PS Microbial Boundstone Slope Shedding – A Model for Carbonate Platform Growth*

By

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Abstract

Characteristics of two prograding steep, high-relief margins fronting deep basins provide a depositional model which may apply elsewhere. Seismic and well data from Tengiz, 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 of northern Spain. 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.

Both examples share a highly productive microbial boundstone slope extending from the platform break 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. The broad depth range of microbial and cement boundstone "factory" increases the potential for production during both lowstands and highstands of sea level and thereby facilitates progradation. Rapid in-situ lithification of the boundstone provides stability to the steep slopes, but also leads to readjustment through shearing and avalanching. Remarkable observations are the contrasts with the Bahamian highstand shedding depositional model, little control by fluctuations in sea level or by paleo-wind directions due to their self-nourishing nature, and the accretion rates of in-situ boundstone.

This new model of "slope" shedding has implications for slope readjustment, slope architecture, sequence stratigraphic models, reservoir characterization, and reservoir modeling, especially given that 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.

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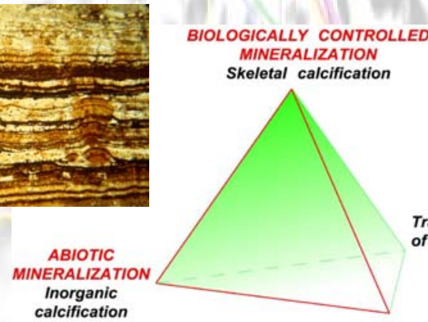
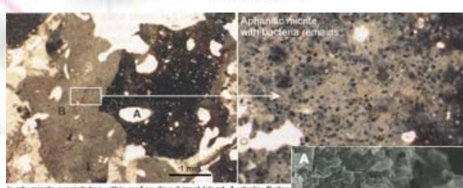
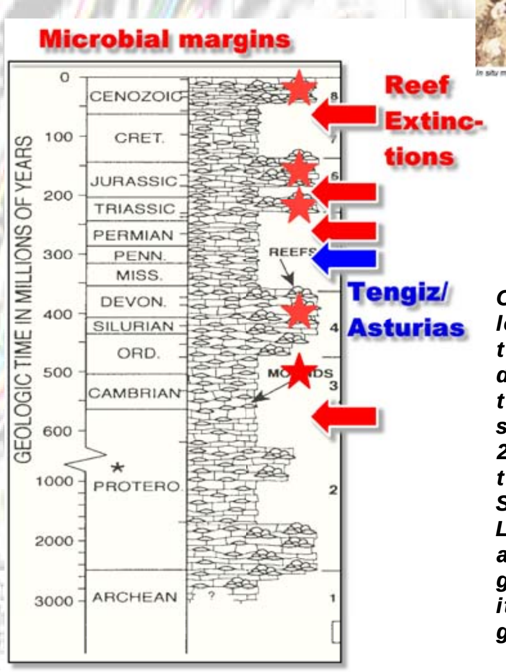
Microbes in the Geologic Record



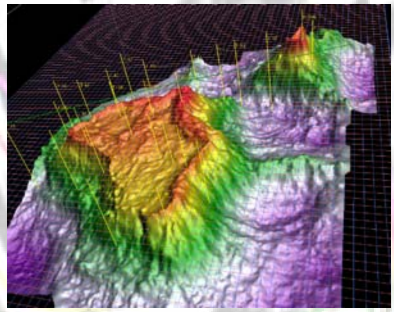


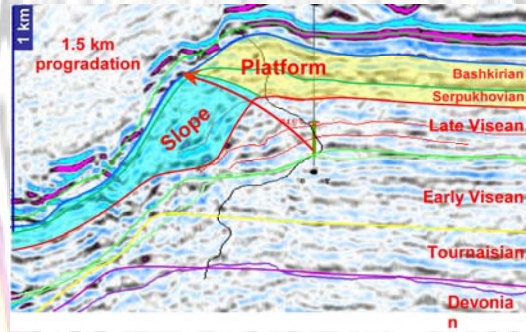
After Lidz et al. (2003)

