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Karst of Western Cuba: Observations, Geomorphology, and Diagenesis

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KARST OF WESTERN CUBA: OBSERVATIONS, GEOMORPHOLOGY, AND DIAGENESIS

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ABSTRACT

In Cuba, we observed many karst features in a variety of hydrogeologic settings. These hydrogeologic settings occur in close proximity only because of the complex tectonic history of the island. We observed caves within rocks ranging from Pleistocene to Jurassic, and representing a range of diagenetic ages from eogenetic to telogenetic. Our observations are from the western one-third of the island of Cuba; however, we believe they are representative of hydrogeologic settings found throughout the island.

In the Viñales region of western Cuba, we observed karstification of the massive platform deposits of the Jurassic. The Jurassic deposits are part of an allochthonous carbonate sequence composed of a tectonically complex, repeating sequence of Jurassic through Eocene thrust sheets. Many of the cave systems, such as Cueva Santo Tomás, form as fracture and bedding controlled river systems within the resistant Jurassic rocks, which stand in relief as Mogotes. These cave systems typify "continental style" tropical karst seen on islands such as Puerto Rico. These are examples of telogenetic karst, in other words they form late in the diagenetic history of the rock when matrix permeability is very low.

We observed caves formed within late Pleistocene carbonate eolianites on the Hicacos Peninsula east of Matanzas. We documented four intact caves of flank margin style, including the partially fractured controlled Cueva Ambrosio. They display many features associated with caves formed in saltwater-freshwater mixing zone environments – laterally extensive, globular chambers in the flank of the dune with cuspate walls and dead end passages. These caves are representative of eogenetic karst, in other words they formed early in the diagenetic history of the rock when matrix permeability is high.

In addition to the above-mentioned cases, we noted the presence of karst within rocks ranging between the Pleistocene and Jurassic. Of particular interest are rocks of the Miocene. The Miocene karst systems range from low elevation platform flow systems similar to Florida or the Yucatan to isolated tectonic blocks and anticlines. Examples of the prior include major groundwater aquifers in western Cuba, and the latter include complex coastal cave systems along the Matanzas-Varadero coastline.

Our intention with is paper is not to present new interpretations, but rather to introduce a karst region that is little known to North American geologists.

INTRODUCTION

The authors of this paper participated in a Caribbean geology course at the University of South Florida (USF) during the spring of 2004. This graduate level course, cross listed in the Geology and Marine Science departments at the Tampa and St. Petersburg campuses, sought to introduce the students to the complex geology and environs of the Caribbean region. As part of this course, students were given the opportunity to travel to western Cuba during early April of 2004. Permission to conduct this trip was possible since at the time USF had an educational license for study in Cuba. The course instructors, Drs. Richard Davis and Al Hine, arranged the field trip in cooperation with Dr. Manuel Iturralde-Vinent, the

Assistant Director of the Museo Nacional de Historia Natural in Habana. Dr. Iturralde-Vinent hosted the course in Cuba and led the geology field trip. His experience included extensive karst studies in Cuba; thus we found it possible to undertake this survey of Cuban karst. Due to the limited opportunity for North American geologists to travel to Cuba, we felt compelled to present our observations so others would be aware of the remarkable karst features found in western Cuba.

Our field experience lasted eight days. During this time we visited dozens of outcrops, look-out points, points-of-interest, and caves. We covered a large swath of western Cuba around the cities of Pinar del Rio, Viñales, Matanzas, Habana, and Varadero. We discovered that Cuban karst is just as varied as its geologic history.

The field trip made evident to us that Cubans have long acknowledged and respected their karst resources. An atlas of Cuba published in 1970 includes several maps which include karst features (Atlas Nacional de Cuba, 1970). The Escuela de Espeleológica Nacional opened in 1984 and is said to be the oldest of its type in the western hemisphere. The school is located adjacent to the Cueva de Santo Tomás, the longest cave in Cuba with 44.6 km of mapped passage. The nearby Viñales valley, featured in *National Geographic* and a major destination for international eco-tourists, is a UNESCO World Heritage Site containing amazing karst features and the most celebrated tobacco farms in the world. The Hicacos Peninsula and the city of Varadero is a delicate balance between utilization and preservation of its karst features in an area heavily developed for coastal tourism.

