to northeast-southwest parallel faulting which accompanied the general uplift of the Yucatan Platform (Pusey, 1975)

Minor shelters and shallow dolines have been reported from this region. North of Corozalito, numerous circular lakes and ponds exist, with some marked on maps as "cenote." To date, nothing about known solutional features appears to have been published, except for apparent assumptions of very immature karst present on Tertiary carbonates (Placid Oil Company, 1979). Cavernous porosity may exist at depth. Nair (1985) notes artesian flow at 150-200 m depth north of Consejo, with the hydraulic head described as 5-6 m above the ground surface, and originating in proximity to an unconformity thought to be a cave or fracture system. The shallow depth indicates flow in Tertiary carbonates.

GENERAL OBSERVATIONS OF BELIZE KARSTS

SURFACE MORPHOLOGY

Because of the widespread occurrence of carbonate rocks in the humid climate of Belize, the majority of the country can be defined as having at least minimal karst development. Westward, the karsts extend for great distances into Guatemala. The elevations of the major karsts range eastward

from near 800 m above to 100 m below sea level.

Most major karst surfaces display obvious fluvial features or influence: through-flowing streams, poljes, dry dendritic valley networks, and abandoned gorges above caves. Most of the remaining surfaces are similar to the cockpits of the Caves Branch and Chiquibul and usually abut the fluviokarsts. Analysis of sediments and morphologic studies support the idea that these areas were initially developed by non-random fluvial networks centered on points of lithologic weakness. Gradually, the allogenic streams were pirated underground, and evidence of the fluvial networks has been obscured (Miller, 1988).

Isolated limestone towers, and the sizes and extents of flat-floored alluviated dolines, increase with proximity to the lower elevations of the coast. This suggests an evolutionary sequence of fluviokarst to cockpits to towers as downcutting to base level progresses. Large collapse dolines are frequent in Belize, but minor in terms of area. Many are directly attributable to collapse into pre-existing caves.

Runoff in the karsts of Belize is an infrequent occurrence due to the convective nature of most precipitation. In the Caves Branch area, a minimum 12 mm/day of rainfall is needed to generate surface flow into cockpit swallets. Most solute removal takes place internally in what are solutionally "open" systems of relatively high porosity. Boosting of carbon dioxide levels within the aquifer occurs, perhaps due to decay of washed-in vegetation. Resurgent waters are alkaline and usually supersaturated with respect to calcite and dolomite. Overall denudation rates are high, calculated at 0.10-0.13 m/Ka.

CAVES

More than 150 km of cave passage have been surveyed in Belize. The majority are massive tunnels from 20 m to as much as 100 m in width, and have developed on the downfaulted north and south peripheries and western backslope of the horst-structured Maya Mountains. The southernmost systems are sandwiched in the 80 km between the Southern Boundary Fault and the North American-Caribbean tectonic plate margin. The caves are well-mapped, inland, regionally extensive, contain substantial deposits of speleothem, and are in proximity to regional tectonic activity.

These cave populations and cave sizes cannot be known with certainty—there are certainly thousands of unreported caves in Belize. Because of the relative ease of finding trunk conduits, they are likely emphasized out of proportion to their importance, and distort perceptions and conclusions about Belize cave development. The evolution of individual caves are unique to a particular extent beyond general regional patterns, and considerable information about growth and development may be lost through erosion. The known caves may not be representative of the whole.

The oldest caves in Belize appear to be isolated chambers and passages of phreatic origin with minor vertical relief. Trunk conduits developed next, most of which cut through to

the coastal plain at the base of the karsts. These conduits occur as discrete independent systems, each formed by an integrated stream invading from the Maya Mountains, which have karst regions distributed around their north, west, and south sides. The cave systems pass completely beneath the width of individual karsts, with linear extents of up to 15 km.

Every known trunk conduit in Belize is associated with the sinking of chemically aggressive allogenic water originating on the Maya Mountains. These streams are already large, integrated networks before they encounter a limestone where the near-absence of bedding planes provides little resistance to vertical flow in the well-jointed rock. Jointing and topographic dip appear to be the major controls as defined bedding is rare. Although many sections are obviously controlled by a joint visible in the roof, in most instances the initial joint or joints responsible for alignment have been obscured by the size to which the passage has developed. The locations of swallets, *zuhuyhas*, and piratic conduits were influenced by the siting of the trunk conduits, which were targeted for integration of the internal karst runoff.

Large trunk conduits, and apparently even large isolated phreatic chambers, are rare in those areas such as the Yalbac Hills and northern Vaca Plateau. Even though they are lithologically similar to rocks with trunk conduits in other areas, the main difference appears to be the lack of allogenic runoff. Other areas, such as the region continuing north to the Yucatan, may be too low-lying to provide sufficient hydraulic head for widespread subsurface solution at the present elevation of sea level.

COMMON CAVE FEATURES

Briefly, it should be noted that Belize caves commonly contain several types of internal features that are rare elsewhere in the world, yet have not been emphasized in publication about Belizean caves.

"Shields" or "palettes" are frequently large (up to 5 m in diameter) and widespread in Belize, and can be of surprising density—more than 60 were counted in a 100-m-traverse of a cave near Indian Creek, and another 150 were noted in neighboring caves.

"Bellholes" are ubiquitous to every large cave in Belize, occurring in both bedrock and speleothem. These cylindrical, upwardly-tapering ceiling or wall cavities are most likely due to local long-term effects of bat occupation (Miller, 1990b). Their flat, circular counterparts, "bellbasins," are often found vertically beneath bellholes, always containing bat guano. Both features generally decrease in frequency with distance from entrances.

Travertine or speleothem, undermined by floodwaters or toppled by earth movements, form slabs or boulders. They form the majority of collapse materials in many Belize caves, rather than bedrock.

The large, high-ceiling, multi-entrance passages in Belize commonly contain narrow, linear stalagmites aligned with the

passage axes. The passage profiles approximate a Gaussian distribution, and are called "camelbacks." The deflection of dripwaters on their surfaces (and consequent calcite precipitation) has been observed to be a product of wind current alternation and velocity, parallel to the passage trend.

CAVE LEVELS

All of the major karsts of Belize contain multi-level, often regionally-extensive, cave systems. All of the major trunk conduits display the presence of at least two to three levels, and as many as four. Internal vertical relief averages about 100 m, with clearly separated individual levels up to 20-30 m apart. Although the rock is extremely hard, it has also been heavily brecciated with bedding almost nonexistent; the individual levels are thus not controlled by stratigraphic perching.

The vertical relief between levels of similar geomorphic characteristics, but hydrologically independent catchments, is broadly concordant across the entire range of the karst in spite of large differences in elevation. It implies synchronous development by the same general cause. Together with evidence of recent, continuing uplift, the concordant cave levels supports the idea of regional response to episodic tectonic uplift of the Maya Mountains, rather than simple local downcutting responses to erosional lowering of base level.

CAVE AGES

Uranium series dating of speleothem from Belize has only been reported from the Caves Branch area (Miller, 1981a). The base of the oldest of two small stalagmites from Mountain Cow Cave (a high isolated phreatic chamber) gave a date of 176 (+49/-36) KaBP. Two others were dated from trunk conduit passages. One was a small stalagmite growing on cemented cobbles 2 m above the present floor of Actun Chek, and was radiometrically dated to 72.5 (+12.9/-11.6) KaBP. The other was a stalagmite from Lubul Ha. It had been overturned and largely covered by sediment, and gave a date of 102 (+3.9/-3.8) KaBP. These dates show that major cavernous development in the basal 30 m of the Caves Branch Karst was well advanced by about 102 KaBP. Filling episodes of unknown regional significance occurred between 60-105 KaBP in very large, mature trunk conduits.

Clays for paleomagnetic analysis were collected from the higher levels of trunk conduits in the Chiquibul, and from Yax Ta' Ha in the Little Quartz Ridge Karst. These were analyzed by W. Steele of Eastern Washington University and all showed a polarity similar to the present (Miller, 1988).

SUMMARY

Belize has proven a fruitful location for a combination of scientific studies and cave exploration. An integration of the processes that interrelate both the surface and subsurface has been possible, in no small degree due to the great amount of cave exploration and mapping that has occurred during the past

four decades. The overriding importance of fluvial processes in the development of surface karst landforms in Belize have important implications for understanding similar landscapes elsewhere in the tropics and near-tropics. This is also true for the importance of open-system solution within the local Belize aquifers, and the consequent magnitude of dissolution in these tropical waters. The regional scope of the amount of caves surveyed, and the recognition of widespread, concordant cave levels, will eventually lead to determination of any causal effect from the nearby tectonic plate boundary.

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KARSTIFICATION ON THE NORTHERN VACA PLATEAU, BELIZE

PHILIP REEDER

Department of Geography and Geology, University of Nebraska at Omaha, Omaha, Nebraska 68182-1099, U.S.A.

ROBERT BRINKMANN

Department of Geography, University of South Florida, Tampa, Florida 33620, U.S.A.

EDWARD ALT

Department of Geography, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin 53201, U.S.A.

Quantification of limestone petrology and structure in a 25 km² section of the northern Vaca Plateau, Belize, facilitated development of a model of speleogenesis and evolution of area caves and the karst landscape. The limestones in the study area are mostly depositional breccias developed between the mid-Cretaceous and mid-Tertiary adjacent to the emergent Maya Mountain Fault Block. Micritic and some fossiliferous-pelletic lithoclasts of the Cretaceous Campur Formation are cemented by sparite which formed in a shallow-sea high energy environment adjacent to the emergent area. Planes of structural weakness developed in the Campur Limestone have similar orientations to contemporary karst landform features including solution valleys, the long-axis of depressions, and cave passages. This correspondence suggests an important structural control on the formation and evolution of area caves and the karst landscape. Base level modification by way of valley incision and the development of secondary permeability enhanced interfluvial development, causing caves to be truncated along valley sides and abandoned as active flow routes. The dry valleys and stair-step cave profiles indicate that the lowering of base level through time was interspersed with stable periods when horizontal cave passages were excavated.

Geologic, geomorphic, and speleological research has been conducted for six field seasons (1990-1995) within a 25 km² area of the northern Vaca Plateau centered 6 km east of the border between Guatemala and Belize, and 15 km south-southeast of the Augustine Forestry Station (see location map on page 68). The research design for this project includes (1) reconnaissance of surface and subsurface geology and geomorphology, (2) exploration and mapping of caves, (3) collection of rock, soil, and sediment samples, (4) collection of data regarding area joint, fault, dry valley and cave orientations, and (5) the petrographic analysis of carbonate rocks. Our research is the first attempt to quantify physical landscape components in the northern Vaca Plateau (i.e. limestone petrology, structure, geomorphology and hydrology) and to relate these parameters to landscape and cave formation and evolution.

The suite of karst landforms within the study area includes an integrated system of dry karst valleys separated by residual limestone hills and interfluvial, single inlet and compound sinkholes, isolated cockpits, cutters, solution corridors, solution fissures, open joints, and caves. To date, over 100 cave entrances have been located and 60 caves have been explored. The majority of the caves are located along or close to the surface drainage divide between the Macal River (8 km east of the study area) drainage basin, and the Chiquibul River (15 km west) drainage basin. All the caves in the study area are formed in the heavily brecciated Campur Limestone (Figure

1). A breccia is a coarse-grained rock composed of angular broken rock fragments held together by a mineral cement or in a fine-grained matrix (Bates & Jackson, 1987).

Specific research regarding the physical landscape in this portion of Belize has not been conducted previously. The only sources for such information are very general country-wide or regional assessments, citations in publications regarding the Mountain Pine Ridge and Maya Mountain section of Belize, or detailed studies in other areas with similar geologic characteristics.

PREVIOUS WORK

Ower (1928) produced a manuscript on the geology of British Honduras (now Belize). Therein, the Cretaceous limestones in west-central Belize were mentioned, but few details were presented. Dickenson and Weisbord (1931) described the Cretaceous limestones in Belize generally, but provided few specific details. Flores (1952) reviewed the nature of the Cretaceous limestones in northern Belize, and in 1957 Dixon produced an 85 page monograph on the geology of southern Belize wherein the Cretaceous limestones were discussed. Wright and others (1959) discussed the geology of the Vaca Plateau as part of a land use survey of British Honduras. Because of its unique geology, the Vaca Plateau was considered a major subregion in their land use classification, but they

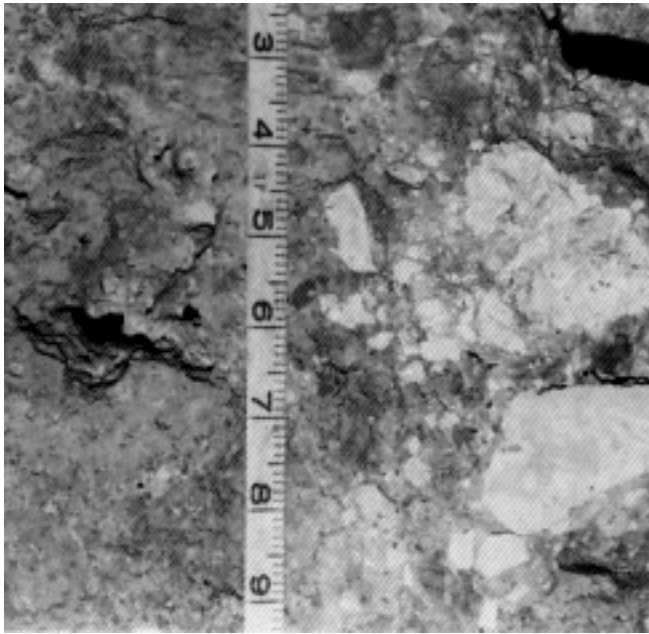


Figure 1. Limestone breccia composed of micritic lithoclasts. Scale is in tenths of feet (0.1 ft = 3 cm).

misinterpreted the geology in that they indicated it is “horizontally bedded limestone” with no mention made of brecciation.

Detailed information regarding the Cretaceous limestones found in the Coban-Purulha area of central Guatemala was presented by Walper (1960). Walper was probably the first geologist to propose that the breccias of the Ixcoy Formation (the upper Ixcoy is analogous with the Campur Formation in Belize) originated as depositional breccias, “pseudobreccias” or both (Blount & Moore, 1969). Lattimore (1962) noted shale and limestone pebble conglomerates overlain by angular carbonate boulders in a clay matrix in the Ixcoy Formation and determined that the boulders are composed of carbonate clasts in a matrix of fine-crystalline, occluded dolomite. He suggested that the breccia formed by carbonate dissolution, collapse and recementation. Vinson (1962) published a detailed description of the Upper Cretaceous stratigraphy of Guatemala, with references to Belize. He described the Campur Formation, relates it to other Upper Cretaceous formations in Guatemala and Belize, and summarized the paleoenvironmental conditions under which these formations were deposited. Blount and Moore (1969) discussed the formation of carbonate breccias in the Ixcoy Formation in a 250 km² area in east-central Guatemala. They classified and posed formative mechanisms for five different types of breccias, including depositional breccias, non-depositional breccias (evaporite-solution collapse, tectonic, caliche breccias), and pseudobreccias.

The oldest rocks exposed in Belize are the 350 million year old granitic rocks of the Mountain Pine Ridge portion of the

Maya Mountains which border the eastern edge of the northern Vaca Plateau. Bateson and Hall (1971 & 1977), Hall and Bateson (1972), Bateson (1972), and Kesler and others (1974), discussed various aspects of the Mountain Pine Ridge Granite, and the metasedimentary rocks of the upper Paleozoic aged Santa Rosa Group which comprise a major portion of the Maya Mountains. They also discussed the relationship between the Campur Limestone and the Santa Rosa Group, which in places it unconformably overlies (Figure 2).

In 1984, Hartshorn et al. published an environmental profile of Belize which generally described the soils, geology, and hydrology. Day (1986) described slope form and process in the Campur Limestone in the Hummingbird Karst region of central Belize. Miller (1986, 1987, 1989, 1990) provided details about the Campur Formation on the southern Vaca Plateau which was studied in conjunction with the exploration of the Chiquibul Cave System (55 km of mapped cave passage). The Chiquibul River, which receives allogenic recharge from the Maya Mountains, has played an important role in the creation of this extensive cave system. Most of the caves are developed in brecciated limestone and are influenced by joint sets and topographic dip (Miller, 1986). It is estimated that the development of the karst in the southern Vaca Plateau began around 700,000 years BP (Miller, 1990).