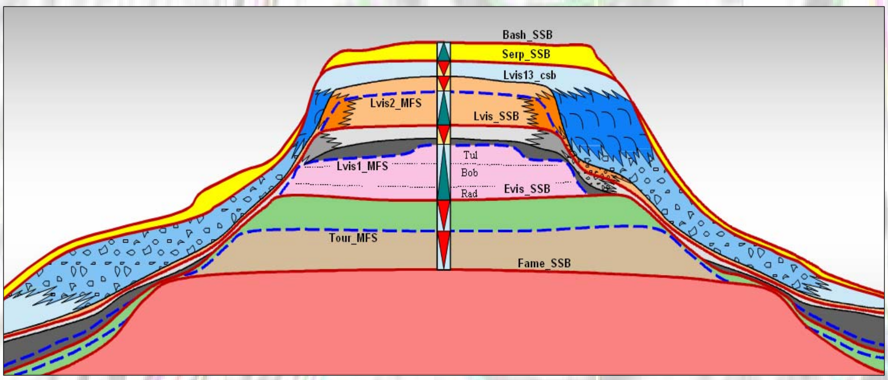


Outcrops in Asturias, Spain, and the Tengiz field in Kazakhstan are the locations of spectacular Late Paleozoic carbonate platform margins, that document the mostly underexposed role of microbes. Microbial deposits appear to be scarce in the Recent BUT built platform margins throughout most of the geological record, often following extinctions of skeletal reef intervals. In contrast, coralgal reefs are NOT the rule (only 25% in the Cenozoic). Microbes are thought to have dominated most of the geological record since five-hundred-and-thirty million years. Scanning electron microscope images from sediment samples from Lagoa Vermelha in Brazil, shown above, and many other locations around the world demonstrate the close association of bacteria with the generation of sediment particles in the Recent. From these observations it can be extrapolated that similar bacterial processes mediated the growth of sediments in the geological record as well.