GEOLOGIC HISTORY OF WESTERN CUBA CARBONATES

Cuba is a tectonically complex island. Its geological history is rich in diversity, and spans the entirety of the Mesozoic and Cenozoic. Though we covered less than one-quarter of the country during our visit to western Cuba, we feel that our field sites highlight the primary divisions of carbonate karst aquifers of the island nation.

Karstified carbonate rocks cover approximately 73,250 km^2 or 66% of Cuba. During sea-level lowstands, an additional 67,830 km^2 of shallow water karstified carbonates are exposed (Iturralde-Vinent and Gutiérrez Domech, 1999). Carbonate karst aquifers are the primary source of water and therefore essential to the future needs of the country.

Western Cuba is unique in that disparate geologic provinces are in geographic proximity. It is the complex tectonic history of the island that makes this possible. In this section, we will discuss the diagenetic differences between old and young carbonates and the timeline of events that constructed the present western Cuban landscape.

Eogenetic and Telogenetic Karst

In western Cuba, Carbonate rocks range in age from recent to late Jurassic (150 Ma). Cretaceous and Jurassic limestones in western Cuba are part of the Guaniguanico Allochthonous Terrane. These carbonates are telogenetic (Choquette and Pray, 1970) because they have experienced significant diagenetic alteration including burial and uplift. These telogenetic carbonates are restricted to the Sierra de Los Organos and the Sierra del Rosario in the Pinar del Rio Province (Figure 1). Miocene through Recent limestones are expansive in Cuba (Figure 1) and are separated from the Guaniguanico Terrane by the Pinar Fault. These carbonates are *in situ* and have experienced little burial and tectonics. These are eogenetic limestones as described by Choquette and Pray (1970).

Eogenetic and telogenetic carbonate rocks differ with respect to permeability and porosity. Eogenetic carbonate rocks retain significant matrix permeability and porosity (Budd and Vacher, 2004), and may be up to 50,000 times more permeable than telogenetic carbonates (Florea and Vacher, 2005). This difference in matrix permeability between eogenetic and telogenetic karst

