Non-Actualistic Carbonate Deposystems: Revising The Carbonate Factory-Depth Paradigm*

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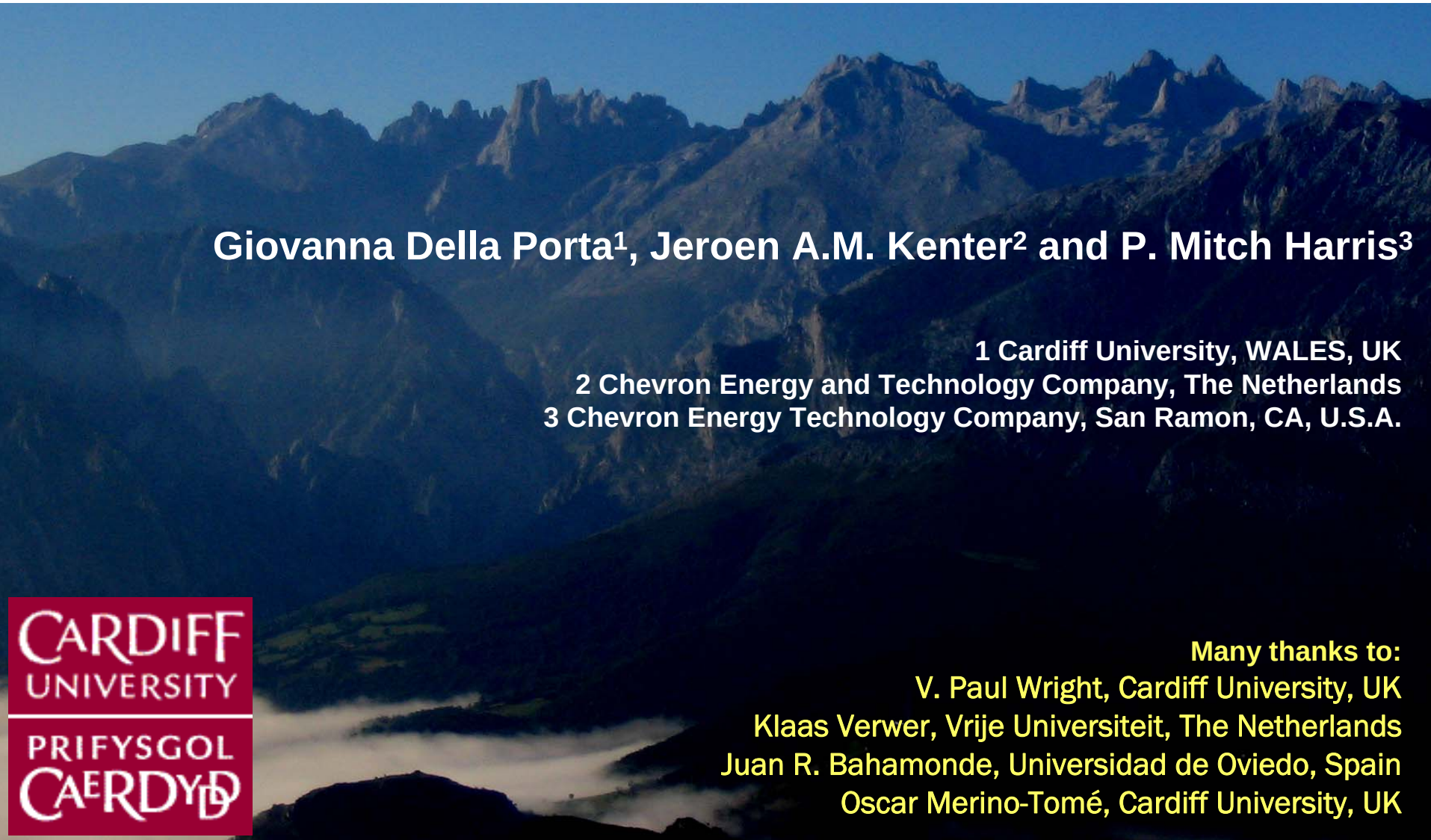
Abstract

Non-actualistic (e.g., deviating from depositional models developed for recent deposystems) carbonate platforms are not the exception in the geologic record because of the wide range of biological and environmental factors controlling facies character and architecture.

A fundamental concept 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, high rates of carbonate production extend on the slope down to dys-/aphotic depths and new production-water depth profiles must be developed.

Studies of Carboniferous (Asturias, Pricaspian Basin) and Permian (Capitan Reef) high-relief carbonate platforms have shown that the microbial-boundstone production extends to 300m water depth: 1) the detrital lower slope consists mostly of matrix-free cemented rudstone sourced by the slope boundstone with subordinated platform-top-derived material; 2) carbonate production on the slope is controlled by environmental parameters (temperature, nutrients, oxygenation) that are water-depth dependent, but the microbial boundstone response to relative sea-level changes differs from modern reefs; 3) carbonate growth is not seriously reduced during sea-level falls because it can continue downslope, 4) progradation can take place at high rates despite the lack of platform-top shedding (slope vs. highstand shedding); 5) concepts of leeward progradational vs. windward aggradational margins have to be revised. Paleozoic high-relief platforms with microbial boundstone-dominated margins seem to have developed in mesotrophic, starved restricted basins with oxygen-depleted bottom waters that would not be suitable settings for the recent coral-reef rimmed platforms.

NON-ACTUALISTIC CARBONATE DEPOSYSTEM: Revising The Carbonate Factory-Depth Paradigm



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At the search for patterns

- Conceptual models are necessary for interpretation and prediction
- Model simplicity vs. stratigraphic complexity (space, time, incomplete record, diagenesis)
- Models need eventually to be revised

The carbonate factory represents the space where carbonate sediment is produced but also the processes that led to carbonate production

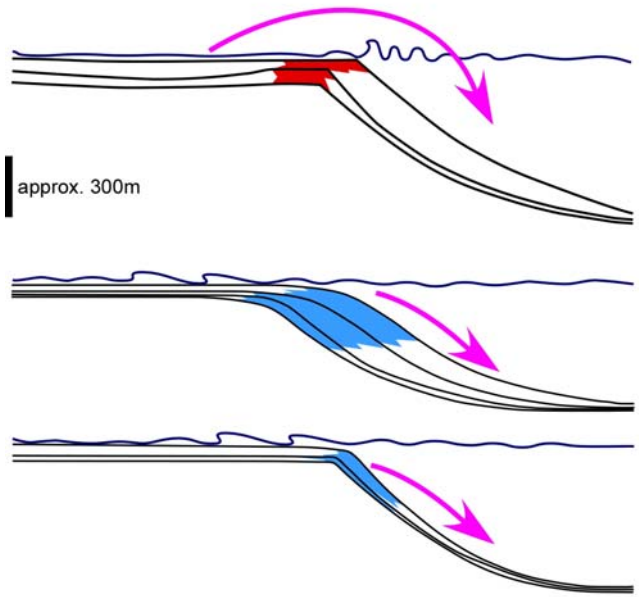
(from Schlager, 2003 after many sources)

- Models developed for the Recent cannot always answer the complexity of the geologic record
- Little is known about many processes not in fashion in modern settings

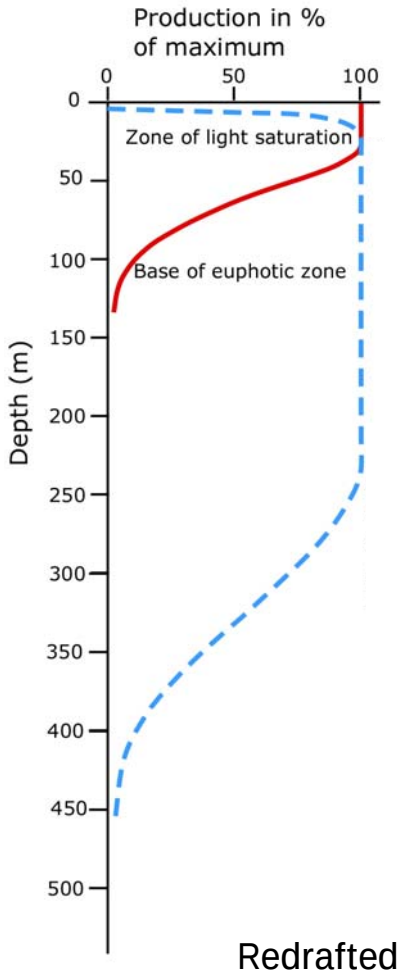
- Several carbonate factories and lack of pure end-members (*a continuum, spatially and temporally dynamic? cf. Wright and Burgess, 2005*)
- Different production rates, depth windows and DIFFERENT RESPONSES to changes in accommodation space and environmental conditions

Non-actualistic carbonate platforms: the paradigm shift

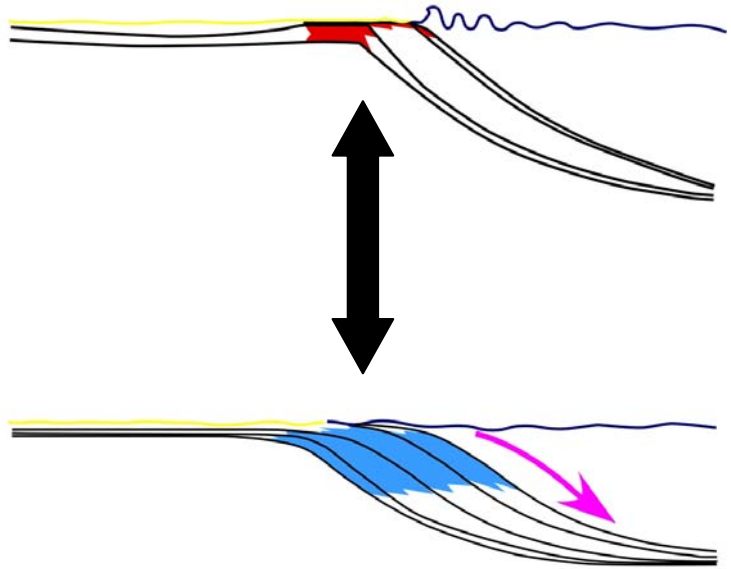
Recent
coral reef-rimmed platforms



Late Palaeozoic
microbial boundstone
flat-topped platforms



Highstand PLATFORM shedding
Highstand (leeward) progradation
Lowstand platform shut down

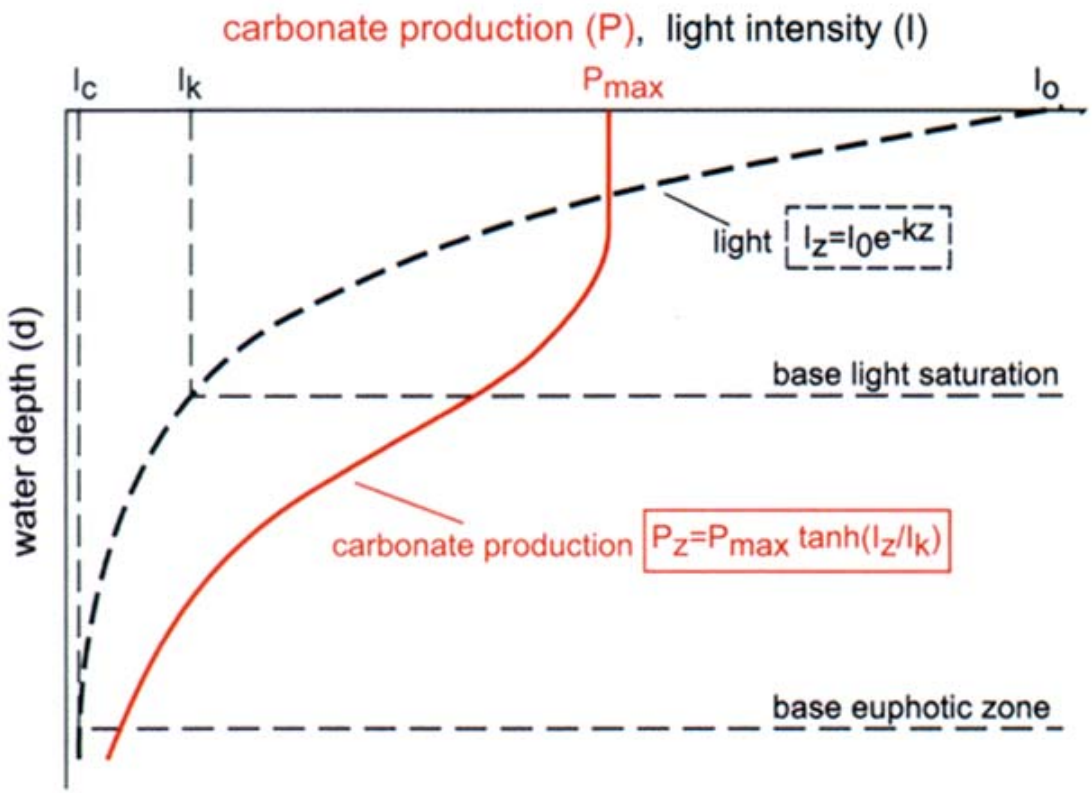


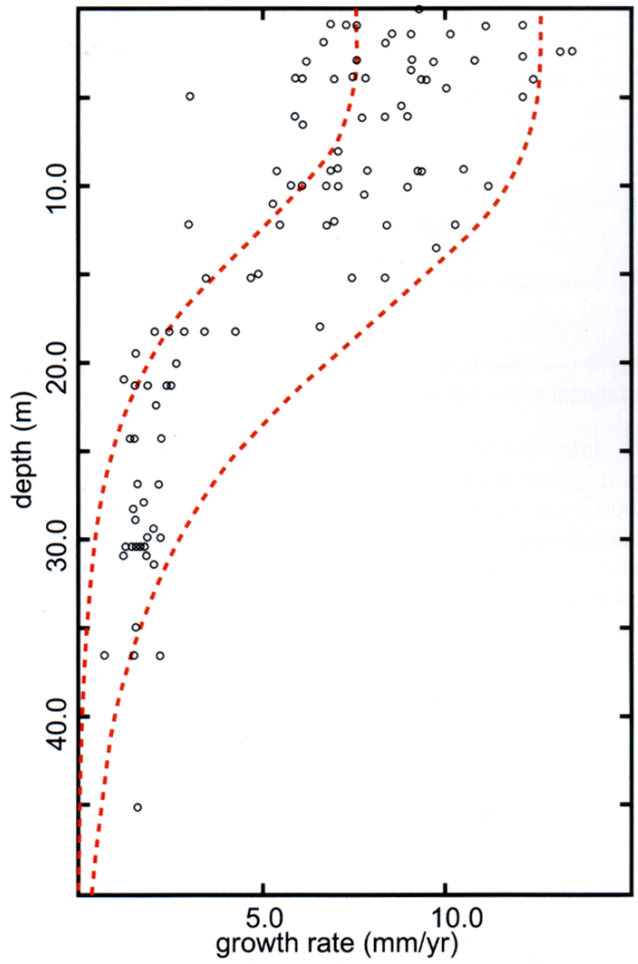
Any SL stand SLOPE shedding
Progradation at any SL stand
Lowstand downslope growth