Tengiz Field, Kazakhstan

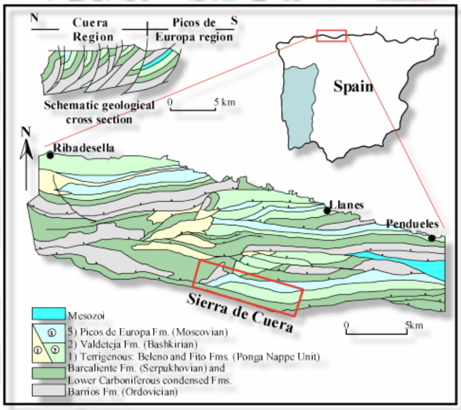




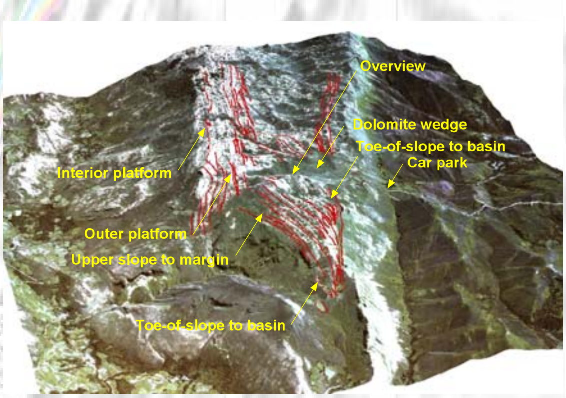


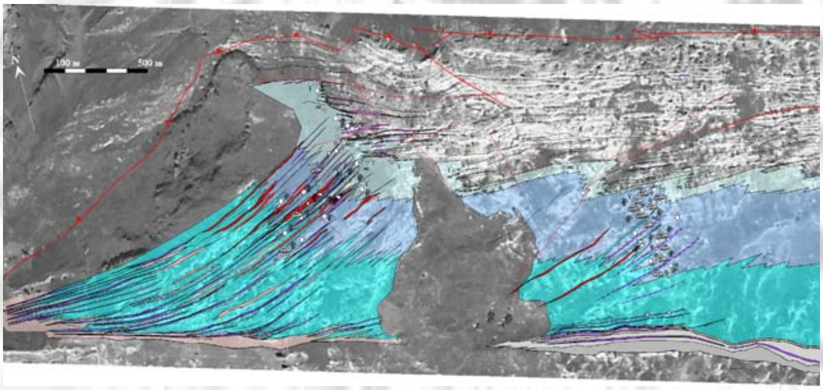
Tengiz field in western Kazakhstan produces oil from an isolated carbonate platform and its flanks. The Late Visean and Serpukhovian is characterized by several kilometers of platform progradation, followed by drowning and termination of the platform in the early Bashkirian. Platform to basin relief approached 1.5 km. One of the uncertainties of the Tengiz buildup was the nature of the high rising Late Visean to Serpukhovian flanks or slopes (0-700 m below the platform break) that comprise some 25% of the reservoir volume. Detailed observations and analog studies in northern Spain confirmed the presence of a "deep" microbial cement "reef" that extends from sea level down to more than 300 m below sea level.

Asturias Outcrops, Spain

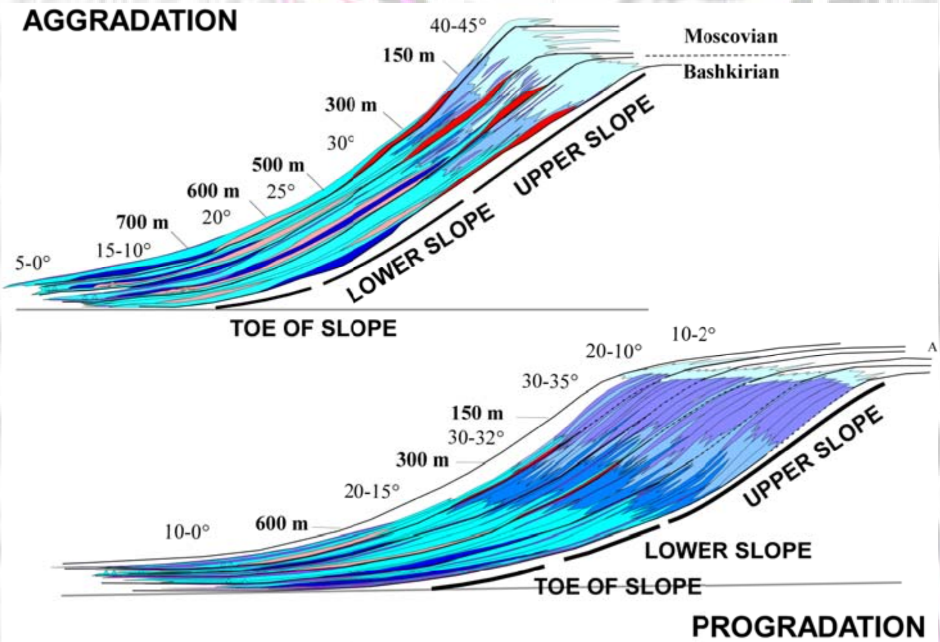


The understanding of the character and spatial distribution of lithofacies in the slope accelerated when an equivalent outcrop analog in northern Spain was studied. Upper to middle slope lithofacies are dominated by: 1) massive "cabbage-shaped" to "wave laminated" micrite-cement boundstone with dominant marine cements (25-60%) in primary cm-dm irregular-shaped voids with minor skeletal grains; 2) micrite-cement boundstone with minor "growth" structures, few primary voids, minor cement (<25%) and abundant platform-derived skeletal grains and; 3) mosaic breccia of in-place collapsed boundstone. Microfilamental fossils are abundant and interpreted as cyanobacterial species. It is most likely that microbes have played a role in the genesis of the peloidal and accretionary fabrics and mediated the growth of marine cements.

