

CEMENTATION ON MARGINAL SLOPES AND HIGH-RESOLUTION SEQUENCE STRATIGRAPHY – A TRIBUTE TO G. MICHAEL GRAMMER

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MIKE'S CONTRIBUTIONS

- Mike recognized the importance of micritic cementation on the marginal carbonate slopes in the modern and ancient.
- He quantified the rate of early marine cementation with an innovative open-ocean experiment and by dating botryoidal cements in Belize and the Bahamas, confirming that syndepositional marine cementation may not be limited to very shallow subtidal and intertidal environments.
- Mike's documentation of thickness variations in cycles in the Pennsylvanian strata of the Paradox Basin questioned key assumptions in cyclostratigraphy, such as complete filling of accommodation space and extraction of sea-level amplitude from cycle thickness.

MIKE GRAMMER

Mike Grammer was a longtime member and dear friend of the CSL, first as a student, then as a postdoc, and finally as an assistant professor before leaving to pursue his career at other universities. For the last 14 years he was the Regents Professor of Geology and Chesapeake Energy Endowed Chair of Petroleum Geology at Oklahoma State University. Mike was a first-rate scientist, teacher and mentor, who received awards for both teaching and scientific achievement from AAPG. I want to honor him by presenting three of his major contributions to carbonate geology.

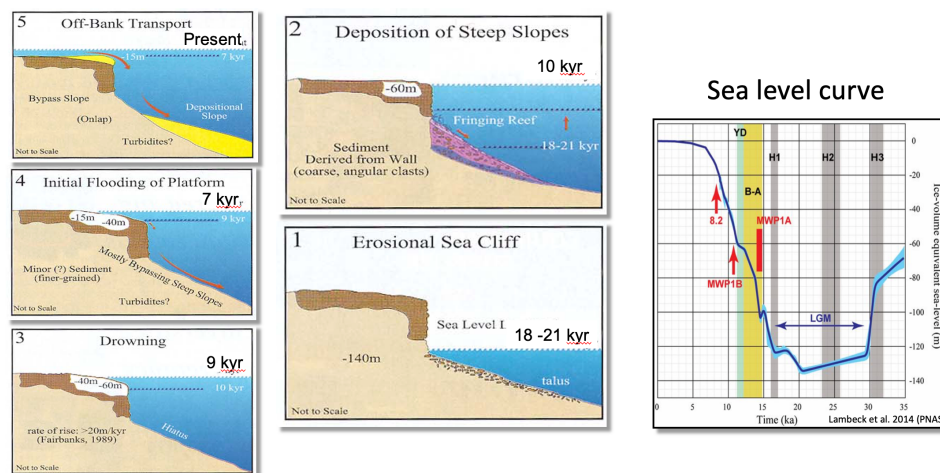


Figure 1: Platform margin evolution at the southern end of the Tongue of the Ocean from Grammer et al. (1993). Age dates document the development of a fringing reef on the marginal slope during the deglaciation and the micritic cementation of the reef and its rubble.

MICROBIAL CEMENTS IN MARGINAL SLOPES

Mike Grammer used 135 dives with a research submersible to investigate the steep margin and marginal slope in the Tongue of the Ocean. The outcome was a careful documentation of the morphology of the top 365 m of the slope and margin. The margin has three elements: the near-vertical escarpment (to -100 m) above a 35–45° cemented slope to ~200 m that is overlapped by a non-cemented sediment wedge. The cemented slope is dated from 13,935 to 10,790 years, placing it into the fast sea-level rise during the deglaciation after the last glacial maximum (LGM). Cementation of the steep slope is mostly by micritic Mg-calcite that occurs in a variety of forms, including micritic rinds, peloidal cement, and bladed Mg-calcite (Fig. 2). Aragonite needle cement and botryoidal cements form much of the less abundant crystalline cement.

