Development and Future Frontiers for Carbonate Coastal and Island Karst

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COASTAL CAVE SURVEY — *dedicated to the exploration, study, and preservation of coastal caves*

CIKM — CHARACTERIZATION OF KARST PROCESSES

Part 1: Development

Background image: Looking east out of the Hartford Cave entrance, Rum Cay, Bahamas

ABSTRACT: Coastal and island karst as a subfield of general karst studies became established in the 1980s with the development of the flank margin model to explain caves in coastal and inland carbonate cliffs that had phreatic dissolutional surfaces, lacked epigenic forms, and were not wave action or tafoni in origin. Two decades of examination of localities world-wide generated two important additional concepts: 1) there is a significant difference between *karst on islands*, which is karst typical of that seen in interior continental settings, and *island karst*, which invokes the interaction of freshwater-seawater mixing and sea-level change to produce unique karst features; and 2) the Carbonate Island Karst Model (CIKM), which takes into account the diagenetic condition of the carbonate rock, and its distribution relative to insoluble rocks, if present. Continental carbonate coasts, such as Yucatan, became part of the model. The role of organic loading and decay, and discharge flow velocity, were characterized. A final significant development was that flank margin caves were seen to develop rapidly, within a few thousand years, but to persist under proper conditions, for millions of years. Coastal karren's unique morphologies were seen to be an outcome of eogenetic carbonate rock in a coastal environment.

Many unanswered questions remain. The role of tidal forcing on flow dynamics and geochemistry in flank margin caves has not been fully explained. As the caves are mixing chambers within a diffuse flow system, cave flow is assumed to be laminar and phreatic morphologies are consistent with that view, but the actual nature of the flow, including vertical density convection, remains a topic of debate. An international meeting in 2014 failed to reach a consensus as to whether flank margin caves were hypogene or not. Two hydrological questions: the role of island size, and continental coastal discharge regimes, have had initial investigation, but more needs to be done. Initial study as to what actually happens at the wall-rock and fluid interface has been inconclusive. The nature of contaminant transport and residence time in coastal karst remains a frontier. Flank margin caves may be the most abundant dissolutional cave type in the world, warranting additional research.