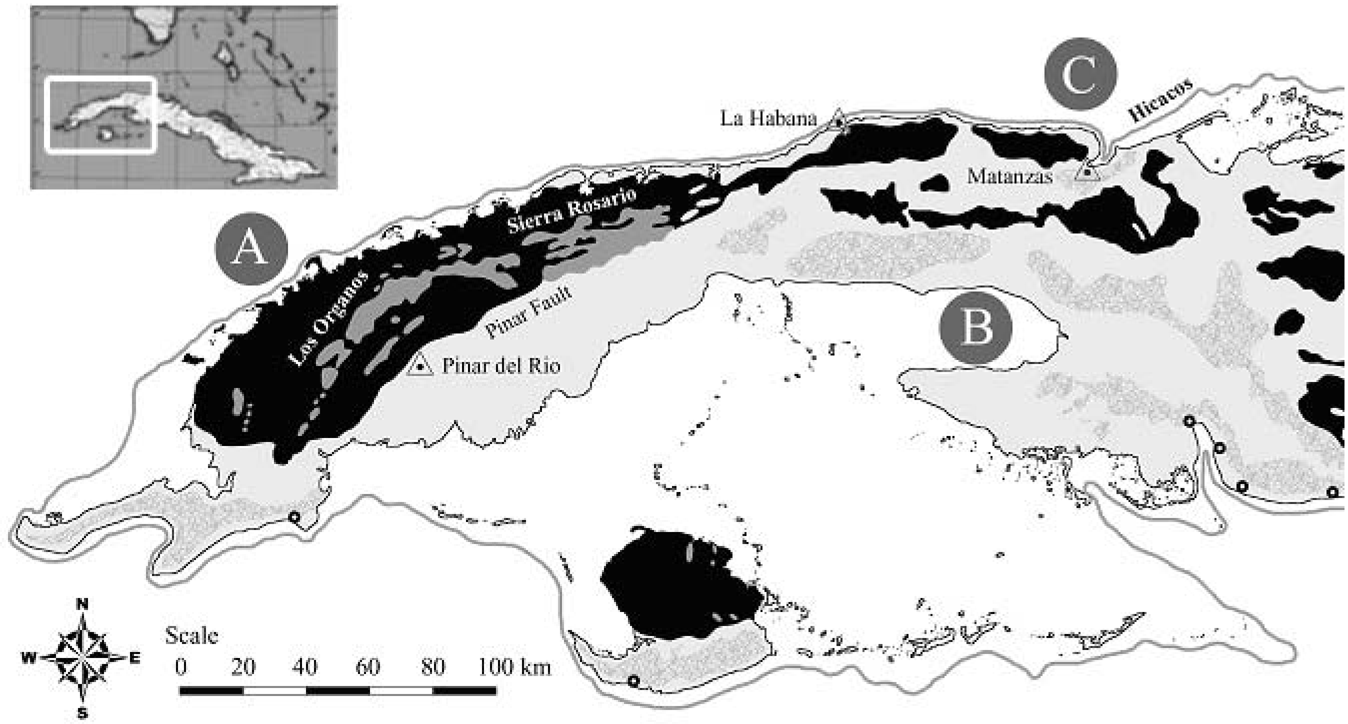

Figure 1. Simplified geologic map of western Cuba. Study area highlighted in inset map. White areas outlined by the light grey line represent the extent of the shallow marine platform. Shaded regions are dry land. Black areas indicate non-carbonate rocks, dark grey areas are telogenetic carbonates (Cretaceous-Jurassic), light grey areas are eogenetic carbonates (Miocene and younger). Textured regions have significant karst landform development. Open circles are springs. Major cities and chief geographical features cited in text are labeled. (A) Guaniguanico Allochthonous Terrane. (B) Habana and Matanzas karst plain and shallow marine shelf. (C) Hicacos Peninsula and Varadero Beach.

aquifers has important implications when considering groundwater flow, conduit morphology, and aquifer response (Florea and Vacher, 2005).

Tectonic History of Western Cuba

Guaniguanico Allochthonous Terrane. North and west of the Pinar Fault, the Guaniguanico Allochthonous Terrane consists of Jurassicand Cretaceous limestones and siliciclastics transported from the proto-Yucatan Peninsula during NNE motion of the Caribbean Plate in the mid-to late Cretaceous along with complex ophiolite sequences derived from the proto-Caribbean seafloor (Figure 1). The Sierra de Los Organos are composed primarily of shallow water carbonates (Jagua and Guasasa Formation) imbricated during the Paleogene by low-angle thrust faults into a series of flat-lying nappes (Gordon et al., 1997). This Paleogene orogenic event is associated with the collision of the leading edge of the Caribbean Plate with the Florida-Bahamas Carbonate Platform. The Sierra del Rosario are composed of deep water carbonates and siliciclastics (Artemisa and Santa Teresa Formations) thrust over younger rocks during the Paleogene (Gordon et al., 1997).

A significant unconformity is present at the top of the Cretaceous section in the Guaniguanico Terrane. At some locations a thick layer of mega-breccia caps the upper-Cretaceous carbonates. These are interpreted to be bank-margin mega-turbidites associated with the Chicxulub impact event (Pszczolkowski et al., 1992).