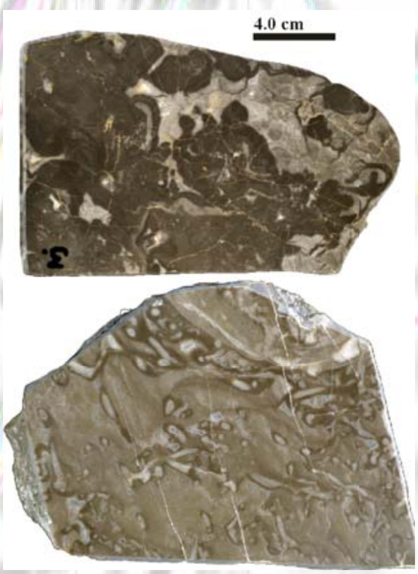




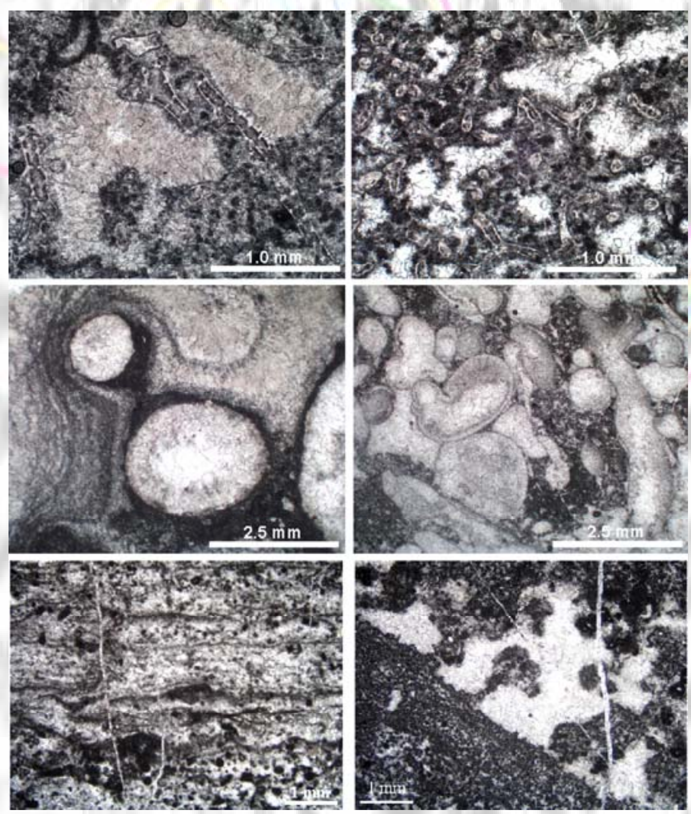
Asturias Slope Profiles and Rock Types

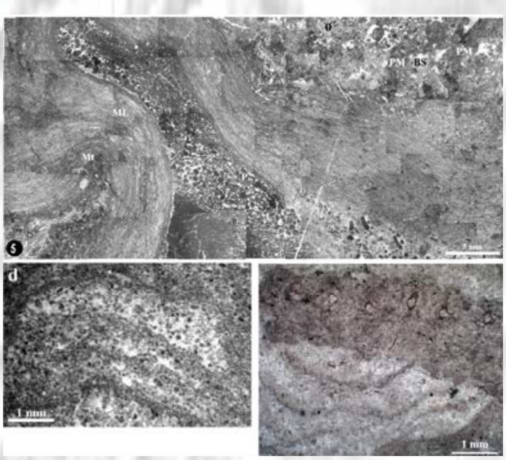


The rock types and their spatial distribution were mapped on outcrop and integrated with orthorectified aerial photos and DGPS tracked stratal patterns. Here, the slope environment shows different colors that correspond to each of the major facies. Most important is that the upper slope is dominated by in situ accretionary microbial cement boundstone and is the sole provider of detritus to the lower slope. Only in the toe of slope is platform top derived sand and rubble deposited.