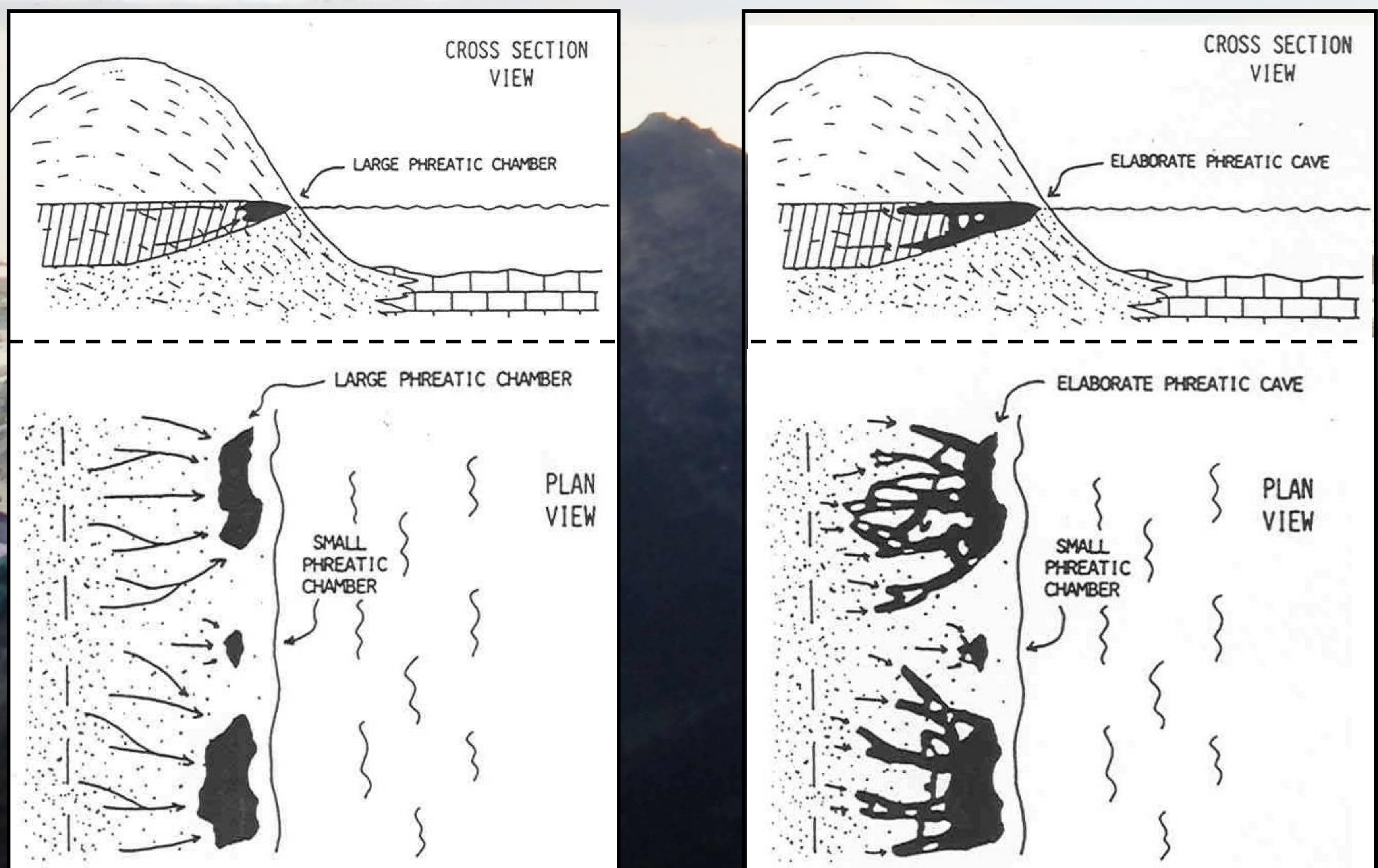


Figure 1: The initial new model for carbonate island and coastal karst was the *flank margin cave* model, which explained these caves as the result of mixed water dissolution, decay of organics, and discharge concentration under a laminar flow regime. The model first appeared in 1988 (Mylroie, 1988; 1990).

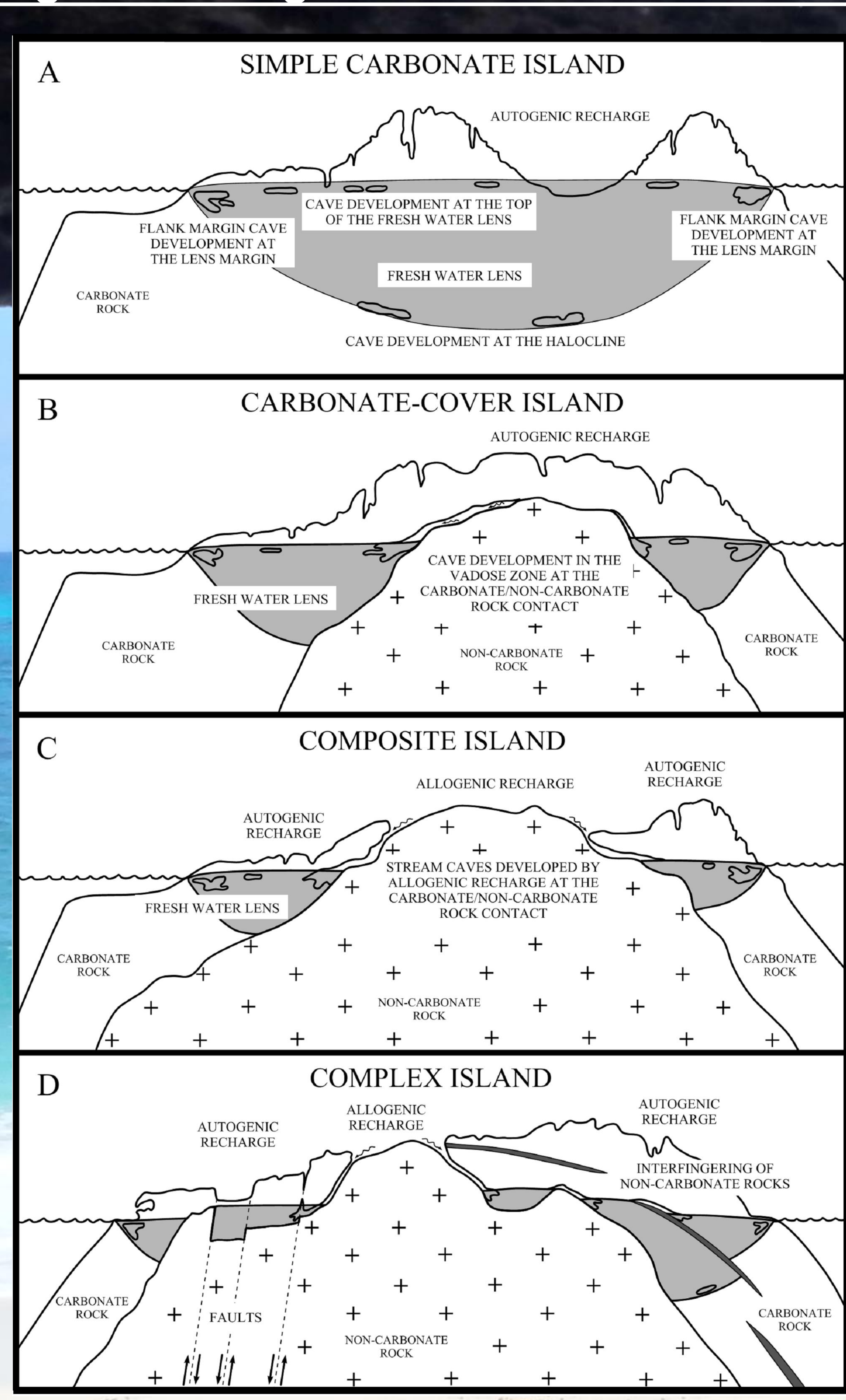


Figure 2: Work on Bermuda, Isla de Mona, and the Marianas Islands lead to the development of the *Carbonate Island Karst Model*, or CIKM. The model took into account the relationship of carbonate rocks to sea level, other lithologies, and structure.

Figure 3: One of the important distinctions to arise from early work was to differentiate between *karst on islands*, typical of any karst area, and *island karst*, unique to carbonates in coastal settings. The left image is mogotes on Puerto Rico, not unique to island settings; the right image is a series of flank margin caves, Rum Cay, Bahamas, unique to coastal carbonate settings.

