STEEP MICROBIAL BOUNDSTONE MARGINS - RETHINKING THE CARBONATE FACTORY-DEPTH PARADIGM

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KEY POINTS

- Outcrop and subsurface examples of a highly productive microbial boundstone factory extending from the platform break significantly down the slope provide sedimentological insight and a depositional model to be used elsewhere.
- When the dominant factory is microbially induced as in the examples considered here, high rates of carbonate production extend to great depths and new production-water depth profiles should be considered.

METHODS AND RESULTS

Outcrops of two prograding steep, high-relief margins fronting deep basins - Asturias, northern Spain and the Capitan shelf margin in the Guadalupe Mountains of West Texas/New Mexico - serve as important analogs for hydrocarbon reservoirs in steep-sided isolated platforms of the North Caspian Basin, Kazakhstan, such as Tengiz, and more importantly provide sedimentological insight and a depositional model to be used elsewhere. Results are particularly relevant to current studies at the CSL. Seismic and well data from Tengiz (Collins et al., 2006, 2013), one of the larger fields in the Pricaspian Basin characterized by Latest Visean and Serpukhovian progradation, corroborate outcrop patterns of Serpukhovian to Moscovian progradation in Asturias (Della Porta et al., 2003, 2004). These margins show progradation of up to 5 km and more than 10 km, respectively, despite the high-relief (up to 600 m) and their steep (~20-32°) nature. The prograding Guadalupian Capitan Reef Margin displays similar geometries and progradation rates (Kerans and Tinker, 1999; Harris and Saller, 1999).

These examples share a highly productive microbial boundstone factory extending from the platform/shelf break down the slope to nearly 300 m (or more) depth and a lower slope dominated by (mega)breccias and grain flow deposits derived from the margin and slope itself (Figs. 1 and 2). Carbonate production on the slope may have been controlled by availability of organic substrates, microbial communities and environmental parameters (temperature, saturation state of sea water, nutrients, oxygen levels, degree of agitation) that are as well affected by water depth but they are not limited to the shallowest photic zone, as in recent reefs. The broad depth range of a microbial and cement boundstone "factory" increases the potential for production during both lowstands and highstands of sea level and thereby facilitates progradation (Kenter et al., 2005). Rapid in situ lithification of the boundstone provides stability to the steep slopes but also leads to readjustment through shearing and avalanching. This model of "slope" shedding has implications for slope readjustment, slope architecture, sequence stratigraphic models, and reservoir characterization. And as shown by the Tengiz example, the isotropic character of microbial boundstone will reduce the potential for coherent seismic reflections to develop and possibly invoke, under certain stress regimes, shattering and fracturing thereby generating significant non-matrix permeability.

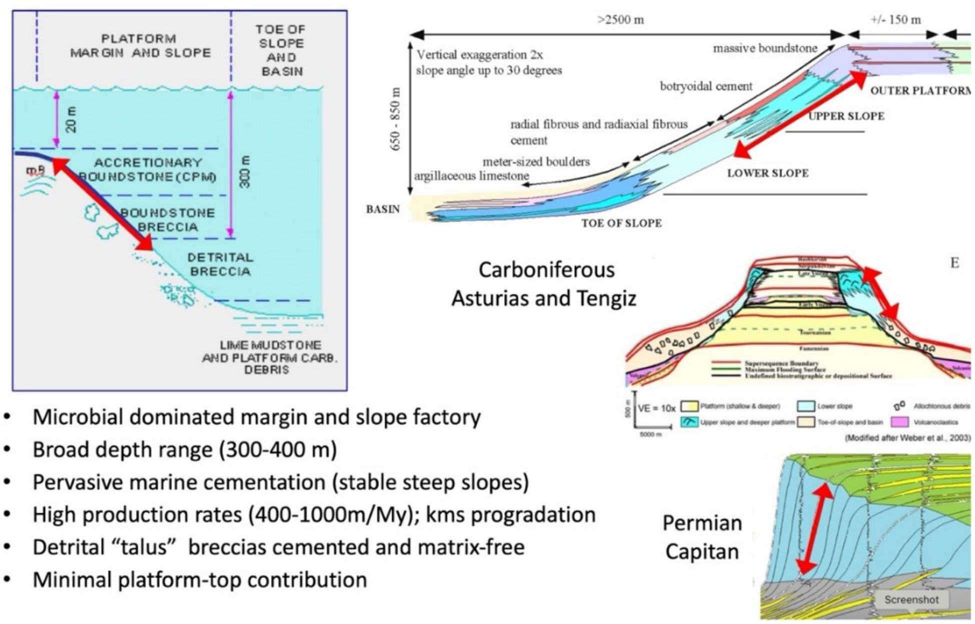

Figure 1: Depositional model for Late Paleozoic high-relief microbial boundstone slopes. Red arrows denote depth range of the microbial boundstone factory in each example.

