THE UNIVERSITY OF TEXAS AT AUSTIN

Sea-level Rise, Depth-dependent Carbonate Growth, and The Paradox of Drowned Platforms

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ABSTRACT

A mathematical model of carbonate platform sedimentation is presented in which the depth-dependent carbonate growth rate determines the depositional rate of a platform top responding to relative sea-level rise. This model predicts that carbonate platform evolution is primarily controlled by the initial water depth and the sediment production rate at the initial depth, rather than by the maximum potential production rate and imposed rate of relative sea-level rise. A long-standing paradox in the understanding of drowned carbonate platforms in the geological record is based on comparing relatively slow long-term rates of relative sea-level rise with maximum growth potentials of healthy platforms.

The model presented here demonstrates that a carbonate platform could be paradoxically drowned by a constant relative sea-level rise when the rate is still less than the maximum carbonate production potential. This does not require other external controls of environmental change, such as nutrient supply or siliciclastic sedimentation. If the rate of relative sea-level rise is higher than the production rate at the initial water depth, the top of the carbonate platform gradually drops below the active photic zone and drowns even if the rate of relative sea-level rise is lower than the maximum carbonate accumulation growth potential. This result effectively resolves the paradox of a drowned carbonate platform. Test runs conducted at bracketed rates of relative sea-level rise have determined how fast the system catches up and maintains the "keep-up" phase, which is a measure of the time necessary for the basin to respond fully to the external forcing. The transition from the catch-up to the keep-up phases can be delayed by a time interval associated with ecological reestablishment after platform flooding. The carbonate model here employs a logistic equation to model the colonization of carbonate-producing marine organisms and captures the initial time interval for full ecological reestablishment. The increase in delay time due to the self-organized processes associated with biological colonization, implies a greater likelihood of a wide range of slow relative sea-level rise rates that could cause slowly drowned carbonate platforms and reefs.

PARADOX

Orders of Magnitude Higher

Maximum aggradation rate potential in modern marine carbonate reefs and platforms: 10^0 - 10 mm/yr

Maximum aggradation rate of coral reefs: ~ 10^2 mm/yr (Schlager, 1981)

Long-term rate of relative sea-level rise (RSLR, defined as the sum of sea-level rise and subsidence)

Long-term tectonic subsidence rate: 10^{-2} - 10^0 mm/yr

Eustatic sea-level change: 10^{-1} - 10^1 mm/yr

Many Drowned Carbonate Platforms and Reeefs

This imbalance between the high growth potential of the carbonate systems and the relatively low rates of extrinsic forcing, however, contrasts with the common observation in the geological record that many fossilized marine carbonate platforms and reefs have been drowned (Kendall & Schlager, 1981; Schlager, 1981). This has constituted **the paradox of drowned carbonate platforms** (Schlager, 1981).

STILL PARADOX?

Possible Causes

1. Tectonic pulses:
   Fault driven pulses of tectonic subsidence
   (Rees, 1986; Rosales, 1999; Ruiz-Ortiz et al., 2004; Wilson, 2000)
2. Pulses in global sea-level rise
   Melting pulses of the polar ice caps (Webster et al., 2004)
3. Regional deterioration
   Plate motion that transports the carbonate platforms to higher latitudes
   (Wilson et al., 1998)
4. Extreme anoxic envents
   Change in water temperature and nutrient level
   (Hallock and Schlager, 1986; Philip and Airaudcrumiere, 1991)

YES, STILL PARADOX!

Exact Drowning Mechanism

1. The minimum RSLR rate that is required to drown the platform?
2. Any case that exists for drowning with long-term slow RSLR?

CARBONATE PLATFORM MODEL

Platform Growth Function

$$\frac{d\eta}{dt} = G_m e^{-kgH} - S_m e^{-ksH}$$

Platform top accumulation rate: Balance between carbonate sediment production ***G*** [L/T] and surface erosion ***S*** [L/T].