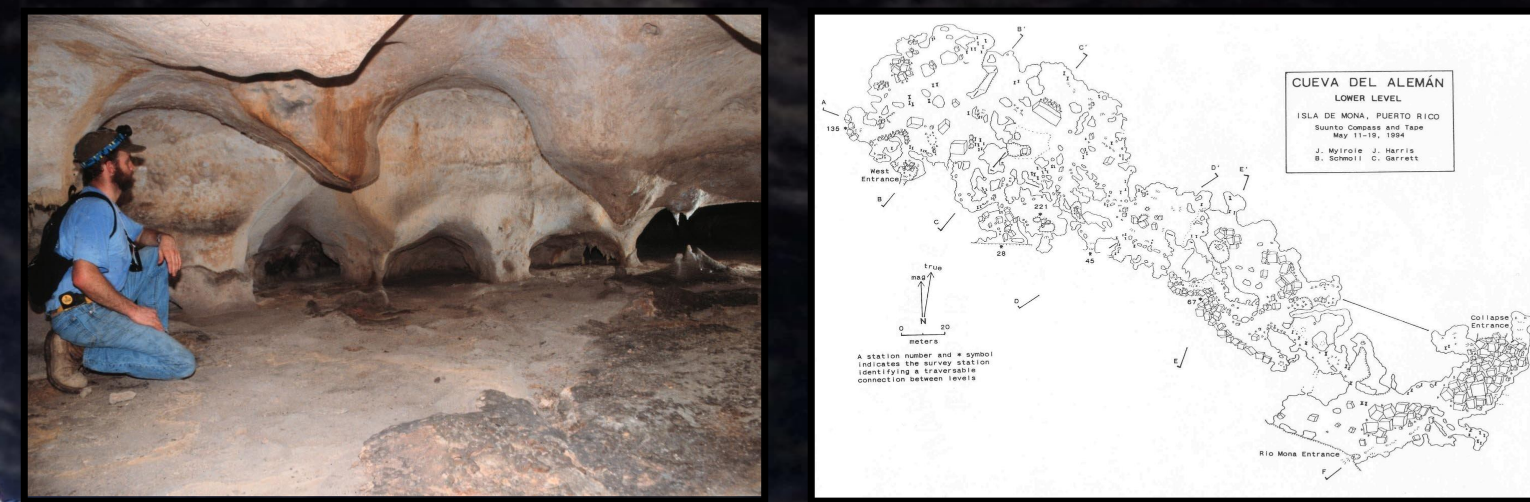


Figure 4: Flank margin caves, at the wall scale (left) and at the cave scale (right), have a unique pattern of connected globular chambers. Morphometric analysis of these patterns revealed useful information.

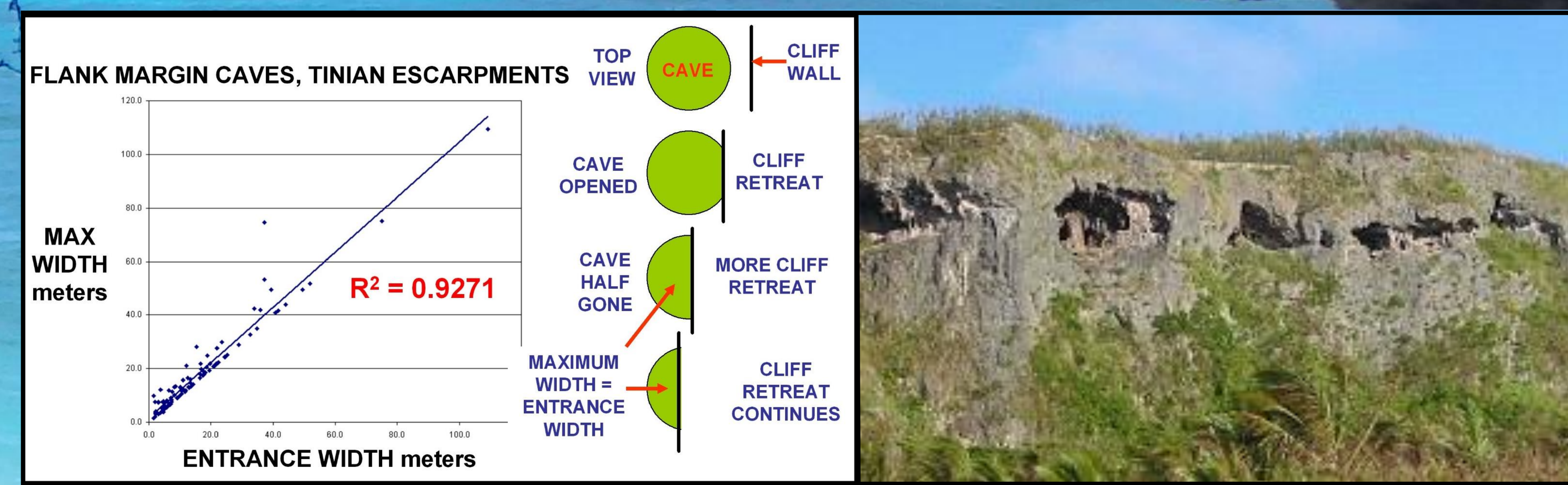


Figure 5: Metrics involving entrance and interior dimensions help determine the degree of cave breaching, and hence the rate of denudation.