GEOLOGIC SETTING

The most complete description of the Campur Formation is provided by Vinson (1962). The type section for the Campur Limestone is located in central Guatemala near the town of Languin, where a nearly complete but faulted 808-m-thick sequence is exposed. A complete 850-m-thick reference section exists near the type section, on the flanks of Chinaja Mountain. Vinson (1962) describes the Campur Formation as composed of principally gray, gray-brown, and tan limestones which were deposited in reef-associated environments. The formation contains minor amounts of dolomite, and locally is interbedded with thin beds of shale, siltstone, and limestone breccia or conglomerate. Along the flanks of the Maya Mountains is an unconformity which represents transgressive onlap of the Campur Formation onto the older Coban Formation (Figure 2). The Maya Mountains are an extension of the Libertad Arch, which is an east/west striking anticlinal structure that extends almost the entire width of north-central Guatemala (Weyl, 1980). The Maya Mountains are an uplifted fault block consisting of a synclorium trending east-northeast, and sloping to the northwest at about ten degrees following the dip of the geologic structures (Weyl, 1980). The Maya Mountains are bordered on the north and south by major faults (Bateson & Hall, 1977). The structure of the western boundary of the Maya Mountain fault block is completely obscured by the Cretaceous limestones which lie unconformably on the metasediments of the Santa Rosa Group. The Campur Limestone is a common outcrop in both Guatemala and Belize,

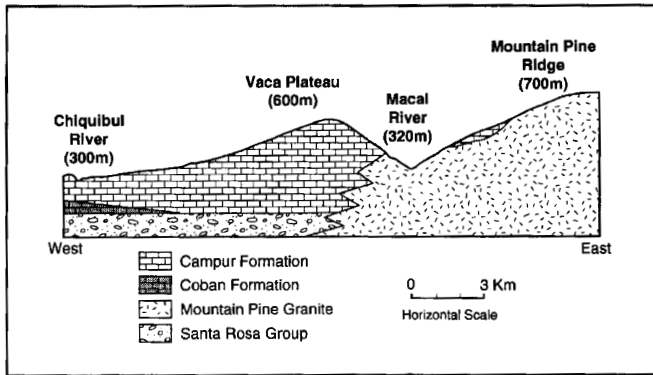


Figure 2. Generalized lithologic section across the western flank of the Mountain Pine Ridge and the Northern Vaca Plateau (structural features are not shown).

and it forms karst topography in both countries (Vinson, 1962). The main orogeny which deformed the Maya Mountain Block occurred in the Permian and early Triassic. Between the middle Cretaceous and mid-Tertiary, the block was subjected to periodic uplift (Bateson & Hall, 1977).

Blount and Moore (1969) completed a detailed study of the Cretaceous breccias in the Chiantla Mountain area. They recognized five types of carbonate breccia, and determined that depositional breccias as thick as 500 m are widespread within the Cretaceous Ixcoy Formation. They determined that the lithoclasts within the breccia were eroded from adjacent emergent areas, which probably resulted from faulting (Blount & Moore, 1969). They also found a 250-m-thick sequence of evaporite solution breccias in the lower part of the Ixcoy Formation, which correlates with the Lower to Upper Cretaceous Coban Formation which underlies the Campur Limestone in Belize. Tectonic breccias were noted to form by fracturing during periods of deformation associated with faulting. Caliche breccias formed by caliche cementation of carbonate rubble at the base of slopes (Blount & Moore, 1969), and localized pseudobreccias formed by selective grain growth.

RESEARCH METHODS

Data regarding the petrology of the Campur Formation in the study area were obtained by analyzing thin sections prepared from 25 rock samples. Rock specimens were collected at five general landscape positions and were grouped as follows: (1) residual hilltops (7 samples), (2) residual hillside slopes (9 samples), (3) dry valley bottoms (2 samples), (4) cave entrances (4 samples), and (5) cave walls (3 samples). Three of the cave entrance samples were collected in dry valley bottoms, and one was from a residual hillside slope. The cave passages from which samples were collected have entrances located on a residual hilltop (1 sample) and on a residual hillside slope (2 samples).

Thin section analysis was used to identify rock constituents. Initial investigation indicated a large degree of heterogeneity, making the point count method of analysis (Folk, 1962) inadequate. On brecciated rocks the point count method may be misleading because of variations in lithology of the clasts, and the type and amount of cement. The relative abundance of sparite, micrite, fossils or other characteristics becomes meaningless in these rocks, and it is more appropriate to classify the rock by using field relationships, stratigraphy and petrographic analysis. The samples were therefore classified first using systems described by Pettijohn (1975), and then as described by Blount and Moore (1969).

Data were also compiled on the orientation of 133 dry valleys within and adjacent to the study area using topographic map sheet 28 from map series E755 (scale 1:50,000, 40-m contour interval). The long axis orientations of 40 sinkholes were also obtained from this map. The orientations of 29 cave passages in nine different caves in the study area were derived from cave maps (Reeder, 1993). Dry valley, depression long axis, and cave passage trends were plotted on rose diagrams using 100 class intervals. Preferred orientations were estimated visually from the rose diagrams.

PETROLOGY OF THE CAMPUR LIMESTONE ON THE NORTHERN VACA PLATEAU

Twenty-one samples from the study area are classified as breccias and four are classified as non-breccias. Using Pettijohn's (1975) system, the breccias were classified into four types: (1) micrite clasts dominate, sparite cement (12 samples) (Figure 3a); (2) sparite clasts dominate, sparite cement (3 samples) (Figure 3b); (3) fossiliferous micrite clasts dominate, sparite cement (3 samples) (Figure 3c); and (4) pelleted micrite clasts dominate, sparite cement (3 samples) (Figure 3d). The non-breccias were classified as follows: (1) micrite dominates with some pellets (2 samples) (Figure 3e); and (2) sparite (2 samples) (Figure 3f).

The four breccia types were further classified using Blount and Moore's (1969) system, which is based upon the origin of the breccias as determined from field relationships, stratigraphy, and petrographic analysis. All 21 breccia samples are lithoclastic (reworked fragments of an older lithified limestone). They consist primarily of pre-existing limestone fragments with some samples containing rudistid (a bivalve mollusk) fossil fragments and/or pellets (probably mollusk feces). The clasts are considered lithoclasts, rather than intraclasts (penecontemporaneous, usually weakly consolidated carbonate sediment that eroded from adjoining parts of the sea floor (Folk, 1962), because the lithoclastic interval is over 200 m, based upon the elevation difference between breccias found deep in vertical caves and on the highest hilltops.

In 12 samples, micrite clasts dominate and the matrix is sparite (Figure 3a). The lithology of the lithoclasts is similar to non-lithoclastic limestones from the same formation, indi-

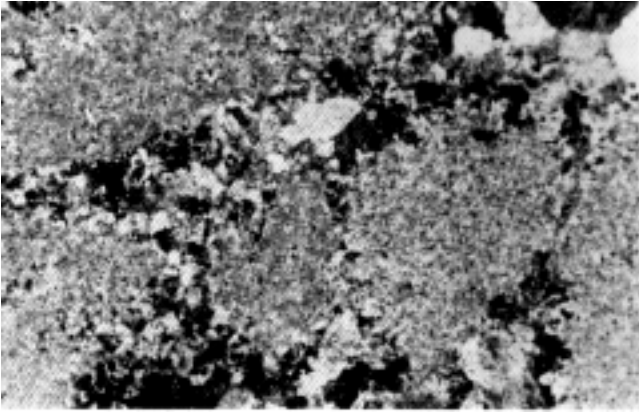


Figure 3a.

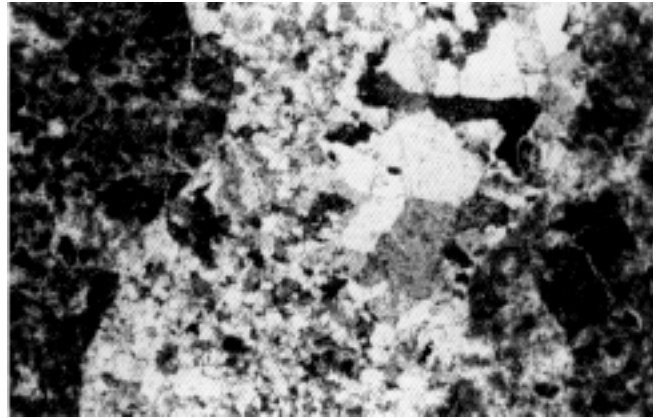


Figure 3d.

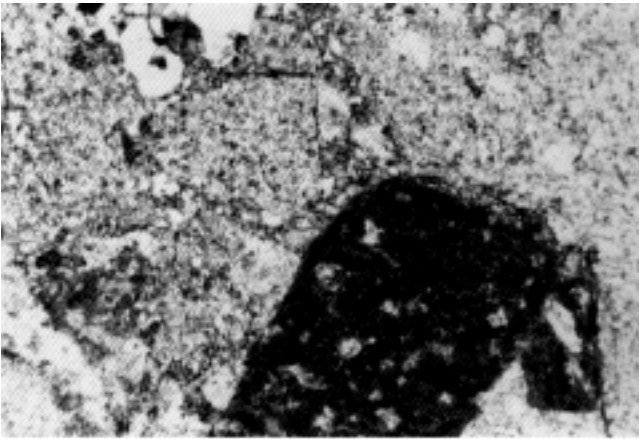


Figure 3b.

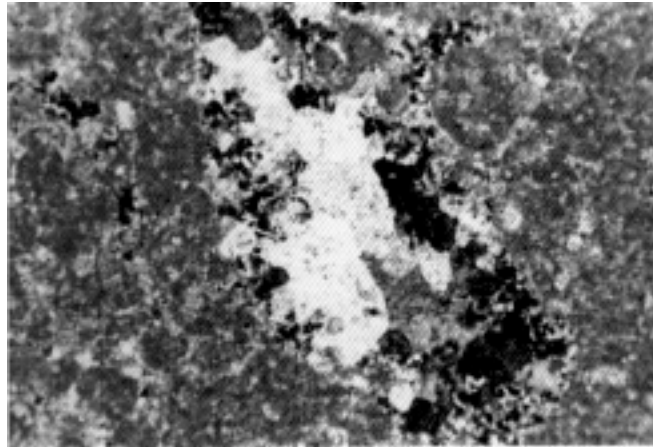


Figure 3e.

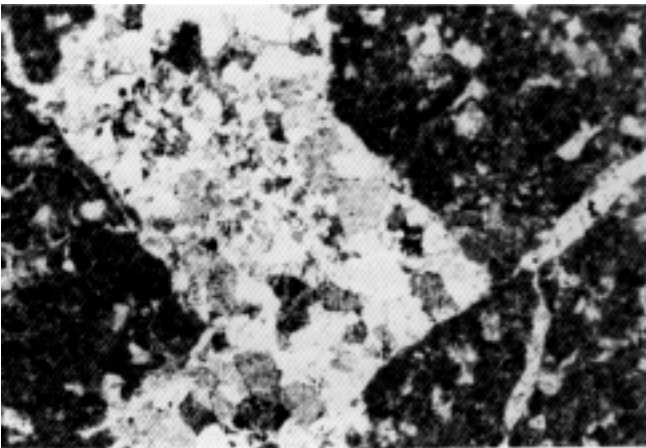


Figure 3c.

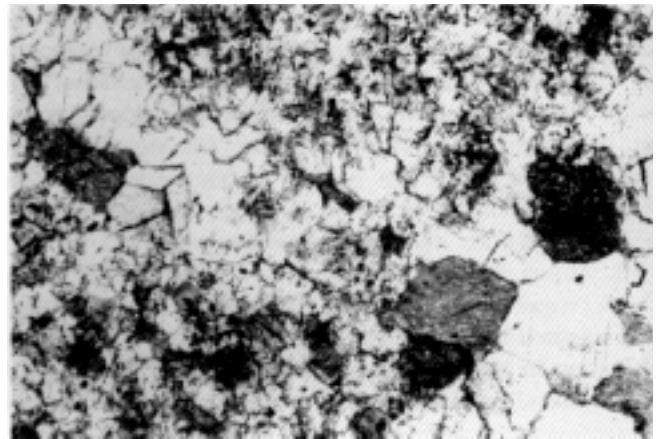


Figure 3f.

Figure 3. Thin sections of breccias and individual clasts. They are classified as follows: 3a: depositional breccia, micrite clasts dominate, sparite cement; 3b: tectonic breccia, sparite clasts dominate, sparite cement; 3c: depositional breccia, fossiliferous micrite clasts dominate, sparite cement; 3d: depositional breccia, pelleted micrite dominates, sparite cement; 3e: non-breccia, micrite clast with pellets; and 3f: non-breccia, sparite clast. (magnification 4X)

cating they are intraformational (from the same geologic formation). Based upon these characteristics, and criteria outlined by Blount and Moore (1969), these samples are designated depositional breccias. They probably formed when uplift along major faults caused certain areas to become emergent. Erosion then transported weathered micritic clasts from emergent areas to nearby areas (based upon the angularity of the lithoclasts), where they were deposited with lime muds. The sparite cement formed in the high energy environment adjacent to the emergent areas. Stylolitic contacts are rare in these specimens which suggests limited pressure solution in a deeper water environment.

In three other breccia samples, sparite clasts are embedded in a secondary matrix of sparry calcite cement (Figure 3b). The clasts also contain a small amount of micrite. These breccias have very angular clasts, and contain numerous matching clast boundaries. Clast size is highly variable, and the sparry calcite, which is simple vein fill, is continuous with smaller veins of calcite present within the clasts. These specimens are classified as tectonic breccias (Blount & Moore, 1969). Tectonic breccias with a matrix of secondary sparry calcite result from the precipitation of calcite in voids caused by fracturing, but without dislocation of breccia clasts. These tectonic breccias probably formed near faults tributary to the larger faults north and south of the study area. Two of these samples were collected near the bottom of dry karst valleys, which may be fault controlled, and the third sample was collected from the top of an outcrop in an area of narrow, deep, cave entrances. The transformation of the micrite in the clasts to sparite may be a direct result of tectonic activity.

In three samples, fossiliferous micrite clasts dominate within a sparite cement (Figure 3c). The fossils appear to be broken rudistid fragments and, as discussed above, the lithoclasts are intraformational. These specimens are classified as depositional breccias. The presence of rudistid fragments within the lithoclasts can be attributed to regional faulting. The rudistid fragments within the micrite lithoclasts represent the lithology of the pre-existing limestone prior to uplift and erosion. Small rudistid banks may have also formed near the edges of uplifted fault blocks, and were later eroded and deposited along with the lithoclasts (Blount & Moore, 1969). All three samples were collected at different topographic positions (hilltop, side slope and valley bottom), perhaps indicating the discontinuous nature of deposition, which seems plausible if the deposition scenario outlined above is correct.

In three samples, pelleted micrite fragments are cemented by sparite (Figure 3d). The pellets within the lithoclasts are probably rudistid feces that mixed with lime muds prior to lithification, uplift and erosion. These specimens are classified as depositional breccias. Two of these samples were collected from hilltops, while the third was collected from the entrance to a vertical cave located on a residual hillside slope.

Two samples classified as non-breccias are probably homogeneous fragments of the breccia. Following Pettijohn's

(1975) classification system, they were dominated by micrite mixed with some pellets and exhibited no veining (Figure 3e). These samples are petrologically similar to the pelleted micrite lithoclasts discussed above, suggesting that they formed in the same paleoenvironment. The thin sections prepared from these samples were probably cut from a single, larger lithoclast, hence the sparite cement was excluded from the sample. Based upon this conclusion, even though the pelleted micrite lithoclasts are not embedded in sparite cement, we believe them to be a part of the breccia. One of these samples was collected from a hilltop, and the other was collected on a residual hillside slope just below a hilltop.

Two other samples were composed entirely of sparite (Figure 3f). Based upon their homogeneous carbonate mineral composition, they were classified as non-breccias, but they are probably directly related to area breccia formation. The intensity of veining in tectonic breccias is noted to increase with proximity to large surface fractures or faults (Blount & Moore, 1969). These two samples probably represent void fill between clasts, rather than a combination of clast and cement. When the thin section was cut, only void fill was included on the slide. These samples were both collected in a dry valley bottom near a fracture controlled cave entrance.

STRUCTURAL CONTROL OF KARST FEATURES

Numerous dry karst valleys, residual limestone hills, single inlet and compound sinkholes, isolated cockpits, cutters, solution corridors, solution fissures, open joints, and caves exist within the study area. The dry valley bottoms are covered by a thick mat of vegetation in various stages of decay which obscures some of these features. The residual hill slope angles range from moderate (30°) to vertical. The moderate to steep (30°-60°) slopes are covered with a thin mat of decaying vegetation, and with increasing slope angle more bedrock is exposed. Prominent escarpments exist at the top and along many of the residual hillside slopes. The relative relief between valley bottoms and hilltops is approximately 100 m.

The existence of the lithoclastic limestones in the study area is associated with uplift caused by faulting and subsequent erosion from the emergent areas of a previously deposited, well lithified carbonate sequence (Blount and Moore, 1969). Very little research has been conducted on faulting within the Cretaceous limestones in Belize, but unnamed east-northeast striking faults exist 8 km south and 12 km north of the study area (Weyl, 1980). It is also likely that smaller faults and fractures are associated with these faults (Alt, 1995). Faults usually occur in groups of the same type, hence larger faults may be accompanied by a set of smaller parallel faults (Park, 1983). A horst, like the east-northeast striking Maya Mountain Block, is often bounded by sets of faults of the same type but opposite movement (Park, 1983). The Maya Mountain Block may therefore be bounded to the west by downthrown fault blocks that generally trend east-northeast.

Fractures and smaller faults associated with larger faults are generally assignable to the same stress that caused the larger faults (Stearns & Friedman, 1977). Experimental results and theory can also be used to predict the relationship between the orientation of the principal stress axis and the development of the two main shear fracture planes. The two resulting fractures have been noted in the literature to form angles of 30° (Billings, 1954) to 45° (Park, 1983). The greatest principal angle of stress in the study area is 67.5° which translates into theoretical fracture orientations between approximately 330° and 345°. But because of the anisotropy of the rock fabric in the Campur Limestone, and hence directional variation in shear strength, prediction of fracture orientations is difficult (Mandl, 1988).

