

THE NATURE OF REEFS IN MIXED CARBONATE– SILICICLASTIC SYSTEMS

Paul (Mitch) Harris

KEY POINTS

- The mixing of carbonates and siliciclastics occurs in a variety of situations, spanning a wide range of timescales and geographic settings (= mixing over time and space).
- When mixing is coeval, reefs can develop under elevated turbidity for short durations; prolonged sediment influx can, however, smother reefal organisms or induce a change in the reefal community, but these stresses can be localized, leading to a reef niche as shown by a key modern example.
- Reefs therefore do occur in mixed settings, but a literature search indicates reef examples in turbid conditions are minimal over geologic time.
- The ultimate reef, and therefore reef reservoir, geometry and turbidity are related in that under these circumstances, reefs are 1) smaller, 2) more elongated, 3) more flat-lying, and 4) more heterogeneous.

RESULTS AND SIGNIFICANCE

Mixing and interbedding of carbonate and siliciclastic sediments are common throughout the geologic record. Because of the importance of this mixing to subsurface investigations, I became most interested at an early stage in my career (Budd and Harris, 1990; Lomando and Harris, 1991) and stayed involved during many projects in the U.S. Permian Basin and Gulf Coast, the Middle East, offshore West Africa, and elsewhere. We learned that these types of depositional mixtures occur at a variety of scales and to all degrees (mixing over time and space), e.g., 1) regionally extensive carbonate and siliciclastic depositional systems can replace one another in time and space; 2) carbonate and siliciclastic facies can be cyclically interbedded or grade laterally into one another; and 3) minor amounts of siliciclastics may occur within a coeval limestone facies or vice versa. It is the coeval mixing situations that are focused on herein, and particularly how reefs respond to the influx of fine sediment.

Specific to reefs, excessive turbidity is generally considered to be unfavorable. For instance, Field et al. (2019) concluded that “the effects of sediment runoff are to shade, abrade, and (or) smother coral and promote macroalgal growth, which in turn leads to further coral smothering and reef loss”. But at the same time, numerous modern reef studies show scleractinian coral reefs respond to sediment stress and thereby persist by exhibiting lower growth rates, fewer species, declining calcification, fewer living corals and, consequently, continued but slower reef accretion. Inhabiting turbid-water settings with high sedimentation rates is also possible through a range of passive and active survival strategies: 1) when water circulation driven by waves and currents flushes fine-grained sediment from the feeding surface of sessile reef organisms; 2) the morphology of reef organisms causes sediment to ‘slide off’ due to gravity; or 3)

organisms respond to sediment inundation with active self-cleaning. So seemingly, if certain conditions are met, the potential is indeed there for reefs to continue developing in turbid-water conditions.

But does an analysis of reef systems over time support the notion that reefs can thrive in mixed settings? Unger et al. (2025) performed a SCOPUS literature search to review case studies of sediment-stressed reefs from the Cambrian to the Recent (n = 39,261) and their results provide valuable insight to this question (Fig. 1). Their examples were selected based on the presence of a mixed carbonate-clastic matrix and the existence of a coral framework, and for each example the system was characterized in terms of sediment input, organism growth forms and the overall reef architecture.

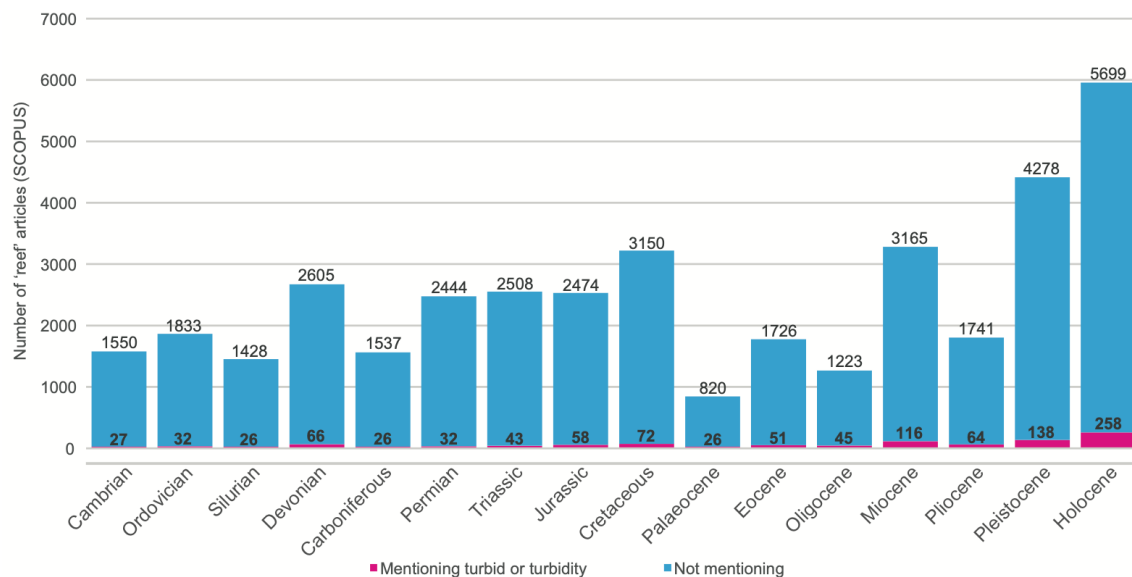


Figure 1: Bar chart showing results from Unger et al. (2025). Their literature search shows there are far more articles for each period that deal with reefs in general than those that also contain 'turbidity' or 'turbid' as keywords.