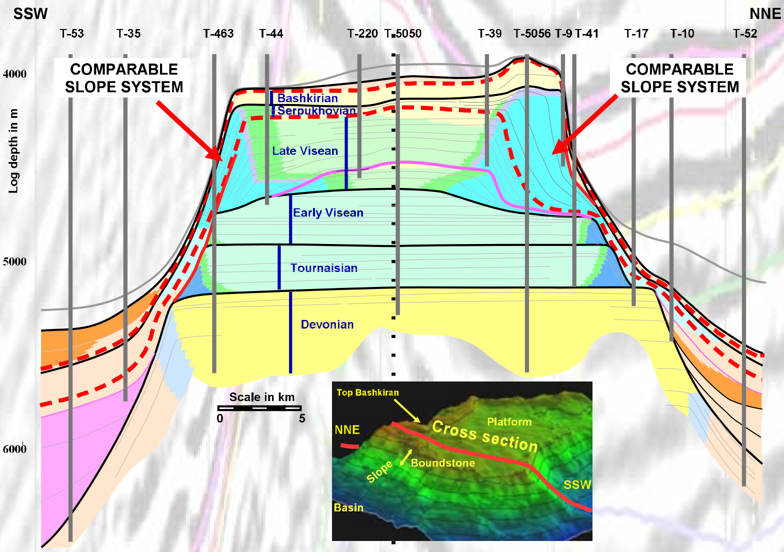


Microbial boundstone shows key attributes in slab and thin section, including clotted peloidal texture, micritic crusts, and accretionary growth forms.

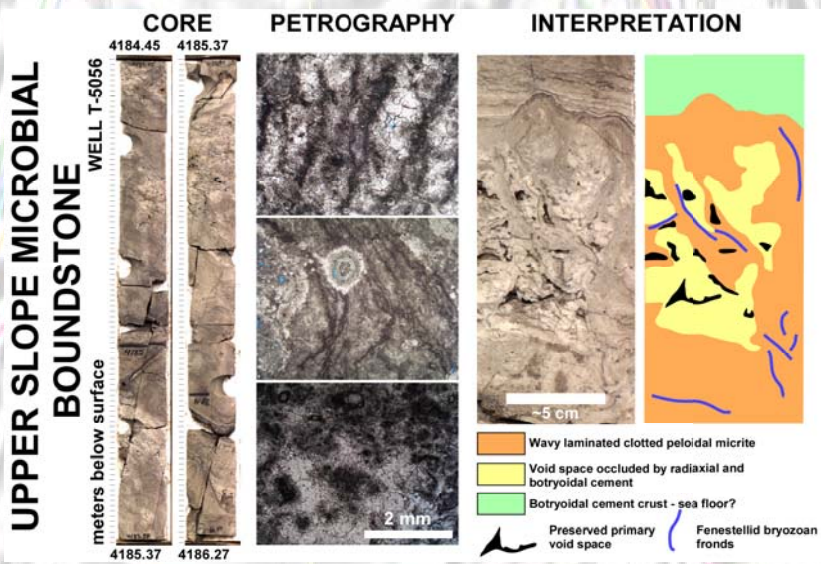




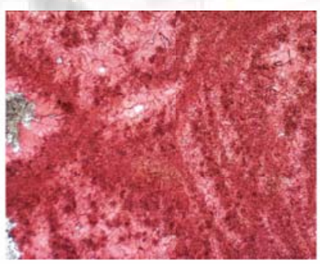
Tengiz Slope Profiles and Rock Types

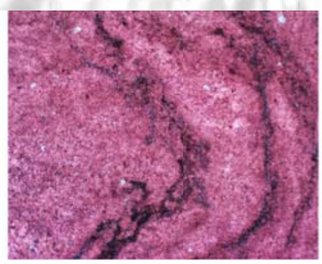


Upper to middle slope lithofacies in core are dominated by: 1) massive "cabbage-shaped" to "wave laminated" micrite-cement boundstone with dominant marine cements (25-60%) in primary cm-dm irregular-shaped voids with minor skeletal grains; 2) micrite-cement boundstone with minor "growth" structures, few primary voids, minor cement (<25%) and abundant platform-derived skeletal grains and; 3) mosaic breccia of in-place collapsed boundstone. Similarly to the Asturian boundstones, it is suggested that microbes have played a role in the genesis of the peloidal and accretionary fabrics and mediated the growth of marine cements.