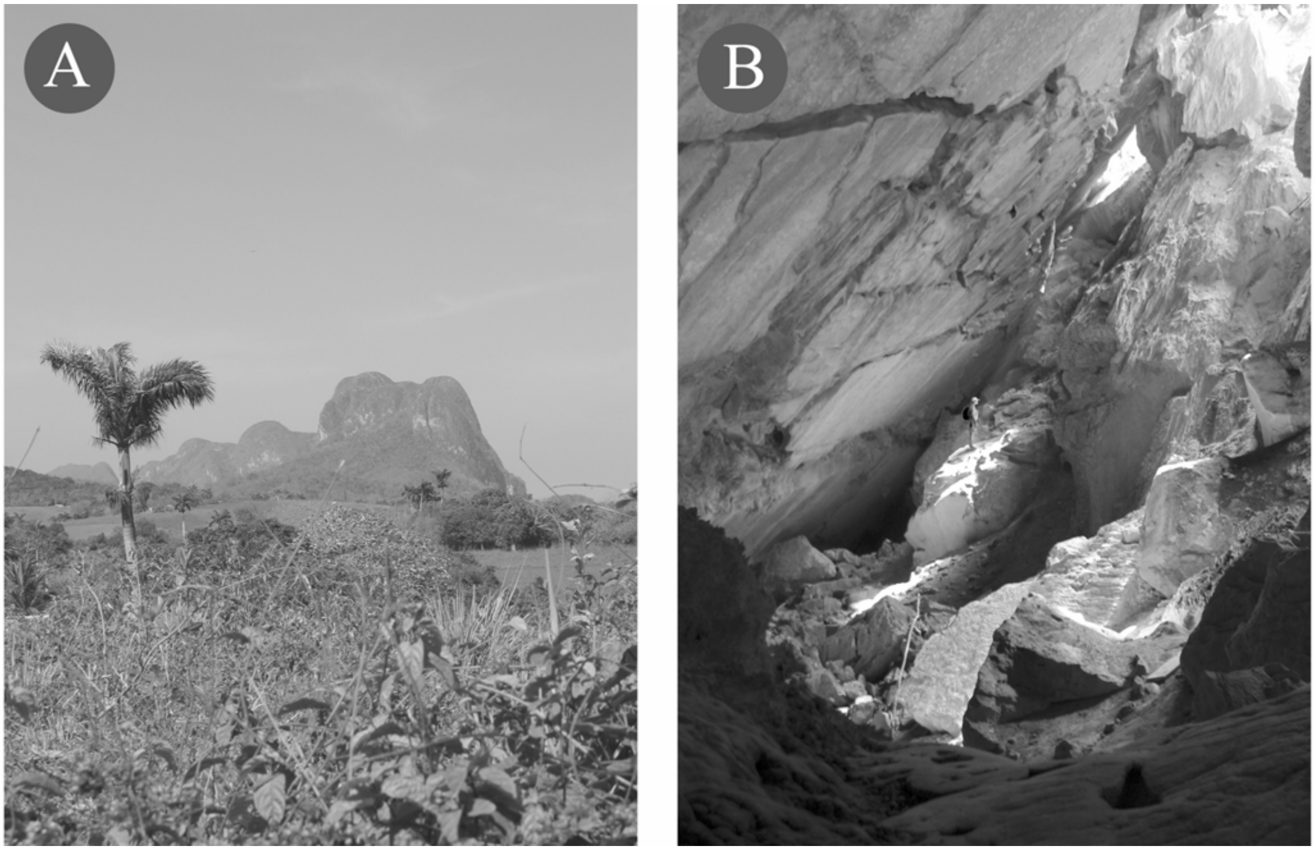

Figure 2. Telogenetic karst from the Viñales Valley. A) Mogotes of the Sierra de Los Organos. Mogotes occur along the strike of the thrust sheet (seen extending into the background), and dip of thrust sheet is to the north (right side of picture). The vertical portion of the mogotes are the massively bedded San Vicente member of the Guasasa Formation. B) Gallery in Cueva de Santo Tomás. The gallery formed along the strike of the beds of the Guasasa Formation. Dip is to the left (north). This gallery opens to a Hoyo (internal sinkhole found within mogotes).

The Pinar Fault, which separates the telogenetic carbonates of the Guaniguanico Terrane from the eogenetic carbonates to the south and east, is of early Eocene age. The fault is one of a series of left-lateral strike-slip faults that subdivide Cuba into geological provinces. These faults, of which the Pinar Fault is the oldest, mark the progressive change in motion of the Caribbean Plate from NNE prior to Eocene to a near East direction today. Subsequent to motion along the Pinar Fault, compression ceased in the Guaniguanico Terrane and the block sutured to the North American Plate.

Miocene and Younger Carbonates. Broad expanses of platform carbonates were deposited during the Tertiary south and east of the Pinar Fault. Of primary importance in western Cuba are thick deposits of Miocene limestones. In the west near Pinar del Rio, thick Quaternary sediments derived from the Guaniguanico Terrane cover the Miocene limestones. As a result the carbonate aquifer is confined and karstification is limited. To the east, south of Habana and Matanzas, Miocene limestones crop at the surface in extensive karst plains. In these regions, karstification is intense to depths of at least 100m (Iturralde-Vinent and Gutiérrez Domech, 1999) and sinkhole and karren development is dense. Freshwater cenotes, springs, and blue holes are common near the transition zone into the shallow marine platform (Atlas Nacional de Cuba, 1970) (Figure 1).