Redrafted from Della Porta (2003), Kenter et al. (2005)

An exception? Carboniferous - Asturias, N Spain; Tengiz, Pricaspian Basin and Permian Capitan Reef, USA

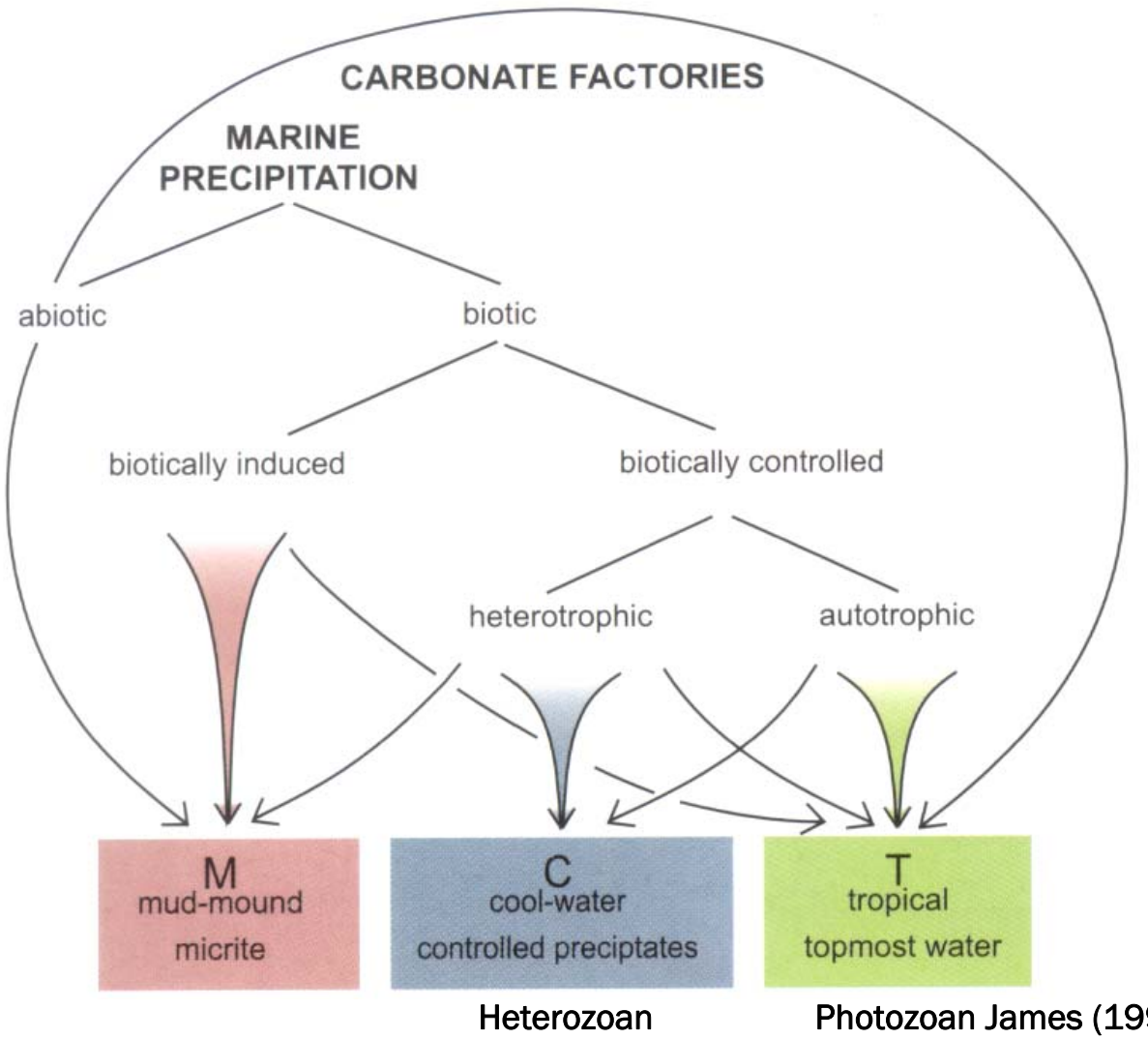
(Coral reef) Carbonate Production vs. Depth





Bosscher and Schlager (1993), from Schlager (2005, SEPM)

Modes of carbonate precipitation and carbonate factories



Schlager (2000, 2003 Int. J. Earth Sci, 92); from Schlager (2005, SEPM)

Microbial carbonates (biologically induced precipitation)

Organo-sedimentary deposits by benthic microbial communities

- trapping and binding detrital sediment
- forming the locus of mineral precipitation (Burne and Moore, 1987)

Processes

Biomineralization :

- Photosynthesis by cyanobacteria
- Heterotrophic bacteria (decay of organic matter via ammonification, nitrate and sulphate reduction).

Organo-mineralization: Non-living reactive organic substrates (bacteria, EPS, sponges)

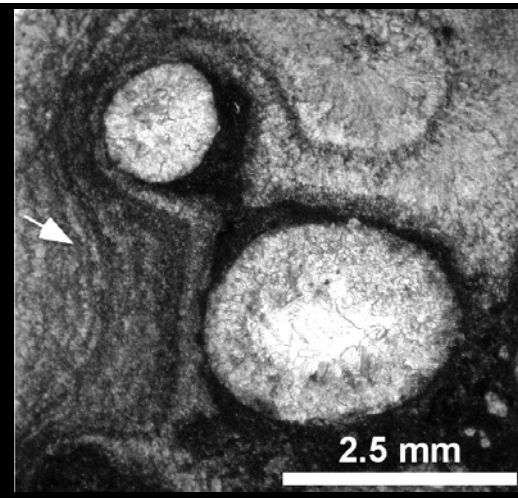
Products:

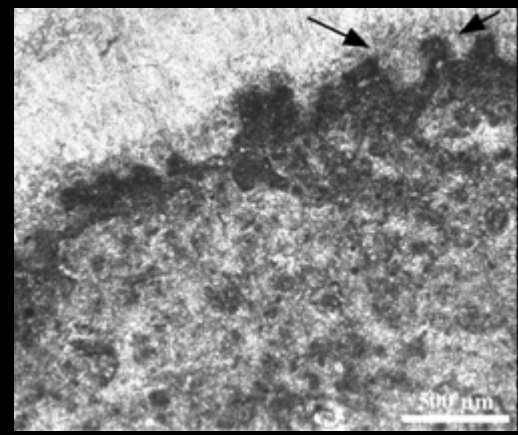
Microscale

- Aphanitic micrite (automicrite)
- peloidal
- laminae

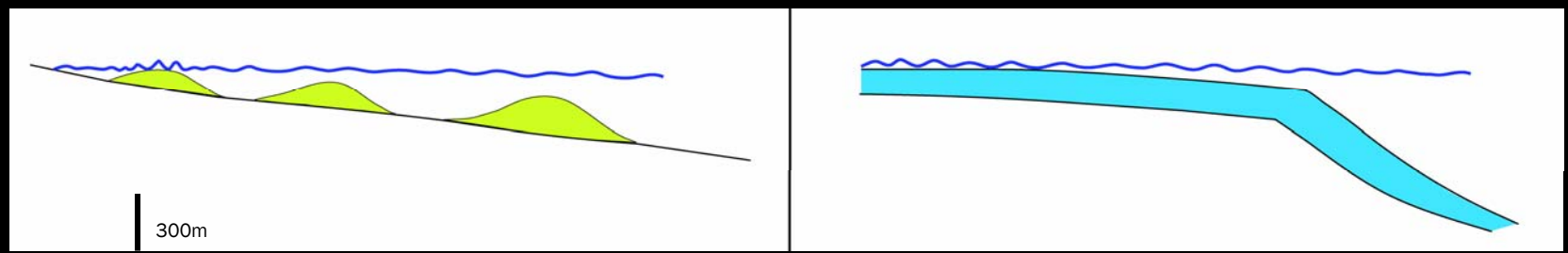
Macroscale

- Mounds
- Margin-slope



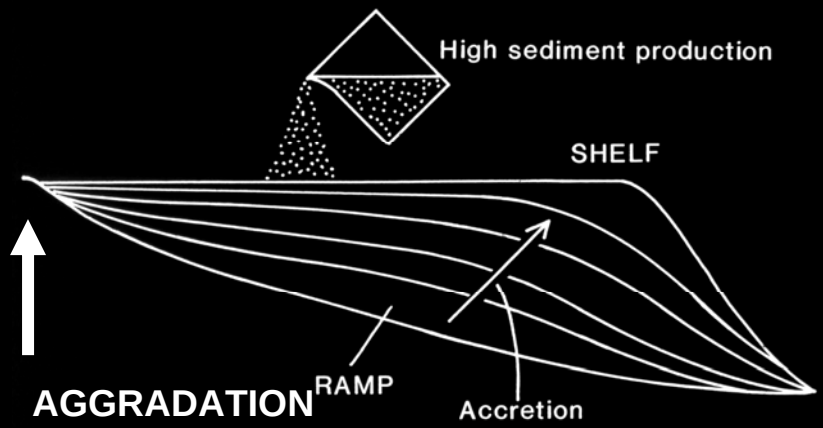


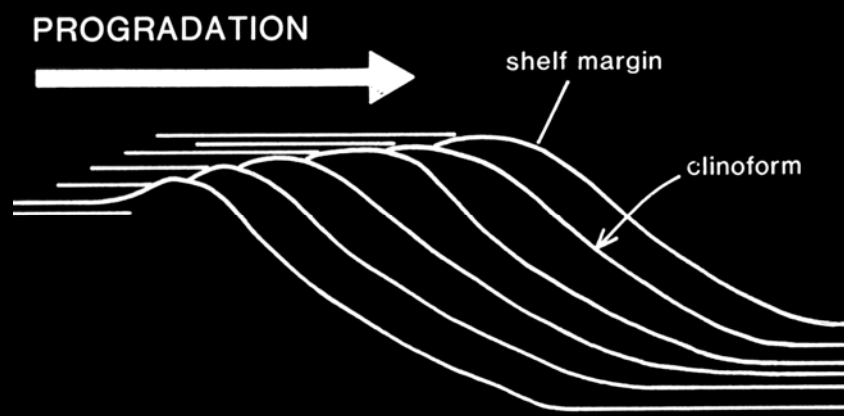
Carboniferous Asturias (Della Porta 2003)