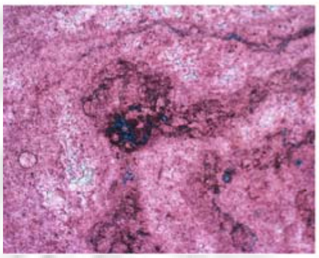


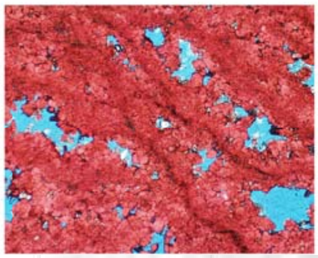
Laminated micrite and marine cement

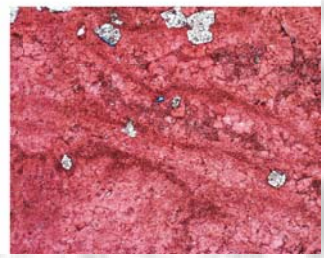




Recrystallized textures

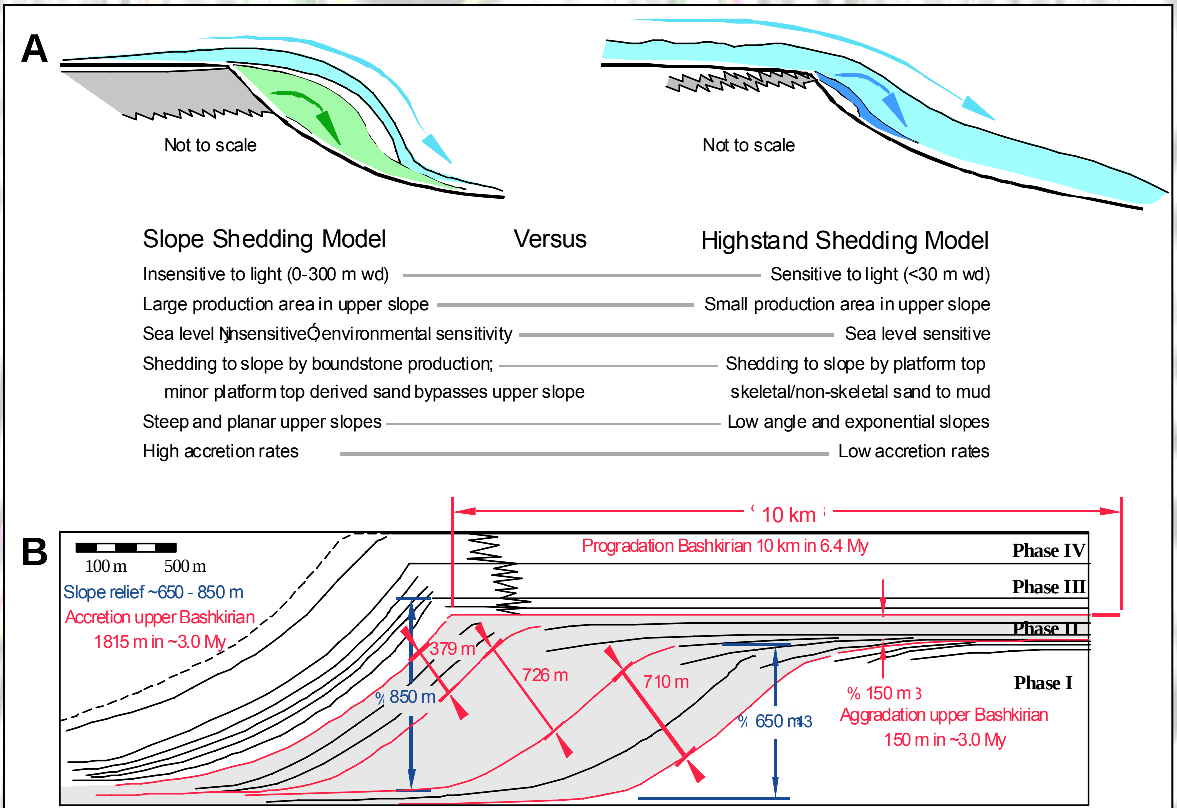






Implications of Microbial Boundstone Slopes

Both Tengiz and Asturias share a highly productive microbial cement boundstone factory extending from the platform break to nearly 300 m of water depth and a lower slope dominated by (mega) breccias and grain flow deposits derived from the margin and slope itself. The broad depth range of microbial cement boundstone increases the potential for production during both lowstands and highstands of sea level and thereby facilitates progradation. This contrasts sharply with the Bahamian highstand shedding concept that is based on domination of sediment supply during highstands of sea level only. Rapid in situ lithification of the boundstone provides stability to the steep slopes, but also leads to readjustment through shearing and avalanching. Remarkable observations to both Tengiz and Asturias are the rates of in-situ boundstone growth (and as result progradation rates) that equal those of Recent coralgal (skeletal) reef systems and the asymmetric distribution not related to paleo wind directions. What controls the microbial cement boundstone formation remains a debate but its presence is a key factor in the progradational geometry of these and possibly many other older, and younger, margins.



(Modified after Della Porta et al, 2003)

Geometry and rates (1)	Sierra de Cuera (Kenter et al., 2003b; Della Porta et al., 2003)	Tengiz	WGBB (Eberli et al., 1994)	Capitan Reef (Tinker, 1998; Kerans and Tinker, 1999)