Based upon the down valley axis of orientation for 133 dry valleys in and adjacent to the study area, rose diagrams were prepared. Dry valley orientations were measured in the Chiquibul (n=69) and Macal (n=64) drainage basins and plotted on separate rose diagrams (Figures 4 & 5). The valleys in the Macal River drainage basin have a pronounced northeast orientation, with 24 valleys (38%) oriented between 10° and 60° (Figure 4). Within this 50° range, the modal orientation is 30° (n=8). A less prominent trend is to the northwest, with 14 valleys (21%) oriented between 300° and 335°. Within this 35° range, the modal orientation is 310° (n=6). Fifty-nine percent of the measured valley orientations generally coincide with the fractures theorized by Billings (1954) and Park (1983), the orientation of the Maya Mountain Block, possible minor faults, and/or the documented faults located north and south of the study area.

The dry valleys in the Chiquibul drainage basin have a pronounced northwest orientation with 25 valleys (34%) oriented between 300° and 350° (Figure 5). Within this 50° range, the modal orientation is 320° (n=7). Another prominent trend is west to southwest (280° to 220°) where 30 valleys (43%) are oriented. These ranges of valley orientations (77% of the total valleys measured) generally coincide with the theorized fracture orientations (34%), and the orientation of the Maya Mountain Block and existing and postulated fault orientations (43%).

Based upon the long axis orientations of 40 sinkholes in and adjacent to the study area, a rose diagram was prepared which includes data from both the Macal and the Chiquibul River drainage basins (Figure 6). The long axis orientations have a pronounced northeast through east trend, with 20 sinkholes (50%) oriented between 20° and 90°. Within this 70° range, the modal orientations are 40° and 80° (n=5). Another prominent trend is northwest through west, with 15 sinkholes (37%) oriented between 130° and 100°. Within this 30° range, the modal orientation is 130° (n=6).

Based upon the sinkhole long axis data, it appears that lines of structural weakness within the bedrock influence sinkhole orientation. Sinkholes often form along high permeability pathways through the vadose zone. These areas are often sites

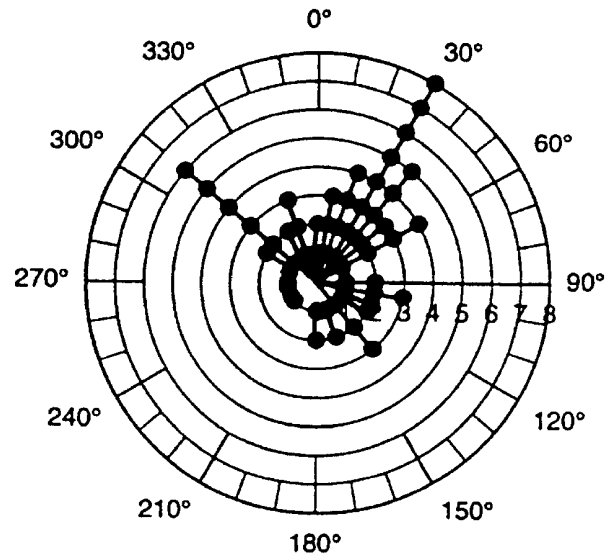


Figure 4. Down valley orientations in the Macal River drainage basin (n = 64).

of fracture concentrations and fracture intersections (White, 1988). Sinkholes form by some combination of dissolution and collapse. Collapse can originate at some depth in the bedrock if it is assisted by fracture zones. The land surface is lowered by a combination of dissolution and mechanical erosion because the underlying bedrock is weakened by vertical dissolution along joints and fractures (White, 1988).

Sinkholes may become elongated along lines of major weakness. Fifty percent of the measured sinkholes trend northeast through east which corresponds with the orientations

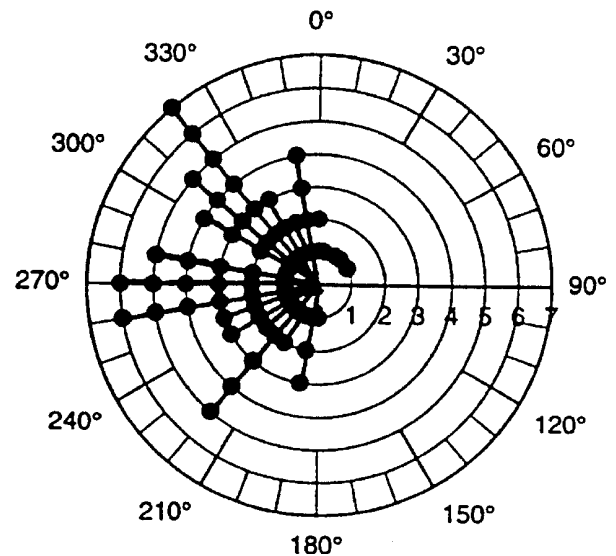


Figure 5. Down valley orientations in the Chiquibul River drainage basin (n = 69).

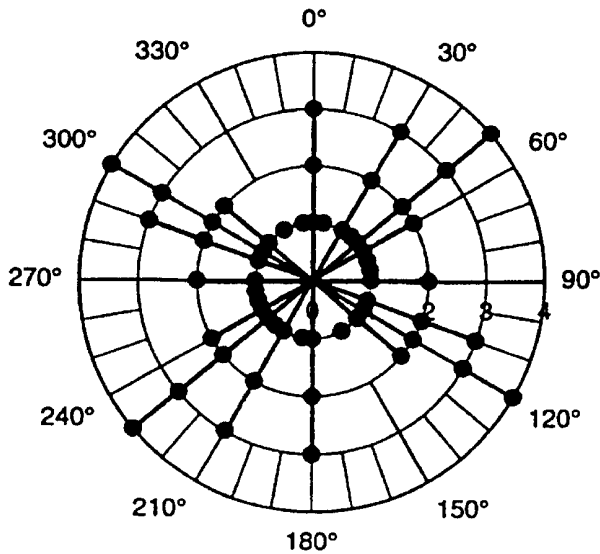


Figure 6. Depression long axis orientations in the Macal and Chiquibul drainage basins (n = 69).

of the Maya Mountain Block, the faults located north and south of the study area, and the postulated orientation of unknown faults. Thirty-seven percent of the sinkholes trend northwest through west which generally corresponds with the theorized orientation of fractures.

Based upon the orientation of 29 segments of cave passage in nine surveyed caves, a rose diagram was prepared (Figure 7). The cave passages have a pronounced northeast-southwest trend, with 10 cave passages (34%) oriented between 30° and

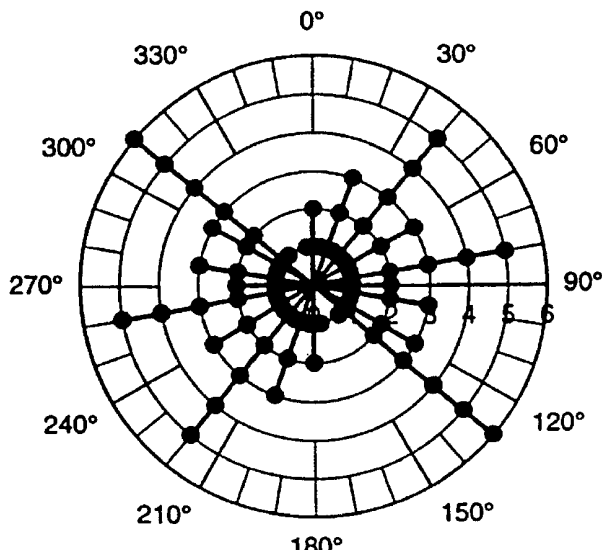


Figure 7. Orientation of 29 segments of cave passage in nine caves in the Macal and Chiquibul drainage basins.

60°. Within this 30° range the modal trend is 50° (n=4). Another prominent trend is northwest-southeast, with nine cave passages (31%) oriented between 110° and 130°. Within this 20° range the modal trend is 120° (n=4). A minor north-south trend also exists, with three cave passages (10%) oriented at 0°.

The orientations of the cave passages also indicate structural control. Based upon field observations, the Campur Limestone contains very few bedding planes, and cave formation is focused along planes of weakness such as joints, fractures and faults. Cave passages oriented northeast-southwest (34%) correspond with the orientation of the Maya Mountain Block, the faults located north and south of the study area, and faults which are theorized to exist based upon known fault orientations. Cave passages oriented northwest-southeast (31%) correspond with the theorized orientation of fractures in the study area. Exploration and survey of the caves indicate that joints structurally control the cave pattern, and no direct evidence of faulting has been found.

KARST LANDSCAPE FORMATION AND EVOLUTION

As indicated by Miller (1990), the karst in the southern Vaca Plateau (Chiquibul region) began to develop around 700,000 years BP. The limestones in the northern Vaca Plateau are of similar age and composition, but because the study area is located at a drainage divide and is dominated by autogenic recharge, the Chiquibul area is probably geomorphically younger. In the Chiquibul region, recharge water flows westward from the Maya Mountains drainage divide across the Carboniferous-Permian metamorphosed fine-grained argillaceous rocks of the Santa Rosa Group (Weyl, 1980). This allogenic recharge is highly undersaturated with calcium carbonate (CaCO₃) because the waters have not contacted the Campur Limestone. These allogenic waters represent an import of energy capable of both chemical and mechanical work (Ford & Williams, 1989).

Recharge on the northern Vaca Plateau is entirely autogenic with water derived entirely from meteoric precipitation falling on the Campur Limestone. Allogenic recharge water flowing west from the Mountain Pine Ridge section of the Maya Mountains is intercepted by the south-north flowing Macal River before contacting the Campur Limestone. Karst areas with large inputs of allogenic water experience more chemical erosion than areas entirely recharged by autogenic water, with the size of the catchment area contributing allogenic recharge greatly influencing the rate of solution. For these reasons, development of the karst on the northern Vaca Plateau differs from that in the Chiquibul area.

Currently, autogenic recharge in the study area enters the subsurface drainage network by diffuse means and at discrete locations. Infiltration through area soils is more common than discrete input (which usually occurs where structural features extend to and are open at the surface). The deepest cave dis-

covered thus far in the study area (105 m) extends 95 m below dry valley elevations, but active flow has never been observed in caves or dry valleys even after heavy, prolonged precipitation events. However, fieldwork has been conducted during the dry season, and it is possible that limited surface and vadose flow does occur during the wet season.

Valleys in the study area are mostly interconnected and are bounded by interfluvial residual hills. Drainage through the dry valley systems is deranged. Remnant stream channels are rare and only short (< 5 m), isolated segments of channel are found, which terminate at discrete recharge points into the subsurface drainage network.

Periodic uplift forming or accentuating lines of structural weakness occurred adjacent to, or within these limestone breccias into mid-Tertiary time. Faulting in northern Central America continued into the Quaternary (Weyl, 1980) with numerous fault systems like the Chixoy-Polochic and Motagua in Guatemala still active. It is probable that valleys trend along lines of structural weakness such as faults, fractures and joints. The previously discussed results regarding dry valley and sinkhole long axis orientations indicate that area geologic structures influence valley and sinkhole orientations.

Surface streams formerly flowed across the karst landscape along lines of structural weakness. As the subsurface drainage network developed, secondary permeability increased and a portion of the surface flow moved into the subsurface. Eventually, all surface flow was pirated to the subsurface, surface stream channels were abandoned, and slope processes along the valley sides buried the valley bottoms and the former stream channels. The residual hills in the study area are the remains of the interfluves between the integrated valley systems. On many of the hills, dissolutionally sculpted features such as solution corridors, fissures, and natural bridges indicate integrated surface and phreatic flow in the geologic past. Many of these features are located 150 m above the contemporary dry valley bottoms.

Sinkholes (and several cockpits) in and adjacent to the study area range in size from a few meters across to over 1 km and occur in variable topographic positions. Miller (1987) determined that sinkholes in Serranx, Guatemala marked the location of dissected river valleys that have become unrecognizable because of karstic collapse. Some of the larger sinkholes (cockpits) in the study area may have formed in this way, while smaller sinkholes formed as the buoyant support was lost as base level was lowered, and the land surface subsequently collapsed.

Contemporary base level in the study area is now controlled by the Chiquibul River to the west and the Macal River to the east. The maximum relief between the highest point in the study area (approximately 600 m above mean sea level) and the Macal (320 m) and Chiquibul rivers (300 m) is 280 m. Taking into account the hydraulic gradient between the elevated portions of the Vaca Plateau and base level, the depth to the water table is probably greater than 250 m.

Caves in the study area contain both horizontal and vertical passages. The caves fall into the following genetic patterns: (1) blind vertical shafts, (2) vertical shafts connected to horizontal passages, (3) multiple drop vertical caves, (4) shelter caves, and (5) horizontal caves. Within some of these patterns, variations result from differences in site-specific geologic conditions, topographic position and evolution.

The majority of cave entrances are vertical and formed by dissolution along planes of structural weakness that extend to the surface. Some of the entrance shafts comprise the full extent of the cave, while others lead to horizontal segments of passage. These horizontal passages sometimes intersect other shafts, which in turn often intersect additional horizontal passage. Hence, some caves exhibit a stair-step profile in which the vertical extent of the cave is achieved by a series of drops offset by sections of more gently inclined passage (White, 1988).

Some caves are entirely horizontal in profile. Shelter type caves are dissolution pockets in the limestone bedrock that were exposed by erosion, or they formed by stoping within a surface exposure along planes of structural weakness. Other horizontal caves are remnants of meandering phreatic tubes which, in some cases, have been modified by vadose flow as regional base level was lowered. Some caves appear to have formed entirely within the vadose zone.

Certain cave patterns correspond with particular landscape positions, while others occur throughout the study area. Caves with vertical entrances generally occur on residual hill slopes, in the bottom of sinkholes, or on hilltops. They are rarely found in valley bottoms. The profiles of all types of cave in the study area indicate strong vertical control. This is attributed to the numerous fractures and possible faults within the bedrock. Because bedding planes are few, most caves have developed along vertical planes of structural weakness. Vertical caves are generally not exposed within dry valley bottoms because they have been filled with organic material, soil, and sediment from slope wash. The few vertical entrances not blocked by debris in valley bottoms are discrete recharge points that are kept open by shaft flow during the wet season. Shafts on hilltops are usually blind, and are blocked by breakdown.

In many caves, entrance shafts lead to segments of horizontal passage. The entrances to these caves are generally located on residual hillside slopes or sinkhole bottoms on side slopes. Many of the entrances are located at topographic positions not affected by slope wash, hence, they are not clogged with debris. The entrances in sinkhole bottoms are kept open by concentrated recharge during the wet season. The horizontal sections of passage generally follow the same trends as the lines of structural weakness; these passages probably formed by lateral chemical erosion during periods when the water table was stable. In many caves the horizontal passages connect to another shaft. These shafts formed as base level was

lowered and recharge was focused vertically along lines of weakness, and the horizontal passages formed under a stable water table. Some caves have as many as four horizontal levels connected by shafts. The deepest cave has three horizontal levels which are connected by drops of 60 (the entrance shaft), 20, and 10 m.

Shelter caves occur in all topographic positions in the study area, but are least common on hilltops and most common on or at the base of residual hill slopes. Entirely horizontal caves generally occur on side slopes. A few horizontal caves in the study area appear to have formed entirely in the vadose zone. These caves are generally narrow, tortuous fissures formed by vadose flow moving along planes of structural weakness. Several horizontal caves contain segments of phreatic tubes indicating that they formed below the water table (Figure 8). These caves are, in some cases, located 50 meters above dry valley elevation and 200 meters above the contemporary water table. They formed at a time when base level was higher, contemporary valleys were not as incised or did not exist, and the net thickness of area bedrock was greater because the denudation process was not fully advanced. These caves also provide clues about the evolution of the karst landscape on the northern Vaca Plateau.

Uplift, faulting, and fracturing increased the secondary permeability in the rocks, and autogenic water began to dissolve the nearly pure (98% CaCO_3) limestone along these planes of structural weakness. During this period, the water table was fairly stable and close to the surface, and dissolution tubes began to form in the shallow phreatic system. As the valleys deepened, base level was lowered, the elevation of the water table decreased, interfluvial developed between valleys, and caves in the shallow phreatic zone drained. Phreatic development continued deeper within the landscape, and drained phreatic tubes were modified by vadose flow. These passages developed the classic "keyhole" shape as canyons were cut into the bottom of phreatic tubes (Figure 8).

Valleys continued to widen and deepen, base level and the water table continued to lower, upper level cave passages were abandoned and phreatic development kept pace with the water table. Eventually, almost all surface flow ceased, and flow through the subsurface drainage network was enlarging only areas of preferential flow. Caves higher in the landscape shifted from an erosional stage to depositional and were filled with sediment and formations. Valley widening and incision slowed and the most significant areas of dissolution were below the water table which was probably >300 m below the surface interfluvial.