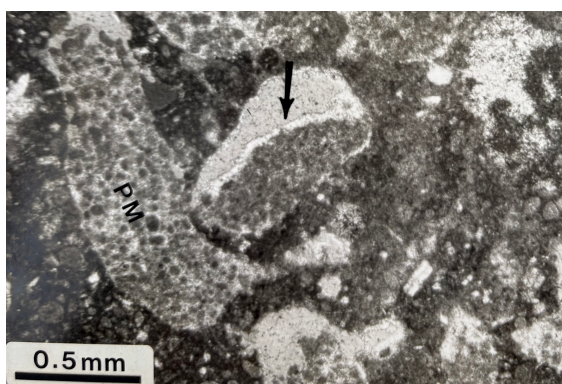


Figure 2: "Peloidal micrite, consisting of rounded, "clotted" grains of micrite that average 20-40 μm in diameter, is relatively common in both interior and surface slope samples. The peloids are always composed of Mg-calcite and are typically cemented with finely crystalline (20-75 μm) bladed Mg-calcite. Peloidal micrite is found only as a pore-filling cement, typically infilling borings and other sheltered cavities in a rock." (Grammer et al. 1993)

In 1993, none of the lowstand reefs that grew during the last glacial maximum and the deglaciation had been drilled, and the abundance of microbialite in their reef framework was not known. The similarity of the microbialites and micritic cements in these lowstand reefs prompted Jesus Reolid and Mike Grammer to reexamine the coeval cemented slope. This re-examination revealed the importance of microbial binding during the transgressive phase of the platform margin (Reolid et al., 2017). These results imply first, that the role of microbial binding in stabilizing slopes is underestimated and, second, that the phase of the microbial binding/cementation is likely related to transgressive phases in the margin evolution.

The ages of microbially cemented slopes in the Bahamas and Belize are coeval with the increased microbialite observed in all cores recovered from lowstand reefs, including the one from offshore Mozambique. This increased contribution of microbial and micritic cement during deglaciation and early transgressions might reflect a general, yet unexplained phenomenon of changing cementation pattern that is related to sea-level fluctuations.

RATE OF EARLY MARINE CEMENTATION

Although submarine cementation had been documented for a long time (James and Ginsburg, 1979), the rates, especially in deeper platform and platform marginal environments, were still in question. In fact, "syndepositional" cementation was suggested to take tens to thousands of years (e.g., James and

Choquette, 1990). With two studies, Mike Grammer provided the first quantitative data for the growth of aragonite cement.

In a first study, Mike collected botryoidal aragonite cements along the steep (35–45°) marginal slopes of the Tongue of the Ocean, Bahamas, and from the slope off the barrier reef in Belize using free-diving research submersibles. Growth rates of marine botryoidal aragonite cements were then determined by accelerator mass spectrometry radiocarbon dating of samples taken at the base and top of individual botryoids. The pore-filling cements, which range from approximately 11,000–13,000 years old, grew at average rates of 8–10 mm/100 yr with maximum rates >25 mm/100 yr (Grammer et al., 1993).

In a subsequent study, Mike deployed substrates containing samples of carbonate sand (ooids) suspended above the seafloor at various depths in the Bahamas to evaluate the rates of cement growth through direct observation (Grammer et al., 1999). The results revealed that cementation produced partial lithification of ooid sands within 8 months and complete lithification after 20 months in water depths of up to 60 m (Fig. 3).

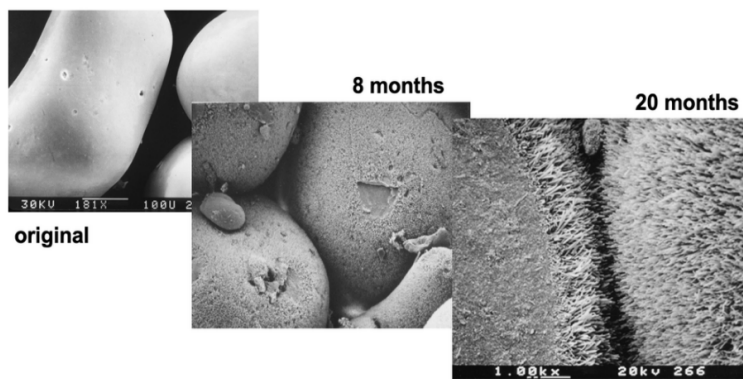


Figure 3: SEM images of the cementation experiment offshore Lee Stocking Island, Bahamas, illustrating the rapid growth of aragonite needle cement on ooid grains. After 20 months the cement is stronger than the grain, indicating that the sediment is transformed into a rock.

