

BUILDING AND SCULPTING THE WESTERN CAICOS MARGIN

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KEY FINDINGS

- Mathematical scaling relationships in real-world measurements suggest that scalloped margins reflect an organizing process, rather than a collection of unrelated erosional and/or collapse features.
- Numerical modeling shows that relatively simple erosion can reproduce the emergence and scaling of scalloped morphology without invoking repeated mass wasting.
- The modeled scallops arise spontaneously from small, random irregularities, providing an example of autogenic pattern formation on a carbonate margin.
- Interaction between evolving topography and focused erosion offers a plausible mechanism through which initially irregular features become organized and progressively coarsen.
- Scalloped margins may therefore record persistent, self-organized sediment-routing processes—not simply a history of slope collapse—changing how we interpret margin morphology and the geological record.

SIGNIFICANCE

Scalloped margins—repeated, bankward-facing embayments along flat-topped carbonate platforms—have commonly been interpreted as scars of large-scale margin collapse. Mullins and Hine (1989) proposed this explanation for Bahamian banks. Subsequent studies supplied more direct evidence of failure: on the Nicaraguan Rise, Hine et al. (1992) linked a scalloped embayment and truncated platform reflections to a basinward megabreccia, while Jo et al. (2015) mapped margin failures and associated debris along southwestern Great Bahama Bank. In China, Lehrmann et al. (2020) documented truncation and gravity-flow deposits at scalloped margins, but also showed that those margins had accreted before they failed. Fullmer and Kerans (2023), by contrast, proposed that cusate longshore accretion can itself produce scalloped outlines, with strandplains and spits focusing sediment delivery toward the basin. The issue, therefore, is not whether carbonate margins can fail or accrete—they demonstrably do both—but how much each process contributes to a given scallop, and what might account for the consistent scaling of scallops across the Bahamas reported by Fullmer and Kerans (2023).

The distinction matters because the same scalloped outline can imply very different histories of platform development. If scallops are primarily constructional, they record the organization of sediment transport and where a platform grew; if they are collapse scars, they record removal of part of an existing margin and transfer of that material to the slope and basin. A margin may also preserve both processes in sequence, as the Chinese examples suggest.

Treating shape alone as a diagnosis therefore risks misreading whether a platform was advancing, retreating, or being reworked. The apparently consistent scaling of Bahamian scallops makes this more than a question of individual case histories: explaining that regularity could help identify the processes—and characteristic length scales—that organize carbonate-platform margins.

The leeward margin of the Caicos platform provides a setting in which to investigate these questions. A comprehensive multibeam dataset acquired aboard the R.V. Hydra, operated by Inkfish, resolves scallop geometry and its variation along strike and dip. We combine these real-world observations with computer modeling to test whether accretion, failure, or their interaction can reproduce the observed forms and scaling. In doing so, we seek to distinguish the processes that initially establish a scalloped margin from those that may subsequently modify it.