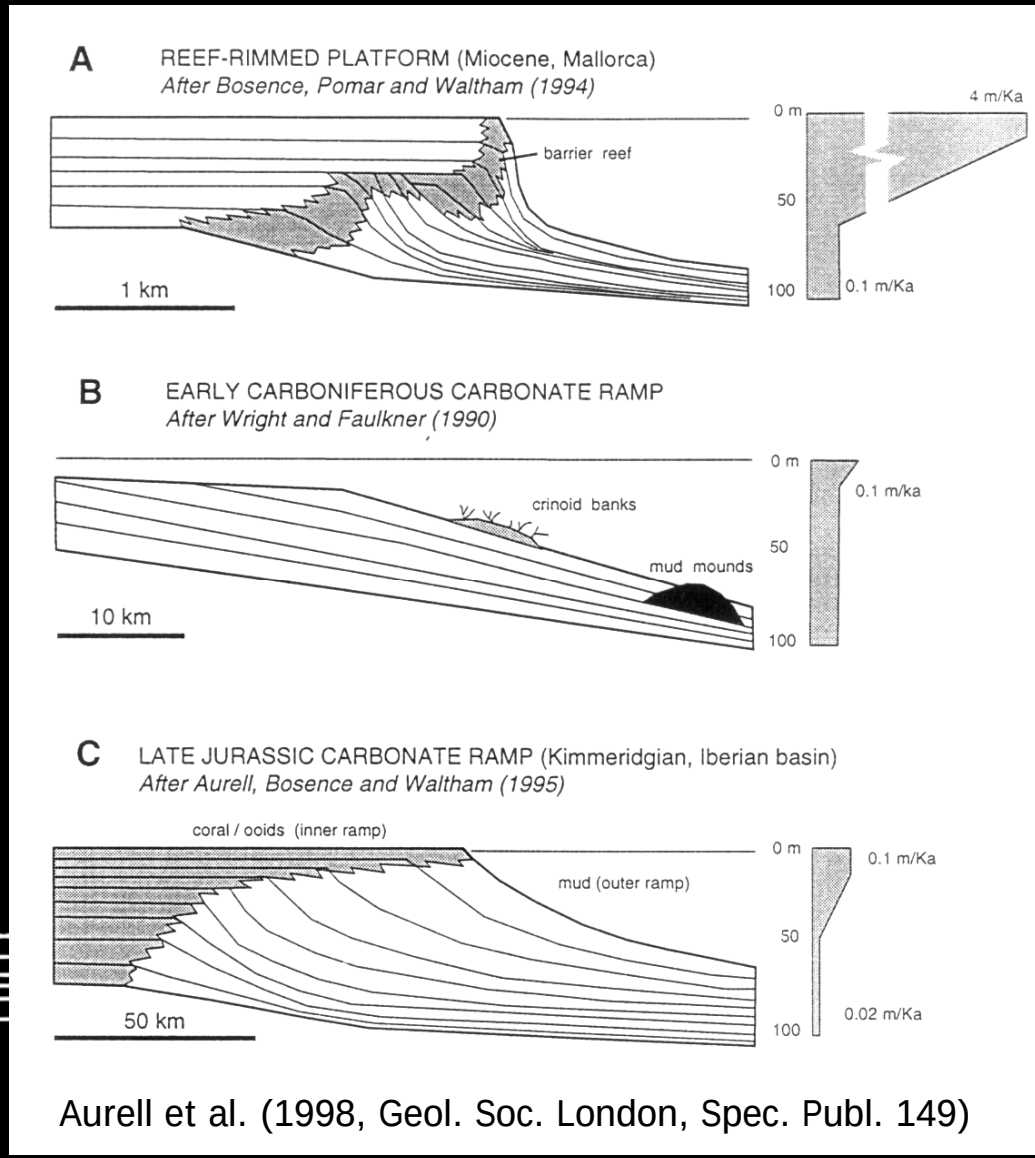


Sources: Reitner et al. (1995), Trichet and Defarge (1996), Neuweiler et al. (1999); Riding, (2000), Arp et al. (2003), Gautret et al. (2007)

Modelling platform geometry

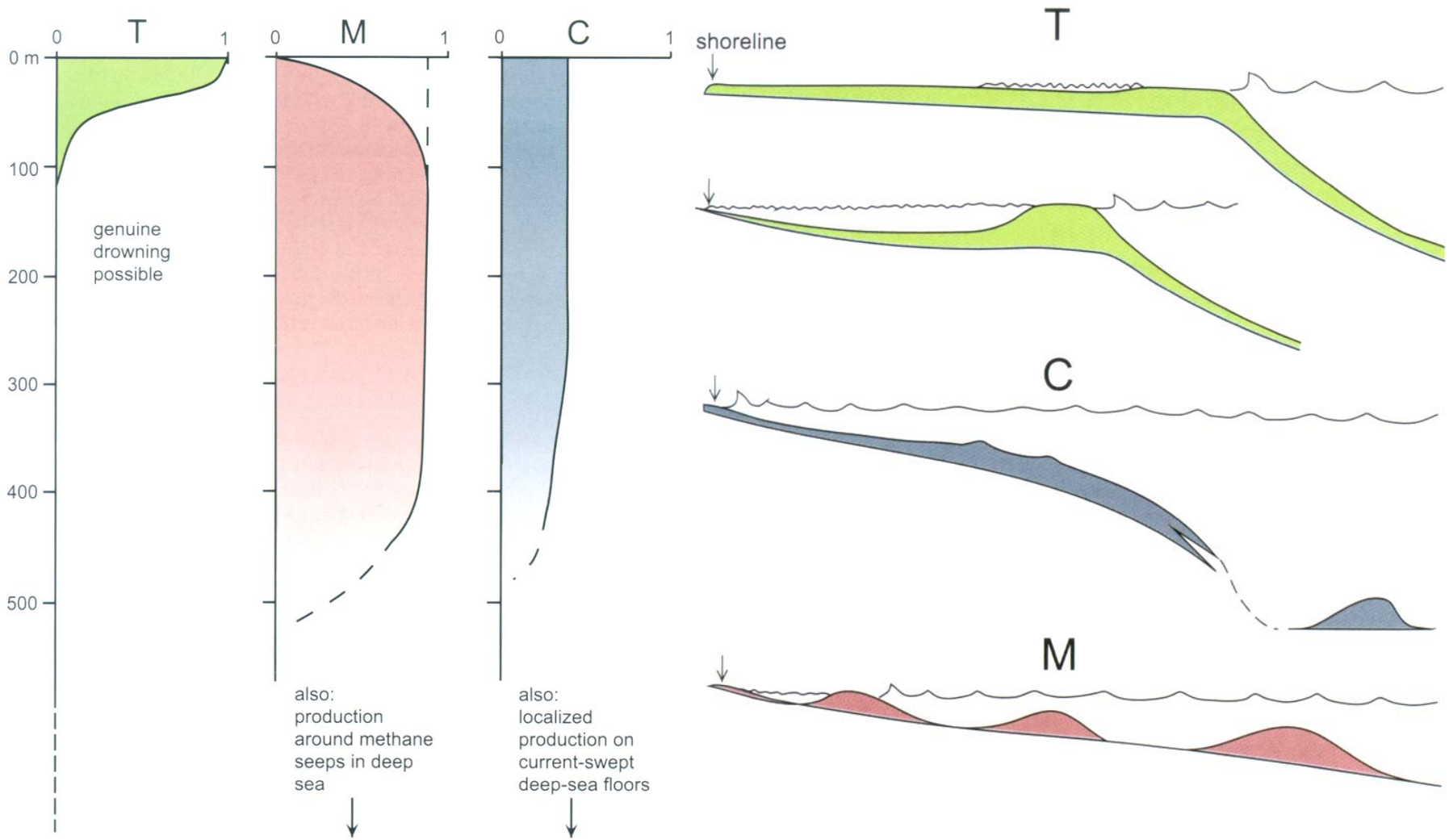






Aurell et al. (1998, Geol. Soc. London, Spec. Publ. 149)

Production-depth profiles and depositional geometry



Schlager (2003) from Schlager (2005)

Types of carbonate platforms: a genetic approach

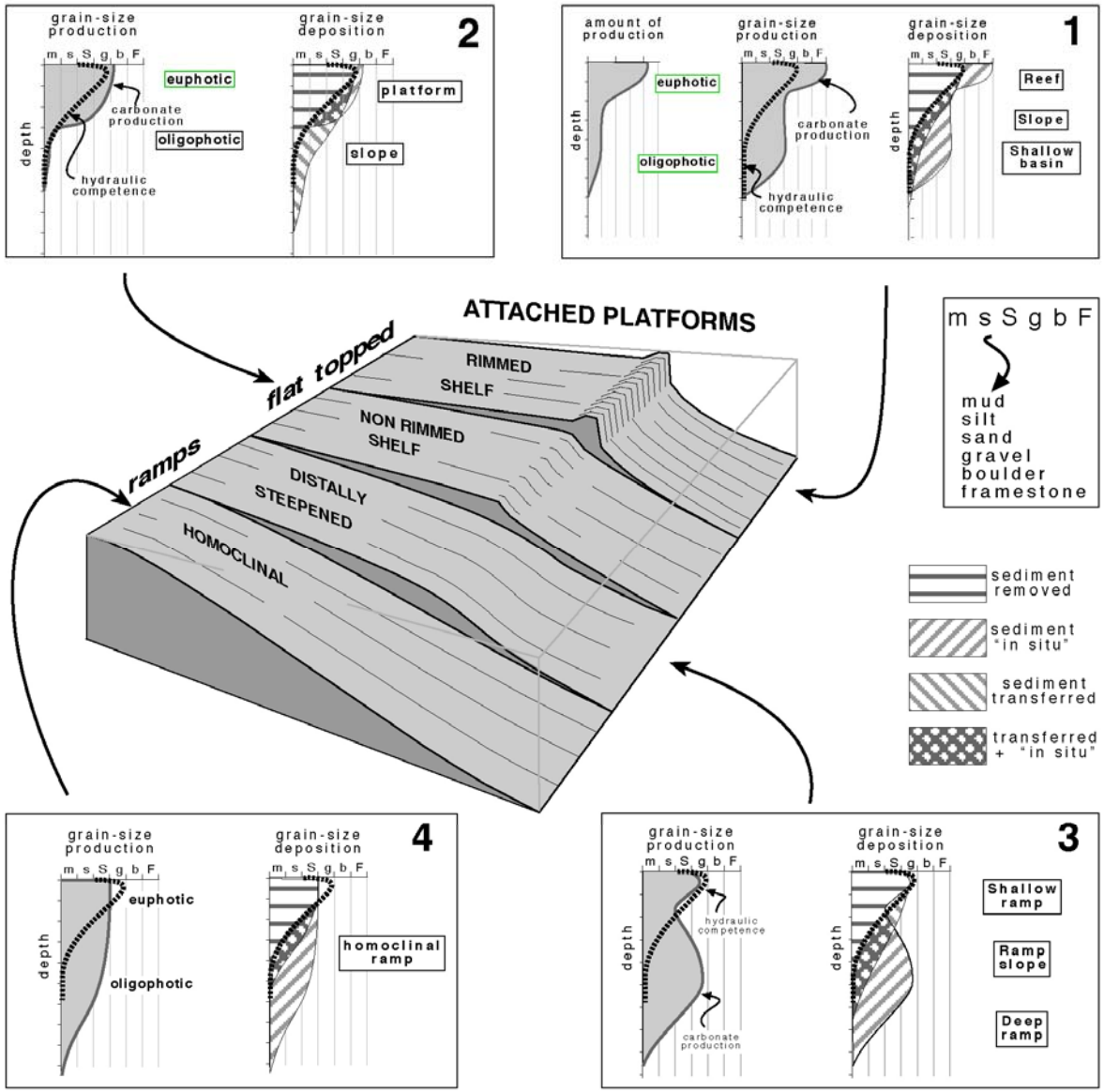
Euphotic gravel-size soft substrate dwellers (rudists)

Microbial Skeletal boundstone

Mud-producing biota

Euphotic removed by downshelf transport

Photo-independent biota

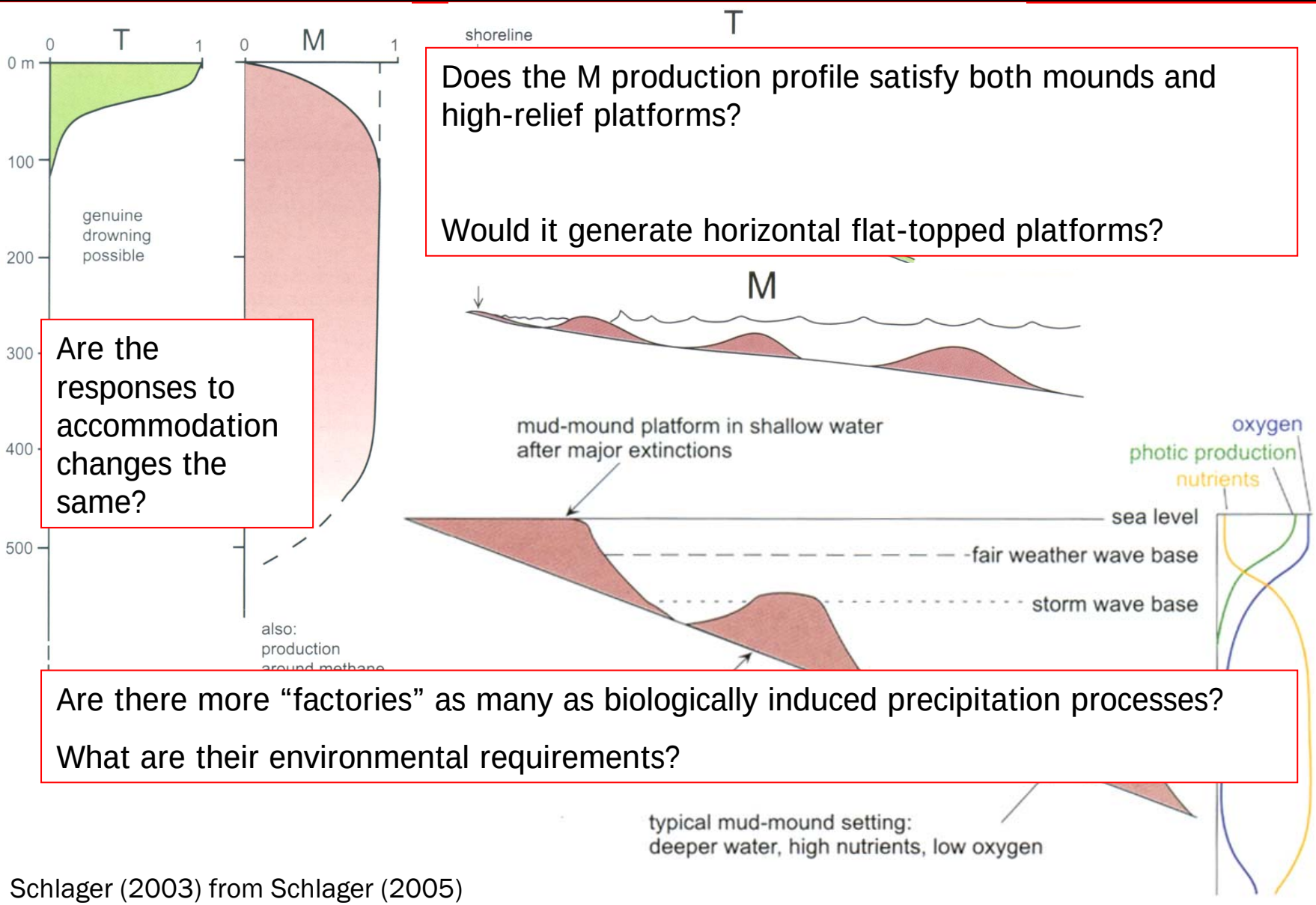


Pomar (2001, Basin Research, Geol. Med.)