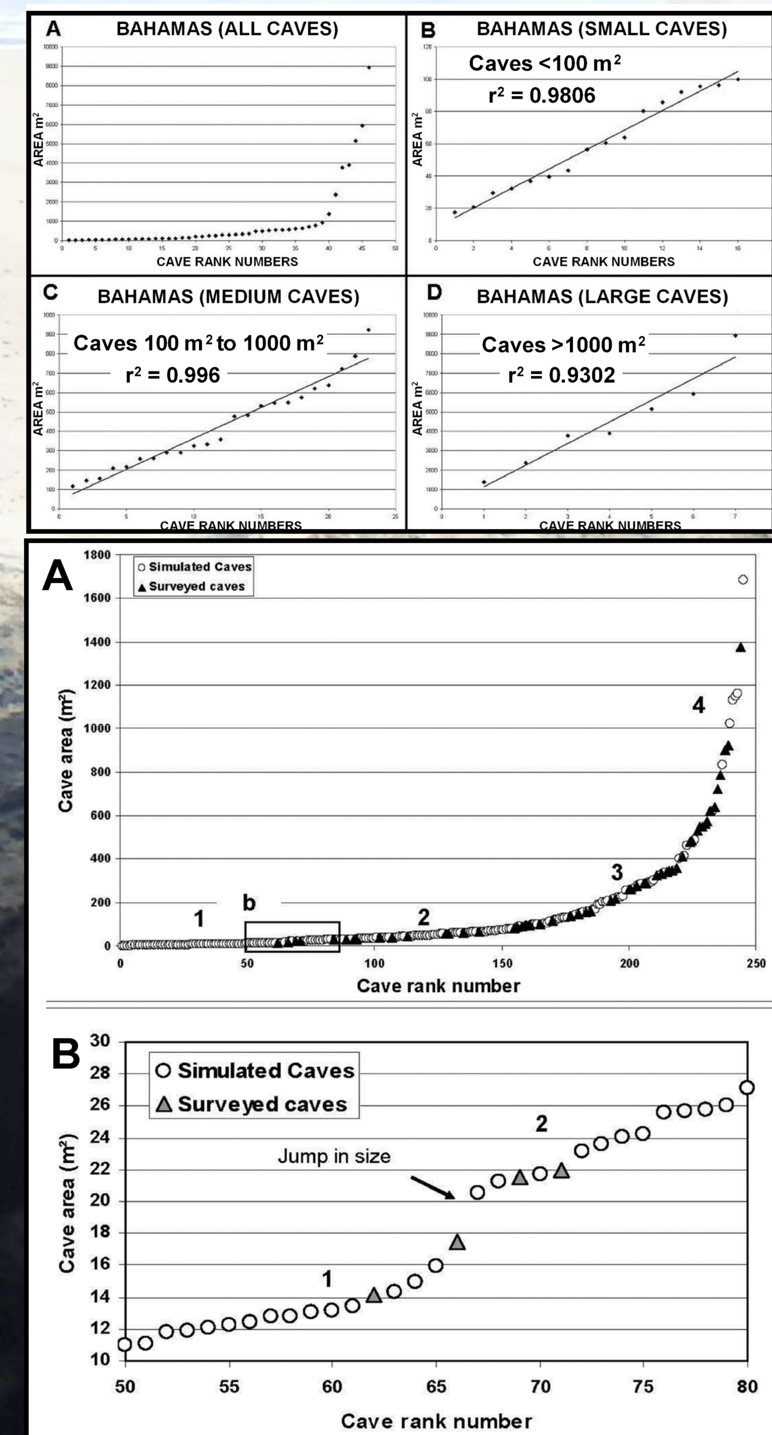


Figure 6: Bahamian caves self select into different size categories, which represent chamber intersections.