Both studies provide the first direct evidence for rates of cementation in deeper marginal environments, and confirm earlier hypotheses that very rapid, syndepositional marine cementation may not be limited to very shallow subtidal and intertidal environments.

LATERAL VARIABILITY OF DEPOSITIONAL CYCLES

Carbonate depositional cycles are deposited during a cycle of relative sea-level rise and fall and are bounded by an exposure horizon. Consequently, they have been exploited to extract past sea-level fluctuations, often with the help of Fisher plots. Fisher plots assume a constant subsidence rate, equal cycle duration, and the complete filling of the accommodation space in each cycle. One analysis in the Paleozoic was done by Goldhammer et al. (1991) in the Pennsylvanian of the Paradox Basin using one measured section along the Honaker Trail. Mike Grammer later measured many sections within the coeval strata in the basin and documented the variability of the cycle thickness (Grammer et al., 1996, 2000). He measured lateral variability within the cycles in both the distribution and thickness of facies. This variability occurred within tens or a few hundred meters, as well as on a kilometer scale, indicating that many of the cycles did not fill all available accommodation space and, thus, cycle thickness is of limited value for assessing sea-level amplitude with cyclostratigraphy.

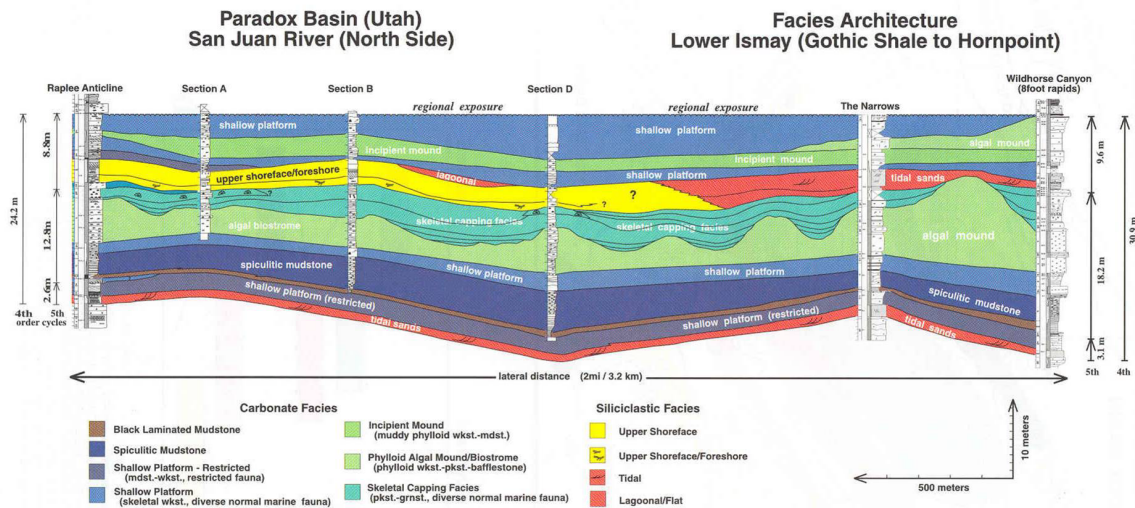


Figure 4: Detailed cross section through the Lower Ismay sequence illustrating the thickness variations in a single 5th-order cycle set. Algal mounds are up to 12 m high and thin laterally into few-meter-thick cycles. These thickness variations indicate unfilled accommodation space and consequently uncertainties when relating thickness of a cycle to sea level amplitude (from Grammer et al., 1996).

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