The contemporary landscape contains numerous karst features that seem out of phase with their topographic position. Large shafts are located on residual hillside slopes with small catchments. Passages containing well developed phreatic tubes are located at the top of narrow interfluvial tens of meters above valley level, and hundreds of meters above the water table. Large sinkholes with sizable catchments are located on

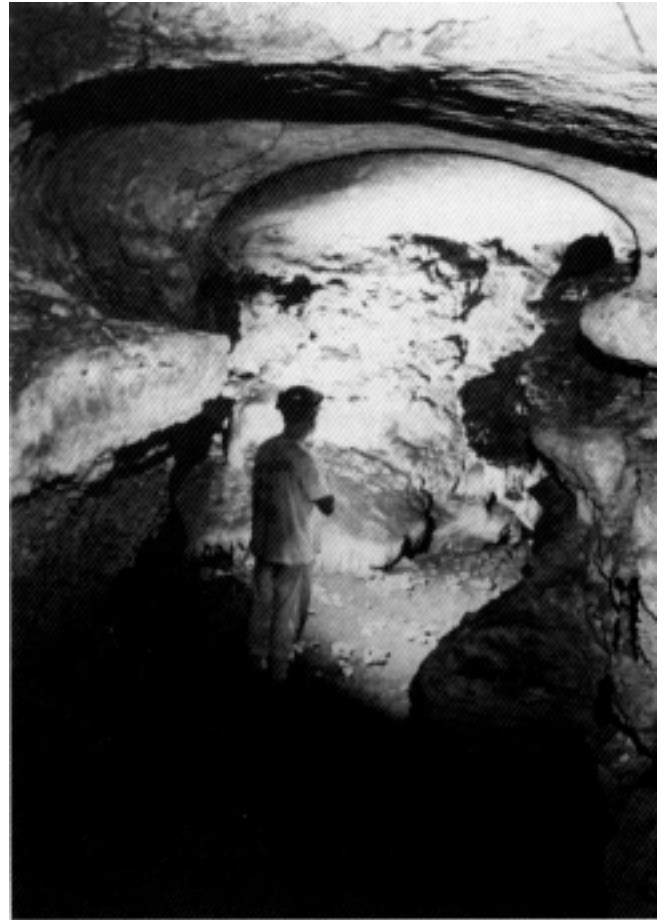


Figure 8. "Keyhole" passage in Bushman Cave. This type of passage formed first under phreatic conditions, and then as regional base level lowered a vadose canyon formed at the base of the tube.

steep residual hill slopes. These features are relicts of the former landscape in that they formed under conditions different from those at present. All of these features show clear evidence that they once transported substantial volumes of water. The contemporary residual hilltops were once in the phreatic zone below valley level. The now hydrologically abandoned shafts on valley side slopes in the contemporary landscape were probably once the focus of recharge waters moving from the surface to the subsurface within an active fluvial system. The sinkholes now located at mid-hill slope were also probably once part of the active fluvial system that existed in valley bottoms.

CONCLUSIONS

Analysis of lithologic and geomorphic features within the 25 km² study area in west-central Belize revealed that the karst landscape is greatly influenced by the lithology and structure of the bedrock. The majority of limestone in the study area

formed adjacent to a structurally emergent area, as a depositional breccia consisting mostly of lithoclasts of micrite with a sparry calcite cement. Variations in composition of the lithoclasts reflect local variations in the depositional environment. Geologic structures including faults, joints, and fractures formed during periods of uplift in and adjacent to the study area. These periods of uplift account for the existence of some tectonic breccias in the study area.

The geologic structures in and adjacent to the study area have similar orientations to karst landforms including solution valleys, depression long axes, and cave passages. This correspondence demonstrates the influence that structure has had on landscape and cave formation and evolution. The evolution of the surface karst landscape and the caves has also been greatly affected by base level modifications. The lowering of base level incised valleys, enhanced interfluvial development, and caused caves within the interfluvies to be truncated along valley sides and abandoned as active flow routes. The stair-step pattern of caves in the study area demonstrates that there have been periodic shifts in base level followed by periods of stability.

Through time, numerous landscape features were abandoned as active zones of solution as regional base level was lowered. They are now fossils representing the former landscape. By studying these features, and related petrology and structure, it was possible to gain a limited understanding of the formation and evolution of the northern Vaca Plateau's caves and karst landscape. Future research in this little studied area of Central American karst will provide additional information about karst processes in the tropics.

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BIOLOGY OF THE CHIQUIBUL CAVE SYSTEM, BELIZE AND GUATEMALA

JAMES R. REDDELL

Texas Memorial Museum, 2400 Trinity, Austin, Texas 78705, U.S.A.

GEORGE VENI

George Veni & Associates, 11304 Candle Park, San Antonio, Texas 78249-4421, U.S.A.

The Chiquibul Cave System is the longest and largest known network of caves in Central America. Most biological collections and observations in the system were conducted in 1986 in the Cebada Cave segment. Other collections were made in 1984 and 1988. At least 70 invertebrate species are known from the system. Many species await study, and of these, two aquatic and five terrestrial species are apparent troglobites. A zonation survey in the entrance of Cebada Cave showed typical forest litter species in all areas. The fauna of the deep zones of the system included only troglaphiles and troglobites. Troglobites were rare and present only in the area farthest from the entrance.

The Chiquibul Cave System is located in a remote and little known area of west-central Belize on the southern Vaca Plateau (see location map on page 68), with its downstream end extending into Guatemala. Primarily comprised of four hydrologically-linked caves (see Miller, Figure 15, this issue), the system formed by the sinking of the Chiquibul River into its present and former subterranean conduits. Its resurgence is in Guatemala. Over 55 km of passages in the system have been surveyed, including the largest known passages and cave room in the Western Hemisphere (Miller, 1989).

The cave fauna of Belize and Guatemala has been poorly studied, with few systematic surveys having been conducted. Most collections have been sporadic and associated with general exploration and mapping expeditions. The only general discussion of the fauna is that of Reddell (1981). Recent work in other parts of Belize has been conducted by William R. Elliott and Stewart B. Peck. The present study of the Chiquibul Cave System is the first comprehensive biological study conducted in Belize. The only other biospeleological studies of the area are the description of a new species of troglobitic crab found by Tom Miller during a 1984 reconnaissance of the Chiquibul area (Hobbs, 1986), and the description of a new species of troglobitic shrimp found by Don Coons in the Chiquibul System's Actun Tunkul segment in 1986 (Hobbs & Hobbs, 1995).

Three expeditions explored the Chiquibul System, making few biological collections in 1984, most in 1986, and additional collections in 1988. This report compiles those data, identifying the discovered species and their habitats.

DESCRIPTION OF THE CHIQUIBUL CAVE SYSTEM

Each year, about 2.5 m of rain falls on the noncarbonate rocks of Belize's Maya Mountains and flows west toward the

karstic Vaca Plateau. The resultant Chiquibul River goes underground about 1 km before reaching the Chiquibul System's Kabal Cave Group, which consists of a series of large, former stream passages that occasionally transmit flood overflows and intersect the underground Chiquibul River in one passage for about 150 m. The upper end of Kabal holds ponded floodwaters with large, washed-in rotting trees and organic debris. Downstream the system holds less water and organic material because fewer collapses intersect the cave. Passages in the cave are generally 10-60 m wide and 10-30 m high.

The downstream end of the Kabal Group is truncated by a valley which is a 1.2-km-stretch of collapsed passage that ends at the entrance of 12-km-long Actun Tunkul. Tunkul is also a former conduit for the Chiquibul River and is only seasonally flooded. With the exception of some short side passages, the cave is a large single passage averaging 40-50 m wide by 20 m high, enlarging in the Belize Chamber to more than 200 m in diameter. Approximately 1 km into the cave, a perennial stream enters from a side passage. In addition, minor seeps occur along the main passage walls. Most of the floor is a thick deposit of sand and silt laden with organic debris. The cave ends in a deep sump about 500 m from the upstream end of Cebada Cave.

The entrance to Cebada Cave is 1.5 km east of the Guatemalan border at the base of a deep collapsed sinkhole, like the other caves of the Chiquibul System. The cave contains the full flow of the underground Chiquibul River, which averages 2-4 m wide and 1-2 m deep, with a baseflow of about 2 m³/s. Annual stream rises greater than 20 m are not unusual, and large amounts of organic debris often enter the cave. The river is flanked by large banks of sand, silt, and some breakdown. Some pools amid the silt banks contain a dark red alga. Upstream, the cave extends south, then east for over 4 km to a

large collapse. The passage is similar to Actun Tunkul but has more side passages and the side passages tend to be longer. The Chiquibul River emerges from the breakdown, and a 2-4 m diameter upper level passage intersects the river 1.1 km upstream near Tunkul. Downstream from the Cebada entrance the river flows about 2.2 km and sumps just before reaching Guatemala. An overflow passage exits to the 500-m-diameter collapsed "Zactun" sinkhole just inside Guatemala, and a large, well-decorated passage intersects the main passage far above flood levels.

The resurgence segment of the cave system is Xibalba. The Chiquibul River enters the cave through breakdown near a collapse-formed "Middle Entrance," and flows down the 2.3-km-long main passage, which averages 70-100 m wide by 30-50 m high. The river discharges from breakdown into a surface river below Xibalba's 200-m-wide by 80-m-high main entrance. Two other significant passages also occur in the cave. One is a dry, upper level, 30-m-wide by 20-m-high passage that extends north from the main entrance for 750 m. The other begins at the Zactun sinkhole and extends as a series of lakes for nearly 3 km to the upstream end of the main passage.

ECOLOGICAL ZONES

The massive size of the Chiquibul entrances and passages, and the volume of floodwaters that flow through them somewhat blur the distinction between the entrance, twilight, and dark zones. Daylight can reach over 200 m into most Chiquibul caves, which are easily accessible by most epigean species. Floods carry ample organic material through the system, in addition to species such as catfish that are common in Cebada Cave.

Specimens were collected by hand throughout most of the cave system. In addition, pitfall traps were placed in five locations in the Cebada Cave entrance area (Figure 1). The pit openings were 2.5 cm in diameter and were covered with a caprock placed 2 cm above. A margarine-oats-sugar bait was placed on the bottom of the caprock.

The following discussion includes the location and general ecological conditions in the parts of the system that were studied. Brief notes are also provided on the fauna in each area.

ACTUN TUNKUL

The only collections in this cave have been of one species each of troglobitic shrimp and crab by Tom Miller and Don Coons. This section should contain a rich troglobitic fauna.

CEBADA CAVE ENTRANCE AREA

The entrance area was divided into three zones (A, B, C) based on available natural light (Figure 1). Bats and cliff swallows inhabited this part of the cave.

Zone A: This zone extended across the passage from the drip-line for about 20 m into the cave. It contained surface fauna and was modestly representative of that ecosystem. It

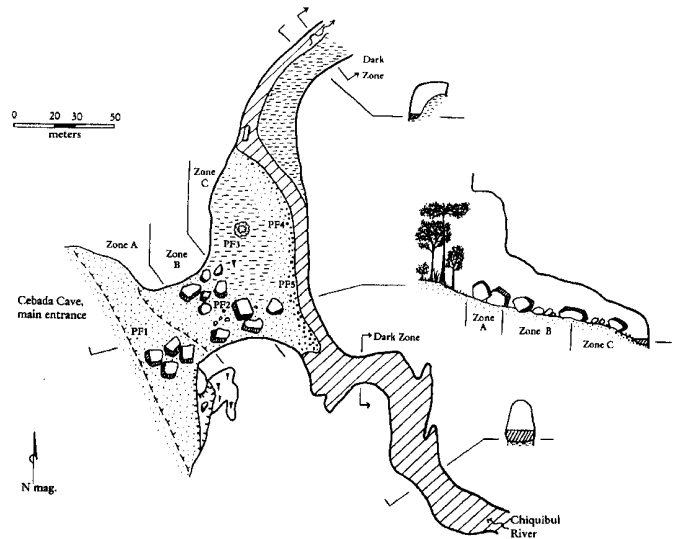


Figure 1. Biotic sampling zones and pitfall trap locations in the main entrance area of Cebada Cave (after Grundy & Whitwell, 1990).

was located under the cave's drip-line and was heavily vegetated due to several hours of daily direct sunlight. The substrate was mostly a dry loose sand. Pitfall trap no. 1 was placed in this zone. One beetle was found in this trap.

Zone B: This zone extended across the passage and into the cave for about 20 m. It had sparse vegetation, including some moss. It received no more than an hour of direct sunlight per day, and was markedly cooler than Zone A. Pitfall trap no. 2 was placed in an area of dry sand substrate. It was more successful than pitfall trap no. 1. The only troglobitic species found in this zone was the collembolan *Troglopedetes* ?n.sp.

Zone C: This zone extended from the stream to the left wall and was about 120 m long. It lacked vegetation. There was seldom direct sunlight and the temperature was near the cave's constant of 22°C. Three pitfall traps were placed in this zone. Pitfall trap no. 3 was placed on wet clay substrate. Pitfall trap no. 4 was placed on dry sand substrate. Pitfall trap no. 5 was placed on wet gravel/cobble with some sand substrate about 2 m from and 0.5 m above the baseflow of the Chiquibul River. This zone contained some surface species but also included the troglobitic isopod *Troglophiloscia* sp. cf. *belizensis* and the collembolan *Troglopedetes* ?n.sp. Troglaphiles included spiders of the subfamily Araneinae and the isopod *Sphaerarmadillo* sp. cf. *schwarzi*. The troglaphilic rove beetle *Homaeotarsus* sp. was especially abundant near the stream. Isopods were found only on wet mud substrate.

UPSTREAM CEBADA CAVE

No differences in faunal variety or abundance occurred between this section and the downstream section (see below), except for the lack of the small carabid beetles found near the

downstream sump. No fauna was observed in the upper level passage, which heads toward Actun Tunkul. No collections were made in this section.

CATFISH PASSAGE

Located about 2 km upstream from the Cebada Cave entrance, this is the most extensive series of passages that feed into the Chiquibul River. The passage does not contain catfish, but is named for a catfish skeleton on a mud bank in the main passage near its entrance. An unidentified water treader collected from a clear, flowing, bedrock-floored pool was the only one seen in the Chiquibul System. Observed, but uncollected, fauna included crabs, amblypygids, and beetles. Terrestrial troglobites included the isopod *Troglophiloscia* sp. cf. *belizensis* and the collembolan *Troglopedetes* ?n.sp. Trogloniles included carabid beetles and the spiders *Metagonia* sp. and an undetermined species of the subfamily Araneinae.

DOWNSTREAM CEBADA CAVE

Small carabid beetles were found only near the downstream sump of Cebada Cave on a predominantly organic rich mud substrate. All other collected fauna (beetles, spiders, springtails, harvestmen, isopods, amblypygids, etc.) were found on sand-silt banks and well above stream level. Representatives of all observed fauna were collected, except for the large population of non-troglobitic catfish. All species found in this area are probably either trogloniles or troglobites. This was the only locality for the troglobitic entotroph of the family Campodeidae. Other troglobites included the isopod *Troglophiloscia* sp. cf. *belizensis*, the pseudoscorpion *Mexobisium goodnighti*, and the collembolan *Troglopedetes* ?n.sp.

ACTUN ZACTUN

A small collection by Olivia Whitwell was made in the twilight zone. It included only amblypygids and scutigermorph centipedes.

XIBALBA (MAIN STREAM PASSAGE)

Only one large spider, about 600 m from the resurgence entrance was collected in this section of the cave. Crickets, bats, and millipede exuviae were observed.

XIBALBA (RB SURVEY)

This is the high level, dry passage near the resurgence. Dry guano covers the floor of the passage's first 300 m to depths of over one meter. This area is often exposed to direct or near-direct sunlight. Invertebrates and guanophiles were not found on the guano, but bats and cliff swallows were observed above it. The passage was dry except for the damp collection site located in the final hundred meters of the passage. All species obtained in this area were trogloniles or troglobites. Crickets were observed throughout the passage. Hundreds of millipede exuviae occurred in the dry part of the passage. Although no

live millipedes were actually observed, they may go there to dry out their new exoskeletons. Troglonitic species include the pseudoscorpion *Mexobisium goodnighti* and undetermined pholcid spiders.

CAVE FAUNA

A minimum of 70 invertebrate species has been found in the Chiquibul Cave System and they are listed in the appendix to this report. Much of the fauna remains unidentified for lack of specialists in specific groups. The cave fauna, as in most large stream caves in Central America, is dominated by epigeal species washed into the cave or attracted to entrance areas by abundant food and shelter.

The aquatic cave fauna is poorly known with only three species recorded. Many small crustaceans probably occur and they may be of considerable interest. The aquatic species include an unidentified catfish of the genus *Rhamdia*, the troglonitic shrimp *Macrobrachium cationium* Hobbs and Hobbs (1995), and the troglonitic crab *Typhlopseudothelphusa acanthochela* Hobbs (1986). The fish and crab occur in all parts of the system. The shrimp is known from the Actun Tunkul section. The troglonitic catfish *R. laticauda typhla* Greenfield, Greenfield, and Woods (1983) occurs in other caves in Belize and could possibly be found in remote parts of the Chiquibul Cave System. All observed catfish in the system, however, appeared to have fully developed eyes and pigment.

The terrestrial cave fauna includes a large number of accidentals and troglonenes, most still unidentified. Few troglobites are known in the cave system but this number should increase with further study. Only four or five species show significant adaptations to the cave environment. The pseudoscorpion *Mexobisium goodnighti* Muchmore (1973) is a highly troglomorphic species known from several other Belize caves. The isopod *Troglophiloscia* sp. cf. *belizensis* is abundant in Cebada Cave. This species was described by Schultz (1984) from caves near Caves Branch and Augustine. An undescribed species of Collembola of the genus *Troglopedetes* was found in several areas of Cebada Cave. This genus is widespread in Middle America (Palacios-Vargas, Ojeda, and Christiansen, 1985). A single specimen of an apparently troglonitic species of the entotroph family Campodeidae was found in the Downstream Section of Cebada Cave. Finally from Xibalba, unidentified juveniles of the spider family Pholcidae were collected. These have reduced eyes and may be an undescribed troglonite. Of special interest is the presence in large numbers of the eyeless isopod *Sphaerarmadillo* sp. cf. *schwarzi*. This species is widespread from caves and leaf litter in Guatemala, Belize, and southern Mexico (Schultz, 1984).

