

Pleistocene-Holocene Karstification of Barbados and its implications for the Devonian Grosmont reservoir

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Summary

About 80% of the surface of Barbados is made up of Quaternary carbonates with ages approximately 800,000 years to recent. These carbonates are extensively overprinted by epigene (top-down) karst processes. Epigene karst features include various types of caves, solution valleys, and sinkholes. Flank margin caves are the most common cave type. Sinkhole density is high, with an average of 5 sinkholes per square km. However, some areas have a much higher density while others are almost devoid of sinkholes. Sinkholes range in diameter from about 10m to 120m and are up to about 15m deep. Another striking morphological karst feature is a network of valleys, locally referred to as gullies. Their origin is problematic and much debated. Most gullies have caves along at least a part of their paths, commonly decorated with flowstone or other speleothems.

A number of lessons learnt from the karst in Barbados can be applied to the Devonian Grosmont reservoir in Alberta, despite the vast differences in age and size. For example, numerous sinkholes identified in seismic images can be interpreted as epigene karst features that developed rapidly on one or several former land surfaces. Drainage patterns akin to the gullies of Barbados can be expected in the Grosmont as well, but not as deep or as densely spaced, and with different orientations. The Grosmont may contain a few stream caves and many more flank margin caves, while the latter should not be as frequent as in Barbados but may be considerably larger.

Integrating these aspects with the known geologic history of the Grosmont platform, it appears that the Grosmont platform was karstified in at least two major epigene episodes. The first episode was a 'warm epigene karstification' during the Jurassic – Cretaceous, for which Barbados provides a useful analog. The second episode was/is a 'cold epigene karstification' that started sometime in the Cenozoic and is continuing to this day. The present repertoire of karst features probably is a composite of these two epigene karstification episodes. In addition, circumstantial evidence suggests that epigene karst gives way to a deep hypogene (bottom-up) karst in the downdip part of the platform. The latter likely has different characteristics, i.e., most notably a maze system of passages rather than a stream system overlain by sinkholes. At present the hypogene karst system in the Grosmont is virtually unexplored.

Introduction

Barbados is located at 13°10' north latitude, 59°35' west longitude, and is about 32 x 23 km in size. Overlying tectonically deformed siliciclastic sediments, about 80% of the surface of the island is made up of Quaternary carbonates with ages approximately 800,000 years to recent (Fig. 1: the siliciclastics are exposed in the Scotland District). These carbonates are a few meters to about 120 m in thickness and form a series of terraces, which were deposited in response to an interplay of tectonic uplift and eustatic sea level changes, with tectonic uplift ranging episodically from ~7 to 440 m per 100,000 years over the past 800,000 years.

Caves

The Quaternary carbonates of Barbados are extensively overprinted by epigene (top-down) karst processes. Epigene karst features include various types of caves, solution valleys (locally called gullies), and sinkholes. Genetically, Barbados has four types of natural caves: (1) stream caves formed by fresh-water dissolution; (2) flank margin caves formed by mixed freshwater-seawater dissolution (this particular form of cave formation may also be considered hypogene, i.e., bottom-up); (3) sea caves formed by seawater corrasion; and (4) hybrid caves that formed by more than one of the above processes. In addition, (5) there are numerous man-made 'caves' and tunnels dug for enhanced drainage after heavy rains. In most cases the mode of cave formation can be determined from cave sizes, passage dimensions, branching patterns, and from morphological features such as wall scalloping, bell holes, and solution pillars. Calcite speleothems have developed almost exclusively in stream and flank margin caves. Stream caves also contain variable amounts of talus (blocks up to many tons in weight fallen off cave roofs) and sediments (mainly mud and minor amounts of coarser debris) deposited by stream flow, whereas flank margin caves are almost devoid of such deposits. Given uplift rates and glacioeustasy, flank margin cave development has been extensive, pervasive, and rapid.

Most caves in Barbados are hybrid caves, whereby glacioeustasy and tectonics caused cave-forming environments to overprint each other. Flank margin caves are the most common cave converted to the hybrid state as they are readily breached and modified by coastal wave processes (Fig. 2) and/or fresh water erosion. To date, we have mapped about 80 flank margin caves and estimate that their total number is in the hundreds. Most are but a few meters in diameter, but some are up to ~100m long and ~15 m in height.

Fresh water stream caves are few but much larger. They are found in the upland island interior. Harrison's Cave has over 2 km of branched passages and is partially developed as a tourist site. Nearby Cole's Cave (Fig. 3) is about the same length but undeveloped. There are at least two other yet shorter stream caves. The stream caves breach whatever other karst features and/or sedimentary boundaries are in their paths.