Euphotic framework-producing biota

Oligophotic coarse grained biota
LBF, red algae

Non-actualistic platform production and geometry



Does the M production profile satisfy both mounds and high-relief platforms?

Would it generate horizontal flat-topped platforms?

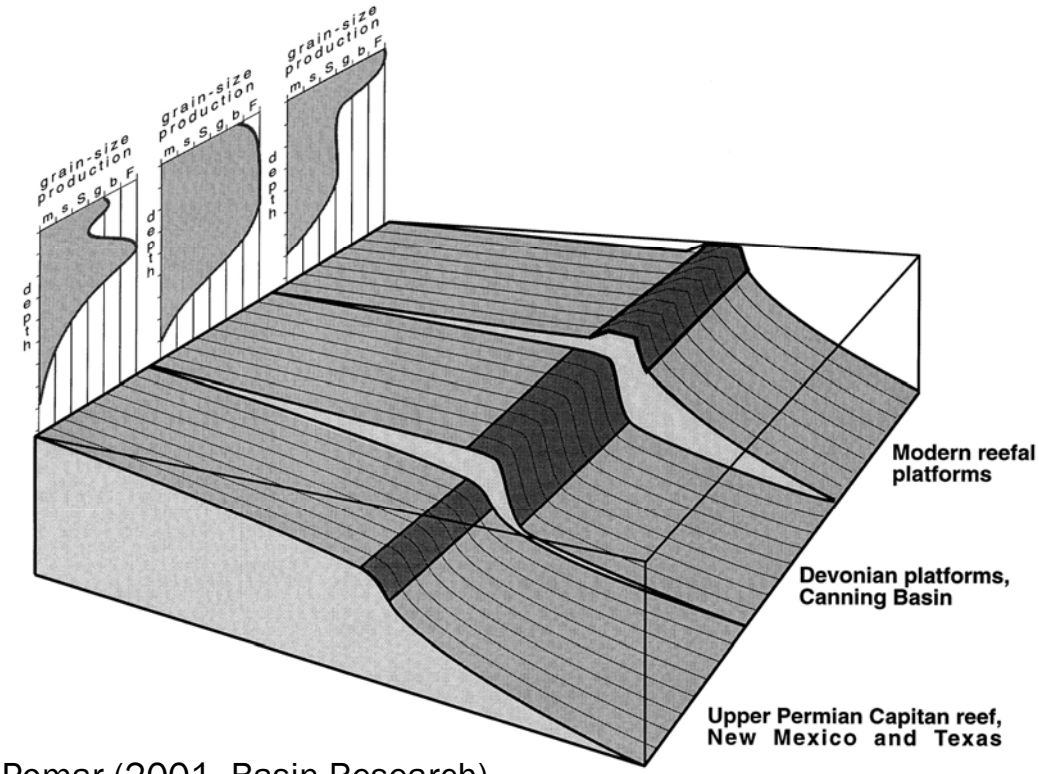
Are the responses to accommodation changes the same?

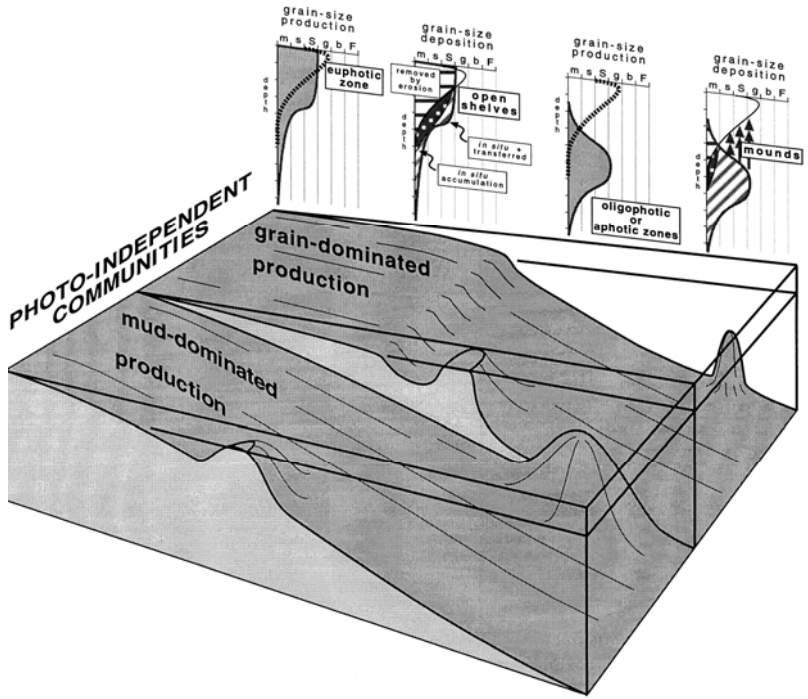
Are there more “factories” as many as biologically induced precipitation processes?

What are their environmental requirements?

Schlager (2003) from Schlager (2005)

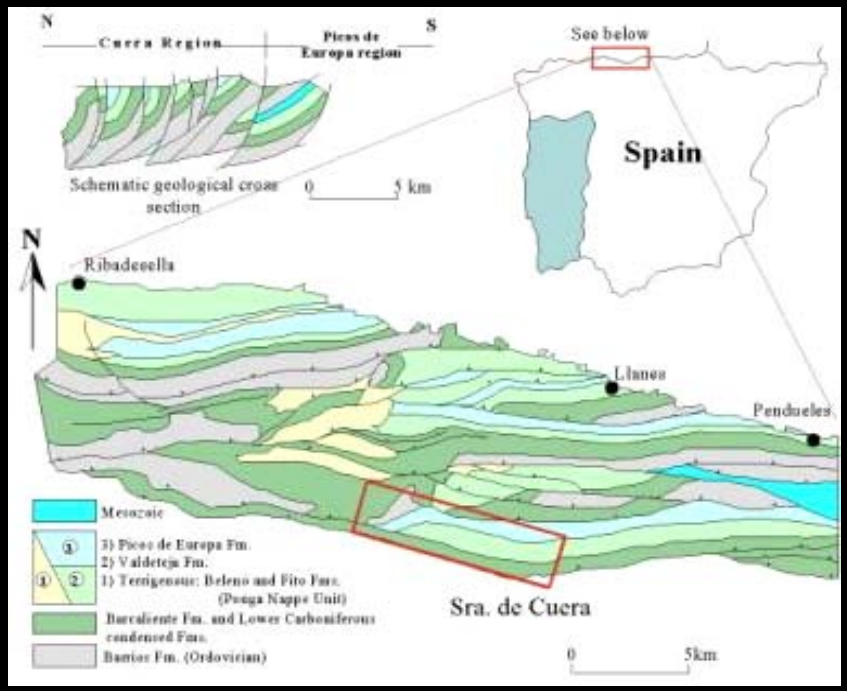
Non-actualistic platform production and geometry

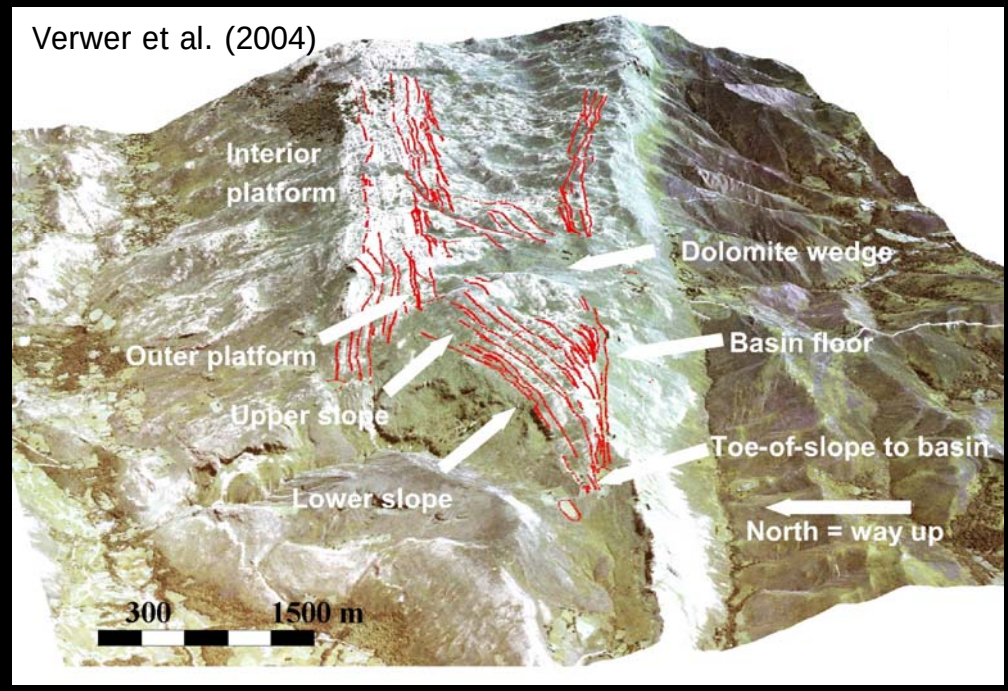


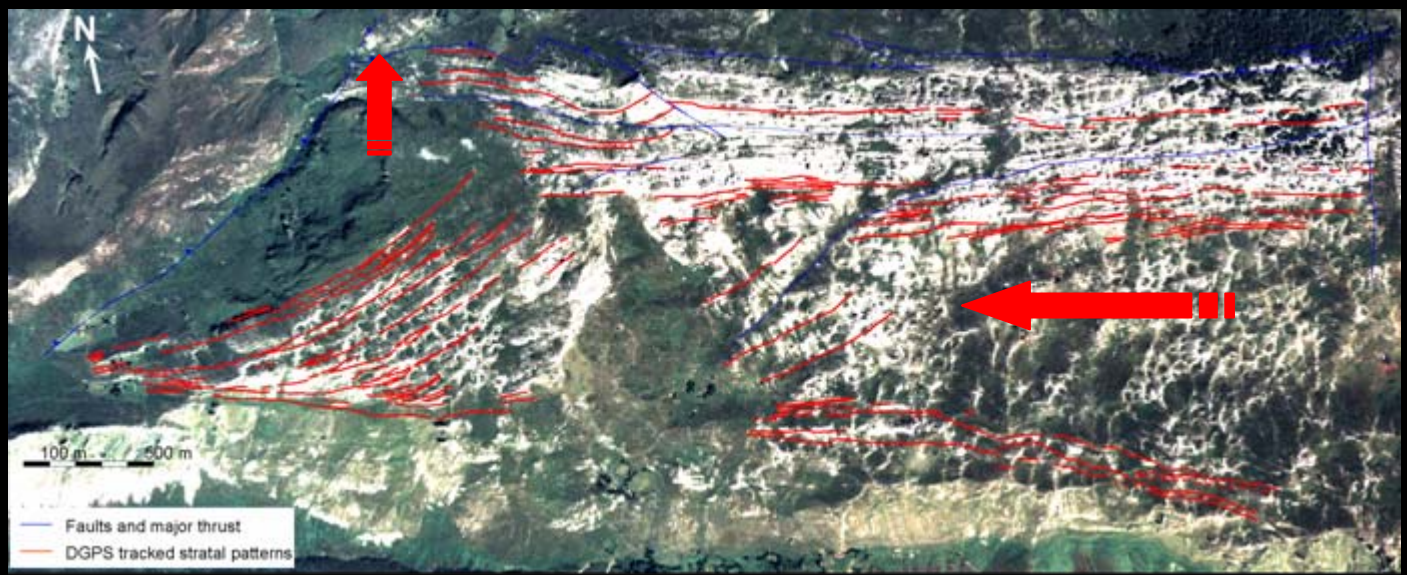


Pomar (2001, Basin Research)

Pennsylvanian high-relief platform (Asturias, N Spain)