Slope height in m	650-800	>1000	400-600	500-600
Lower limit boundstone in m	250-350	250-350	50-100 (8)	400-500
Slope declivity in degrees	25-35	20-35	<5	20-45
Progradation in m	3000 (4)	2500	12969	2852
Aggradation in m	165	95	250	233
P/A (2)	18.2	26.3	45.3	28
Accretion in m (3)	1815	900	1033	1730
Progradation rate in m/My	667-1000 (9)	446	812	528
Accretion rate in m/My (4)(5)	403-605	161	65	320
Growth rate net in m/My	670-1003	(6)	250-1000 (7)	(6)

Notes:

(1) Durations in My (following Gradstein et al., 2004): Serpukhovian 8.3 My; Bashkirian 6.4 My; Pennsylvanian 17.1 My; Miocene - Recent 15.97 My; Capitanian (Seven Rivers and Yates/Tansill Fms) 5.4 My

(2) Ratio of progradation over aggradation (following Kerans and Tinker, 1999)

(3) Accretion in m perpendicular to slope bedding; if needed the sum of a series of vectors (see Figure 8B)

(4) Sierra del Cuera: Upper Bashkirian only, uncertain duration of ~ 3-4.5 My (following Della Porta et al., 2003)

(5) Tengiz: Zapaltyubinski is probably missing due to erosion on platform, but should be present in slope succession

(6) No information

(7) Skeletal metazoan reef growth rate (Schlager, 2000); the "net" accretion rate for WGBB slope is unknown

(8) Generally established lower limit of coral growth

(9) A duration of 6.4±1.8 My for the recorded 10 km of progradation (all of the Bashkirian) would result in a value between 1220-1563 m/My

Kenter et al., Table 2

In conclusion, the role of microbes in the evolution of "reefal" margins has been largely neglected but may present a depositional system with different rules controlling it's spatial distribution and response to climatic and eustatic sea level changes and resulting reservoir properties.