SELF-ORGANIZATION IN CARBONATE DEPOSITIONAL SYSTEMS

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PROJECT OBJECTIVES

- To simulate reefal buildup morphogenesis using a spatially-explicit mathematical model based on partial differential equations (PDEs).
- To track self-organized processes through time and distinguish among alternative mechanisms of reef morphogenesis.
- To use modern shallow-water scleractinian reefs as a model biome for investigating biotic self-organization as a structuring force in carbonate depsitional systems.

PROJECT RATIONALE

Reefs, whether built by scleractinian corals or their more ancient predecessors, have frequently been shown to simultaneously display two important hallmarks of spatial self-organization—scale-invariant patchiness and coherent spatial patterning. Alacranes Reef, situated in the Gulf of Mexico, demonstrates such 'morphogenesis' in exemplary fashion. Importantly, this pattern manifests at scales of tens of meters, to kilometers, which can easily be resolved from orbit (Purkis et al., 2015; Schlager and Purkis, 2015). A hallmark of the emergent patterning induced by self-organization is that it lacks a characteristic scale, as the fractal (power-law) size-frequency distribution of the Alacranes platform-interior reefs demonstrate. Power-law scaling implies one dominant process of reef growth at all scales (Brown et al., 2002). Scale invariance is not only observed within individual reefs, but also for entire archipelagos (Schlager and Purkis, 2013). Emergent patterning is not rare; preliminary results emphasize that 30% of atolls globally show a degree of spatial coherence of their lagoonal reefs and 15% show pronounced regular patterning. Based on the conceptual model proposed by Purkis et al. (2016), frame-building carbonate systems undergo a predictable sequence of emerging self-organized patchiness as ecological stress accumulates.

APPROACH

This project will deliver a mechanistic understanding of the triggers for self-organized patterning in carbonate depositional environments by integrating remote sensing, spatial patterning analysis, numerical morphogenesis modeling and comparisons of modern reefs that inhabit diverse environmental settings. Preliminary results suggest globally observed reef patterns can be clustered into nine groups and correspond to at least two different evolutionary paths in response to different local environmental conditions (Fig. 1). To test this hypothesis and further explore the underlying mechanisms, a mathematical model is developed, driven by four governing equations to describe the dynamics of four state variables: [i] reef biomass

(B; kg/m^2), [ii] sediment accumulation (S; mm), [iii] water depth (w; mm), and [iv] flow velocity (v; m/s).

SIGNIFICANCE

This project has the potential to advance scientific knowledge by a) quantifying a reef morphology that has only been described qualitatively, b) identifying relationships between sea surface temperature (SST), community structure, and reef reticulation, as the cellular nature of a highly developed reticulate reef suggests that the reefs therein may be subject to shallower and warmer waters, c) identifying the key processes driving the formation of reticulate reefs using numerical models, and (d) exploring the possibility of SSO in reticulated reefs and the geological significance of their patterning.

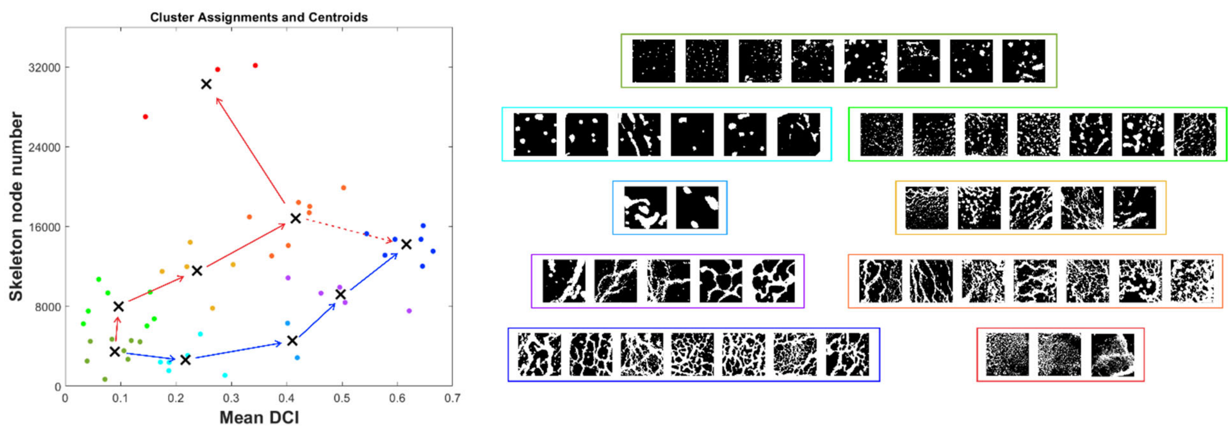

Figure 1: Clustering results of 50 global coral reef patterns showing nine groups and at least two evolution paths.

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