There are some major shortcomings to the Unger et al. (2025) study, however, in that the literature search results were not rigorously examined and the Paleozoic and Mesozoic examples were not as well characterized as Cenozoic ones. Despite these shortcomings, the results shown in Figure 1 are likely a reasonably representative view of how reefs through time have "behaved" in mixed settings with the major, and significant, takeaway being that reef examples in turbid conditions are minimal (note the examples highlighted in red on Figure 1 – only 2.75% of the examples mention turbid or turbidity and only 0.06% mention sediment stress on the reef). Despite this extremely small percentage of 'stressed' reef occurrences, there are significant insights highlighted by those examples: 1) even during times of high sediment fluxes, reef formation takes place if the right bioconstructors find a suitable substrate in moderately turbulent water (i.e., a reef niche); 2) siliciclastic sediment does impact reef morphology by limiting both the vertical and lateral extent of reef development—higher volumes of clastic influx typically result in smaller, more elongate, and flat-lying reefal bodies; and 3) reefs and reef complexes developing

in sediment-stressed settings exhibit lateral and vertical variability (heterogeneity) at a range of scales.

A key modern example (Fig. 2a) illustrates the potential complexity of developing a reef niche and one scenario showing how it can be localized in a mixed setting. Field et al. (2008a,b; 2019), Jokiel et al. (2008), Ogston et al. (2008), and others have examined the south side of Moloka'i in Hawai'i, which hosts a nearly continuous coral reef for approximately 44 km, making this example the longest fringing coral reef in the Hawaiian chain, and arguably the longest in the U.S. array of coral reefs. The combined acreage where live coral exceeds 50% on Figure 2a exceeds 7,600 acres—a sizable footprint. This impressive reef system has developed over the last few thousand years despite immediately fronting an extremely high and steep island that is rapidly weathering. Collectively, the Moloka'i reefs as well as others in the greater Maui area demonstrate that the “relatively healthy” examples suggest important feedbacks including those related to clastic influx promoting survivability: 1) high coral cover provides strong temporal continuity within a reef tract; 2) the large size of each major reef tract provides a measure of insurance for survival; 3) the major reef tracts are separated by distances large enough that a major stress to one reef tract may not affect other areas; and 4) the variety in orientation and shape of the reef tracts provides security against severe natural stresses, such as storms and large waves.

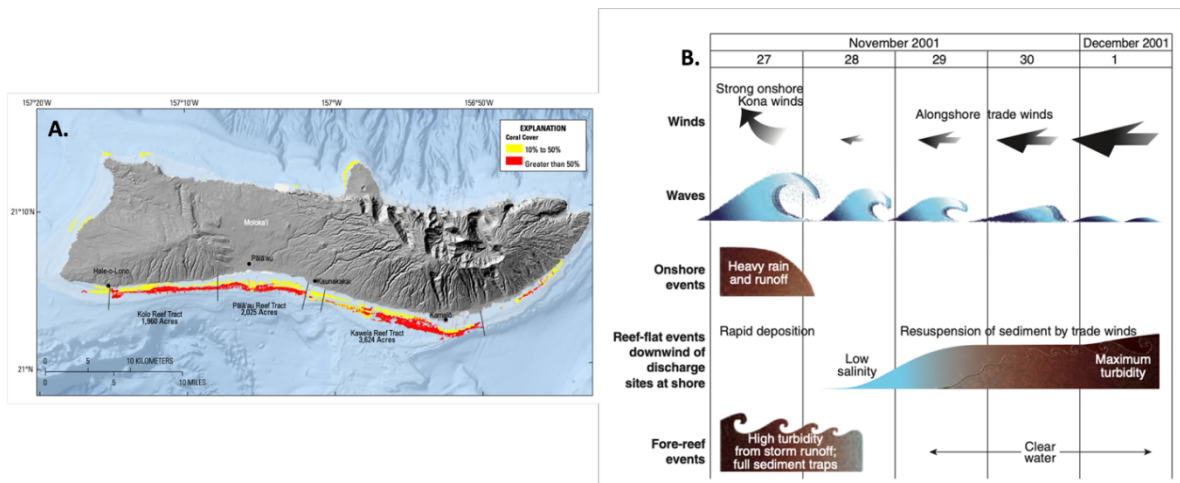


Figure 2: Modern reef example in a mixed setting from Moloka'i, Hawai'i. (A) DEM of Moloka'i from Field et al. (2019) highlighting lengthy fringing reef along southern coastline. (B) Schematic diagram from Field et al. (2008b) summarizing events over a 5-day period influencing turbidity and sediment transport across the reef.