DISCUSSION

The Chiquibul Cave System provides a wide variety of habitats available for colonization by invertebrates. These

habitats range from large vegetated entrance areas to remote subterranean areas characterized by comparatively lower energy levels and extensive deposits of speleothems.

The zonation survey in the entrance area of Cebada Cave shows no distinct demarcation of fauna. The minimal light and absence of vegetation allows a few of the less cave-adapted troglobites to survive. Accidentals and troglaphiles were found in all three zones.

Pitfall trap results in these zones closely reflect the observed fauna except that trap #1 in Zone A was notably unsuccessful. This is probably a direct result of the abundance of food, thus largely negating the attraction of the bait in the trap. The traps in Zones B and C were in areas with less food and therefore the bait was more attractive to more species.

The fauna of the deep zone parts of Cebada Cave (Downstream and the Catfish Passage) and Xibalba is dominated by troglaphiles and troglobites as would be expected in these areas of low energy input. The absence of more accidentals in these flood-prone areas is somewhat surprising, but may be a reflection of the time of collection (near the end of the dry season) and the inability of non-cave adapted species to survive in these areas.

Troglobitic crabs have been found on all types of substrate in Actun Tunkul, Cebada Cave, and Xibalba, but were often close to pools, rimstone dams, and seeps entering the main stream. None were observed feeding, but their slender pinchers are strong enough to snap onto cavers' fingers and get lifted into the air. One female crab bearing 48 young was collected. It is interesting to compare this with specimens of *Typhlopseudothelphusa mocinoi* Rioja from Chiapas. One specimen of this less cave-adapted species contained 57 young while another had 75 eggs (Hobbs, Hobbs & Daniel, 1977). Epigeic species typically produce many more young than this. Based on a 1984 observation in Tunkul, the crabs can grow up to 10-cm-diameter bodies with legs and pinchers of proportional size, although 3-cm-diameter bodies are far more typical.

The ubiquitous catfish of Cebada Cave range from 10-70 cm in length. They exhibit no features of adaptation to the cave environment. However, the younger fish are a medium dark brown to brown-gray color that fades to a pale white to gray as they get older. Dark coloring on the larger, apparently older, fish was found to be a coating of stream silt. No catfish were seen in Xibalba. Apparently the breakdown between Xibalba and Cebada is dense enough to prevent the catfish from swimming through. It would be interesting to study catfish from all parts of the system to see if any demonstrate reduction of eyes and pigment not readily apparent in the cave.

Despite the limitations of this study (lack of collections and intensive studies from other parts of the system) the results are valuable in demonstrating the patterns of colonization in the system. Other troglobitic groups present in Belize caves (schizomids, charontid amblypygids, ochyroceratid spiders, vachoniid pseudoscorpions, phalangid harvestmen, and

cambalid millipedes) may well occur in the Chiquibul System. We urge that other studies of this type be conducted in other large cave systems in Belize.

ACKNOWLEDGMENTS

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APPENDIX

The following is a complete list of fauna collected from the Chiquibul Cave System. Specimens of many groups were sent to specialists for identification but remain unstudied. Where possible the number of specimens is given. Records are separated by separate cave segments with the areas in the cave placed in parentheses.

PHYLUM NEMATOMORPHA

CLASS GORDIOIDA (gordion worms)

Undetermined material (parasite)

Record. BELIZE: Cebada Cave (Zone C).

Comment. One adult gordion worm was collected. The host is unknown.

PHYLUM MOLLUSCA

CLASS GASTROPODA (snails)

Undetermined material

Records. BELIZE: Cebada Cave (Zones A, B). GUATEMALA: Xibalba (RB Survey).

Comment. Dry shells of about six species are represented by the above records. This material probably washed into the cave and probably should not be considered part of the true cave fauna.

PHYLUM ARTHROPODA

CLASS ARACHNIDA

Order Amblypygida

Family Phrynidae

Paraphrynus sp. (troglophile)

Records. BELIZE: Cebada Cave (Downstream; Catfish Passage). GUATEMALA: Actun Zactun (Twilight Zone).

Comment. No specimens were collected from the Catfish Passage of Cebada Cave but are probably the same as in other parts of the system.

Order Pseudoscorpionida (pseudoscorpions)

Undetermined material

Record. BELIZE: Cebada Cave (3 km upstream of entrance).

Comment. One specimen from this locality awaits study.

Family Bochicidae

Mexobisium goodnighti Muchmore (troglomite)

Records. BELIZE: Cebada Cave (Downstream). GUATEMALA: Xibalba (RB Survey).

Comment. This collection included one male, 4 females, and one nymph from Cebada Cave and 1 female from Xibalba.

Order Araneae (spiders)

Family Agelenidae

Undetermined genus and species

Record. BELIZE: Cebada Cave (Zone A).

Comment. Two immature specimens of this family were collected.

Family Araneidae

Undetermined genus and species of the subfamily

Araneinae

Records. BELIZE: Cebada Cave (Catfish Passage; Zones A, B, C).

Comment. This material requires further study.

Micrathena sp. (accidental)

Record. BELIZE: Cebada Cave (Zone B).

Comment. A single male of this genus was collected.

Cupiennius sp. (accidental)

Record. BELIZE: Cebada Cave (Zone A).

Comment. A single immature specimen was collected.

Family Pholcidae

Undetermined genus and species (troglomite)

Record. GUATEMALA: Xibalba (RB Survey).

Comment. Only two immature specimens of this species with reduced eyes were obtained.

Metagonia sp. (troglophile)

Record. BELIZE: Cebada Cave (Catfish Passage).

Comment. Only single fragmented female was available for study.

Metagonia n.sp. (troglophile)

Record. BELIZE: Cebada Cave (Downstream).

Family Salticidae

Undetermined genus and species (accidental)

Record. BELIZE: Cebada Cave (Zone B).

Comment. One specimen of this family was collected.

Family Scytodidae

Scytodes sp. (?troglophile)

Record. BELIZE: Cebada Cave (Zone B).

Comment. A single female of this genus was collected.

Family Sicariidae

Loxosceles yucatanana Chamberlin and Ivie (troglophile)

Record. GUATEMALA: Xibalba (RB Survey)

Comments. One female was collected. This species is widespread throughout the Yucatán Peninsula and Belize.

Family Uloboridae

Philoponella sp. (?accidental)

Record. BELIZE: Cebada Cave (Zone B).

Comment. One female was collected.

Order Opiliona (harvestmen)

Family Sclerosomatidae

Geaya belizensis Goodnight and Goodnight (troglone)

Records. BELIZE: Cebada Cave (Catfish Passage; Zones B, C; and Pitfall Traps 2-5).

Comment. The following material was collected from each part of the cave: Catfish Passage (6 juveniles), Zone B (1 male, 2 females, 4 juveniles), Zone C (11 juveniles), Pitfall Trap 2 (14 juveniles), Pitfall Trap 3 (1 juvenile), Pitfall Trap 4 (3 juveniles), Pitfall Trap 5 (1 juvenile).

Order Acarida (mites and ticks)

Undetermined material

Record. BELIZE: Cebada Cave (Zone B).

Comment. One mite was collected.

Suborder Metastigmata (ticks)

Family Ixodidae

Amblyomma sp. (parasite)

Record. BELIZE: Cebada Cave (Zone C).

Comment. A single nymph was taken from a human host.

Ixodes (Ixodes) boliviensis Neumann (parasite)

Record. BELIZE: Cebada Cave (Zone C).

Comment. One female was taken from a human host. This species has been reported from man and a wide variety of wild and domesticated hosts.

Suborder Prostigmata (mites)

Family ?Trombidiidae

Undetermined genus and species

Record. GUATEMALA: Xibalba (RB Survey).

Comment. Four mites possibly belonging to this family were collected.

CLASS CRUSTACEA

Order Isopoda

Suborder Oniscoidea

Family Oniscidae

Records. BELIZE: Cebada Cave (Zone A, B).

Comment. One specimen of this epigeal species was found in each zone.

Family Philosciidae

Troglyphoscia sp. cf. *belizensis* Schultz

Records. BELIZE: Cebada Cave (Catfish Passage; Downstream; Zone C; Pitfall Trap 3).

Comment. This species was abundant throughout Cebada Cave. The following material was collected: Catfish Passage (1), Downstream (4), Zone C (3), Pitfall Trap 3 (7).

Family Sphaeroniscidae

Sphaerarmadillo sp. cf. *schwarzi* Richardson (troglophile)

Records. BELIZE: Cebada Cave (Downstream; Zones B, C; Pitfall Trap 3). GUATEMALA: Xibalba.

Comment. Specimens of this family are abundant in moister parts of the cave. The following material was collected: Downstream (4), Zone B (4), Zone C (2), Pitfall Trap 3 (5), Xibalba (1).

Order Decapoda

Family Palaemonidae (shrimp)

Macrobrachium cationium Hobbs and Hobbs (troglomite)

Record. BELIZE: Actun Tunkul.

Comment. This species is also known from Actun Chapat, Cayo District, Belize.

Family Pseudothelphusidae (crabs)

Typhlopseudothelphusa acanthochela Hobbs (troglomite)

Records. BELIZE: Cebada Cave (Downstream; Catfish Passage); Actun Tunkul.

Comment. This species is also known from Actun Chapat, Cayo District, Belize. One of three specimens from Cebada Cave carried 48 young. Specimens were seen but not collected from the Catfish Passage.

CLASS ENTOGNATHA

Order Collembola (springtails)

Family Entomobryidae

Troglopedetes n.sp. (troglomite)

Records. BELIZE: Cebada Cave (Catfish Passage; Downstream; Zones B, C; Pitfall Traps 2-5).

Comment. This undescribed species is widespread in caves throughout Belize. It was abundant in all parts of the cave.

Order Entotrophi (entotrophs)

Family Campodeidae

Undetermined genus and species (troglomite)

Record. Cebada Cave (Downstream).

Comment. This species appears to be highly troglomorphic. A single specimen was collected.

CLASS INSECTA (insects)

Undetermined material (larvae)

Records. BELIZE: Cebada Cave (Zone B; Pitfall Trap 2).

Comment. This material is under study.

Order Orthoptera

Undetermined material (accidental)

Record. GUATEMALA: Xibalba.

Comment. Only one specimen was collected.

Family Gryllidae (true crickets)

Undetermined genus and species (?troglophile)

Records. GUATEMALA: Xibalba (Middle Entrance; RB Survey).

Comment. Specimens from the Middle Entrance were taken from under bats.

Order Blattaria (roaches)

Undetermined material (accidental)

Record. BELIZE: Cebada Cave (Zone A).

Comment. One dead specimen was collected.

Order Hemiptera (true bugs)

Undetermined material (?accidental)

Records. BELIZE: Cebada Cave (Catfish Passage; Zone B).

Comment. A water treader from the Catfish Passage was taken from a clear, flowing, bedrock-floored pool.

Order Homoptera

Undetermined material (accidental)

Record. BELIZE: Cebada Cave (Zone A).

Comment. One specimen was collected.

Family Aphididae (aphids)

Undetermined genus and species (accidental)

Record. BELIZE: Cebada Cave (Zone B).

Comment. One specimen was collected.

Order Coleoptera (beetles)

Undetermined material

Records. BELIZE: Cebada Cave (Pitfall Trap 4; Catfish Passage).

Comment. Two or more species of undetermined beetles were collected. No specimens were obtained from the Catfish Passage. This material is presently under study.

Family Carabidae (ground beetles)

Undetermined genus and species (troglophile)

Records. BELIZE: Cebada Cave (Catfish Passage; Downstream). GUATEMALA: Xibalba.

Comment. In the downstream section these were present near the sump on an organically rich mud substrate.

Family Curculionidae (weevils)

Undetermined genus and species (accidental)

Record. Cebada Cave (Zone B).

Cossonus sp. (accidental)

Record. BELIZE: Cebada Cave (Zone C).

Pseudopentarthrum sp. (accidental)

Record. BELIZE: Cebada Cave (Zone A).

Family Dryopidae (long-toed water beetles)

Helichus sp. (accidental)

Record. BELIZE: Cebada Cave (Zone B).

Family Elateridae (click beetles)

Agrypnus sp. (accidental)

Record. BELIZE: Cebada Cave (Zone B).

Horistonotus sp. (accidental)

Record. Cebada Cave (Zone C).

Family Endomychidae (handsome fungus beetles)

Anamorphus sp. (accidental)

Record. BELIZE: Cebada Cave (Zone A).

Family Pselaphidae (mold beetles)

Scalenarthrus sp. (?accidental)

Record. BELIZE: Cebada Cave (Pitfall Trap 2).

Comment. Two specimens of this genus were collected.

Family Staphylinidae (rove beetles)

Homaotarsus sp. (troglophile)

Records. BELIZE: Cebada Cave (Zone C; Pitfall Traps 3, 5).

Comment. This species was extremely abundant with 34 specimens taken from pitfall trap no. 5.

Scopaeus sp. (?accidental)

Record. BELIZE: Cebada Cave (Zone B).

Comment. Only two specimens of this genus were found.

Stannoderus sp. (?accidental)

Record. BELIZE: Cebada Cave (Zone B).

Comment. A single specimen was collected.

Stenus sp. (?accidental)

Record. BELIZE: Cebada Cave (Zone A).

Comment. A single specimen was collected.

Order Lepidoptera (moths)

Undetermined material

Records. BELIZE: Cebada Cave (Zones A, B, C).

Order Hymenoptera

Undetermined material

Records. BELIZE: Cebada Cave (Zones A, B).

Family Formicidae (ants)

Azteca sp. (accidental)

Record. BELIZE: Cebada Cave (Zone A).

Comment. Six specimens of this genus were collected.

Camponotus abdominalis (Fabricius) (accidental)

Record. BELIZE: Cebada Cave (Zone A).

Comment. One specimen of this species was collected.

Crematogaster sumichrasti Mayr (accidental)

Record. BELIZE: Cebada Cave (Zone A).

Comment. Six specimens of this species were collected.

Pachycondyla carinulata (Roger) (accidental)

Record. BELIZE: Cebada Cave (Zone B).

Comment. One specimen of this species was collected.

Paratrechina sp. (accidental)

Record. BELIZE: Cebada Cave (Zone A).

Comment. One specimen of this genus was collected.

Pheidole punctatissima Roger (accidental)

Record. BELIZE: Cebada Cave (Zone A).

Comment. One specimen of this species was collected.

Solenopsis geminata (Fabricius) (accidental)

Record. BELIZE: Cebada Cave (Zone C).

Comment. One specimen of this species was collected.

Wasmannia auropunctata (Roger) (accidental)

Record. BELIZE: Cebada Cave (Zone A).

Comment. Four specimens of this species were collected.

Order Diptera (flies)

Undetermined material

Records. BELIZE: Cebada Cave (Downstream; Entrance area; Zone B, C; Pitfall Traps 2, 3, 5).

Comment. Numerous species are represented in these collections. This material is all under study.

Family Sphaeroceridae (small dung flies)

Opalimosina n.sp. (?accidental)

Record. BELIZE: Cebada Cave (Zone A).

CLASS CHILOPODA (centipedes)

Order Scutigleromorpha

Undetermined material

Records. BELIZE: Cebada Cave (Downstream). GUATEMALA: Actun Zactun (Twilight Zone).

CLASS DIPLOPODA (millipedes)

Order Spirostreptida

Family Spirostreptidae

BIOLOGY OF THE CHIQUIBUL CAVE SYSTEM

Orthoporus sp. (troglophile)

Record. GUATEMALA: Xibalba (RB Survey).

Order Polydesmida

Family Pyrgodesmidae

Undetermined genus and species (troglophile)

Record. BELIZE: Cebada Cave (Downstream).

PHYLUM CHORDATA

CLASS TELEOSTOMI

Order Cypriniformes

Family Pimelodidae (catfish)

Rhamdia sp. (troglophile)

Records. BELIZE: Cebada Cave (Upstream; Downstream); Actun Tunkul. GUATEMALA: Xibalba (Main Stream Passage).

Comment. Catfish from the Chiquibul System show no obvious signs of cave adaptation.

Order Synbranchiformes

Family Synbranchidae

Undetermined genus and species

Record. BELIZE: Actun Tunkul.

Comment. Several eels were observed in this cave by Logan McNatt (pers. comm., 1995).

CLASS AVES

Order Passeriformes

Family Hirundinidae

Undetermined genus and species

Records. BELIZE: Cebada Cave (Entrance Area). GUATEMALA: Xibalba (Entrance Area).

Comment. No specimens were collected.

CLASS MAMMALIA

Order Chiroptera

Undetermined material

Records. BELIZE: Cebada Cave (Entrance Area). GUATEMALA: Xibalba (Main Stream Passage; RB Survey).

Comment. No specimens of bat were collected.

CONSERVATION OF KARST IN BELIZE

MICHAEL DAY

Department of Geography, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin 53201, U.S.A.

