

A MODEL FOR PREDICTING THE OCCURENCE OF COLLAPSE FEATURES ON CARBONATE ISLANDS AND COASTLINES

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ABSTRACT

In the mid 1970s, Jim Quinlan had originally described the caves of Isla de Mona, Puerto Rico as "phantasmagorical" sea caves and attributed their origin to littoral erosion. Though he was not quite satisfied with that characterization, it was the only model that came close to explaining the existence of the very large caves of Mona. In the early 1990's, a cave genesis model originally developed from the Bahamas was applied to cave development on Isla de Mona. This model explains caves, not only on Isla de Mona but on carbonate islands in general, as being the result of mixing zone dissolution in the distal margin of the fresh-water lens, under the flank of the enclosing land mass. Field work in the geologically complex Mariana Islands in the late 1990s resulted in the development of the Carbonate Island Karst Model, or CIKM, which integrated the various components controlling cave and karst development on carbonate islands. Characterization of cave types on carbonate islands was attempted using morphometric analysis of cave size and shape parameters, with limited success. Current research on seemingly random collapse features on carbonate islands, called "banana holes" in the Bahamas, has identified them as facies restricted and may provide a predictive measure of these features. Coastal reentrants, long thought to be stable because they are protected from wave energy, are now recognized as important sites for flank margin cave development. These features are not always evident if their entrances have not yet been erosionally breached. Flank margin caves and other associated features that occur on carbonate islands pose unique environmental problems with respect to residential and commercial development. These features tend to have a shallow horizon of development along with thin overburden making them prone to collapse. The current model for the development of coastal karst features provides a mode for predicting the location of potential collapses.

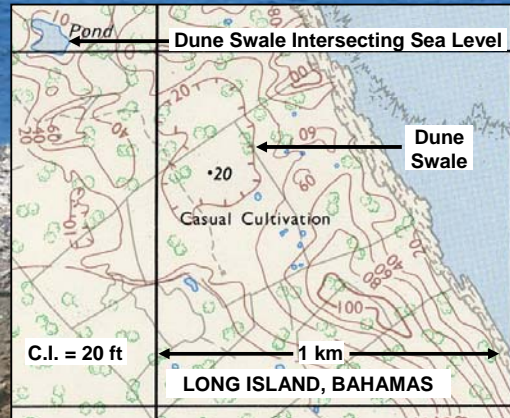


Figure 2: Closed contour depressions in youthful carbonate islands are commonly *constructional*, i.e. produced by deposition, as in the eolian swales shown above, or formed as uplifted fossil lagoons.



Figure 3: Locations of field sites around the world.

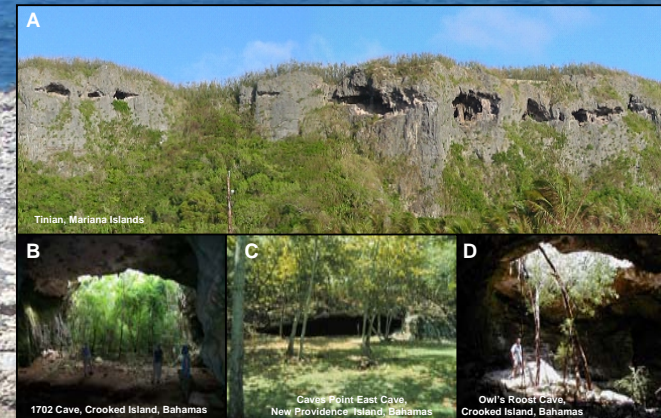


Figure 5: Cliffside retreat, as in A and C above, or roof failure, as in B and D above, are easily predictable if the past lens margin position is known. As a result, collapse risk can be determined.



Figure 6: Banana Holes, San Salvador, Bahamas (so named for the crops grown in them), are vertical-walled depressions fully (A) or partially (B) collapsed, developed in subtidal to supratidal facies (C) found in island interiors away from the lens margin.

