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Large-Scale Export of Shallow Water Carbonate Sediment to Deep Water Settings: Findings from the Tropical Atlantic, Pacific and Indian Oceans

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In 1975 Conrad Neumann and Lynton Land introduced the concepts of *Overproduction* and *Export* of shallow water carbonate to deep water settings. Connie referred to his process sketch as "the muddy bucket emptying itself" via off-bank transport during storms. This outlook was in sharp contrast with the Darwinian carbonate platform model in which a "living rim" (coral reef) filled the bucket (atoll-lagoon) via on-bank transport during storms. The muddy bucket sketch has largely remained an inferential cartoon, awaiting solid observational data, for nearly 50 years.

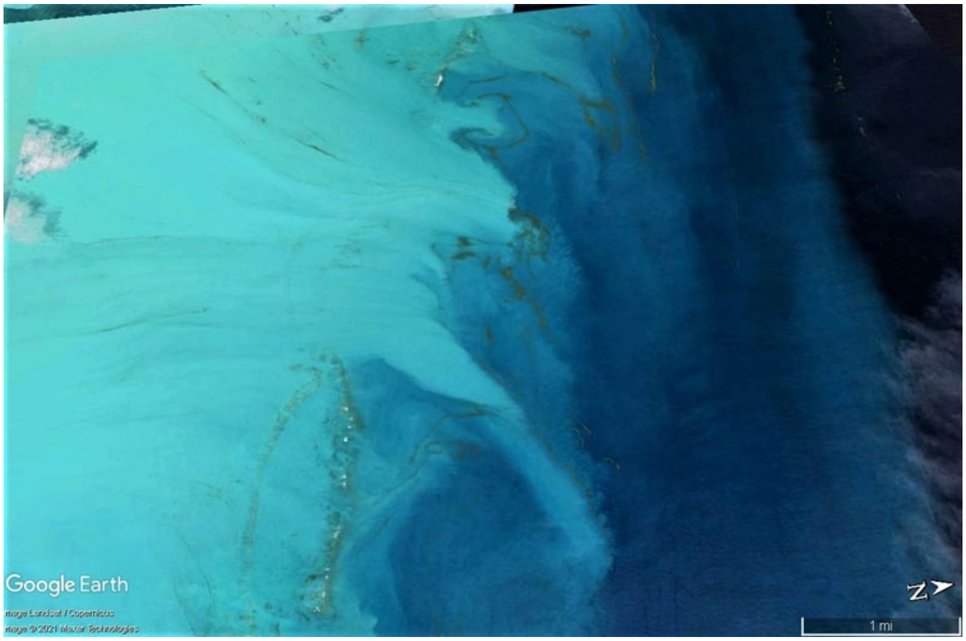
In the last 3 years Earth Observing Satellites (EOS) have revolutionized process sedimentology on the global scale. EOS use Moderate Resolution Remote Sensors (MRRS, 150-500 m), High Resolution Remote Sensors (HRRS, 15-50 m) and Very High-Resolution Remote Sensors (VHRRS, 15-50 cm). By combining images, sedimentological processes can be examined and measured with continuity over the full spectrum of time-space scales.

In this paper large scale sediment export from the shallow to deep is examined from three vast carbonate domains of the modern Earth: a) the Western Tropical Atlantic Ocean (WTAO) including the Bahamas and South Florida, b) the Western Tropical Pacific Ocean (WTPO) with a focus on the Coral Sea and, c) the Eastern Tropical Indian Ocean (ETIO) with a focus on the North Australian Shelf.

In all cases the heavy lifting is done by Tropical Low-Pressure Storms - hurricanes in the Atlantic and cyclones in the Pacific and Indian Oceans. Cold Front storms are of secondary consequence in the northern tier of the WTAO only. Storm characteristics are important in suspending sediment and providing lateral (off-bank) motion. The storm: a) must be Category 3 or higher with an Integrated Kinetic Energy (IKE) of ~100 terajoules, b) it must be slow-moving (6-14 kph) to allow effective fluid coupling between the lower atmosphere and upper ocean, and c) it must score a "direct hit" on the target with the eye passing very close to the source of carbonate. Finally: d) a "stall" of 6-30 hours over the target allows for maximum fluid coupling leading to maximum suspension and off-bank transport.

Apex export events were examined for each domain. The apex event identified for the WTAO is the strike of Hurricane Dorian on Little Bahama Bank in 2019. In the Coral Sea Cyclone Wati's remarkable disturbance of Bellona Plateau (2006) is the deepest (50-100 m) suspension event ever recorded. Cyclone Rusty's strike (2013) on the 80-Mile Beach embayment of the North Aussie Shelf moved inshore aragonite over 300 km across the shelf to the upper slope.
The examples presented here are the largest occurrences of suspension and shedding of shallow-water carbonate to deep-water settings ever documented. The amount of carbonate mobilized is measured in billions to trillions of kgs per event. The material shed is mostly inorganically precipitated aragonite in the WTAO and North Aussie Shelf with a mixture of skeletal materials for the Coral Sea.

These findings hold major implications for: a) shallow-to-deep carbonate sedimentology and stratigraphy, b) platform growth by progradation, c) rapid sequestration of metastable aragonite and d) CO_2 cycling in tropical seas.



Shedding of lobes of sand and mud over the north margin of Little Bahama Bank during Hurricane Dorian, September 2019. Sand cascades directly over the edge while mud remains suspended for days and hundreds of kilometers. Maxar *Ikonos* image, VHRRS.