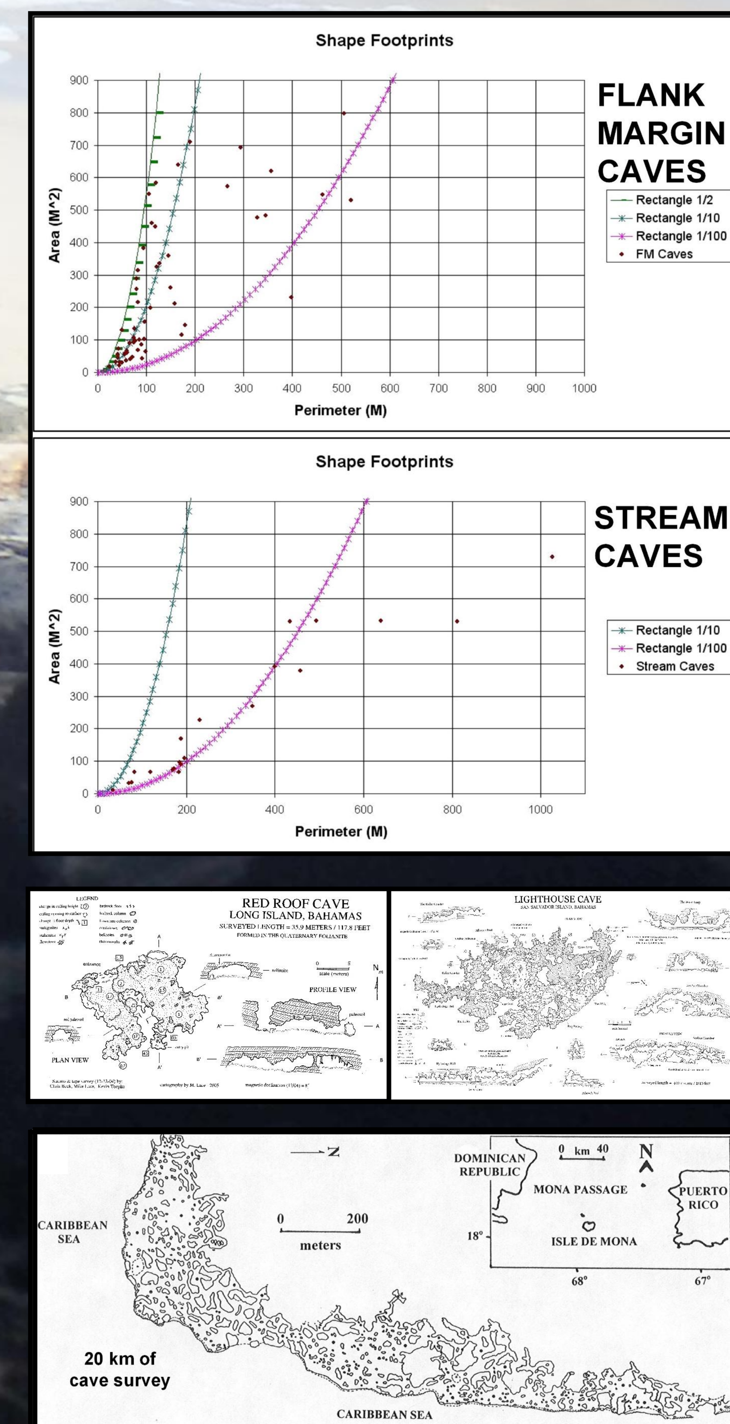
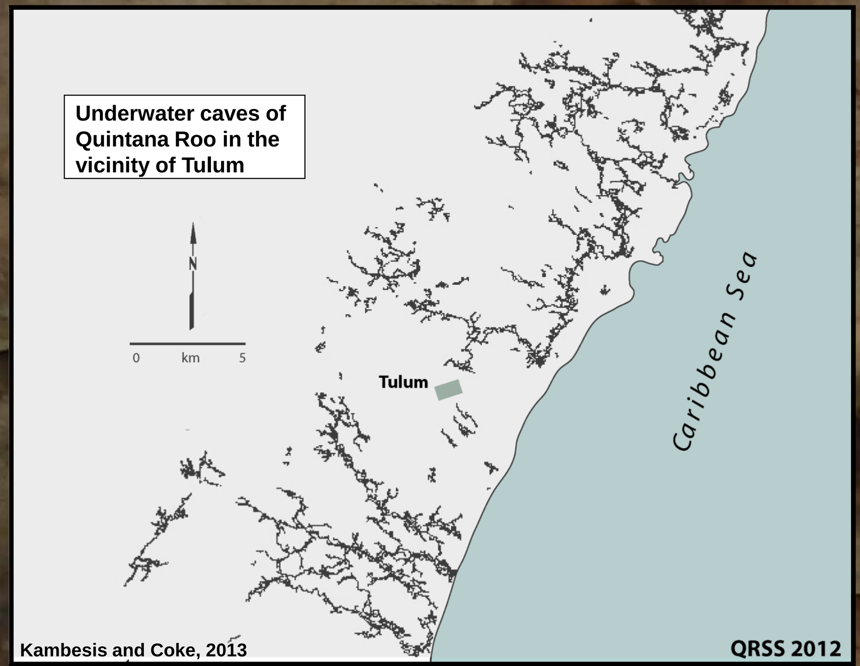


Figure 7: Area vs Perimeter plots show that flank margin caves grow large by aligning to the lens margin.

Part 2: Frontiers

Platform Size Problem

Carbonate Continental Coasts



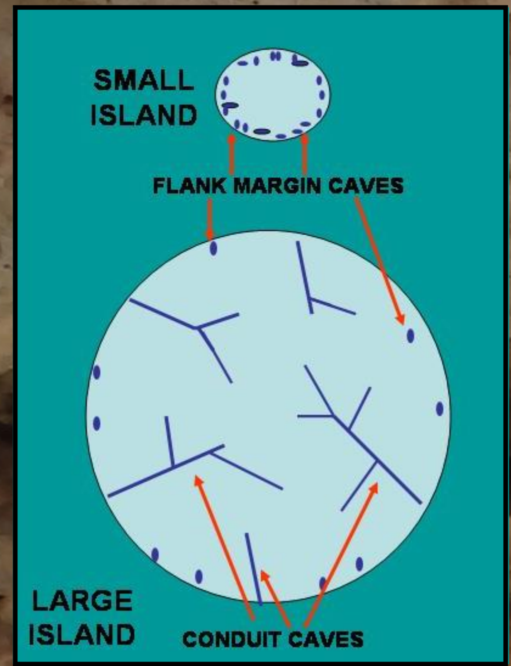


Figure 8: Continental carbonate coasts, such as in Quintana Roo, Mexico, behave as a large island and have over 1,000 km of surveyed cave produced by the interaction of conduit flow with mixing dissolution. Cave passage (left), cenote (right).