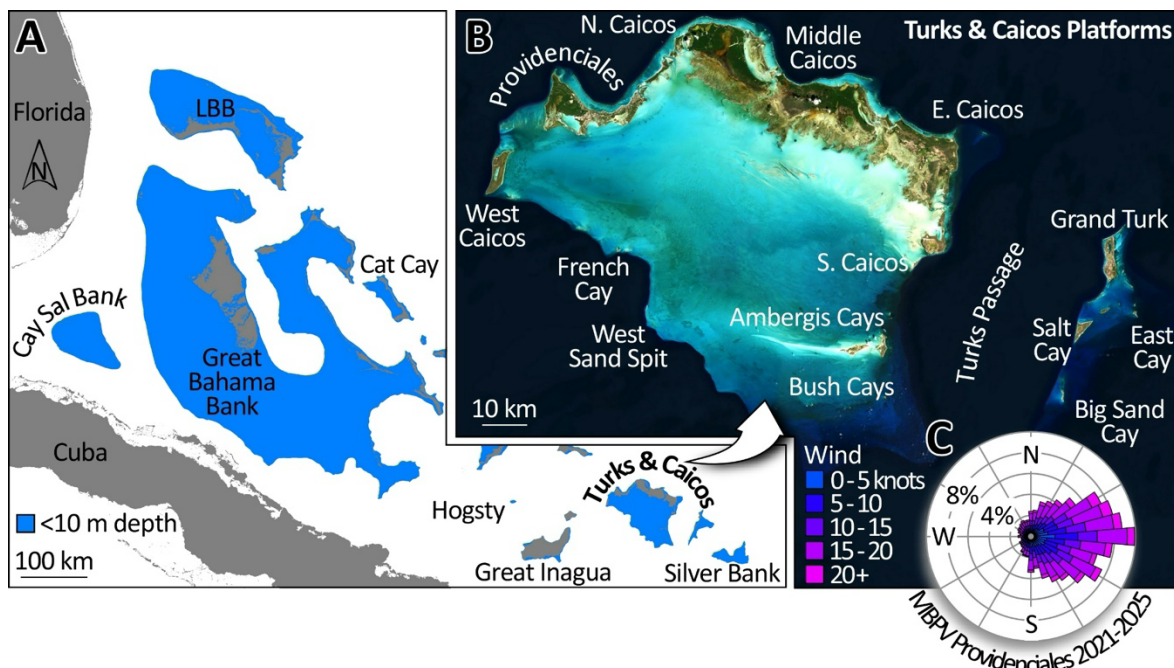


Figure 1: Regional setting of the Caicos platform and wind conditions. (A) Location of the Turks and Caicos platforms relative to Florida, Cuba, and the Bahamian banks. Blue shading denotes areas shallower than 10 m; the box marks the area enlarged in (B). (B) Satellite image of the Caicos and Turks platforms, showing the principal islands and cays and the leeward, southern margin of the Caicos platform. (C) Wind rose showing wind direction and speed classes (knots).

DATA AND METHODS

We developed a process-based numerical experiment representing a 400-km-long carbonate-platform margin with a Caicos-like cross-margin profile. The profile was discretized at 250-m spacing on a 50×400 km grid, with periodic boundaries along the margin. The initial margin was nearly straight and was perturbed by low-amplitude broadband roughness (10 m RMS; wavelengths 2–50 km), so the model contained no preferred scallop wavelength. Cross-margin density-current and sediment-flux pathways were routed over the evolving

bathymetry. Erosion responded to routed sediment concentration and local bed coupling, with enhanced abrasion where flow and sediment converged. Bed coupling increased with slope to the independently identified 35° declivity breakpoint and declined on steeper slopes to represent density-current bypass (Fig. 2). Localized, finite-duration perturbations allowed smaller recesses to emerge within larger catchments, but did not prescribe their final dimensions.

The model was run for 50,000 iterations using our frozen v6.47 parameterization, with bathymetry and morphology recorded at regular intervals. At each checkpoint, we extracted the –100 m contour as the planform margin and identified scallops as recesses bounded by neighboring promontories after light, three-cell along-margin smoothing. Scallop wavelength (L) was measured as the along-margin distance between bounding promontories, and amplitude (A) as the maximum cross-margin recession relative to that aperture (Fig. 3). A minimum resolved wavelength of 2 km was imposed for population statistics. Modeled A–L distributions were compared post hoc with digitized visible margin scallops and the published Fullmer and Kerans (2023) power law (Fig. 4). Neither those observations nor the fitted power law entered the erosion, routing, nucleation, or competition rules.