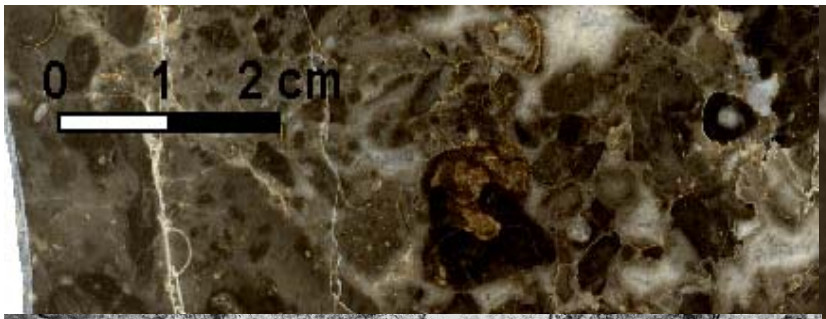


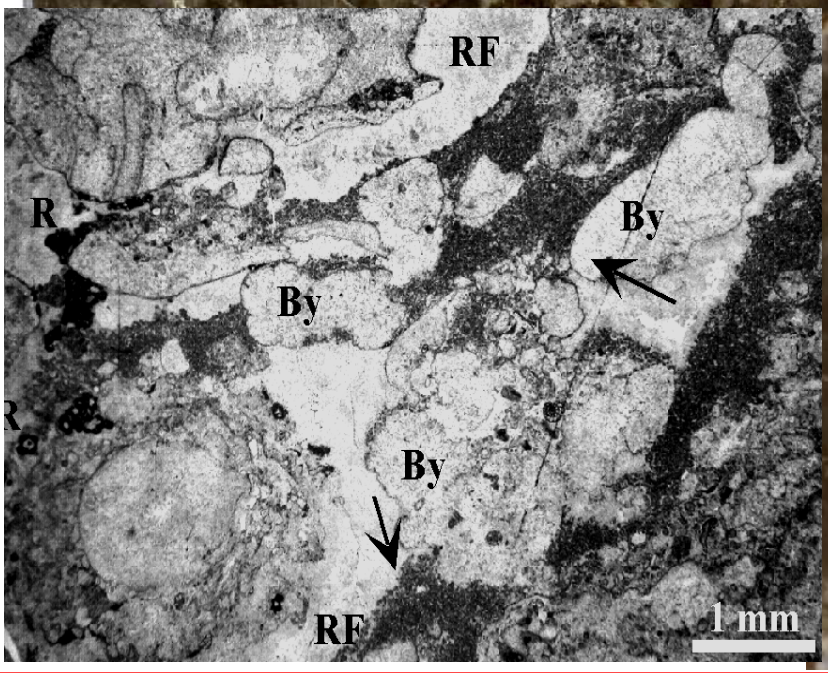
Della Porta et al. (2003, 2004)

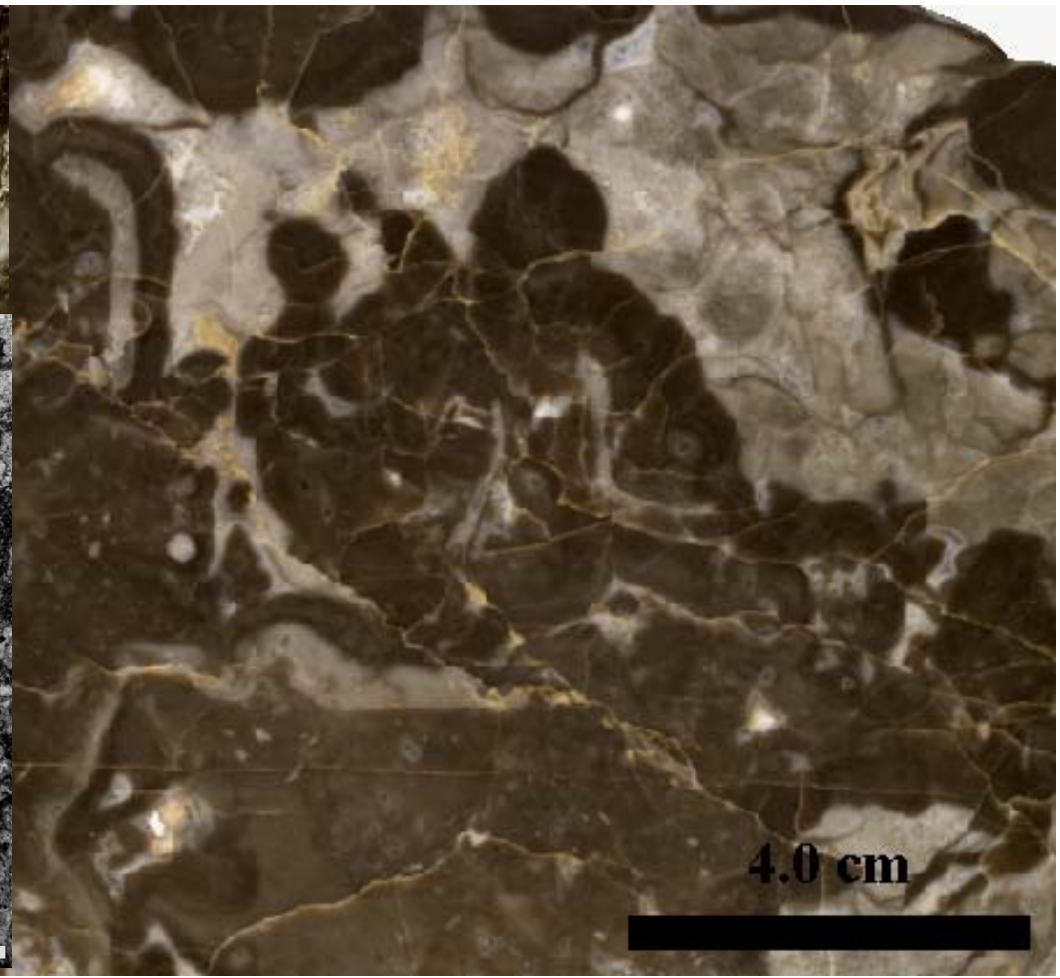
- high relief (600-800m)
- steep (30-40˚) clinoforms
- >3 km of basinward progradation

Self-nourished Slope

- Upper slope: Cement-rich microbial boundstone from 10-20m to 300-400 m depth (30-40% slope)
- Lower slope: Detrital matrix-free cemented boundstone breccias (50% slope)
- Minimum platform-top contribution (10-15% slope)

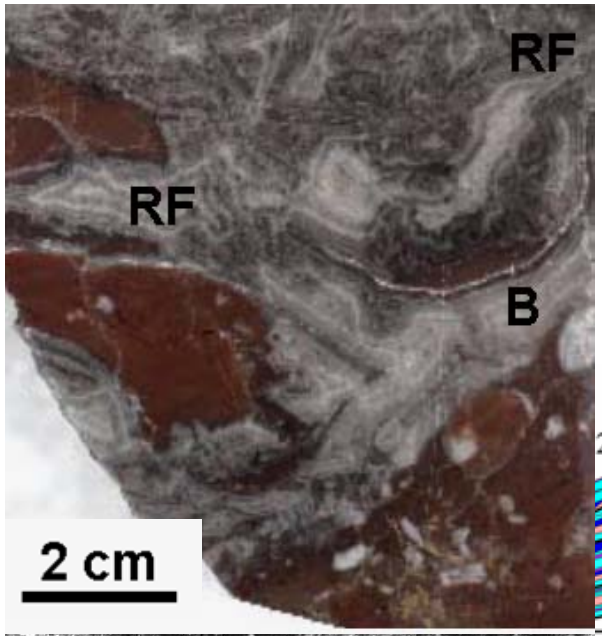


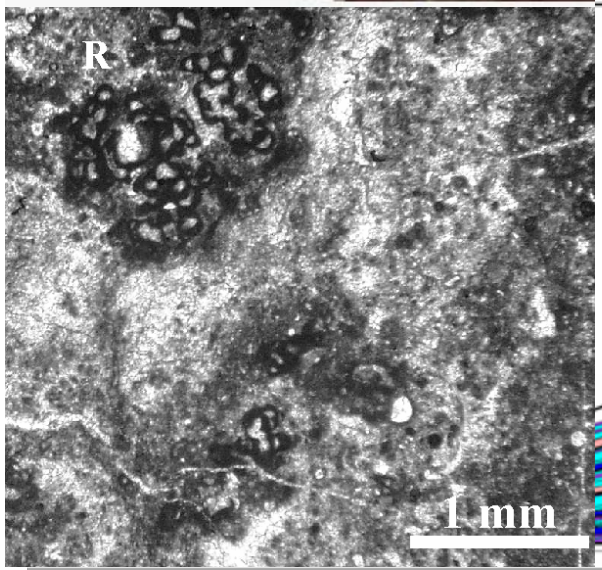


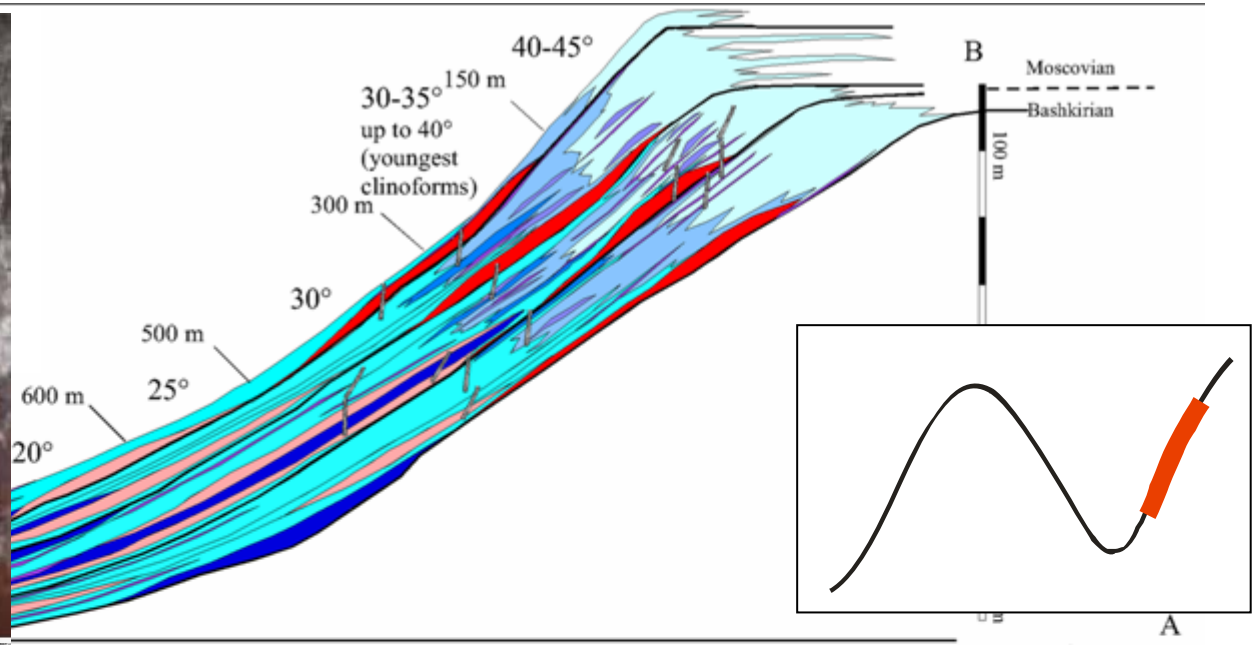


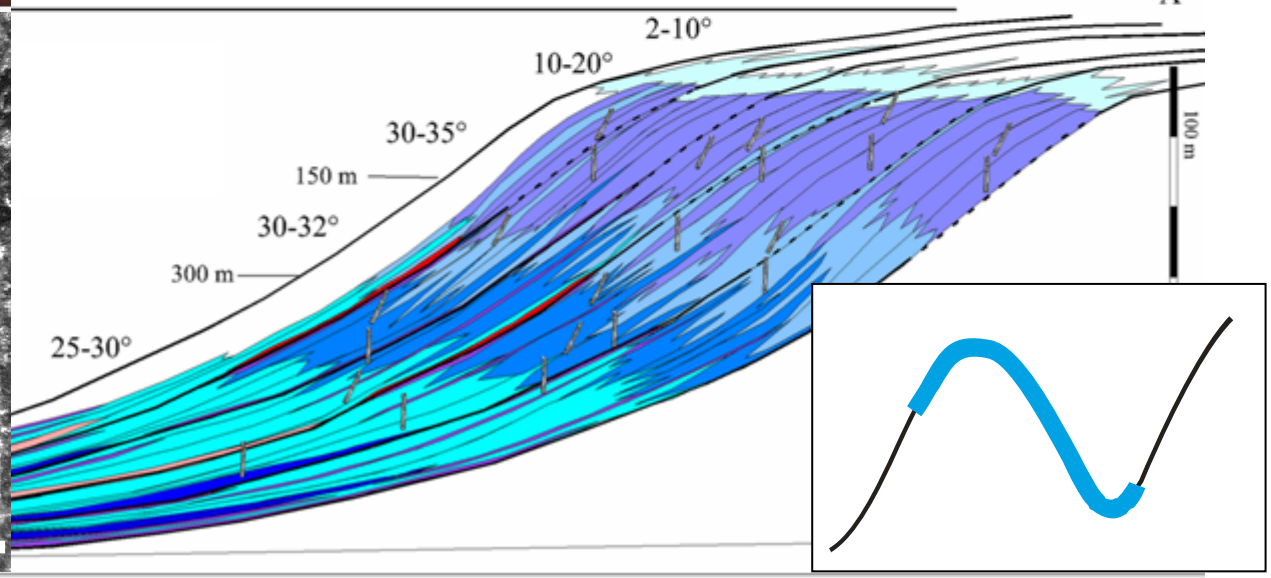
Della Porta et al. (2003, Facies); Kenter, Harris and Della Porta (2005, Sed. Geol.)