Hypogene Problem

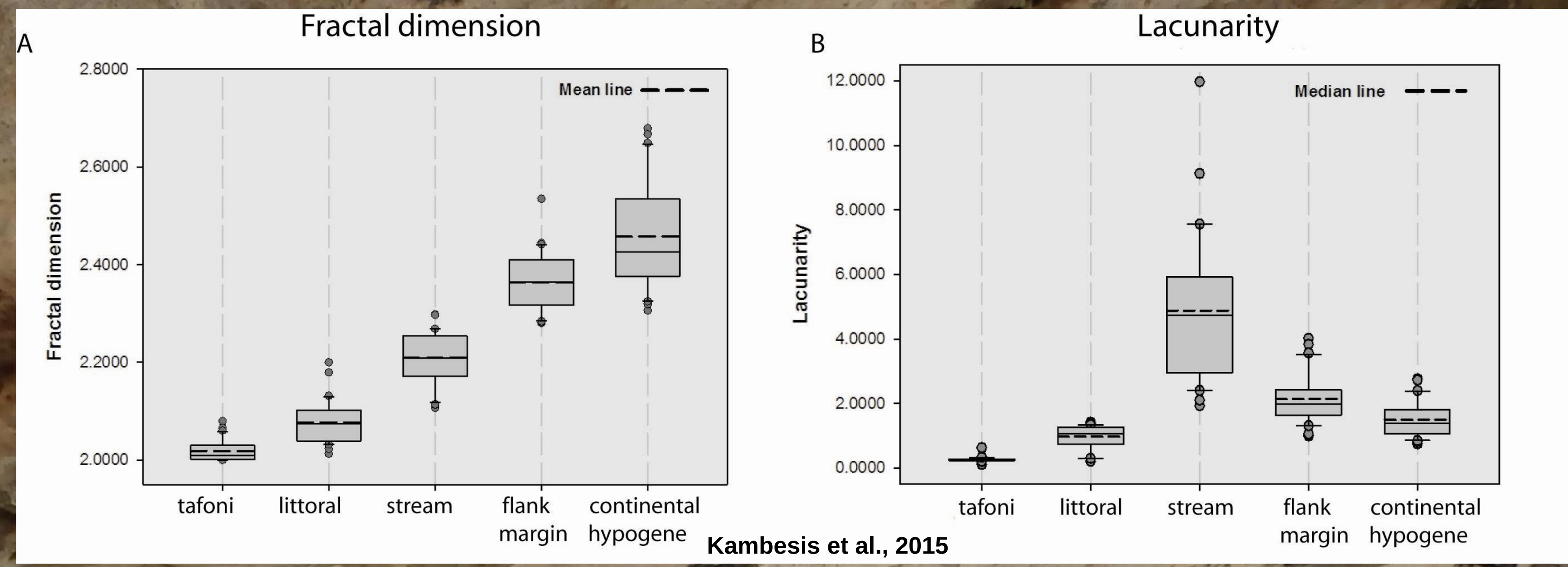


Figure 10: Fractal analysis of flank margin caves versus other cave types indicates they have a unique pattern that may be caused by their unique speleogenetic environment.

Hybrid Cave Problem

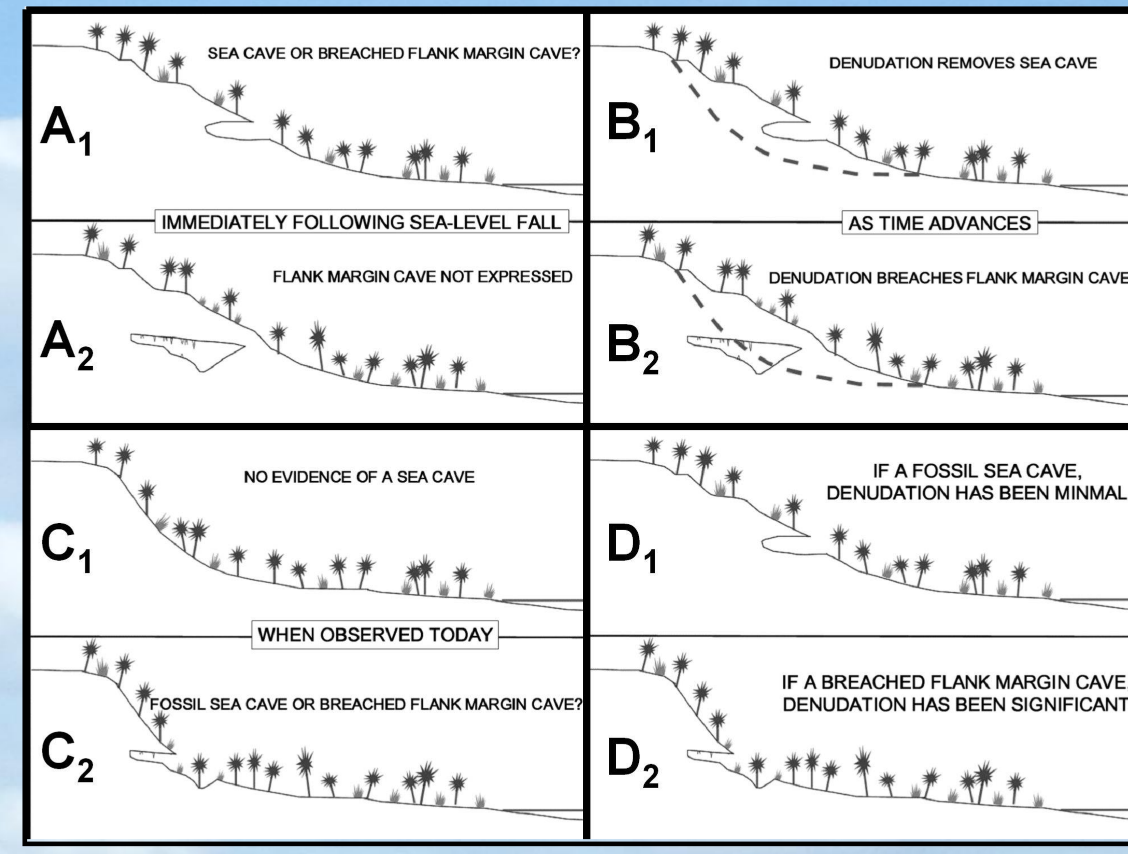
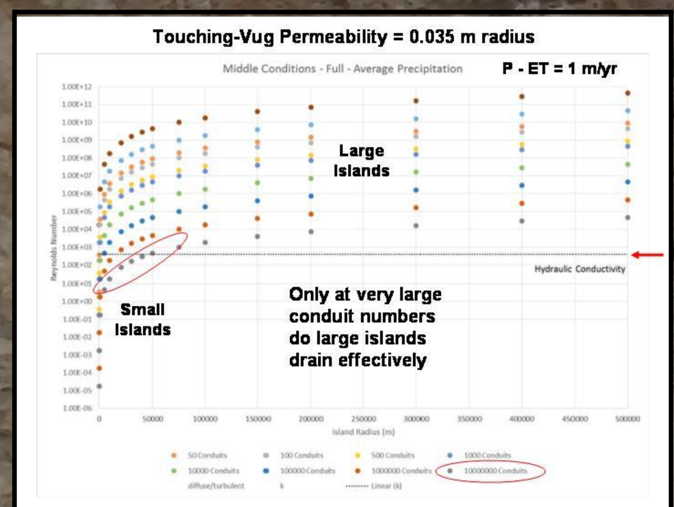