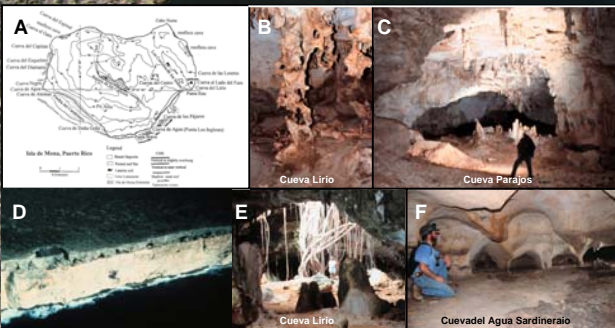


Figure 1: Isla de Mona, Puerto Rico (A), which grabbed Jim Quinlan's attention because of its speleothems (B), large rooms (C), many cave entrances (D), collapses (E), and speleogens (F).



Figure 4: The Flank Margin Model of cave formation (A & B) predicts the position of phreatic subsurface voids (C & D) formed in a stable fresh-water lens.

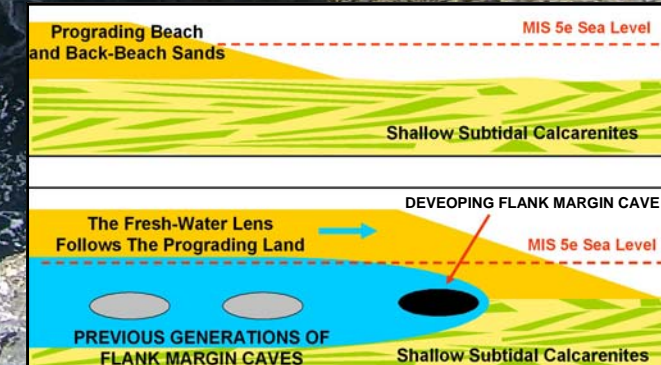


Figure 7: Recent work has established that banana holes form in prograding standplains, and are a predictable occurrence.

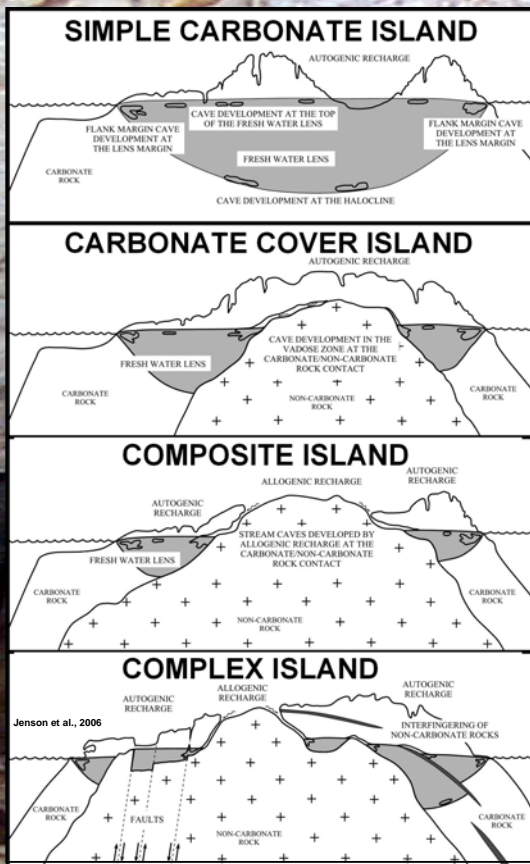


Figure 8: Collapse prediction becomes more difficult as island complexity increases as a result of interaction with structure and non-carbonate rocks.

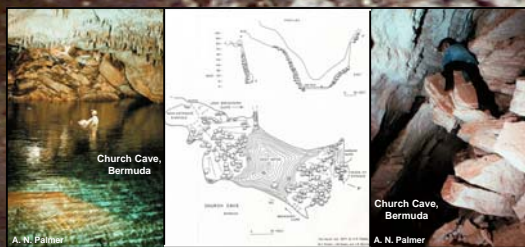


Figure 9: Bermuda, at a glacioeustatic sea-level lowstand, is a *Carbonate Cover Island*. Caves developed at the carbonate-basalt contact under vadose conditions capture water flow, grow large, and progradationally stope upward to form large collapse chambers. Successful collapse prediction requires knowledge of the topography of the subsurface carbonate-basalt contact.