Karst areas in Belize are coming under increasing pressure from agriculture and other commerce. Opportunely protected karst areas are incorporated within forest reserves, national parks, wildlife sanctuaries, nature reserves, archaeological reserves, private conservation and management areas, and special development areas.

The total area of karst afforded nominal protection is about 3400 km², or about 68% of the total. Incorporating special development areas, the protected karst area is about 4300 km², or 86% of the total. Even the more conservative percentage is unparalleled in Central America and the Caribbean, and perhaps the world.

Significant protected karst areas include the Chiquibul, Blue Hole and Five Blues Lake national parks, the Bladen, Aquas Turbias and Tapir Mountain nature reserves, the Monkey Bay Wildlife Sanctuary, the Rio Bravo Conservation and Management Area, and the Caracol, Xunantunich, Cahal Pech and El Pilar archaeological reserves. Extensive karst areas are located within the Vaca, Columbia River, Sibun, and Manatee forest reserves. The Manatee and Cayo West special development areas have considerable karstic components.

Throughout the world, karst landscapes are increasingly subject to human impacts (Gillieson & Smith, 1989; Sauro et al., 1991; Williams, 1993; Ford, 1993). Karst regions in the Caribbean and in Central America have come under particular pressures from agricultural and industrial expansion (Day, 1993a), and the karst of Belize is itself experiencing increasing environmental stress (Day, 1987, 1991, 1993b; Day & Rosen, 1989).

General issues of human encroachment and accelerating land "development" aside, karst landscapes in Belize and elsewhere merit conservation for a variety of reasons. Many are areas of special scientific interest; others are areas of outstanding natural beauty. They often represent significant floral and faunal refuges, and they function as valuable hydrologic reservoirs. Many are of archaeological significance, and they are all intrinsically fragile, being susceptible to rapid deterioration of soil, water and other natural resources. Particular challenges to the integrity of karst terrains in Belize include increases in agricultural development, especially citrus cultivation, indiscriminate forest clearance, quarrying, and water contamination. Caves are at risk from this general suite of impacts, plus increasing recreational activities and rampant looting of archaeological artifacts.

At the same time, there is increasing awareness in Belize of the need to establish protected areas, which are set aside for specific purposes and generally managed for conservation of resources (Nicolait, 1995). Sixty-two percent of land in Belize is under public ownership, and about 28% is demarcated as government forest reserves (Nicolait, 1991). Currently, conservation areas include twenty forest reserves, seven national parks, two wildlife sanctuaries, four nature reserves, and five archaeological reserves, plus at least twenty private conserva-

tion and management areas and six special development areas (Figure 1; Table 1). These protected areas and sites in Belize encompass a wide range of designations and purposes, but collectively they account for over 30% of Belize's land area (Nicolait, 1992). Many of these protected areas include karst landscapes, and it is upon them that this paper is focused.

KARST DISTRIBUTION

Carbonate bedrock underlies over 50% of Belize's land area of approximately 23,000 km², but not all of this is extensively karstified. In particular, Tertiary limestones, which underlie the northern 35% of the country give rise to karst only locally, notably in the Rio Bravo area in the northwest of the Orange Walk District and in the Yalbac Hills of the Cayo District (see location map on page 68, and Miller's Figure 4 in this issue).

Karst topography is more pronounced on the Cretaceous limestones which flank the Maya Mountains. Karst covers about 2,000 km² in a belt that is located north and west of the Maya Mountains and south of the Belize River Valley (Day, 1993b), and a similar area of karst is developed south of the Maya Mountains, primarily in the Toledo District (see Miller's Figure 4). In total, the karst area of Belize accrues to about 5,000 km², or about 22% of the country's land area (Day, 1993a).

PROTECTED AREAS LEGISLATION

Valuable general reviews of Belize's protected areas and the legislation pertaining to them are provided by Munro (1983), Zisman (1989), Zisman and Munro (1989), and

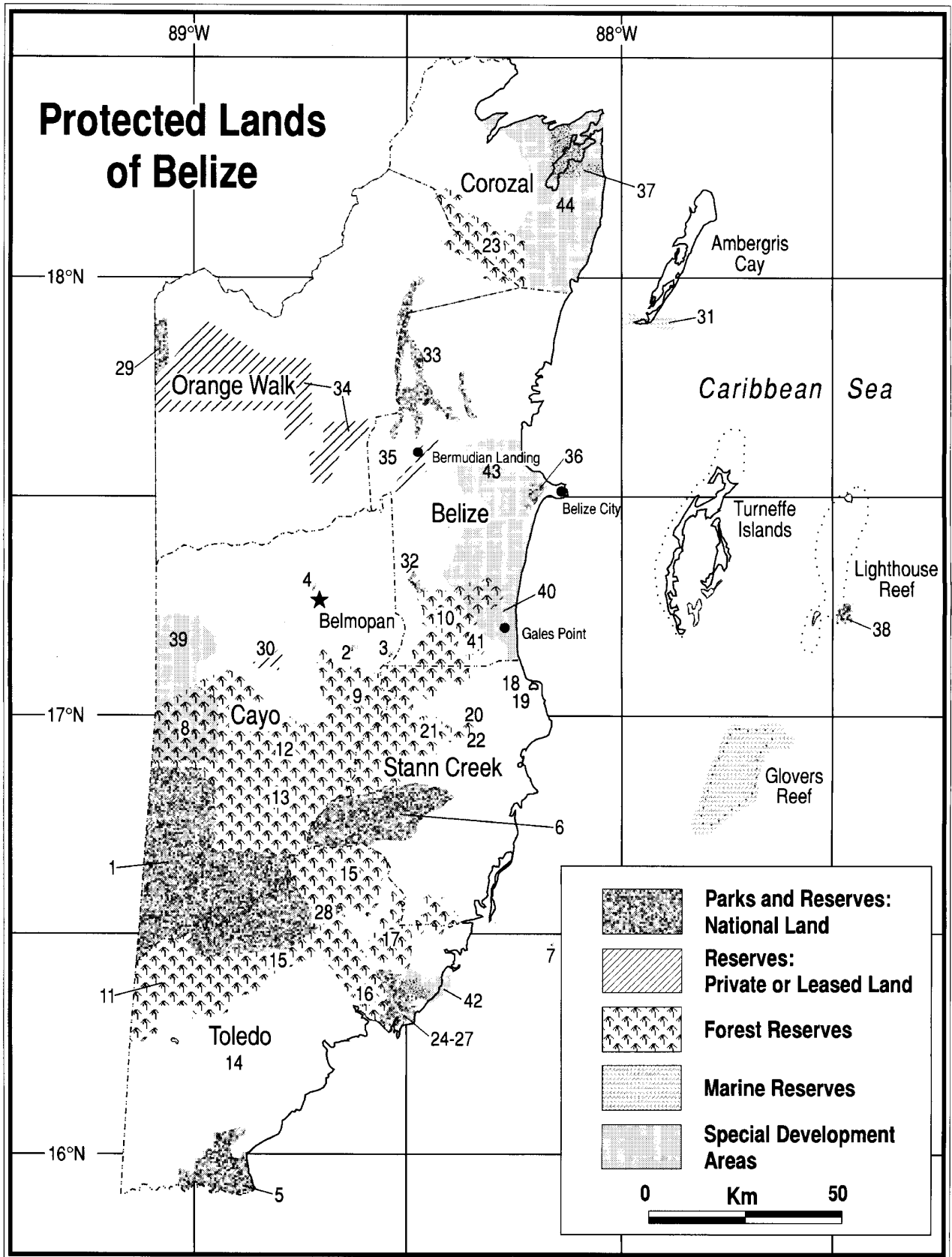


Figure 1.

Table 1. Conservation Areas in Belize
(numbers correspond to those on Figure 1)

National Parks	Area (ha)	Karst
1 Chiquibul	186,490	Mostly
2 Blue Hole	233	All
3 Five Blues Lake	358	All
4 Guanacaste	21	Little
5 Sarstoon	16,600	None
6 Cockscomb Basin	41,540	None
7 Laughing Bird Caye	1	Reef
Forest Reserves		
8 Vaca	21,000	Mostly
9 Sibun	42,975	Little
10 Manatee	45,789	Mostly
11 Columbia River	44,030	Some
12 Mountain Pine Ridge	51,500	Little
13 Chiquibul	184,900	Little
14 Machaca	2,300	None
15 Maya Mountain	92,700	None
16 Deep River	59,100	Some
17 Swasey Bladen	6,200	Some
18 Grants Works A	3,240	Some
19 Grants Works B	1,360	Some
20 Silk Grass	2,641	None
21 Sittee River	38,008	None
22 Commerce Bight	2,778	None
23 Freshwater Creek	30,000	Little
24 Mango Creek		None
25 Mango Creek 2		None
26 Mango Creek 3		None
27 Mango Creek 4		None
(Total Mango Creek Area)	23,228	
Nature Reserves		
28 Bladen	40,000	Some
29 Aguas Turbias	3,642	Mostly
30 Tapir Mountain	2,729	All
31 Hol Chan Marine	1,215	Reef
Wildlife Sanctuaries		
32 Monkey Bay	1,037	Mostly
33 Crooked Tree	6,478	Little
Other Reserves		
34 Rio Bravo	101,000	Some
35 Bermudian Landing	4,664	None
36 Burdon Canal	8	None
37 Shipstern	8,906	Little
National Monuments		
38 Half Moon Caye	18	Reef
Special Development Areas		
39 Cayo West	43,354	Mostly
40 Manatee	47,350	Mostly
41 Manatee West	48,000	Mostly
42 Monkey River	50,000	None
43 Burrel Boom-Hattieville	40,485	Little
44 Corozal East	79,453	Little

Nicolait (1995). Only legislation that is of particular relevance to the conservation of karst areas is considered here.

In a general context, environmental conservation and rational natural resource utilization are promulgated under the Environmental Protection Act of 1992. Although there are no formal criteria governing the designation of protected areas in Belize, certain elements are deemed important: "...richness in biodiversity, populations of endangered species, importance to watershed management, unusual or scenic features, presence of Maya ruins and ancient monuments, and value for recreation and ecotourism" (Nicolait, 1995).

One piece of important pre-independence (1981) legislation is the Forest Ordinance, first enacted in 1926, then revised in 1958 and 1980 (Zisman, 1989; Nicolait, 1995). The Forest Ordinance provides for the establishment of forest reserves, which are intended for forest production and watershed protection, and for the licensing and regulation of forestry activities (G.O.B., 1992). Several of the 20 forest reserves include karst landscapes, notably Vaca, Sibun, Manatee, and Columbia River.

The National Parks Systems Act, enacted in 1981 and entered into force in January 1982, provides the legal basis for the creation of national parks, nature reserves, wildlife sanctuaries and natural monuments (Nicolait, 1995). The Chief Forest Officer is responsible for administration of the National Parks System, and ultimate authority for the designation of protected areas under this act is currently lodged with the Minister of Natural Resources, although this is subject to change by Prime Ministerial fiat (Nicolait, 1995). Significantly, the existing language of the National Park Systems Act (Part II, 3-2) "...empowers the Minister to alter or vary any protected area established under the act or to declare it to cease to be a protected area" (Nicolait, 1995).

Under the National Parks Systems Act, national parks are established for protection and conservation of natural resources and scenic areas for the good of the public (GOB, 1993a). Although these lands cannot be sold or leased for agricultural or industrial use, logging, energy exploration, and tourism developments may be allowed by permit or concession. This also applies to natural monuments, areas conserving significant natural features of particular value for research, education, and public appreciation (GOB, 1993a). Significant karst is developed within several of the seven national parks, notably Chiquibul, Blue Hole and Five Blues Lake (Figure 1; Table 1).

Nature reserves provide for the protection of biological resources and to maintain undisturbed habitats and ecosystems for scientific study and provision of genetic banks (GOB, 1993a). By contrast, wildlife sanctuaries are conservation areas devoted to more specific biotic goals requiring greater human manipulation (GOB, 1993a). The Wildlife Protection Act of 1981 specifically regulates faunal protection. Nature reserves and wildlife sanctuaries with significant karst terrain include Bladen, Aguas Turbias, and Tapir Mountain (Figure 1;

Table 1).

Archaeological reserves are established to protect ancient and historical sites for scientific study, education and recreation (Nicolait, 1995). Nominal protection of such sites is provided by the Ancient Monuments and Antiquities Ordinance of 1971. Since all caves are potential or actual archeological sites, access to them is restricted and exploration or excavation requires permission from the Commissioner of Archaeology. Specific archaeological reserves in karst terrain include the Maya sites at Caracol, Xunantunich, Cahal Pech, and El Pilar.

Under the auspices of the Land Utilization Act of 1991, Special Development Areas (SDAs) are zoned for land use on the basis of the following: 1) protection of the environment, forestry, and recreational land, 2) avoidance of unsuitable and unfeasible development on marginal or poorly-accessed land, 3) identification and protection of viable agricultural land, 4) accommodation of rural residential use, and 5) necessary urban expansion (GOB, 1993b). Three SDAs have received ministerial approval and three others have been approved locally and are under consideration by the Land Utilization Authority. Those with significant karstic components are Manatee, Manatee West, and Cayo West (Figure 1; Table 1).

In general then, Belize possesses a sound legislative base for the designation and conservation of protected areas, and has to date established 44 such areas (Table 1), although not all of these encompass karst landscapes. Problems remain in that protected areas can be dereserved by ministerial decision, no single ministry is responsible for protected areas creation or maintenance, and human and financial resources are inadequate for planning, management, and enforcement of regulations (Day, 1987; Nicolait, 1995).

CONSERVATION OF KARST

Conservation of karst in Belize has been effected largely by indirect means. Very few karst areas or sites are protected primarily because they are recognized for their scientific importance, and in many cases it is unclear whether protected limestone tracts are even recognized as being karst landscapes. The coincidence between protected areas and karst terrain is largely opportune, although it reflects the areal extent and the relative inaccessibility of the karst landscapes and their significance in other contexts. Although protected areas legislation is in place, de facto enforcement of regulations is hampered by lack of human and financial resources.

In particular, karst in Belize is afforded protection because of its importance as forest and wildlife reserves, because of its archaeological significance, because of its potential value in ecotourism, and because of its inherent unsuitability for large-scale mechanized agriculture. This notwithstanding, some 15% of Belizean karst is currently under agriculture (Day, 1993a) and many of the karst areas are coming under increased resource pressures, especially clearance for citrus cultivation and small-scale mixed farming (Day, 1993b).

These pressures are particularly acute in the Boundary Fault Karst Area and the Yalbac Hills (see Miller's Figure 4, this issue).

Much of the Belizean karst is conserved because of its forest resources. Approximately 66% of Belize has some broadleaf tree cover, and at least 33% of that is on steep slopes which require protection (GOB, 1993b). Belize is a participant in the United Nations Tropical Forest Action Plan (TFAP), and in May 1992 began a \$14 million Forest Planning and Management Project which is designed "...to provide for the identification and rational allocation of land for forest, agriculture and other uses; and to ensure the national forest estate will be managed on a sustainable basis and provide an adequate return on investment" (GOB, 1993b, p.13). Under the auspices of TFAP, a project funded by the United States Agency for International Development, the Natural Resource Management and Protection Project aims to identify critical habitat areas requiring protection. Forested karst areas under particular pressure include those in the forest reserves of the Cayo and Toledo districts (Figure 1).

Karst areas are also conserved in order to ensure safe drinking water supplies under the government's Rural Water Supply and Sanitation Programme. In small dispersed communities, handpump wells are installed at an overall ratio of 1 per 10 families (GOB, 1993b). In larger and more cohesive settlements, electric pumps recharge elevated holding tanks from which water is distributed by gravity feed (G.O.B., 1993b). Contamination of karst aquifers is an increasing problem as a result of increased agriculture in the Cayo and Orange Walk Districts (Figure 1).

Increasingly, karst areas are protected because they correspond with important floral and faunal reservoirs and have a role to play in maintaining biodiversity. Wildlands and wildlife conservation also have an important economic component in the form of ecotourism. Along similar lines, pre-European Maya archaeological sites are an increasing focus of visitor activity, and these sites are "...almost exclusively in limestone areas" (Hartshorn et al., 1984, p.21). Despite the nominal protection accorded by law, looting of archeological sites, including caves, remains a serious problem (Hartshorn et al., 1984), particularly in the sparsely populated forest reserves of the Cayo and Toledo districts (Figure 1).

One traditionally important factor in karst and other land conservation in Belize is the low population density, which at about 8 persons per square kilometer is the lowest in the karstlands of Central America and the Caribbean (Day, 1993a). Contributory factors include the concentration of population in urban centers in non-karst regions, and the ruggedness and relative inaccessibility of many karst locales.

Including both public and private land reserves, the total area of karst landscape in Belize which is afforded at least some degree of protection is approximately 3,400 km², or about 68% of the total karst extent. Incorporating karst terrain within designated Special Development Areas, the protected

karst area rises to about 4,300 km², or 86% of the total karst region. Even the former, more conservative percentage of karst terrain under at least some measure of conservation is unparalleled in Central America and the Caribbean, and perhaps throughout the world.

PROTECTED KARST AREAS

The following is a summary of the protected areas that encompass significant karst landscapes in terms of extent, scientific interest and accessibility. Other, smaller karst areas are also protected but are not considered in detail here.