Figure 12: Flank margin caves, due to their origin at the lens and land boundary, are vulnerable to exposure by erosion and overprinting by marine processes; differentiating such *hybrid caves* can be difficult. Flank margin cave breached by wave erosion (left), wave action attacking coastal cliff (right), on Barbados.

Background Image: Breached flank margin cave as a residual coastal notch, Cayman Brac.

Platform Size Problem

Large Carbonate Banks



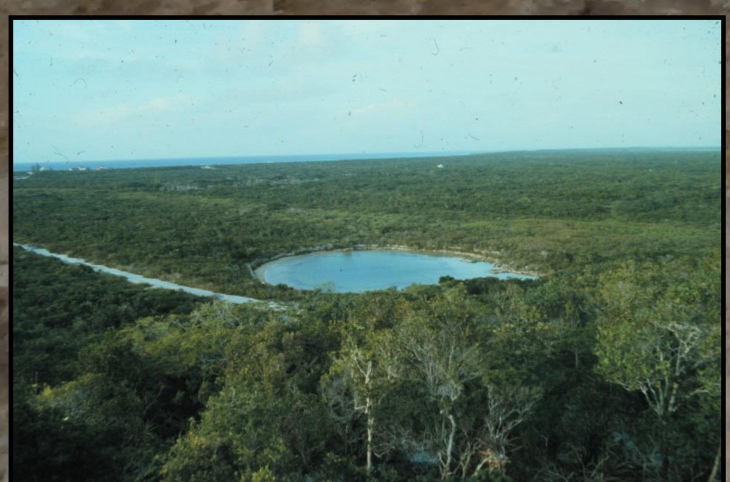
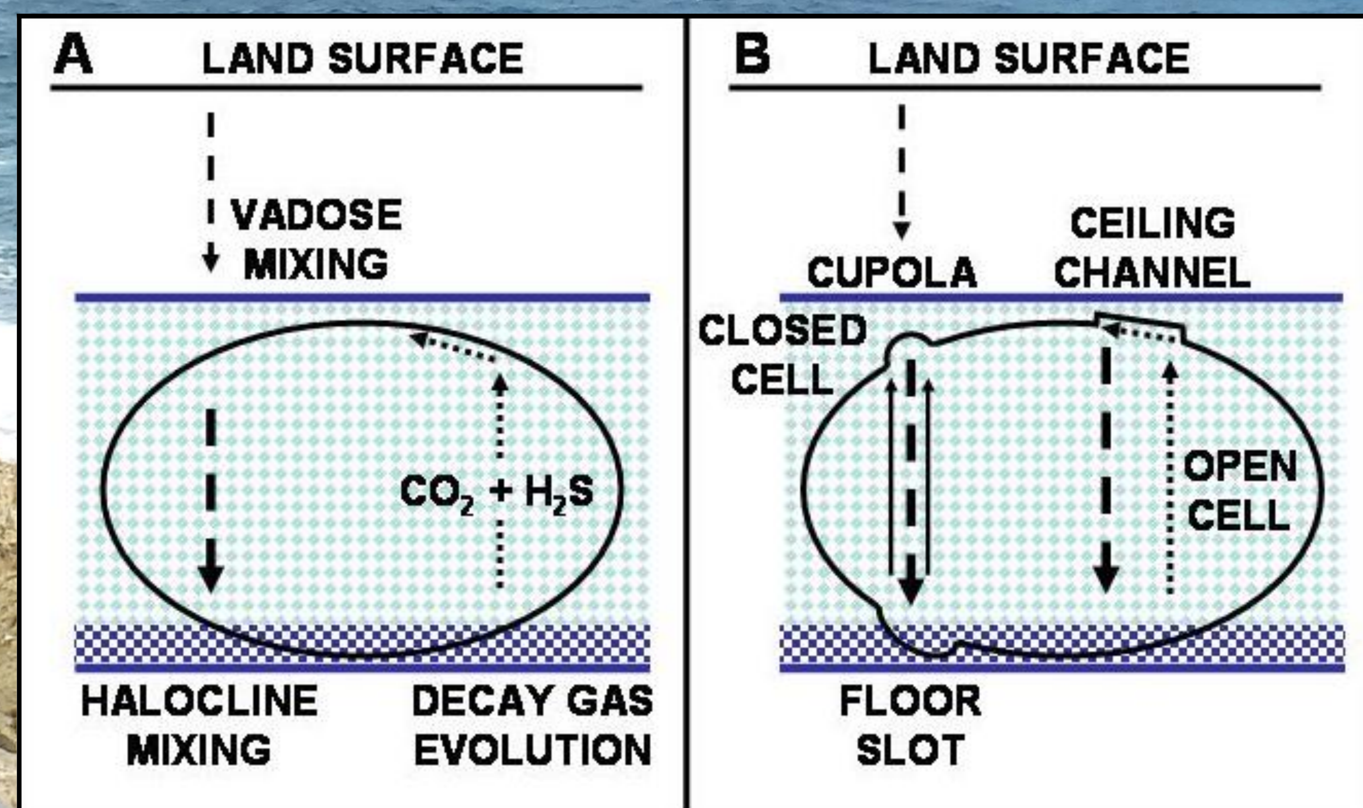