η = platform top elevation

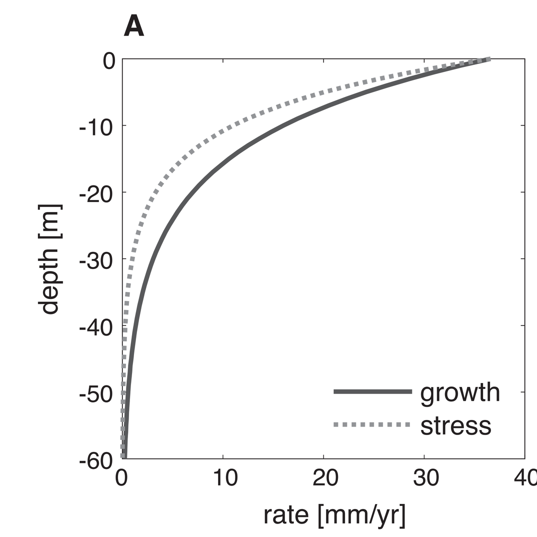
G_m, S_m= the maximum growth & stress rates

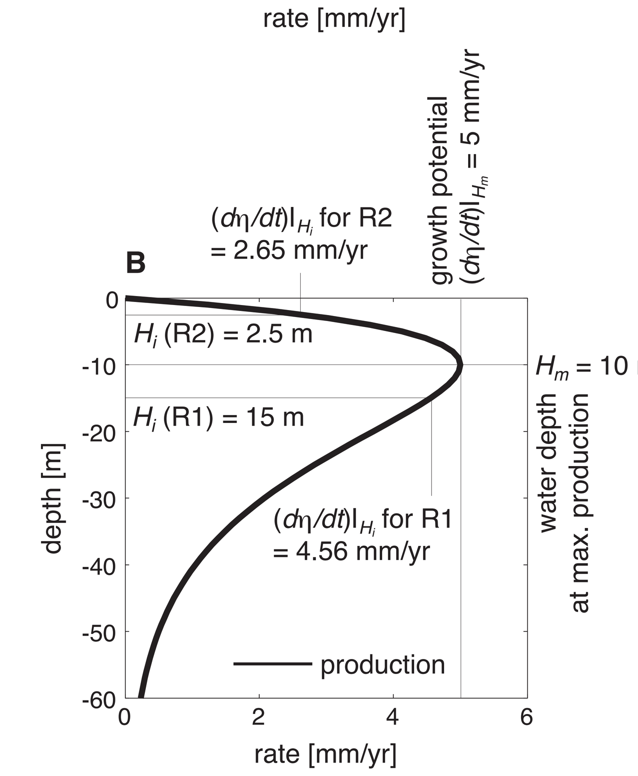
kg, ks = the growth & stress exponents

H = water depth

1. ***G***: Byproducts of photosynthesis by in-situ organisms, depending on light availability
2. ***S***: Wave Erosion

- Maximum growth rate: $d\eta_M$ = 5 mm/yr
- Water depth at Max growth rate: Hm = 10 m





Governing Equation: Basin Evolution

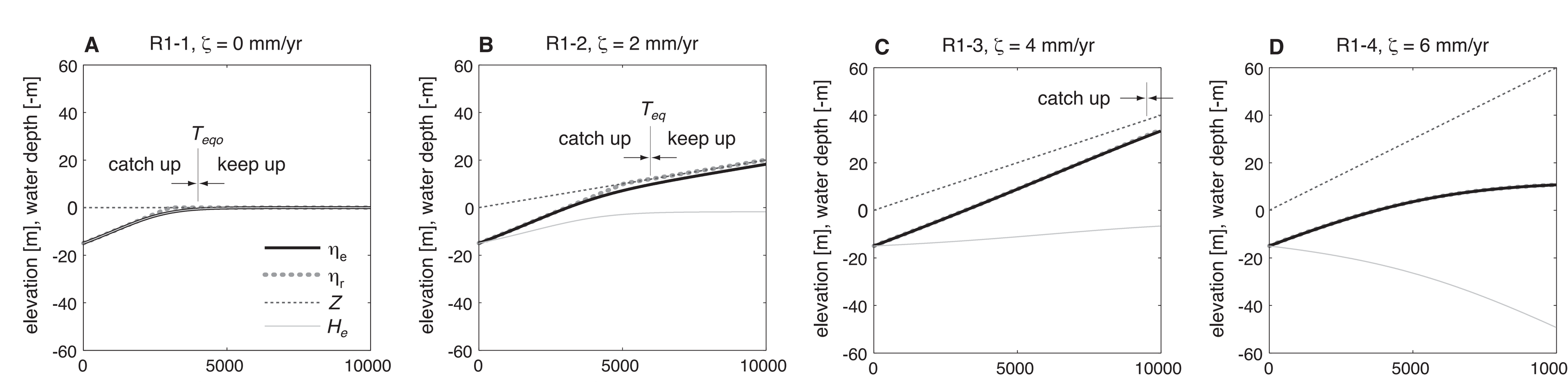
$$\frac{dH}{dt} = \zeta - \frac{d\eta}{dt}$$

ζ denotes RSLR rate [L/T]