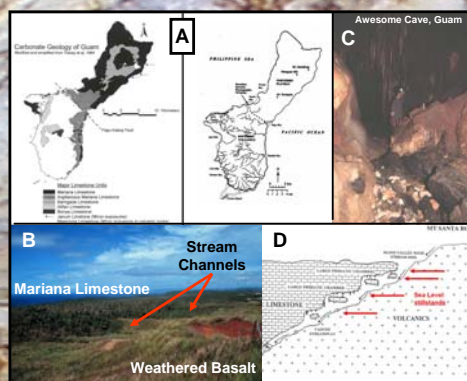


Figure 10: Guam as a *Composite Island* (A), with basalt outcropping on the surface (B) to create allogenic recharge that sinks into caves, with basalt perching the streams (C & D). Pauses in tectonic uplift create large chambers where the descending stream met the fresh-water lens (D).

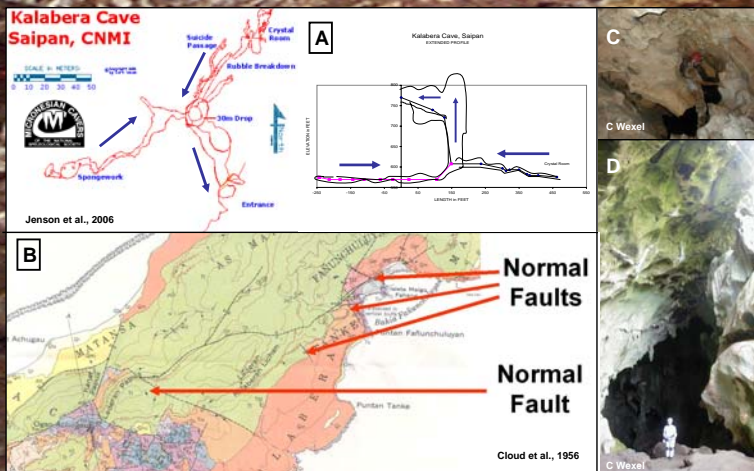


Figure 11: Kalabera Cave, Saipan (A), a *Complex Island*. The cave is in a hydrologic block isolated and confined by faulting and volcanoclastics (B), which has resulted in phreatic flow along strike (C) to a 30 m vertical rise to the entrance (D).

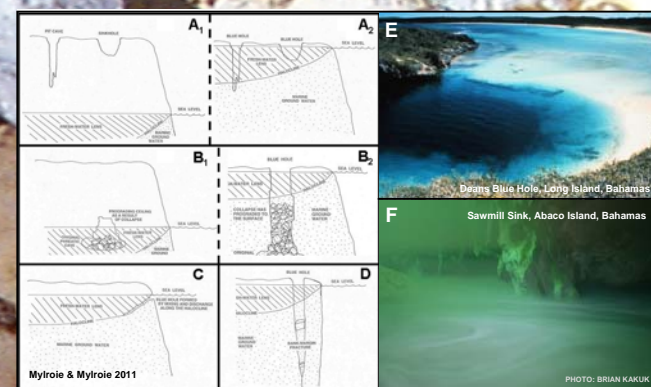


Figure 12: Blue holes are common feature in the Bahamas; the cenotes of the Yucatan are similar in appearance and origin. Blue holes are polygenetic, panels A-D represent mechanisms of blue hole formation (note that panel C is misleading due to vertical exaggeration). Blue holes are named for their deep blue color (E), a result of their great depth (in this case >200m). Exotic biogeochemistry may be active due to organic loading (F). Large progradational collapse features, as shown in (B), result from large conduits that develop at depth when the banks are exposed during glacioeustatic sea-level lowstands, and the large increase in exposed platform favors conduit development.

CONCLUSIONS

Classic conical sinkholes produced by dissolution of carbonate bedrock are rare in youthful carbonate islands, because the limestones are eogenetic and pass meteoric water directly to the subsurface. Large closed contour depressions are primarily constructional in origin. The vast majority of sinkholes are the result of bedrock collapse. Flank margin cave collapse is easily predictable based on their spatial linkage to the lens margin. Banana holes can form a field of collapse risk, as they are a special case of flank margin cave produced when the lens margin migrated during coastal progradation, yielding a large areal footprint.

When island (or continental coastal carbonate) complexity increases, and non-carbonate rocks interact with the fresh-water lens, a variety of scenarios can result that produce large voids. The majority of these voids form from perching of vadose water on non-carbonate rocks, or the addition of large point sources of recharge to the fresh-water lens. In special cases, confined conditions and phreatic lift passages can occur. Blue holes are polygenetic, and within platforms, they are proxies for large conduits at depth. For these complex settings, a complete understanding of the local geology is essential.

Citations

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