Results from the very thorough studies of these reefs suggest one manner in which a reef niche can develop. In essence, in this particular example of mixing the reef-flat and reef crest/fore-reef are decoupled in the short term leading to the better development of a reef niche farther from the shoreline (~1 km). To illustrate, note on Figure 2b that the rainfall and wave stress are at a maximum on November 27 and wave-induced turbidity was immediate on both the reef-flat and fore-reef. But sedimentation and maximum turbidity came later on the reef-flat than the fore-reef as terrigenous flood deposits were gradually and increasingly resuspended by trade-wind waves and transported west by currents.

The various drivers impacting reef growth and sediment transport work together in a complex manner as shown by this example to localize niches for potential reef development in a mixed system setting.

IMPLICATIONS

Studies of modern reefs suggest turbidity will seemingly kill reefal organisms or induce a change in the reefal community. But the modern example cited shows how the impact of fine siliciclastics can be distributed unevenly within a reef system, so that a reef niche can develop and reefs can locally thrive in a mixed setting. But did ancient reef communities (e.g., microbial, Paleozoic corals, stromatoporoids, phylloid algae, rudists) behave in a similar fashion to modern corals? Likely not, so undoubtedly a better understanding of the behavior of reef formers in the past is needed to better understand the possible occurrence of reefs and their characteristics in mixed settings over geologic time. Of particular importance in the context of subsurface analog relevance, the review of reefs through time suggests reef and reef reservoir geometries under sediment influx are 1) smaller, 2) more elongated, 3) more flat-lying (biostromes), and 4) more heterogeneous. But are these really universal rules and therefore predictable?

REFERENCES

- Budd, D.A. and Harris, P.M. (eds.), 1990, Carbonate - Siliciclastic Mixtures: SEPM Reprint Series No. 14, 272 p.
- Field, M.E., Cochran, S.A., Logan, J.B., and Storlazzi, C.D. (eds.), 2008a, The coral reef of south Moloka'i, Hawai'i - portrait of a sediment-threatened fringing reef: U.S. Geological Survey Scientific Investigations Report 2007-5101, 180 p.
- Field, M.E., Bothner, M.E., Chavez, Jr., P.S., Cochran, S.A., Jokiel, P.L., Ogston, A.S., Katherine Presto, M., and Storlazzi, C.D., 2008b, The effects of a Kona storm on the Moloka'i reef: November and December 2001, in Field, M.E., Cochran, S.A., Logan, J.B., and Storlazzi, C.D. (eds.), 2008, The coral reef of south Moloka'i, Hawai'i - portrait of a sediment-threatened fringing reef: U.S. Geological Survey Scientific Investigations Report 2007-5101, p. 159-164.
- Field, M.E., Storlazzi, C.D., Gibbs, A.E., D'Antonio, N.L., and Cochran, S.A., 2019, The major coral reefs of Maui Nui, Hawai'i - Distribution, physical characteristics, oceanographic controls, and environmental threats: U.S. Geological Survey Open-File Report 2019-1019, 71 p.
- Jokiel, P.L., Brown, E.K., Rodgers, K.S., and Smith, W.R., 2008, Reef corals and the coral reefs of South Moloka'i, in Field, M.E., Cochran, S.A., Logan, J.B., and Storlazzi, C.D. (eds.), 2008, The coral reef of south Moloka'i, Hawai'i - portrait of a sediment-threatened fringing reef: U.S. Geological Survey Scientific Investigations Report 2007-5101, p. 43-50.
- Lomando, A.J. and Harris, P.M. (eds.), 1991, Mixed Carbonate - Siliciclastic Sequences: SEPM Core Workshop No. 15, 568 p.
- Ogston, A.S., Katherine Presto, M., Storlazzi, C.D., and Field, M.E., 2008, Causes of turbidity on the Moloka'i reef flat and resulting sediment-transport patterns, in Field, M.E., Cochran, S.A., Logan, J.B., and Storlazzi, C.D. (eds.), 2008, The coral reef of south Moloka'i, Hawai'i - portrait of a sediment-threatened fringing reef: U.S. Geological Survey Scientific Investigations Report 2007-5101, p. 153-158.
- Unger, T., Lokier, S.W., Aretz, M., Saillol, M. and Immenhauser, A., 2025, Sediment-stressed reefs over the past 420 Myr: The Depositional Record, 00, 1-23.