The largest area of protected karst in Belize is in the Chiquibul National Park, designated in 1991, which covers 186,490 ha (1,865 km²) in the western Cayo District (Figure 1). Formerly part of the Chiquibul Forest Reserve, the park surrounds the important Caracol Archaeological Reserve, and also incorporates parts of the extensive Chiquibul Cave System, the total surveyed length of which exceeds 55 km (Miller, 1990). Development pressures here are minor, but archaeological looting is a serious problem.

The Rio Bravo Conservation and Management Area in the Orange Walk District (Figure 1) encompasses approximately 101,000 ha (1,010 km²) of private and public land (Zisman, 1989; Nicolait, 1991; GOB, 1992; anon, 1994). It is managed by the Programme for Belize, a non-governmental organization established in 1988 and whose overall goal is "...to promote the conservation of the natural heritage of Belize and to promote wise use of its natural resources" (anon, 1994:19). The main threats to karst in the northern districts are agricultural development and water contamination.

The Vaca Forest Reserve, designated in 1991, covers 21,000 ha (210 km²) in the Cayo District, adjoining the Chiquibul National Park and the Cayo West Special Development Area (Figure 1). The reserve contains extensive fluviokarst and significant evidence of Maya occupation (Alt, 1994; Reeder, 1993). Small areas of karst, which include the Rio Frio caves, occur in the adjacent Mountain Pine Ridge Forest Reserve.

The Bladen Nature Reserve, created in 1991, covers some 40,000 ha (400 km²) on the southern fringes of the Maya Mountains in the Toledo District (Figure 1). The karst in the southern part of the Reserve is rugged and little-explored, containing at least one Maya site, named Quebrada del Oro (Nicolait, 1991). The Columbia River Forest Reserve, also in the Toledo District (Figure 1), covers some 44,030 ha (440 km²), part of which is karst, around the upper reaches of the Rio Grande (Zisman, 1989). Within the Forest Reserve, a 2,340 ha (23 km²) nature reserve within the karst was gazetted in 1968 but abandoned in 1978 (Zisman, 1989). Karst in the southern districts is subject to logging and agricultural expansion pressures.

Two small but significant karst areas protected in the eastern Cayo District are the Blue Hole and Five Blues Lake

national parks in the Boundary Fault Karst Area (Figure 1). The Blue Hole itself is a karst window, and has been a site of scientific and tourist attention at least since completion of the Hummingbird Highway in 1954 (Day, 1987; 1992). The Blue Hole National Park, established in 1986 and managed by the Belize Audubon Society (BAS), covers 233 ha (2.3 km²) and also incorporates St. Herman's, Petroglyph, and Mountain Cow caves (Zisman, 1989), receiving some 6,000 visitors annually (BAS, 1993). Five Blues Lake National Park was established in 1991 and covers 358 ha (3.6 km²) centered on the 3 ha (0.03 km²) sinkhole lake after which the park is named. Additional karst is conserved within the adjacent 42,967 ha (430 km²) Sibun Forest Reserve (Figure 1). The karst along the Hummingbird Highway have come under increasing pressure in recent years from a combination of agricultural and population growth, mining, and recreation (Day, 1987, 1993b).

Tapir Mountain Nature Reserve, known until 1994 as Society Hall Nature Preserve, was established in 1986 and covers 2,729 ha (27 km²) of little-known karst north of the Mountain Pine Ridge between Barton Creek and Roaring Creek in the Cayo District (Figure 1). The Reserve is managed by the Belize Audubon Society. The Monkey Bay Wildlife Sanctuary, straddling the Sibun River in the western Belize District, was established in 1991 and covers 1,037 ha (10 km²), including cockpit and tower karst with several caves, adjacent to the 45,789 ha (458 km²) Manatee Forest Reserve (Figure 1), which also contains extensive karst. The Aguas Turbias Nature Reserve, of which a portion is karstic, covers 3,642 ha (3.6 km²) in the northwestern corner of the Orange Walk District bordering both Mexico and Guatemala (Figure 1).

The Manatee Special Development Area extends over 47,350 ha (474 km²) in the coastal Belize District south of the Sibun River (Figure 1), where it encompasses the cockpit and tower karst in the eastern extent of the Sibun-Manatee Karst Area. The Cayo West Special Development Area covers 43,354 ha (434 km²) in the western Cayo District (Figure 1), incorporating subdued karst terrain in the upper Belize River Valley and more dramatic karst abutting the Vaca Forest Preserve.

CONCLUSION

As karst landscapes in Belize come under increasing human pressure, it seems appropriate to enact conservation measures to protect the karst environment, particularly the forests, wildlife, soils, water, and archeological resources, all of which have scientific, aesthetic, and economic significance. Belize has a sound legislative base for establishment of a variety of protected areas, and has afforded at least some measure of protection to over 30% of its land area. Within this, some 68% of the karst landscape has received some degree of protection, a figure far surpassing that of any other country in the region. Much of the karst is not widely recognized as such,

and is conserved indirectly because of its overall environmental value. Its future conservation is not assured, but dynamic protection of its attendant forest, wildlife and archeological resources is encouraging.

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- Marochov, N. & Williams, N. (1989). Queen Mary College Speleological Expedition to Belize 1988. *Caves and Caving* 43: 8-11. Concise description of the work done by the 1988 QMC Expedition with many maps and photo's. Describes work in White Ridge (Darby Pat/White Ridge systems (incl. half page survey), Mines of Moria, Barton Creek (Actun Zotziha, the Hole in Six), and at Gracy Rock (Gibnut Cave).
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- Reeder, P. (1991). The 1990 and 1991 Speleological Expeditions to the Northern Vaca Plateau, Belize. *NSS Bulletin* 53(2):122. Abstract of a talk at the 1991 NSS Convention. Describes reconnaissance expeditions to Spanish Waterhole area which have discovered about 50 caves.
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- Sarbu, S. (1990). Personal Communication with Malcolm Foyle. 6pp. Notes about the diving done by Sarbu in while in Belize with Tom Ilffe. Includes diagrams of Giant Cave, Caye Chapel Cave and Columbus Caye Blue Hole.
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- Shaeffer, B. & Cobb, A. (1991). The NSS Maya Caves Project, Belize CA. *NSS Bulletin* 53(1): 30. Abstract of presentation at 1988 NSS Convention. Project to catalogue caves in the Toledo district. Exploration at Blue Creek, Deep River, Rio Grande and Edwards Central.
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- Stratford, T. (1992). Below Belize (Review). *International Caver* 5: 39. Review of *Below Belize* (report of the 1988 QMC Expedition and the 1989 Anglo Canadian Expedition).
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- Whitwell, O. (1988). International Exploits-Belize, May 1988. *BC Caver* 2(3): 7-10. Brief account of the 1988 Chiquibul expedition.
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- Williams, N. (1992). *Below Belize 1991*. Below Belize 1991 Expedition/WCC. 17pp. Report of the 1991 Expedition to the Quartz Ridge. Includes discussion of geology, topography, flora and fauna. The expedition explored the sinks on the western end of the ridge and discovered many small caves but no extensive systems were found. Report includes 10 photos, 3 location maps, 14 A4 surveys, A3 survey of Actun Xibalda.
- Williams, N. (1989). Letters; Queen Mary College Speleological Expedition 1988. *Caves and Caving* 45:31. Response to Miller's letter in *Caves and Caving* 44.
- Williams, N. (1988). Expedition Explores Maya Mountain Caves. *Amandala* 962. Publication of press release on 1988 QMC Expedition in Belizean local paper.
- Williams, N. (1987). Caving in Belize. *Caves and Caving* 37: 7. A one page introduction to Belize for cavers. Includes small photos of St Herman's and the Blue Hole at Caves Branch but no cave specific information.
- Williams, N. (1987). *Queen Mary College Speleological Expedition to Belize*. Unpublished report & 56 color plates 9pp. First time traveller's guide to Belize.
- Williams, N. & Clark, T. (1990). *Queen Mary College Below Belize 1988*. N.N. Williams/QMC Expeditions Committee. 213pp. Very detailed report on the logistics of the organization of the 1988 Queen Mary College Expedition. Includes chapters on finance and fundraising, shipping, transport, food, equipment photography and projects to study bats and fish. Appendices include the original survey data from the expedition and references. 19 photographs but no surveys.
- Williams, P. (1976). Flagellate Infections in Cave Dwelling Sand Flies (Diptera, psychodidae) in Belize. *Bulletin of Entomological Research* 65: 615-629. The author studied infections in sandflies in Millionario Cave and Augustine Caves. He suggests a possible mechanism for transmission of the infection.
- Williams, P. (1976). The Form of *Lutzomyia Beltrani* (Vargas & Dias Najera)(Diptera, Psychodidae). *Bulletin of Entomological Research* 65: 595-599. Taxonomic article on a species of sand fly found in caves at Augustine and San Antonio.

- Williams, P. (1976). The Plebotomine Sandflies (Kiptera, Psychodidae) of Caves in Belize, Central America. *Bulletin of Entomological Research* 65: 601-614. The author studied sandflies in Millionario Cave, Augustine Caves and at San Antonio. (Sandflies are significant because of their ability to carry Leishmaniasis among other diseases.)
- Winsler, S. & Winsler, N. (eds) (1988). Queen Mary College Speleological Expedition to Belize 1988. *Royal Geographic Society Expedition Yearbook, 1988*: 12,95-96. Summary of the work done by the 1988 QMC Expedition, area by area. Includes brief descriptions of White Ridge, Gibnut, Five Blues River Cave, No. 3 & 4, Gothic Caverns, Actun Zotziha & Hole in Six. Includes list of expedition members, map and references but no surveys.
- Woods, R.L. Reid, S.T. & Reid, A.L. (1988). The Blue Hole at Lighthouse Reef. *The Field Guide to Ambergris Cae, Belize CA*: 132-137. Description of the flooded cenote at Lighthouse Reef. Principally a guide for sports divers but includes an elevation with notes on speleogenesis, notes on the submarine wildlife of the Caye and a history of exploration.
- Worthington, S. (1986). Belize. *Atlas Des Grandes Cavites Du Monde*. Courbon & Chabert (eds) UIS/FFS: 28-29. Short summary of caves and caving in Belize. Includes list of significant caves, plus some references. In French.
- Wright, A.C.S., Romney, D.H. & Arbuckle, R.H. (1959). *Land in British Honduras, Report of the Land Use Survey Team*. Colonial Research Publication (24) HMSO. 327pp & maps. The definitive work on the soils and landform of Belize. The country is divided into 24 sub-areas and the landform, soils, vegetation and agriculture of each is described and discussed. Suggestions for land use are proposed. The text also includes a discussion of geology, geomorphology and anthropology. Caves are only mentioned in passing but are mentioned under the appropriate sub area headings. Appendices and maps include a list of flora, soils, population, rainfall and ancient Mayan sites.
- Yonge, C. (1988). Discovery: Exploring the Caves of the Maya. *Explore Magazine* 34: 44-50. Calgary, Alberta. "Adventure" magazine article about the Chiquibul explorations by a participant in the 1986 trip. Includes account of exploration in Actun Tun Kul and Cebada. Photographs of caves, crab and artifacts (in color).
- Young, W.F. (1961). Spelunking in British Honduras. *International Speleologist* 1(1): 5-13. A description of the caves of Belize by the earliest explorer of modern times. Ford Young, in association with Frank Norris, visited "Ben Lomond...just west of the Southern end of Northern Lagoon" and Manatee Caves. They also visited caves in the Indian Creek area at Caves Branch and in the Chiquibul as well as well known archaeological sites in the company of the then Archaeological commissioner, A.H. Anderson. A map of major sites is included.
- 1:50,000 Survey of Belize in 41 sheets. Mostly prepared from aerial photographs in uninhabited areas. Contour intervals vary from sheet to sheet. Many errors in watercourse mapping in karst areas. Sheets show several caves, some named, some not. In particular Sheet 21 (Gracy Rock), Sheet 23 (Vaca), Sheet 24 (Barton and Roaring Creek), Sheet 25 (Caves Branch, Indian Creek), Sheet 26 (White Ridge), Sheet 28 (Rio Frio), Sheet 33 (Chiquibul), Sheet 34 (Eduardo Quiroz), Sheet 37 (Little Quartz Ridge), Sheet 41 (Blue Creek).
- A0 Surveys of Caves Discovered on 1991 Little Quartz Ridge Expedition. Published in reduced form in the expedition report.
- A0 Survey of Cebada Cave Resulting from 1986 and 1988 Expeditions.
- A1 Surveys of Box Ch'iich', Tunichil Muknal, Sunken Forest plus (A2) Tan U Wüyül and Ya'ax Kan. Published in reduced format in *Below Belize* (1992).

CAVE SCIENCE NEWS

NEW SECOND DEEPEST CAVE IN THE WORLD

The Cavers Digest on the Internet carried a recent report that a Polish Expedition connected Vogelshacht and Lamprechtsofen, two caves in the Leoganger Steinberger area of Austria. The connection moves the system, now 1535 m deep, into the slot as second deepest explored cave in the world.

THEME SESSION ON EVAPORITE KARST IN OCTOBER

“Evaporite Karst: Origins, Processes, Landforms, Examples, and Impacts” will be the theme of a special oral session at the upcoming national meeting of the Geological Society of America. The meeting is to be held in Denver, Colorado, on October 27-31, 1996. The session is co-sponsored by the Hydrogeology and Engineering Geology Divisions of GSA. Kenneth S. Johnson of the Oklahoma Geological Survey and James T. Neal of Sandia National Laboratories will chair the session. Abstracts were due on July 9th. The day and time of this session will be Wednesday, October 30, 1996 at 1:30 PM.

ANDERSON WINS AWARD FOR KARST HYDROLOGY PAPER

Eric Anderson, NSS # 41495, of Hermitage, Tennessee has won special recognition at the regional science fair at Vanderbilt University by the Association of Women Geoscientists and by the American Meteorological Society. His paper, “Comparison of Physical & Chemical Discharge To Determine the Relationship Of Two Springs at Woodlawn Memorial Park, Nashville, Tennessee”, was also presented as a poster session at the 1996 NSS Convention in Salida, Colorado. Anderson is a 10th grade student at Martin Luther King Magnet High School for Science. Nashville Grotto member and hydrologist, Geary Schindel, was his adult sponsor during the four month research project.

EXPLORATION EDITOR REPLACEMENT NEEDED

The *Journal of Cave and Karst Studies* is looking for a new Associate Editor of Exploration. The former Exploration Editor of the *NSS Bulletin*, Louise Hose, has resigned to become the Editor of the *Journal*. The responsibilities of the Associate Editors are to solicit articles, arrange for appropriate reviews for papers within their fields of expertise, work with authors to prepare their manuscripts for publication, make recommendations concerning acceptance and rejection of submitted papers, and assist the Editor in gathering material for the

non-refereed sections of the *Journal*.

The *Journal* seeks to strengthen its exploration department and is looking for a pro-active caver with contacts in the exploration community. Interested candidates are asked to send a letter of interest and a curriculum vitae or resume by October 15, 1996 to:

Louise D. Hose
Environmental Studies Program
Westminster College
Fulton, MO 65251-1299

HOSE AND PISAROWICZ APPROVED BY NSS BOARD

The National Speleological Society Board of Governors approved the appointments of Louise D. Hose, PhD, as the new Editor of the *Journal of Cave and Karst Studies* and James A. Pisarowicz, PhD, as the Production Editor. Their appointments started with volume 58.

Both Hose and Pisarowicz have moved since they served as the Interim Editors of the first issue of volume 58. Their new addresses appear on the masthead of this issue. The Littleton, Colorado address given for the *Journal* in the first issue will continue to serve the *Journal* but will not be as timely as the new address in Fulton, Missouri.

INTERNATIONAL SPELEO EVENTS CALENDAR ON-LINE

The International Union of Speleology (UIS) has placed a Calendar of International Speleo Events on its world-wide web page according to Peter Matthews in a recent Cavers Digest. Their intention is to keep the calendar more current than the printed version in the *UIS Bulletin*. The address is:

<http://rubens.its.unimelb.edu.au/~pgm/uis/events.html>

Anybody or organization organizing a major caving, speleological or related event, or expedition may send details to the calendar web editor, Roger Taylor, by using the on-line form on the calendar web pages, or by mailing them to:

Mr. Roger Taylor
32 Medina Rd
Glen Waverley, Vic 3150
AUSTRALIA

**AMERICAN ASSOCIATION FOR THE
ADVANCEMENT OF SCIENCE ANNUAL MEETING
AND SCIENCE EXPOSITION, BALTIMORE, MD**

FEBRUARY 13, 1996

**TRACK: 'EXAMINING GLOBAL CHANGE'
SYMPOSIUM: "INTERACTIONS OF KARST
GEOLOGY AND ECOLOGY"**

Symposia Abstracts

**A CHEMOAUTOTROPHIC SUBTERRANEAN
ECOSYSTEM: BIOLOGICAL AND GEOLOGICAL
IMPLICATIONS**

Serban M. Sarbu, University of Cincinnati, Cincinnati OH
45221-0006

Thomas C. Kane, University of Cincinnati, Cincinnati OH
45221-0006

An unusual groundwater ecosystem was recently discovered in a thermal sulfidic cave in southeastern Romania. The numerous species of invertebrates discovered in the cave, most of them previously undescribed, live in an atmosphere that is very poor in oxygen and very rich in carbon dioxide. This groundwater ecosystem is isolated from the surface and does not receive allochthonous organic inputs of photosynthetic origin. Characteristic of this ecosystem is that it contains bacteria that produce organic matter using energy derived from the oxidation of hydrogen sulfide present in the thermo-mineral waters that flood the lower level of the cave. Microbial mats consisting of fungi and chemoautotrophic bacteria occur on the walls of the cave and are also found floating on the surface of the sulfidic water in the cave. This is the first known subterranean ecosystem that is completely chemoautotrophically based. In this regard it shares much in common with the deep sea vent communities discovered in the 1970s. Paleogeographical and molecular biological evidence support the hypothesis that some of the species living in this ecosystem have been isolated from the surface for several million years. Recent geomicrobiological studies indicate that sulfur oxidizing microbes inhabiting the cave affect limestone dissolution through the production of sulfuric acid.