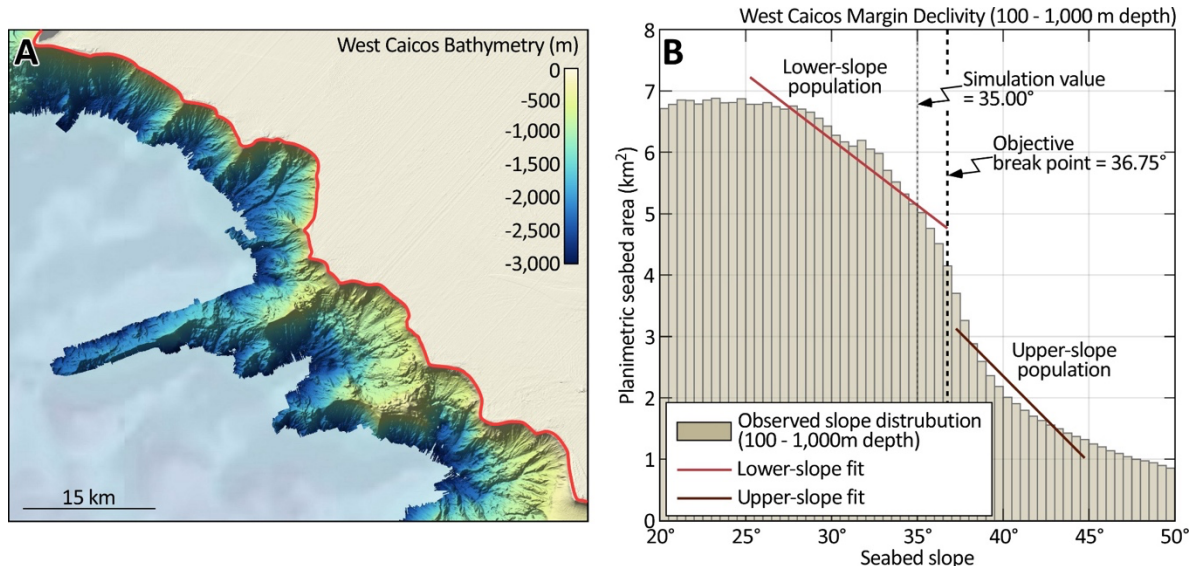


Figure 2: Bathymetry and seabed-slope distribution along the West Caicos margin. (A) Multibeam bathymetry of the West Caicos margin, showing the irregular platform edge (red line) and adjacent slope. (B) Area-weighted distribution of seabed slope angles between 100 and 1,000 m water depth. The two fitted trends (red and brown lines) describe the lower- and higher-angle parts of the distribution, respectively. The vertical markers show the failure angle used in the simulation (35°) and the objectively determined breakpoint between fitted trends (36.75°).

RESULTS

Starting from a near-linear synthetic margin perturbed only by low-amplitude, wavelength-free roughness, the model spontaneously developed an irregular erosional planform (Fig. 3). Incipient recesses were visible by 10–20k iterations and subsequently enlarged, interacted, and merged. By 30–50k iterations, the initially fine-scale irregularity had reorganized into fewer, broader scallops,

demonstrating progressive planform coarsening without an imposed scallop wavelength or a mass-wasting mechanism. Across the full 400-km synthetic margin, the number of detected scallops decreased from 57 at 10k iterations to 52 at 50k, while the maximum detected wavelength increased from 12.25 to 14.50 km.