Progradational vs. aggradational slope built by light-independent microbialites: two factories?

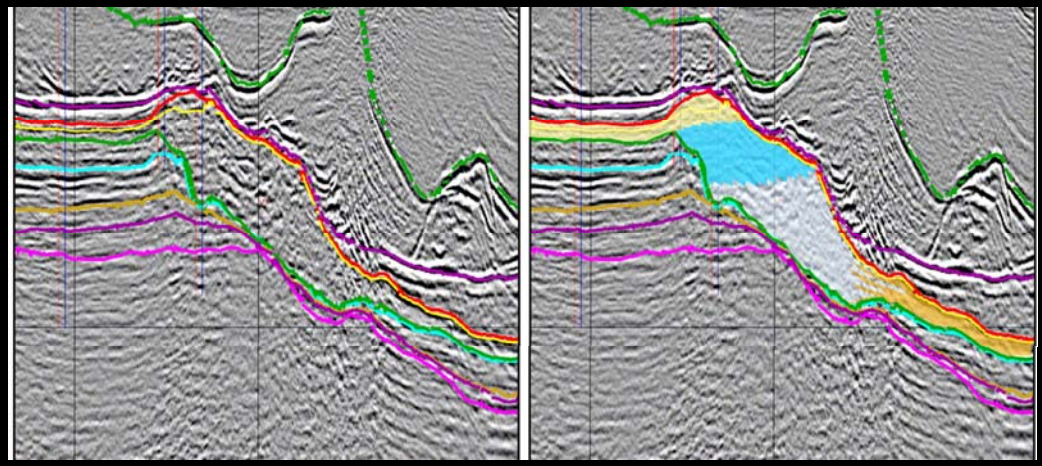


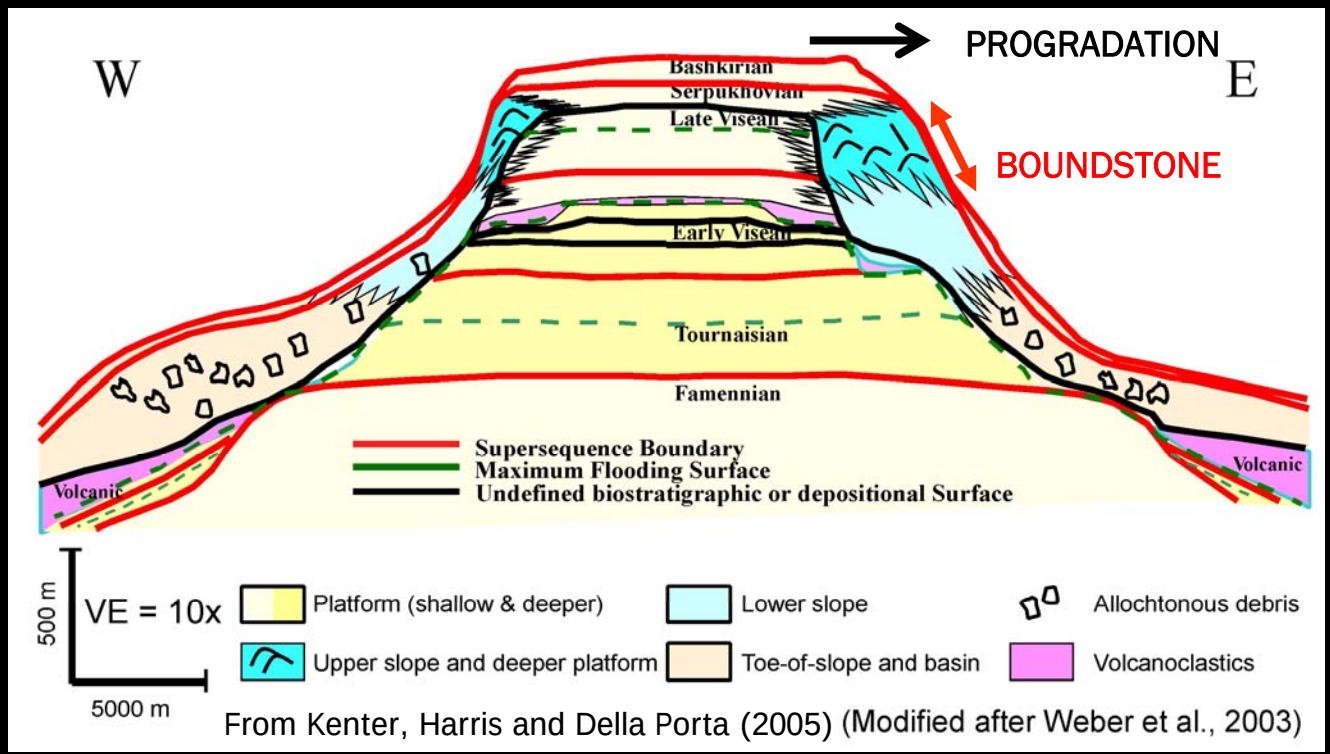






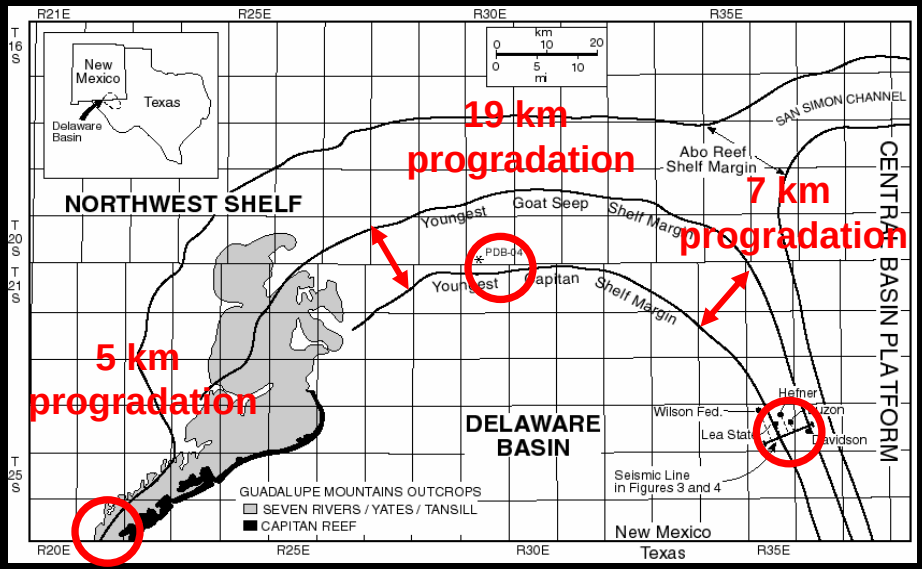
Tengiz (Carboniferous, Pricaspian Basin)
upper slope cement-rich microbial boundstone (>400m depth)

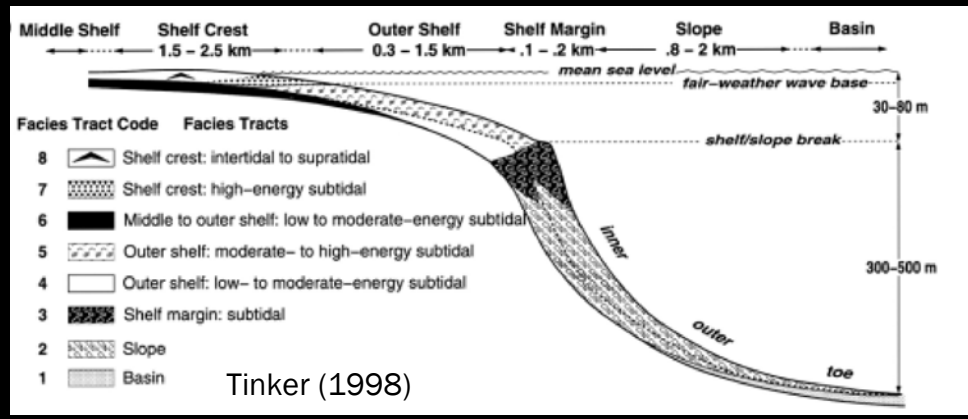




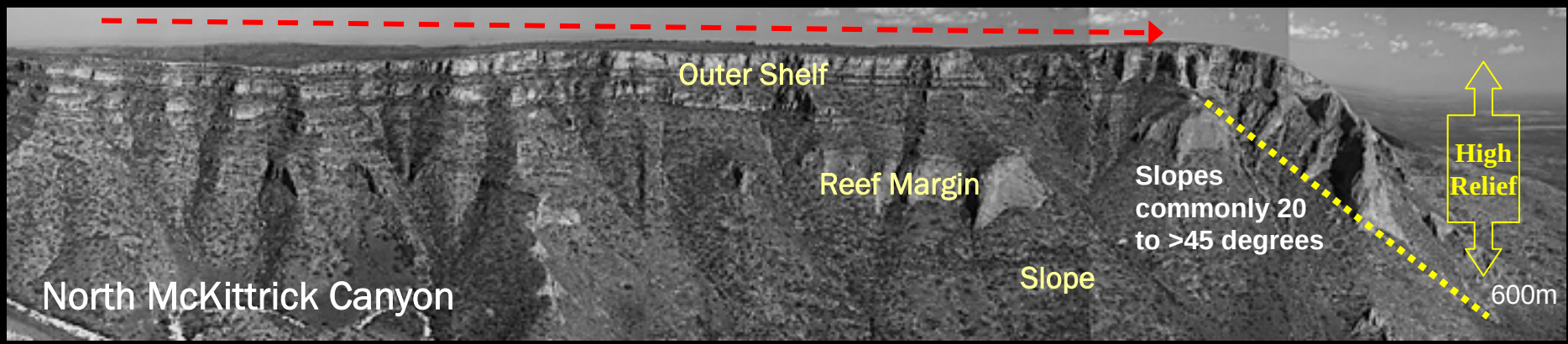
From Kenter, Harris and Della Porta (2005) (Modified after Weber et al., 2003)

Capitan shelf margin (Permian, TX-NM)
upper slope cemented microbial boundstone (30-150m depth)



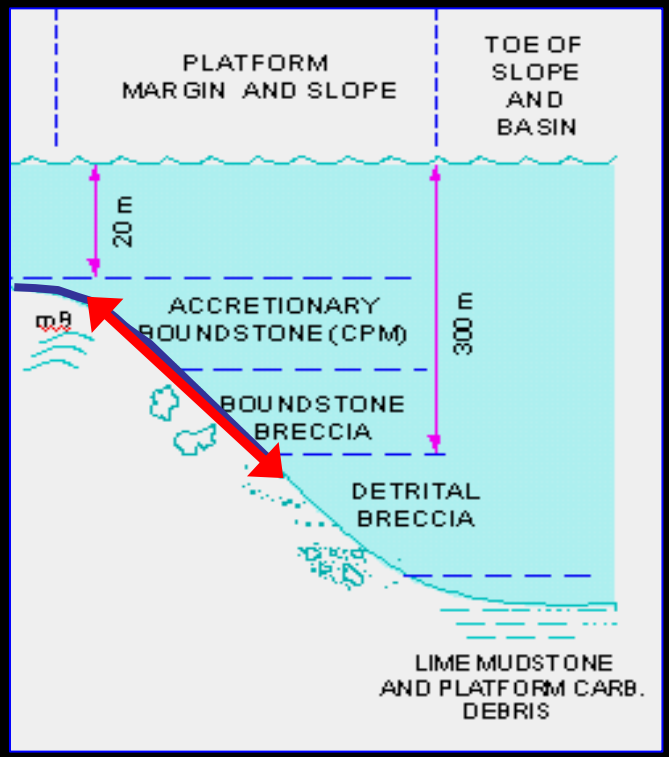


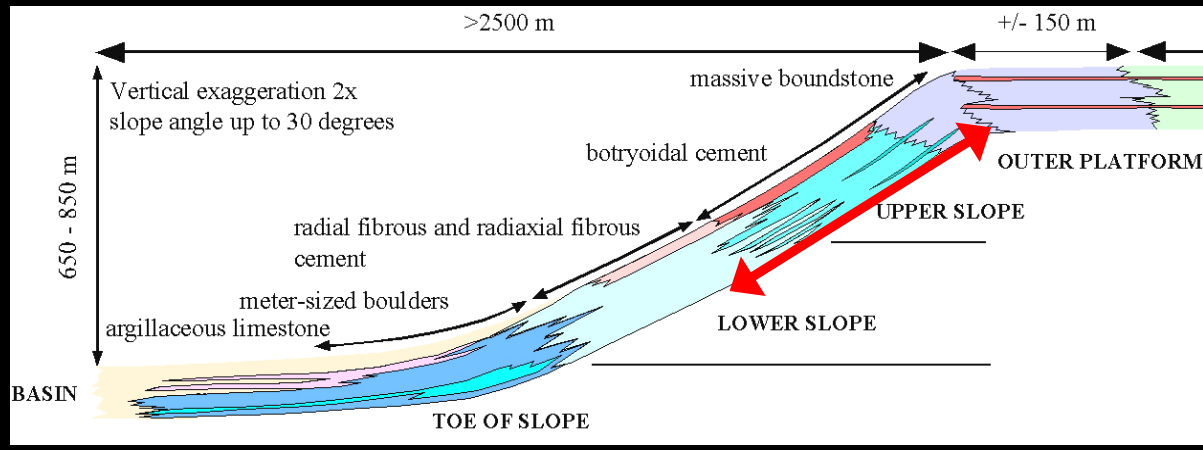
- Boundstone (calcisponges, bryozoans, *Archaeolithoporella*, botryoidal cement)
- Downslope in-situ boundstone breccias
- Toe of slope minimal platform top input
- Km's progradation