Sinkholes

The present carbonate-covered land surface of the island is pockmarked by 2830 sinkholes, which amounts to about 5 sinkholes per square km on average. However, some areas have a much higher density while others are almost devoid of sinkholes (Fig. 4). The reasons for this uneven distribution are under investigation. Sinkholes range in diameter from about 10m to 120m and are up to about 15m deep, and cave entrances are visible in some of them (Fig. 5). Most sinkholes formed over the last 500,000 years, attesting to their relatively rapid formation.

Gullies

Another striking morphological karst feature is dozens of branching valleys, locally referred to as gullies. Their origin is problematic and much debated. From the air, the gullies resemble a network of narrow creeks in the highlands, which merge progressively to fewer and wider rivers that run toward the northern, western, and southern coastlines (Fig. 6). Although dry over most of the year, the gullies form an important part of the surface drainage system of the island. They quickly flood and carry huge amount of water during heavy rainfalls. The origin of the gullies was complex. Sinkholes can connect to elongate solution features called 'solution valleys', and at least some of Barbados' gullies may have formed in this way. Most gullies, however, have a hybrid origin and probably formed by the combined effects of surface erosion, subsurface dissolution, global sea level fluctuations, and local tectonic uplift. Most gullies have caves along at least a part of their paths, commonly decorated with flowstone or other speleothems (Fig. 7). Most of these caves are flank margin caves overprinted by fresh water speleogenesis, later cut open by fresh water erosion.

Application to the Grosmont reservoir

A number of lessons learnt from the karst in Barbados can be applied to the Devonian Grosmont reservoir in Alberta, despite the vast differences in age and size. For example, numerous sinkholes identified in seismic images can be interpreted as epigene karst features that developed rapidly on one or several former land surfaces. Also, at least some sinkholes can be expected to provide fluid passageways across reservoir levels. Drainage patterns akin to the gullies of Barbados can be expected in the Grosmont as well, but not as deep or as densely spaced, and with different orientations. The Grosmont may contain a few stream caves and many more flank margin caves, while the latter should not be as frequent as in Barbados but may be considerably larger, considering the tectonically relatively stable position of the Grosmont platform. However, recognition of the mode of cave formation probably will remain elusive in the Grosmont at least for the relatively small caves. This is because a genetic interpretation requires human inspection of cave wall morphology, which is impossible in the Grosmont reservoir.

Integrating these aspects with the known geologic history of the Grosmont platform, it appears that the Grosmont platform was karstified in at least two major epigene episodes. The first episode was a 'warm epigene karstification' during the Jurassic – Cretaceous, for which Barbados provides a useful analog. The second episode was/is a 'cold epigene karstification' that started sometime in the Cenozoic and is continuing to this day. The present repertoire of karst features probably is a composite of these two epigene karstification episodes. In addition, circumstantial evidence suggests that epigene karst gives way to a deep hypogene (bottom-up) karst in the downdip part of the platform. The latter likely has different characteristics, i.e., most notably a maze system of passages rather than a stream system overlain by sinkholes. At present the hypogene karst system in the Grosmont is virtually unexplored.