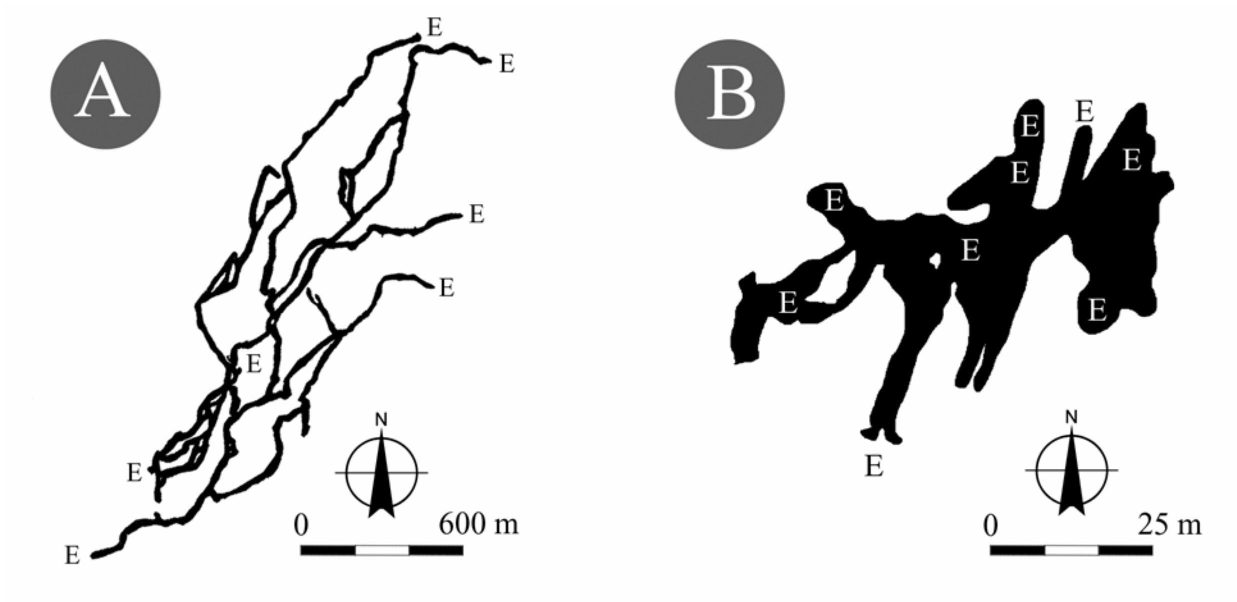

Figure 3. A) Schematic of Cueva de Santo Tomás, a telogenetic cave found in the Jurassic limestones of the Viñales region. B) Schematic of Cueva Ambrosio, a eogenetic cave found in late Pleistocene eolianites in the Hicacos Peninsula.

We ask the reader to consider the similarities the Miocene carbonate aquifer of western Cuba shares with the Eocene and Oligocene Floridan Aquifer System of west central Florida (Florea and Vacher, 2005). Both are eogenetic from the perspective of diagenetic alteration. Both are split into confined and unconfined sections. Finally, both gently transition onto broad marine platforms.

Although the similarities are pronounced, one marked difference separates Florida from Cuba. Unlike the passive continental margins of Florida, the shallow marine platforms of Cuba are productive carbonate sediment factories free from the huge siliciclastic inputs that stifled carbonate production in Florida during the Miocene. As a result, significant Plio-Pleistocene and Holocene carbonates fringe the Cuban mainland as off-lapping stratigraphic units (similar to that found along the Yucatan Peninsula coast) or as small carbonate islands (with hydrogeologic similarities to small islands in the Bahamas).

The short distances in Cuba between carbonate rocks of very different geologic origin and age make the island nation a unique place to study karst geomorphology and hydrogeology. We feel that a detailed study of carbonates in Cuba has served to help unravel the complex geologic history of carbonate platforms in the Caribbean region. Further study of Cuban karst will be a keystone in our understanding of circum-Caribbean karst; serving as the link between eogenetic karst of the Bahamas, Florida, and the Yucatan, and telogenetic karst of Central America.