MODELING RESULTS

R1 Deep-water Platform

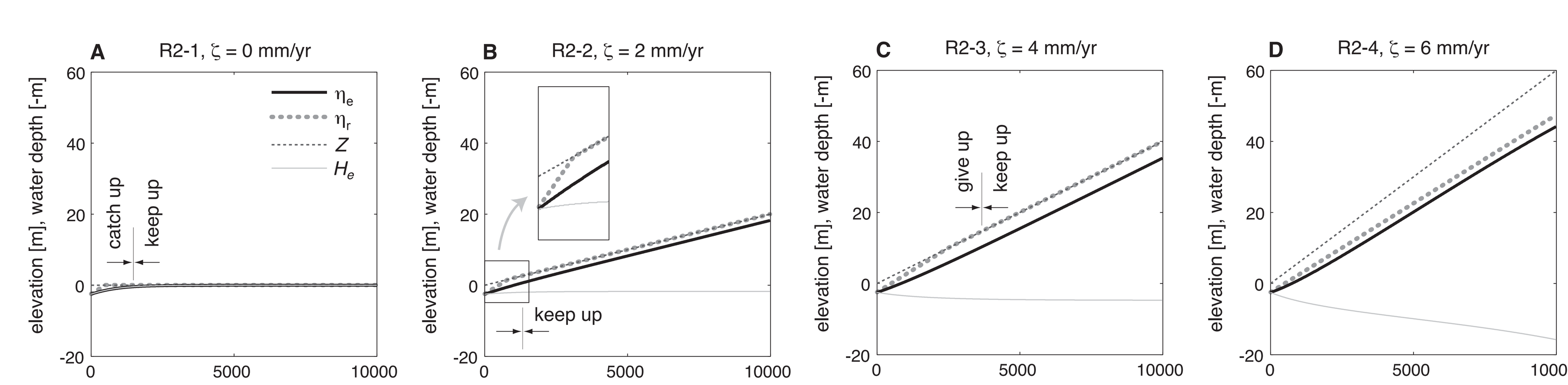
Initial water depth Hi = 15 m, and RSLR rates = 0, 2, 4, and 6 mm/yr



RSLR > $d\eta_M$ ➔ Drown

R2 Shallow-water Platform

Initial water depth Hi = 2.5 m, and RSLR rates = 0, 2, 4, and 6 mm/yr



RSLR > $d\eta_M$ ➔ Drown

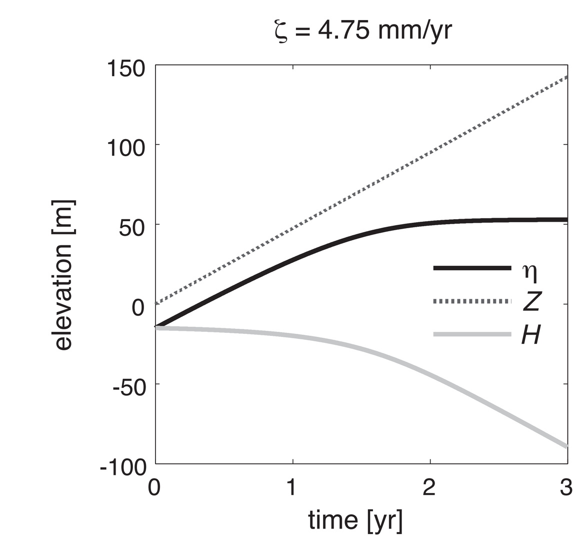
Three different carbonate stratigraphic responses to RSLR:

1. keeping-up (KU: maintaining constant water depth during the sea-level rise)
2. catching-up (CU: recovering and beginning to outpace the sea-level rise)
3. giving-up (GU: still growing but with a lower rate than sea-level rise)

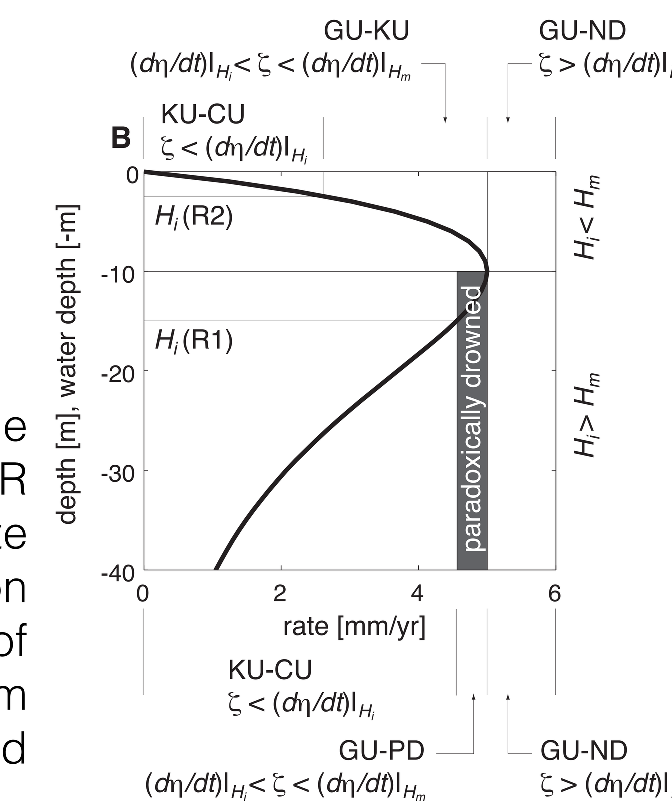
SLOW DROWNING?