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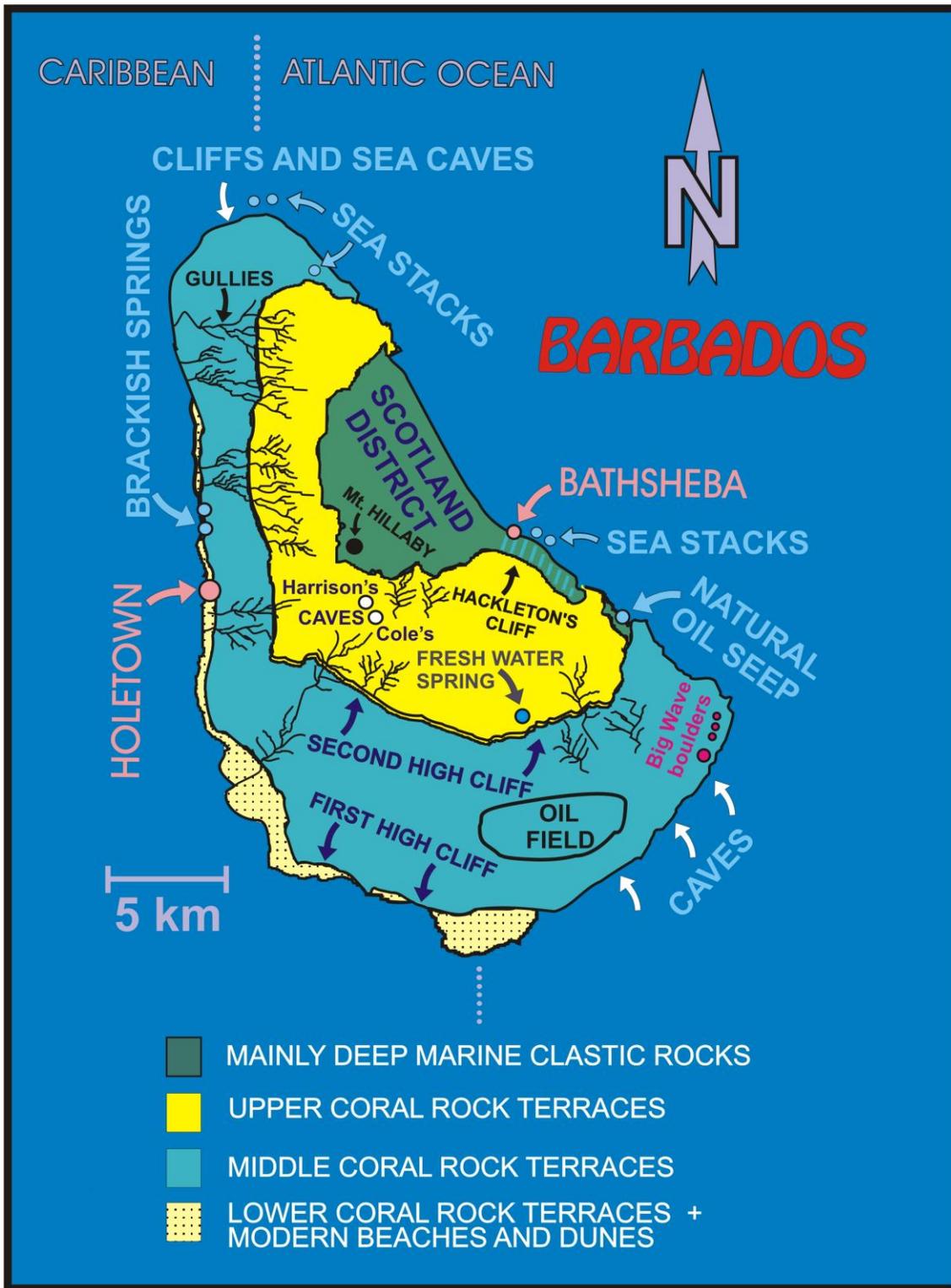


Fig. 1: Map of Barbados, showing the major geologic units and other significant features. Modified from Machel, 1999.



Fig. 2: Flank margin cave near North Point of the island, cut open by cliff erosion.