TELOGENETIC KARST OF THE VIÑALES VALLEY

The Viñales Valley of western Cuba consists of a repeating sequence of allochthonous Jurassic through early Eocene thrust sheets (Figure 1). These thrust sheets are composed of shallow marine deposits, predominately limestone. Due to plate motion, burial, and uplift, the Jurassic age Jagua and Guasasa Formations of this region have telogenetic properties similar to limestones in continental settings, i.e. primary porosity and

Figure 4. Eogenetic karst of the Hicacos Peninsula. A) Interplay of tourism and karst features. B) Horizontal notches of unclear origin. Continuous nature of upper notch suggests bio-erosion origin. Discontinuous lower notches resemble breached voids . C) Cueva Pirata, a cabaret bar inside a cave. D) Picture from inside Cueva Ambrosio, showing typical morphologies found in flank margin caves.

permeability are greatly reduced, and secondary porosity dominates.

The Viñales Valley is famous for its broad karst towers known as mogotes. The Viñales mogotes rise as much as 200 m above the valley floor (Figure 2A). The upper parts are typically vertical exposing the massively bedded Jurassic San Vicente member of the Guasasa Formation (Iturralde-Vinent, 1995). Fractures in the Guasasa Formation are intensely karstified, assisting cliff retreat of the mogote margins (Figure 2A). Large voids extend into the mogote interiors from the cliff face. These are an indication of formerly active cave systems. Limestone talus from cliff retreat can be found at the base of most mogotes.Collectively the mogotes make up the Sierra de Los Organos.

Internally, mogotes contain complex systems of multi-level braided network caves. The upper cave levels are high above the surrounding valley and the lowest easily accessible caves are concurrent with present-day base-level where active cave development is occurring. Internal sinkholes (or Hoyos) in the mogotes commonly extend from the top of the mogotes down to base-level and intersect caves. Cueva de Santo Tomás (44.6km) is a good example of the large cave systems that can form within mogotes (Iturralde-Vinent and Domech, 1999) (Figure 3A). In upper levels of this cave we observed large galleries formed along fractures and following the strike of the dipping beds of the Guasasa Formation (Figure 2B).

Some karst features in the Viñales Valley serve as tourist destinations. A large roadside cavern, Cueva de Viñales, has become a nightclub. Motorboat tours take eco-tourists for a short trip through nearby Cueva del Indio. Some of the larger cave systems are open for guided tours. Cueva de Santo Tomás, in addition to providing guided tours, is the home of Cuba's Escuela de Espeleológica Nacional, which is said to be the oldest school of speleology in the western hemisphere.

EOGENETIC KARST OF THE HICACOS PIENSULA

The Hicacos peninsula is located on the northwest coast of Cuba near the city of Matanzas and approximately 140 km east of Havana (Figure 1). The peninsula is isolated from the mainland, averages 1 km wide, and extends approximately 20 km northeast into the Straits of Florida. Varadero Beach is a tourist area spanning the length of the Hicacos Peninsula, and is characterized by large resorts and hotels constructed along dunes at higher elevations. The core of the peninsula is composed of Holocene and late Pleistocene carbonate eolianites. The late Pleistocene eolianites reach elevations of 5 to 8 meters above sea level. North-northeasterly winds and the Gulf Stream aided deposition. The eolianites are bioclastic, with a fringing coral reef source area. The Hicacos Peninsula eolianites display strong eogenetic karst development characterized by intense notching, pits and caves. We documented notches on the south-eastern face of the dune, facing the mainland of Cuba (Figure 4A). As with notches on carbonate islands, the origin of these notches is unclear (Reece et al., 2005). It is possible that many of these notches may be bio-enhanced wave cut notches; however, many (such as those in Figures 4A and B) display morphologies inconsistent with this interpretation.

We documented four intact caves in the eolianites. These caves contain many features associated with dissolution in saltwater-freshwater mixing zone environments – laterally extensive, globular chambers in the flank of the dune with cuspate walls and dead end passages (Figures 4C and D) (Mylroie and Carew, 1995). Vertical entrances consist of what appear to be vertical shafts and breached bell holes. Horizontal entrances likely formed by hillside retreat. The notches and flank margin type halo-phreatic caves are consistently found two meters above present sea level; indicating their formation took place during an earlier sea-level highstand. A rise in sea level of two meters would make portions of the Hicacos Peninsula a series of isolated carbonate islands with isolated freshwater lenses.