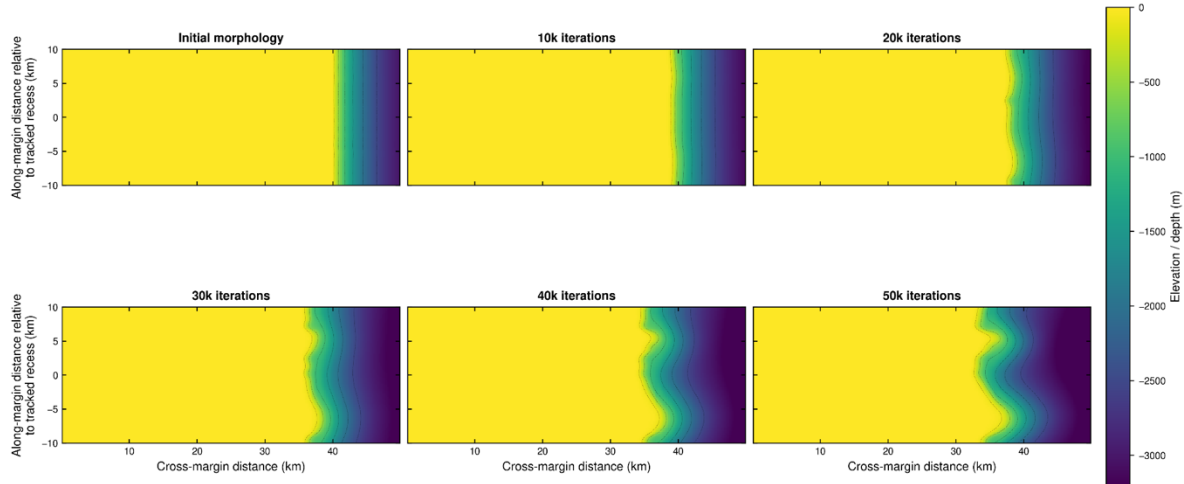


Figure 3: Evolution of a modeled carbonate-platform margin. Bathymetric snapshots show the complete 50 × 20 km model window centered on the tracked recess at the initial condition and after 10k–50k iterations. Axes are plotted at equal scale; colors indicate elevation and water depth, and dotted lines mark bathymetric contours. All panels display the native model grid without spatial interpolation or vertical exaggeration. The sequence demonstrates that scalloped relief can emerge spontaneously from an initially near-linear margin and subsequently organize into broader features. This behavior develops without an imposed scallop wavelength or mass-wasting mechanism.

Scallop amplitude and wavelength evolved systematically through time (Fig. 4). At 10k iterations, the modeled population was concentrated at relatively low amplitudes and plotted predominantly below the empirical Fullmer and Kerans relationship. Subsequent iterations broadened the modeled distribution toward both larger wavelengths and larger amplitudes, while also populating the lower-left portion of amplitude–wavelength space. By 30–50k iterations, much of the modeled population occupied the same intermediate wavelength and amplitude range as the observed scallops, and the upper envelope approached or crossed the empirical trend.

Power-law fits to the modeled populations were positive at every timestep, confirming that larger modeled scallops were consistently associated with greater relief. The fitted exponent varied during early organization—from 2.14 at 10k to 1.29 at 20k—but became more consistent at later stages, ranging from 1.69 to 1.75 between 30k and 50k. These late-stage relationships remained steeper than the observational exponent of 1.054, and modeled relief continued to increase through 50k iterations. The experiment therefore reproduces the emergence, coarsening, and approximate amplitude–wavelength scaling of margin scallops, but does not yet demonstrate convergence to a morphological steady state (Fig. 4).