Drowning under RSLR less than Growth Maximum

Initial water depth = 15 m, and RSLR rate = 4.75 mm/yr < $d\eta_M$



Paradoxically Drowned



Drowning Mechanism

The first-order drowning condition of the RSLR rate is ζ > ($d\eta$ at H initial). The RSLR rate must be higher than the depositional rate at the initial water depth under the condition that $Hi > Hm$. Therefore, there is a range of RSLR rates that are less than the maximum depositional growth rate potential but could drown carbonate reefs and platforms.

WHAT SETS THE INITIAL WATER DEPTH?

Reference time ZERO at the **flooding surface**

Then, Hi = 0?

Population Dynamics

$$\frac{dB^*}{dt} = r_b B^*\left(1 - B^*\right) \;\rightarrow\; \frac{d\eta}{dt} = B^* G_m e^{-kgH} - S_m e^{-ksH}$$

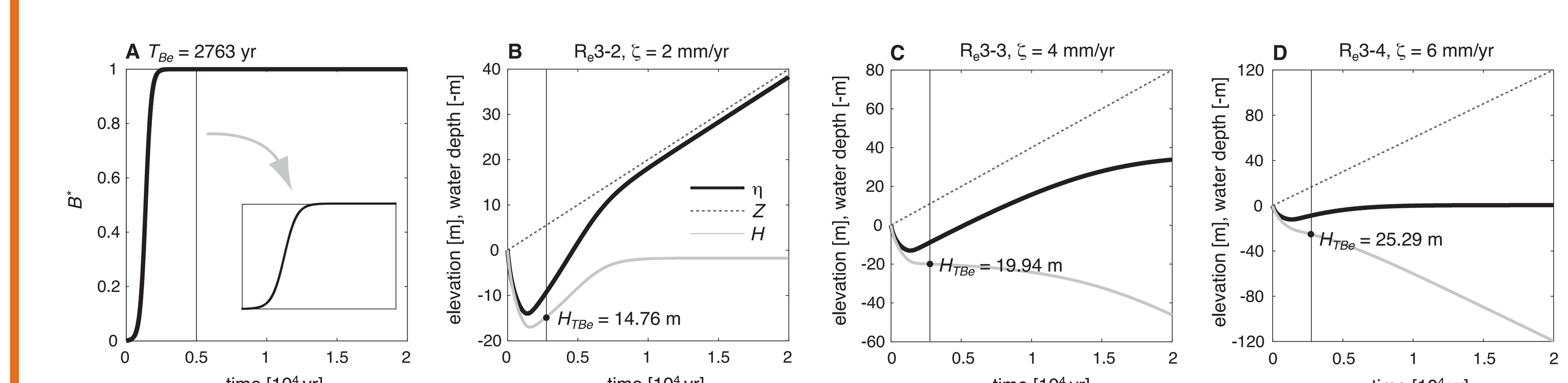
The logistic equation (Enrique, 1976) produces **sigmoidal growth curves** describing the interplay between autogenic growth rate of a population and the environmental constraints such as an available living space.

$B^* = B/Be$,

B = the population of carbonate producing organisms

Be = the equilibrium population

r_b represents the reproduction of an individual organism.



Full Reestablishment for ca. 3 ka ➔ **More Paradoxically Drowned Platforms**

STILL PARADOX?

1. Carbonate basin evolution: The key factors = Imposed RSLR rate & Accumulation rate at the initial water depth (compared to the depth for the max. production)
2. Drowning condtion: In general, the RSLR rate > the carbonate growth potential: More accurately if the accumulation rate at the initial condition < the RSLR rate, the carbonate platform can drown.
3. The reestablishment of the carbonate producing colony controls the initial time delay and causes deeper initial water depth.