Because of the small size of the peninsula, an intimate relationship between karst and tourism has developed. Hotels and resorts are built into the dunes; utilizing notches and caves as closets, storage rooms and quarters for employees. The Varadero Golf Club uses notches and caves for storage and as part of the landscaping (Figure 4B). Cueva Pirata (Figure 4C), contains a bar and a nightly cabaret show. Performers enter and exit the show from caverns hidden behind stage doors. Cueva Musulmanes located within the Hicacos Ecological Reserve has vertical shaft entrances. The main chamber displays globular morphology and cuspate walls, both characteristics of flank margin caves. Cueva Ambrosio is the largest cave visited on the peninsula. The cave appears to be at least partially fracture-controlled (Figure 3B). A photo from the interior of Cueva Amabrosio (Figure 4D) emphasizes the morphologic features found in flank margin caves.

These caves represent the only documented halo-phreatic style caves observed on Cuba thus far. Considering that approximately

4,200 small islands (mainly carbonate) surround the mainland of Cuba, we can assure that there are more out there.

CONCLUDING REMARKS

We consider ourselves to be very fortunate to have had the opportunity to visit Cuba. During our eight days on the island, we met many Cuban karst scientists who were eager to exchange ideas and experiences regarding karst processes. Our intention with this paper is to present only the most general survey of the karst features that we observed in western Cuba. We wish to express that the island of Cuba presents karst scientists a unique opportunity to study a wide variety of caves and karst features in a relatively small geographic region. We observed everything from fracture-controlled braided network caves in Jurassic aged mogotes, to extensive Miocene karst aquifers, to flank margin type caves found in the recent-Pleistocene carbonate eolianites of the Hicacos Peninsula. Due to the complex tectonic history of the island, these diverse geomorphic terranes can be found within 280 km of each other.

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REFERENCES

Atlas Nacional de Cuba, 1970, Academia de Ciencias de Cuba y Academia de Ciencias de URSS, La Habana, 132 p.

Budd, D. A., Vacher, H. L., 2004, Matrix permeability of the confined Floridan Aquifer, *Hydrogeology Journal*, in press.

Choquette, P. W., Pray, L. C., 1970, Geologic nomenclature and classification of porosity in sedimentary carbonates, *American Association of Petroleum Geologists Bulletin*, vol. 54, pp. 207-250.

Cobiella-Reguera, J. L., 1997, The Cretaceous system in Cuba – an overview, Zbl. Geol. Paläont. Teil I, no. 3-6, pp. 431-440.

Gordon, M. B., Mann, P., Cáceres, D, Flores, R., 1997, Cenozoic tectonic history of the North American-Caribbean plate boundary zone in western Cuba, *Journal of Geophysical Research*, vol. 102, no. B5, pp. 10,055-10,082.

Florea, L.J. and Vacher, H.L., 2005, Morphologic Features of Conduits and Aquifer Response in the Unconfined Floridian aquifer system, West Central Florida. *In* Davis, R. L., and Gamble, D. W., eds., Proceedings of the 12th Symposium on the Geology of the Bahamas and Other Carbonate Regions, Gerace Research Center, San Salvador, Bahamas.

Iturralde-Vinent, M. A., 1995, Sedimentary geol ogy of western Cuba (field guide), the 1st SEPM Congress on Sedimentary Geology, Society for Sedimentary Geology, 21 p.

Iturralde-Vinent, M. A., Gutiérrez Domech, M. R., 1999, Some examples of karst development in Cuba. *In* Boletín Informativo de la Comisión de Geoespeleología, no. 14, web version.

Mylroie, J. E., Carew, J. L., and Vacher, H. L., 1995, Karst development in the Bahamas and Bermuda. *In* Curran, H. A. and White, B., eds., Geological Society of America Special Paper 300, Terrestrial and Shallow Marine Geology of the Bahamas and Bermuda, p. 251-267.

Pszczolkowski, A., Garcia, D., Perez, E., 1992, Late Maastrichtian foraminifers, glass fragments and evidence for violent erosion near the K/T boundary in western Cuba, *Conferencia de Geologia del Caribe, Program y Resumenes*, 13a, p. 127.

Reece, M. A., Mylroie, J. E., and Jenson, J. W., 2005, Notches in carbonate cliffs and hillslopes: origins and implications, *In* Davis, R. L., and Gamble, D. W., eds., Proceedings of the 12th Symposium on the Geology of the Bahamas and Other Carbonate Regions, Gerace Research Center, San Salvador, Bahamas.