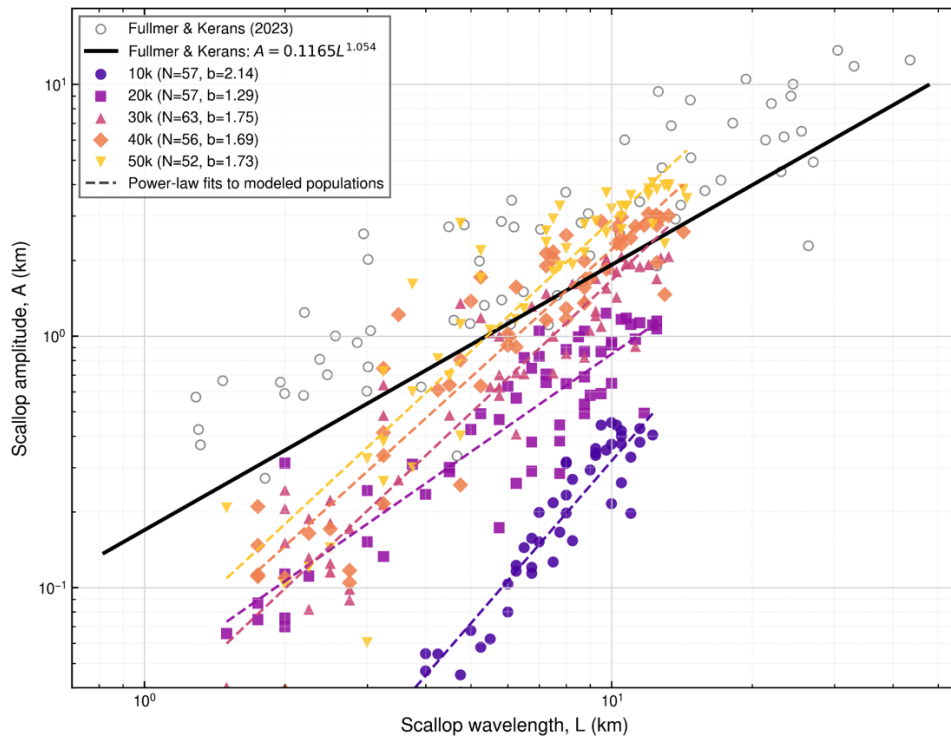


Figure 4: Evolution of modeled scallop amplitude–wavelength scaling. Colored symbols show modeled scallop populations at successive iterations; dashed lines are power-law fits to each population. Open circles and the solid black line represent the digitized Fullmer and Kerans (2023) observations and their empirical scaling relationship, respectively. With continued model evolution, the population expands toward greater amplitude and progressively overlaps the observed amplitude–wavelength field. The model therefore reproduces the expected positive scaling between scallop size and relief, although its late-stage relationships remain steeper than the observational trend.

IMPLICATIONS

The experiments indicate that scalloped carbonate-platform margins can arise through autogenic erosional self-organization, without requiring a prescribed scallop wavelength or episodic mass wasting to initiate their planform. The modeled features develop a systematic amplitude–wavelength relationship and progressively enter the field occupied by natural scallops, suggesting that their characteristic scaling may emerge from interactions among flow focusing, erosion, and evolving topography.

These findings provide a process-based explanation for how large, regularly scaled erosional landforms can develop on carbonate margins without repeated slope failure. This distinction matters because scalloped morphology may record persistent interactions between sediment-gravity flows and margin topography rather than a history dominated by discrete mass-wasting events. Recognizing such autogenic organization could therefore improve interpretation of modern bathymetry, ancient margin architecture, and the processes responsible for sediment transfer into deep water.

REFERENCES

- Fullmer, S., and Kerans, C., 2023. Unveiling the accretionary origins of scalloped carbonate platform margins: Implications for carbonate platform evolution and demise. In *Advances in the Understanding and Interpretation of Carbonates*, SEPM Short Course Notes. <https://doi.org/10.2110/sepmcn.057.02>
- Hine, A.C., Locker, S.D., Tedesco, L.P., Mullins, H.T., Hallock, P., Belknap, D.F., Gonzales, J.L., Neumann, A.C., and Snyder, S.W., 1992. Megabreccia shedding from modern, low-relief carbonate platforms, Nicaraguan Rise. *Geological Society of America Bulletin*, 104, 928–943.
- Jo, A., Eberli, G.P., and Grasmueck, M., 2015. Margin collapse and slope failure along southwestern Great Bahama Bank. *Sedimentary Geology*, 317, 43–52. <https://doi.org/10.1016/j.sedgeo.2014.09.004>
- Lehrmann, D.J., Minzoni, M., Enos, P., Kelleher, C., Stepchinski, L., Li, X., et al., 2020. Giant sector-collapse structures (scalloped margins) of the Yangtze Platform and Great Bank of Guizhou, China: Implications for genesis of collapsed carbonate platform margin systems. *Sedimentology*, 67(6), 3167–3198. <https://doi.org/10.1111/sed.12740>
- Mullins, H.T., and Hine, A.C., 1989. Scalloped bank margins: Beginning of the end for carbonate platforms? *Geology*, 17(1), 30–33. [https://doi.org/10.1130/0091-7613\(1989\)017](https://doi.org/10.1130/0091-7613(1989)017)