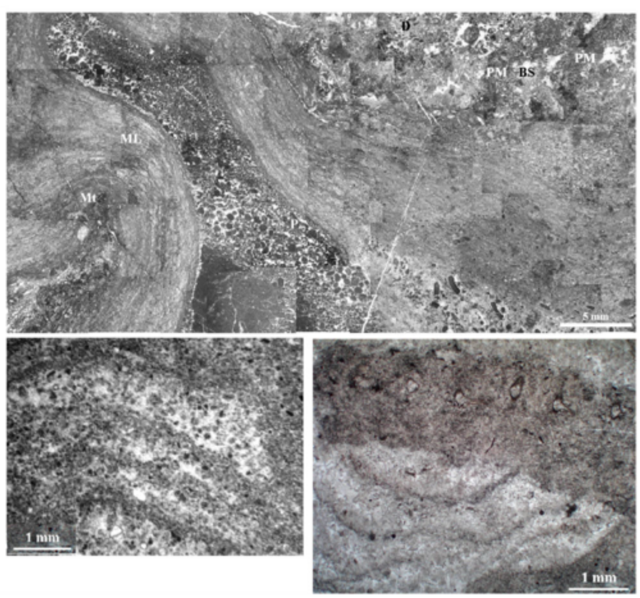

Figure 2: Photomicrographs of Asturias samples of upper slope boundstone showing (top) cabbage to nodular-shaped laminated structures of alternating micrite and thin layers of fibrous cement and microspar; (bottom left) micrite occurring as clotted peloidal fabrics or as peloidal grainstone forming nodular structures with sharp outlines surrounded by radial fibrous cement; and (bottom right) botryoidal (recrystallized) cement alternating with thin micrite laminae.

SIGNIFICANCE

A fundamental concept of carbonate sedimentology derived primarily from the study of modern carbonate settings is the exponential decrease of carbonate production with increasing water depth from a maximum at shallow depths to the base of the photic zone. However, when the dominant factory is microbially induced as in the examples considered herein, high rates of carbonate production extend down the slope to considerable depths and new production-water depth profiles should be considered (Fig, 3).

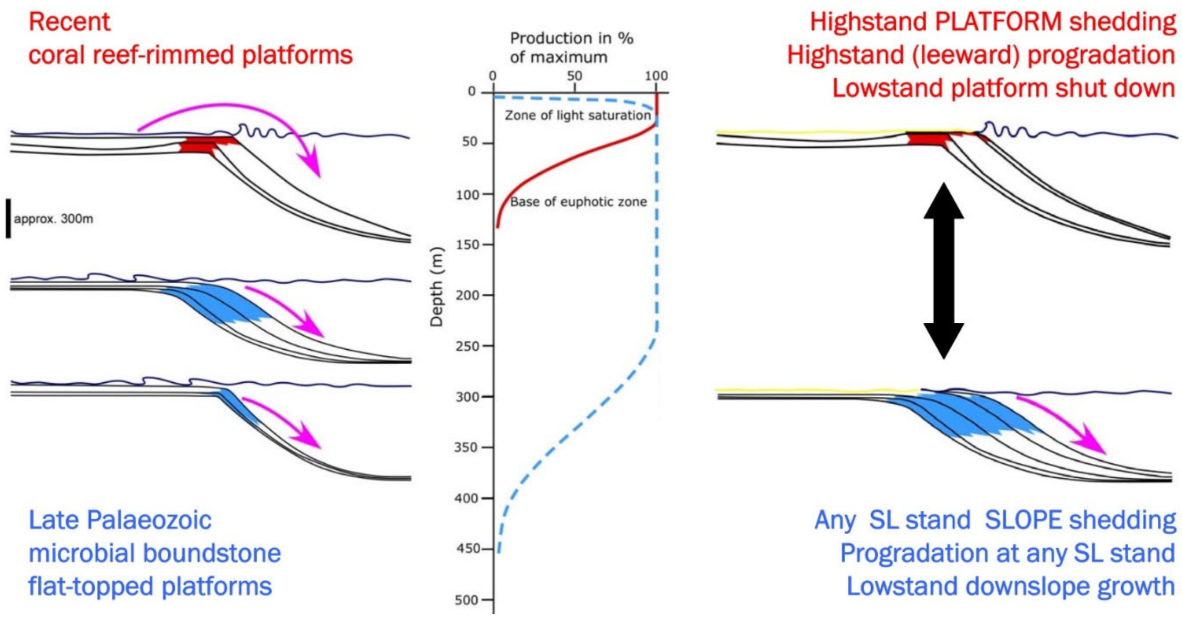

Figure 3: Comparison between the self-nourishing slope and slope shedding model developed from the examples discussed herein (highlightd in blue) with the platform shedding model commonly invoked for modern settings (shown in red). Accepting the former requires a paradigm shift for the carbonate production vs water depth relationship.

Other important aspects demonstrated by the subsurface and outcrop examples are: 1) carbonate production on the slope is controlled by environmental parameters (temperature, nutrients, oxygenation) and the microbial boundstone response to relative sea-level changes differs from modern reefs, 2) carbonate growth is not seriously reduced during sea-level falls because it can continue downslope, 3) progradation can take place at high rates despite the lack of platform top shedding (slope vs. highstand shedding), 4) the detrital lower slope consists mostly of matrix-free cemented rudstone/grainstone sourced by the slope boundstone with subordinate platform top derived material, and 5) generalized concepts of leeward progradational vs. windward aggradational margins need revision because platform margin progradation can be independent from platform-top shedding (and wind direction) and instead dependent on microbial boundstone production on the upper slope.

Consideration of the deeper production aspects of the microbial factory is timely for the CSL given the very recent interest in "*Microbial Cementation from the Shallow to the Deep*" (Eberli et al., 2025), and in particular the ongoing offshore Mozambique core studies and an examination of the cemented slopes in the TOTO, Great Bahama Bank, and the Red Sea. In addition, past work on the microbial aspects of Tengiz samples provides a valuable comparison to the ongoing detailed CSL studies of modern examples by Diaz et al. Andres et al (2012) investigated the presence of physical and chemical evidence of microbial activity in a suite of core samples from the Tengiz slope. The samples contain typical nanoglobules and grainy textures evidencing a distinctive microbial origin. Although the presence of such micro textures was not unexpected, their exquisite preservation considering their age is. This suggests very early, if not instantaneous mineralization and thus stabilization of the slope environment and lack of later destructive re-mineralization.

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