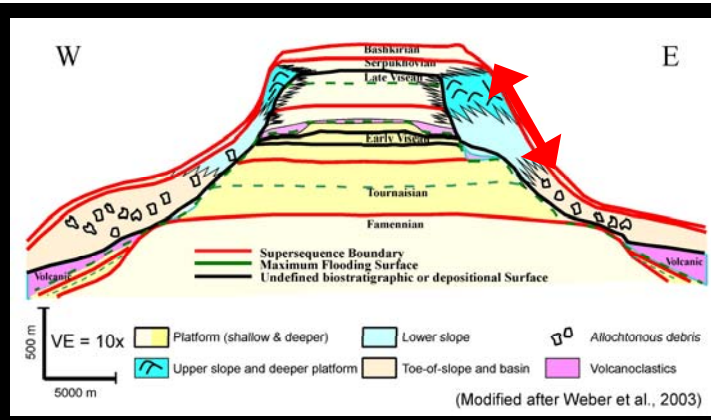
Harris and Saller (1999); Garber et al. (1989); Tinker (1998); Wood et al. (1994)

Depositional model
late Palaeozoic steep high-relief microbial boundstone slopes



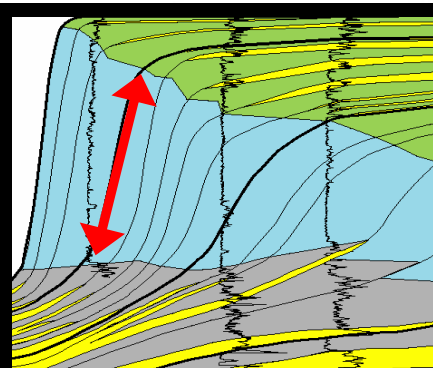


Carboniferous
Northern Spain and
Pricaspian basin



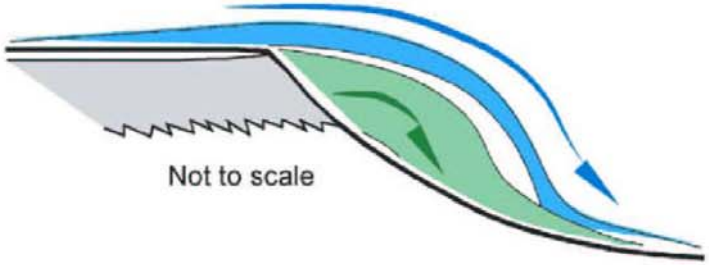
- Microbial dominated margin and slope factory
- Broad depth range (300-400m depth)
- Pervasive marine cementation (stable steep slopes)
- **High production rate** (400-1000m/My) **, km's progradation**
- Detrital "talus" breccias cemented and matrix-free
- Minimal platform-top contribution

Permian
Capitan
Margin
(USA)

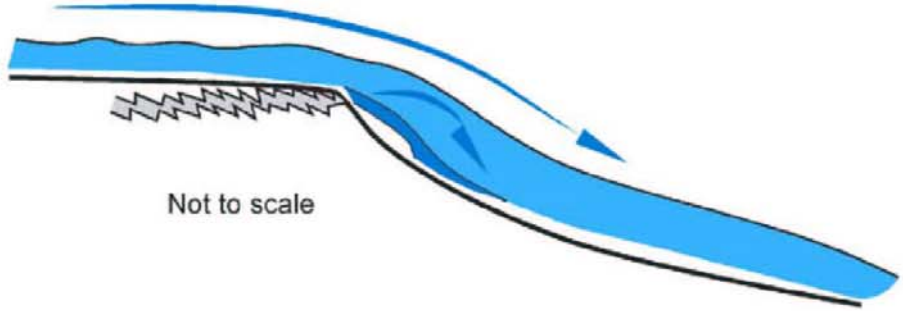


Slope shedding model

Late Palaeozoic microbial boundstone margins and slopes



Modern coral boundstone margins



Slope Shedding Model	Versus	Highstand Shedding Model
Insensitive to light (0-300 m wd)		Sensitive to light (<30 m wd)
Large production area in upper slope		Small production area in upper slope
Sea level "insensitive"; environmental sensitivity		Sea level sensitive
Shedding to slope by boundstone production; minor platform top derived sand bypasses upper slope		Shedding to slope by platform top skeletal/non-skeletal sand to mud
Steep and planar upper slopes		Low angle and exponential slopes
High accretion rates		Low accretion rates

Kenter, Harris and Della Porta 2005

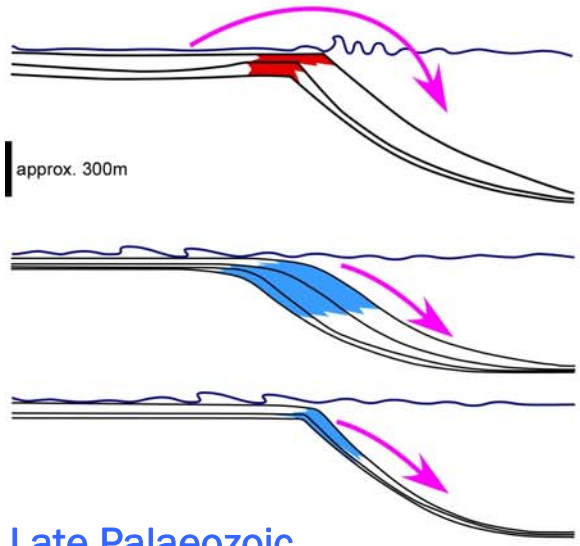
- Slope is "self-nourishing", little contribution from platform top
- High rates of steep slope progradation at any sea-level stand
- Progradation function of boundstone growth vs. off platform (Highstand) shedding

Model for microbial boundstone high-relief slope

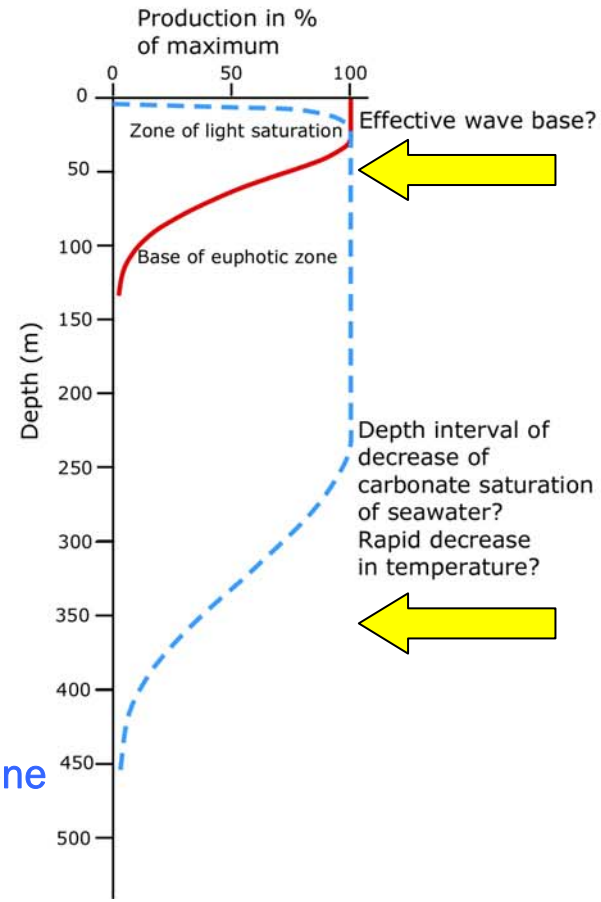
Environmental controls on microbial boundstone growth rate and depth window?

- Tropical settings
- Highly supersaturated waters: high T , low PCO_2, high alkalinity, high pH
- Degradation reactive organic matter (bacteria, EPS, sponges), oxygen depletion.

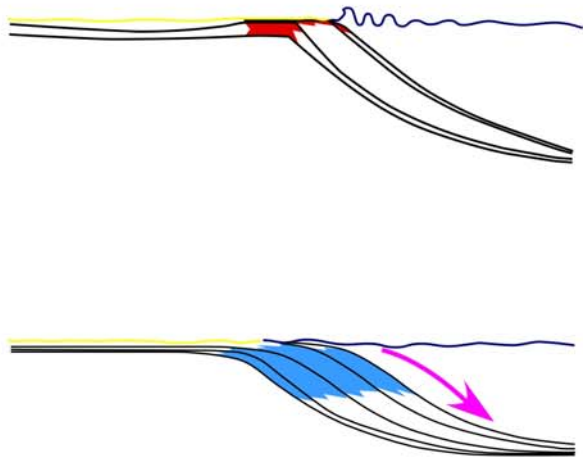
Recent
coral reef-rimmed platforms



Late Palaeozoic
Microbial (cement-rich) boundstone
Flat-topped platforms

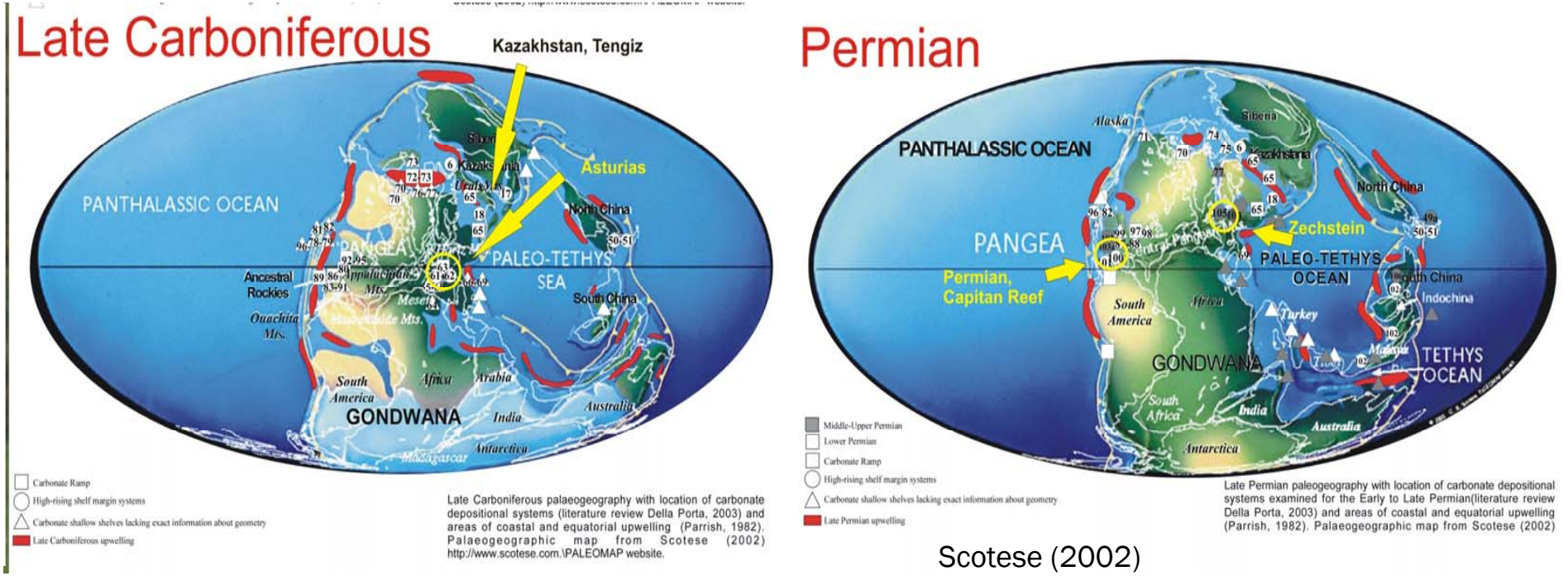


Leeward Progradational margins
Highstand platform shedding
Lowstand shut down



Any SL stand SLOPE shedding
Progradation at any SL stand
Lowstand downslope growth

What localizes microbial high-relief margins?