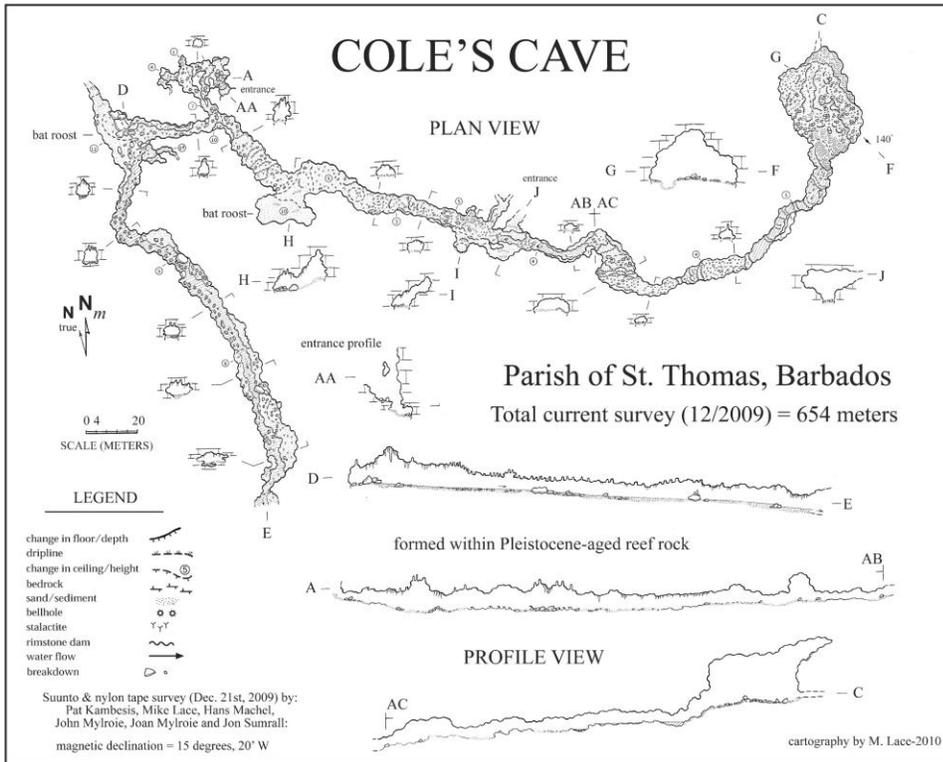


Fig. 3: Incomplete survey map of Cole's Cave, the second longest stream cave of Barbados. Additional passages measuring several hundred meters have yet to be mapped.

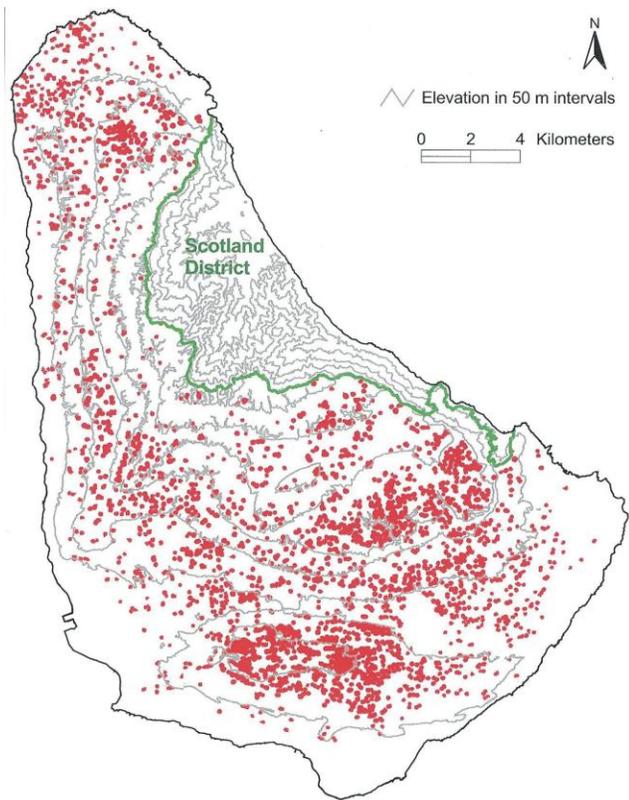


Fig. 4: Distribution of sinkholes, as mapped by Wandelt (2000).



Fig. 5: Sinkhole with cave opening in the Lower Estates, located in the Middle Coral Rock Terrace.

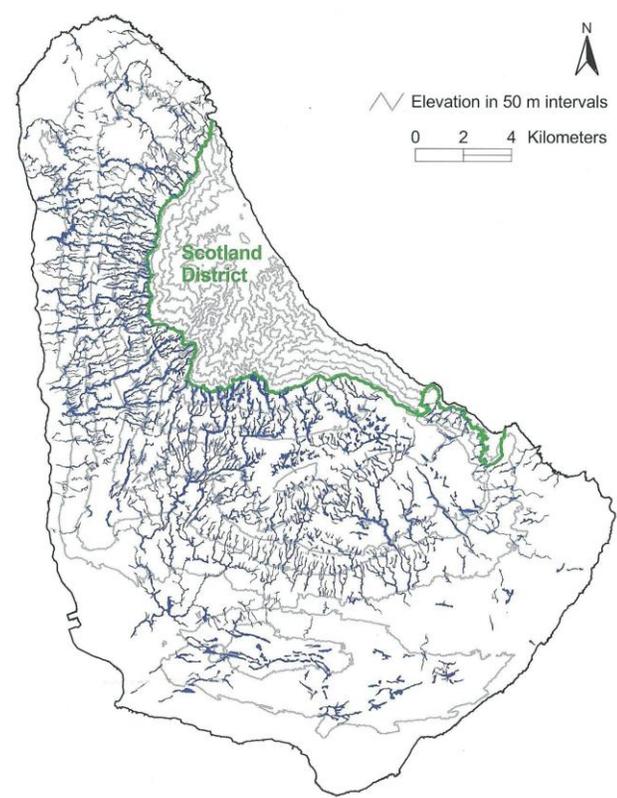


Fig. 6: Overview map of gully system in Barbados. From Schellmann and Radke (2004).



Fig. 7: Large flank margin cave cut open by fresh water erosion. Jack-in-the-Box gully. Person for scale.