Figure 9: At a sea level 10 m below present (90% of the Quaternary) the Bahama Banks are exposed, to create a large island. Conduits form due to area vs perimeter ratio. Collapse of these conduits form many of the inland blue holes (left) and ocean holes (right).

Flow Dynamics Problem



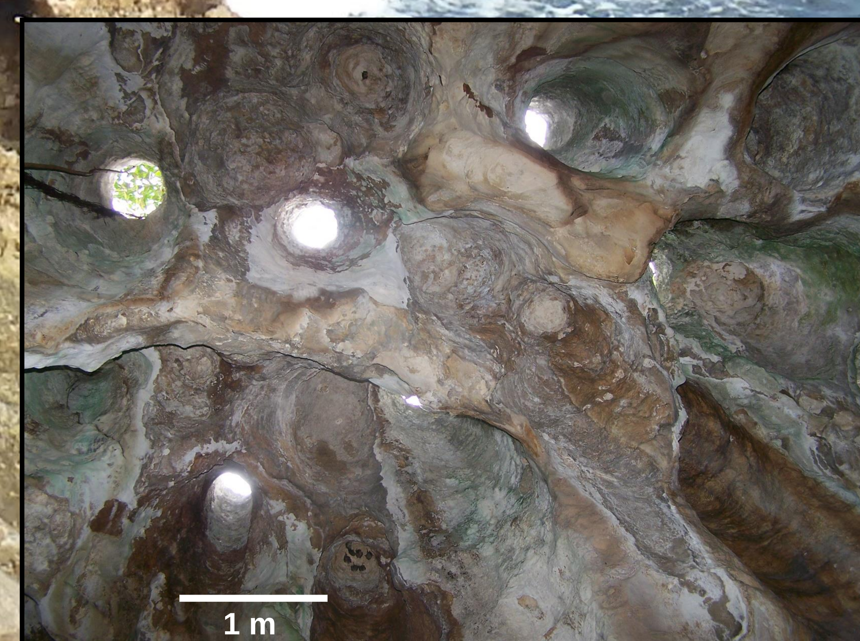
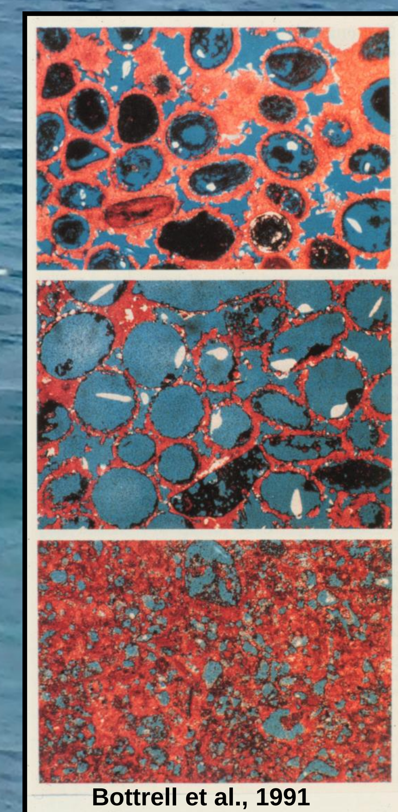


Figure 11: Flank margin caves form in a laminar flow system, but actual flow dynamics, such as vertical convection to form bell holes (left and right images from the Bahamas, looking upwards) are unproven. Tidal effects remain uncertain.

Fluid-Wall Rock Interaction Problem



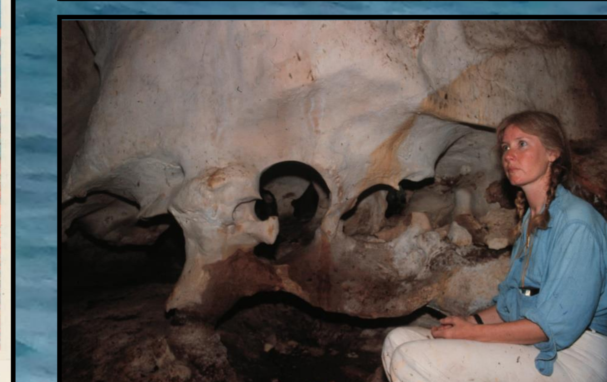


Figure 13: The actual geochemical activity at the chamber-wall rock boundary is not well understood. While the process is extremely powerful, it seems restricted to a narrow front.

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