Scotese (2002)

- high relief on antecedent topography
- Confined/restricted basins
- Oxygen-depleted sea floors (sulphate reduction, high alkalinity and increase saturation)
- Mesotrophic … but phosphates inhibit aragonite and cyanobacteria-related precipitation
- Upwelling? Local overturning, no open ocean (deep cold waters reduce saturation)

Steep slopes vs. ramps: how many “microbial” factories?

late Palaeozoic: many ramps with deep water mud-mounds, rare high-relief microbial boundstone slopes

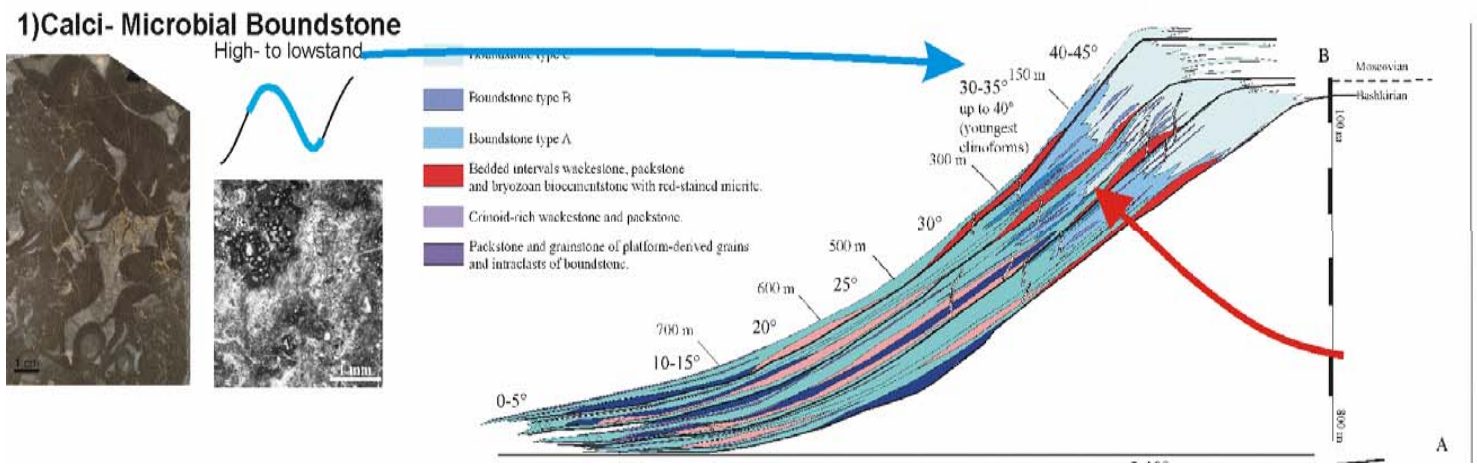
Why many ramps with deep-water mud mounds did not evolve into high-relief?

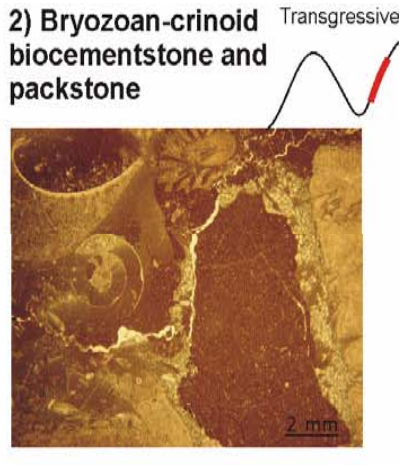
- lower production rate confined in deeper water
- did not form in the ideal setting to promote high rates of growth

Did microbial high-relief platforms developed only after major extinction events and in specific oceanographic/environmental settings?

How many microbial/ biologically induced carbonate factories?

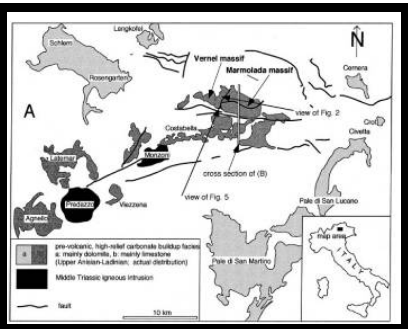
- Calci-microbial vs. Heterotrophic bacteria vs. Organo-mineralization
- Or same “passive” precipitation processes have different rates according to <u>physico-chemical conditions</u> and <u>organic substrates</u> available?





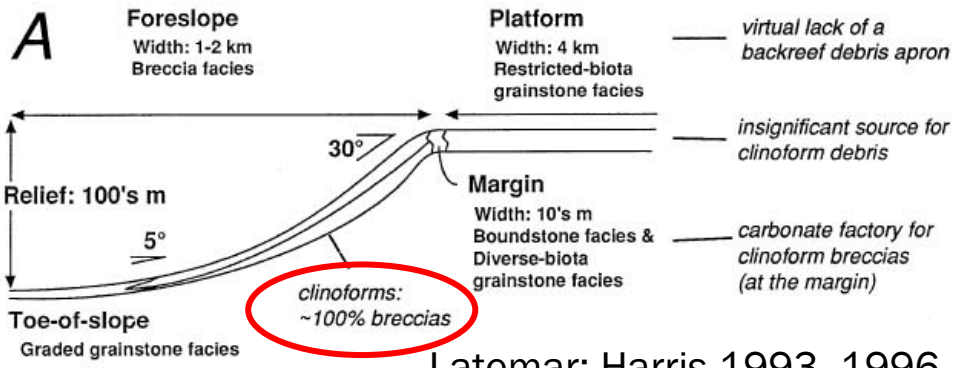
Where/What is the carbonate factory sourcing the progradational slope?

Middle Triassic atolls (Dolomites)

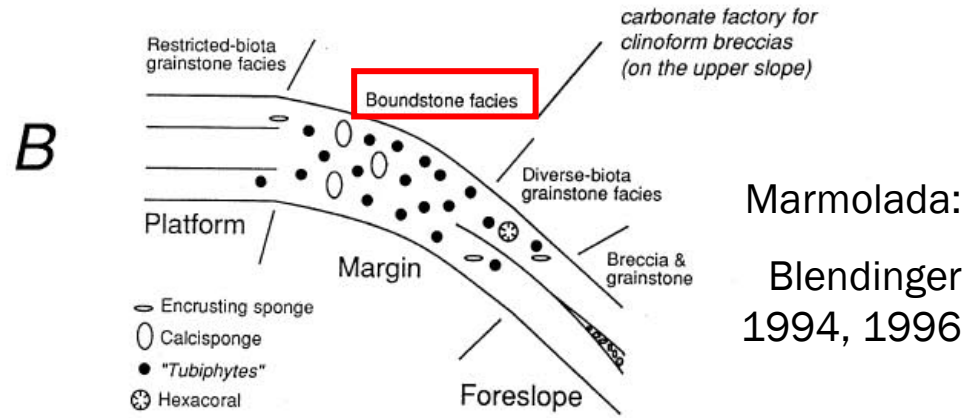


Sella Platform (Keim and Schlager 1999, 2001): Microbial micrite (automicrite) 20% upper slope, down to 200m depth

Cipit Boulders (Russo et al. 1997): Microbial micrite 60%

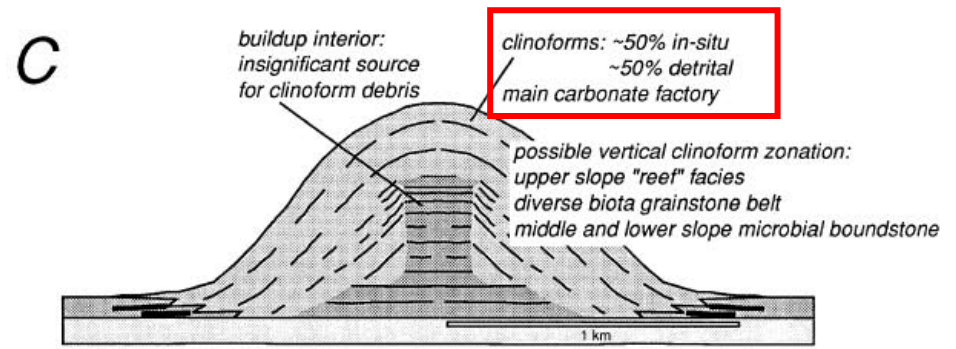


Latemar: Harris 1993, 1996

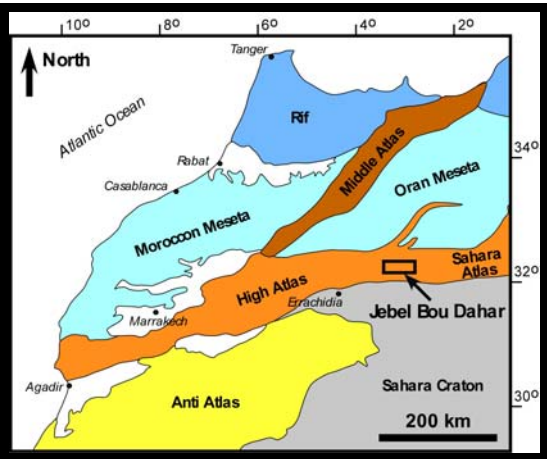


Marmolada:

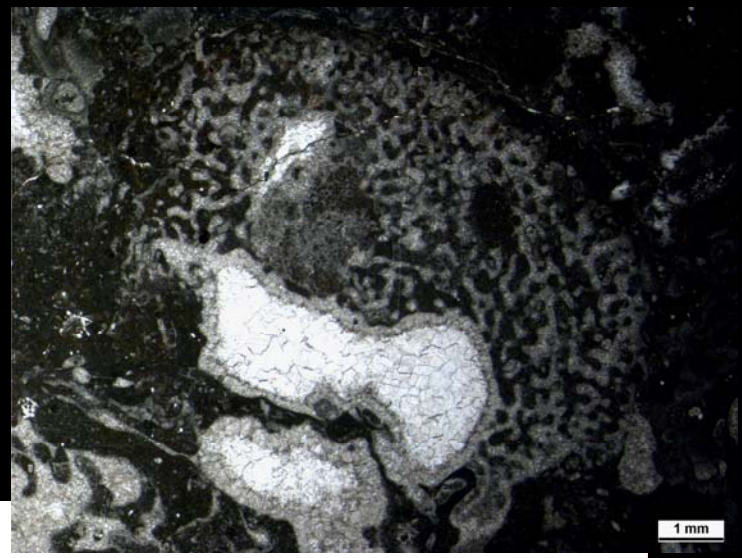
Blendinger 1994, 1996

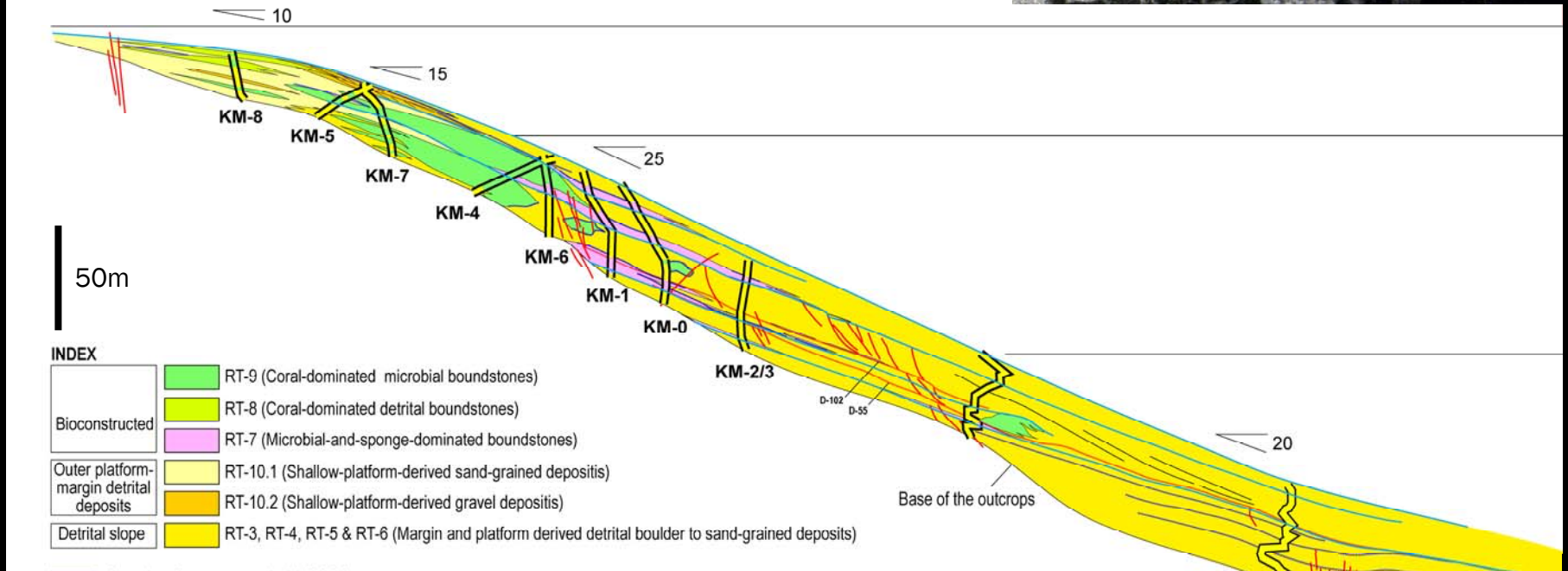


Lower Jurassic (High Atlas, Morocco) upper slope: sponge-microbial boundstones downslope of coral reefs



Merino, Verwer, Della Porta, Kenter in prep.





Summary

Depositional models based on the Recent need to be revised for margins with microbial cement boundstone or coral-microbial associations

- High production, extended depth window
- Carbonate growth not seriously reduced during sea-level falls
- Progradation of steep slope clinoforms independent from platform top shedding (**slope vs. highstand shedding**)
- Revision of leeward progradational vs. windward aggradational margins. Oceanographic control on margin growth?

The "model" provided for progradational, high relief microbial platform margins might be considered for other areas and times.

.....But many aspects of the microbial boundstone precipitation, cementation, and slope processes remain poorly understood.

For interpretation, modelling and prediction we need a better understanding of types, rates and the environmental controls of the "microbial" factories.

Thank you!