**THE SOUTH CHINA KARST DEFORESTATION
ECOLOGICAL DISASTER**

Peter W. Huntoon, University of Wyoming, Department of
Geology and Geophysics. Laramie. WY 82071

The south China karst belt has been profoundly and detrimentally impacted by massive post-1958 deforestation. The subtropical monsoon climate of south China endures an annual flood-drought cycle. This cycle has been sufficiently exacerbated by the loss of the "green reservoir" that desertification has occurred over large areas. A primary impact of deforestation has been lost retention of water in the uplands. Surface runoff has become more flashy and stream discharge reces-

sions brief. The consequence has been increased flood hazards during the rainy season followed by parched conditions during the dry season. Wildlife populations were decimated. Risks of crop failures have risen. Two trends thwart recovery: (1) heavy dependence of the local population on wood for fuel and (2) a population explosion. Reforestation efforts are underway but they are gradually losing to human encroachments. Development of ground water offers a degree of mitigation. However, the thin, shallow karst aquifers present have unusually great lateral hydraulic conductivities allowing for the rapid transmission of large volumes of water out of the region. They also are characterized by having minimal reservoir storage. Remarkable ground water developments, driven by desperation, are proceeding, but they are fraught with desperation owing to the poor aquifer characteristics.

**WATER CHEMISTRY ANALYSIS
OF ANCHIALINE CAVES**

Jill Yager, Antioch College, Environmental and Life Science
Department, 795 Livermore Street

Yellow Springs, OH 45397

Robert Spokane, YSI. Inc. 1725 Brannum Lane
Yellow Springs, OH 45387

Anchialine caves are water-filled caves which occur in coastal karst. The submerged caves have surface openings inland and subsurface connections with sea water. The porous limestone allows the sea water to saturate the rock. This marine influence typically exists as a hypoxic layer of sea water beneath a less dense layer of brackish to fresh water. A distinct density interface delineates not only the salinity but oxygen and temperature differences as well as changes in pH and oxidation-reduction potential (ORP). For example, Cueva de los Carboneros, Cuba, oxygen readings of 0.14 mg/L and ORP of -263 mV were found at a depth 17 m and at 60 m the oxygen was 2.09 mg/L and ORP was 65 mV. Some caves are characterized by the presence of multiple layers, density interfaces. The biogeochemical mechanisms responsible for distinctly defined layers within the water column may be microbial activity, chemical dissolution of the limestone or a combination of the two. Water chemistry was evaluated using a portable sonde (YSI 6000). The data were correlated with fauna collections which consist primarily of crustaceans. Comparisons of water chemistry from several anchialine caves in the Bahamas, Cuba, and Mexico are discussed.

**THE ROLE OF KARST LANDSCAPE EVOLUTION
IN THE ORIGIN AND SPECIATION OF
HYPOGEAN FAUNA**

George Veni, George Veni & Associates, 11304 Candle Park
San Antonio, Texas 78249-4421, USA

The hydrologic and geomorphic development of karst terrains is closely tied to the origin and distribution of their hypogean

or subsurface fauna. The timing of the initial exposure of karstic rock and its development of caves and related voids also marks the time when epigeal species can begin to migrate underground. Once species have evolved into troglobites, weathering of the landscape begins to isolate populations and promote speciation. Erosional removal of surrounding cavernous rock is most effective at isolating species. Fault juxtaposition of karstic against nonkarstic rocks can have similar effects. Terrestrial (nonaquatic) species can be isolated by major stream valleys which may be floored with karstic rock but intersect the water table. As with initial karst development, the dating of these geologic processes can also provide timing constraints on speciation episodes. The distribution of aquatic hypogean species can be useful in delineating aquifer drainage basins. Species common to multiple drainage basins may suggest a hydrologic connection which may not be apparent from the hydrologic data. Hydrologic and ecologic management of karst areas can be enhanced by such geo-ecologic analyses, and additional relationships are being investigated which promise to yield valuable information for both disciplines.

IMPORTANCE OF VERTEBRATE REMAINS FROM CAVES

Rickard S. Toomey, III, Illinois State Museum RCC
1011 East Ash St. Springfield, IL 62703
TOOMEY@museum.state.il.us

Vertebrate remains from caves and karst features provide vital information on past biodiversity, paleoecology, and the development of the modern terrestrial ecosystem. Although most vertebrate-bearing deposits in karst features are of Quaternary age (<2 Ma old), karst associated vertebrate localities from at least as early as the Early Carboniferous are known. Additional important karst related vertebrate sites occur in the Permian, Triassic, and throughout the Tertiary.

Caves and other karst features are important sources of paleoecological data for several reasons. They frequently function as sediment traps over long periods of time (100s to 1000s of years). They also house a variety of vertebrates that provide a constant source of bones from a wide variety of animals. Often bones preserve well in the protected environment provided by karst features and are abundant enough to allow statistical analyses. In addition, the deposits frequently can be dated accurately and precisely.

Vertebrate remains from karst features provide data on paleoecology. They illustrate past biodiversity. The presence of certain taxa provides information on such parameters as climate, vegetation, soil conditions, and community structure of the past. Caves are one of the most important sources of vertebrate remains in the Quaternary. In the FAUNMAP database of US. Quaternary mammal occurrences, approximately 12% of the 2,937 localities are caves. However, occurrences from cave

sites represent about 20% of the total occurrences in the database. Almost 80% of the taxa represented in database occur in cave faunas and 15% occur only in faunas from caves.

EFFECTS OF ENTRANCES ON DISTRIBUTION AND ABUNDANCE OF CAVE ORGANISMS

Kathleen LaVoie, Biology Department, University of
Michigan-Flint, MI

Thomas Poulson, Department of Biological Sciences,
University of Illinois at Chicago, Chicago IL

Kurt Helf, Department of Biological Sciences, University of
Illinois at Chicago, Chicago IL

We operate under several familiar paradigms, one being that the cave environment is constant, except around entrances. However, the environmental factors of primary concern to biologists, temperature and humidity, are influenced by a variety of factors including the Mean Annual Surface Temperature, passage features including contour and slope, the volume of the cave, seasonal surface changes, and entrances. Entrances form essentially at random in caves, primarily related to inputs of water, collapse of passages to the surface, and the random intersection with vertical passages. (It has been estimated that 50-95% of limestone caves have no entrance.) The number, size and position of entrances relative to cave passages has tremendous influence on temperature and humidity. Cave entrances also pose significant management issues, regardless of the status of the entrances as natural, modified natural, or artificial. Entrances are often places of great beauty with fragile speleothems. Entrances are the access point to human use of cave resources, sites of archaeological or historic significance, and the exchange point for air and water. Nutrients enter caves through entrances in the form of litter and organic matter input by troglomorphic animals. Keystone species, which dominate on the basis of size or numbers, such as cave crickets, are particularly important in maintaining the food base of cave communities. Other animals use entrances as refugia.

The Mammoth Cave System in Kentucky is the longest cave in the world with over 330 miles of mapped passage. Its significance is recognized with a World Biosphere designation. With 23 current entrances (plus five closed historic entrances), Mammoth Cave presents a significant management challenge.

I am reporting on some results from our on-going National Park Service funded entrance biomonitoring project. The Park Service is in the process of restoring several entrances, modified and artificial, to their original air-flow status to reduce winter impacts of cold, dry air. In the intervening decades since most of the entrances were modified or opened, significant biological communities have expanded, developed, or been lost. In the first year of study, we are focusing on developing a standardized method for biomonitoring and collecting baseline data for selected entrances and control caves. We are studying

a wide range of cave types, including those that are part of the vast Mammoth Cave system, as well as isolated caves. The more types of habitats we study, the better are our chances of understanding what is really going on with the biology and ecology. The intention is to install air-lock entrances during the second year of the study, with our biomonitoring continuing for a third year to access the impact of the changes. The NPS is collecting data on temperature and humidity at locations inside and outside the caves.

We are concentrating on census of total populations by 10 m transects with particular emphasis on the keystone cricket species, *Hadenoeus subterraneus*, building on more than two decades of observation. Our long-term data have documented the impact of surface weather conditions on limiting foraging by cave crickets, which reduces input of guano, causing decreased abundance and diversity in the guano community. Studies have shown that there are differences in the number and composition of cricket populations in different caves. We are considering whether we are dealing with a metapopulation, where a loose assemblage of local populations is weakly linked by immigration and emigration, or a source/sink situation controlled by habitat heterogeneity. Either model allows cricket populations to spread the risk of local extinction, but also support our efforts to maintain existing habitats. Our studies have allowed us to compare distributions of crickets by age/size classes. We find smaller crickets located closer to entrances for access to foraging. We have observed shifts in distribution on seasonal and even a daily basis. We now recognize that an important measure of habitat suitability is ceiling height and texture, which provides small-scale refugia from temperature and humidity extremes. We are conducting seasonal mark-recapture studies of cave crickets, which again show us seasonal differences and fine-scale differences among and within our study and control caves. Studies of foraging behavior have developed from these observations. On-going modifications to gating plans include the addition of exit and entry points for cave rats and crickets. All of our studies are to be continued as we enter the third year of the study.

RECENT ISSUES OF CAVE AND KARST SCIENCE

The British Cave Research Association publishes a refereed scientific journal called *Cave and Karst Science: The Transactions of the British Cave Research Association* which has a similar mission to the NSS's *Journal of Cave and Karst Studies*. They, also, have made recent changes in the publication, including its name.

The second issue of volume 22, dated October 1995, included the journal's first color photographs on both the cover and accompanying a fine article on the explorations of the 1994 Yangtze Gorge Expedition to Sichuan Province, China which filled the issue.

The final issue of volume 22 (number 3) included the following articles:

The Relationship Between Surface Soils and Cave Sediments in West-central USA

Morphology of Rimstone Pools at Pamukkale, Western Turkey

Some Thoughts on Hydrothermal Caves

The Crystallogenesis of Gypsum Flowers

The Pinnacle Karst of Gunung Api, Mulu, Sarawak

Abstracts of papers presented at the BCRA Cave Science Symposium, February 1996

NSS members may arrange to subscribe to *Cave and Karst Science* through the NSS bookstore.

GUIDE TO AUTHORS

The *Journal of Cave and Karst Studies* is a multidisciplinary journal devoted to cave and karst research. The *Journal* seeks original, unpublished manuscripts concerning the scientific study of caves or other karst features. Authors do not need to be members of the National Speleological Society.

LANGUAGES: Manuscripts must be in English with an abstract, conclusions, and references. An additional abstract in another language may be accepted. Authors are encouraged to write for our combined professional and amateur readership.

CONTENT: Each paper will contain a title with the authors' names and addresses, an abstract, and the text of the paper. Acknowledgments and references follow the text.

ABSTRACTS: An abstract stating the essential points and results must accompany all articles. An abstract is a summary, not a promise of what topics are covered in the paper.

REFERENCES: In the text, references to previously published work should be followed by the relevant author's name and date (and page number, when appropriate) in brackets. All cited references are alphabetical at the end of the manuscript with senior author's last name first, followed by date of publication, title, publisher, volume, and page numbers. See the current issue for examples. Please do not abbreviate periodical titles.

SUBMISSION: Authors should submit two copies of their manuscript (include copies of the illustrations) to the appropriate specialty editor or the senior editor. Manuscript must be typed, double spaced, and single-sided. Authors submitting manuscripts longer than 15 typed pages may be asked to shorten them. Authors will be requested to submit an electronic copy of the text, and black-and-white photograph and brief biography of the author(s) upon acceptance of the paper.

DISCUSSIONS: Critical discussions of papers previously published in the *Journal* are welcome. Authors will be given

an opportunity to reply. Discussions and replies must be limited to a maximum of 1000 words and discussions will be subject to review before publication. Discussions must be received by the Editor within 45 days after the original article appears.

MEASUREMENTS: All measurements will be in Systeme Internationale (metric). Other units will be allowed where necessary if placed in parentheses and following the SI units.

FIGURES: Figures and lettering must be neat and legible. Figure captions should be on a separate sheet of paper and not within the figure. Figures should be numbered in sequence and referred to in the text by inserting (Fig. x). Most figures will be reduced, hence the lettering should be large. Once the paper has been accepted for publication, the original drawing (with corrections where necessary) must be submitted to the editor. Black-and-white photographs must be sharp, high contrast, and printed on glossy paper. Color prints will be printed at author's expense only.

COPYRIGHT: It is the author's responsibility to clear any copyright or acknowledgement matters concerning text, tables, or figures used.

PROCESS: All submitted manuscripts are sent out to two experts in the field. Reviewed manuscripts are then returned to the author for consideration of the referees' remarks and revision, where appropriate. Revised manuscripts are returned to the appropriate associate editor who then recommends acceptance or rejection. Upon acceptance, the author should submit all photographs and original drawings to the editor.

Once the paper has been formatted and laid-out, the senior author will be sent one set of proofs for review. Any corrections, other than printer or editor errors, will be done at the author's expense. Examine the current issue for more information of the format used.



Edward Alt received a Masters Degree in Geography from the University of Wisconsin-Milwaukee in 1994. He completed a thesis that dealt with the geomorphic evolution of the northern Vaca Plateau in West-Central Belize. He has participated in five research expeditions to the Vaca Plateau. He is currently a research associate at the Soils and Physical Geography Lab at the University of Wisconsin-Milwaukee, and is completing course work for certification to teach science in Wisconsin's public schools.

NO PHOTO

Mick Day is a Professor of Geography at the University of Wisconsin-Milwaukee, specializing in tropical karst geomorphology and conservation. He has conducted research in karst areas of the Caribbean, Central America, and Southeast Asia. He has been undertaking research and teaching in Belize since 1975.



Robert Brinkmann is an Associate Professor of Geography at the University of South Florida in Tampa. His areas of research expertise include environmental contamination, soils geography, geoarchaeology, and carbonate petrology. He has conducted karst soil, geomorphology and environmental contamination research in various sections of Florida's karst, with these results published in scientific journals.



Pete Hollings started caving in 1989 with the Royal Holloway and Bedford New College Caving Club at the University of London. On the completion of a BS in Geology, he joined two Mendip-based clubs, the West London Caving Club and the Mendip Caving Group. In 1994, he moved to Saskatoon, Canada, in order to undertake doctoral studies at the University of Saskatchewan. He now caves in the Canadian Rockies during the summer and heads south in the winter to participate in the work of the Proyecto Espeleológico Purificación.



Logan McNatt began caving in 1968 and started working as an archaeologist in 1972. He has extensively explored and worked in caves throughout Texas, Mexico, and, especially, Belize. In 1972, he co-discovered and explored Mexico's El Sótano del Barro, one of the world's largest and deepest pits. He first visited Belize in 1973, and lived there from 1983 through 1993, working primarily in the field of Mayan cave archaeology. He currently works for the Archaeological Survey Program of the Texas Park and Wildlife Department.



James Reddell is the Assistant Curator of Entomology for the Texas Memorial Museum at the University of Texas. Cave biology has been his passion since he began caving in 1959. He has described dozens of new species, and published hundreds of reports on the caves and cave fauna of Texas, Mexico, and Central America. He founded the Texas Speleological Survey in 1961, and has since directed it or been a director of its board.

Philip Reeder is an Assistant Professor of Geography at the University of Nebraska at Omaha. He has been exploring caves for the last 22 years, and has been conducting scientific research in caves, and karst areas since 1985. Both his Masters and Doctoral theses were on karst topics and most of his 40 professional publications deal with caves and karst. He has caved and conducted karst research in Florida, Georgia, Kentucky, Wisconsin, Mexico, Cuba, Belize, Peru, New Zealand, and the Philippines.

Photo Opposite



Tom Miller received his PhD in geology from McMaster University in 1982. He began working in Belize in 1973, eventually leading to his dissertation titled "Hydrochemistry, hydrology, and morphology of the Caves Branch Karst, Belize." He has been a Fulbright Fellow, Jason V Expedition hydrologist, and directed the National Geographic-funded Chiquibul expeditions. He is a Lew Bicking Awardee, cave diver, NSS Fellow, chairs the Papoose Cave Project in Idaho, and has been on the NSS Bulletin Board of Editors and the Journal of Cave and Karst Studies Advisory Board.



George Veni is owner of George Veni and Associates, specializing in environmental management consulting for caves and karst terrains. He began caving in 1975, and since has caved and conducted research in several countries and U.S. states. He is a PhD hydrogeologist who has also worked extensively in cave archaeology and biology. He has written widely on technical and non-technical caving subjects, and is the Executive Secretary of the NSS Geology and Geography Section, President of the Texas Speleological Survey, and coordinator of several caving projects.



National Speleological Society
2813 Cave Avenue
Huntsville, Alabama 35810-4431