Continental Shelves as the Lowstand Fluvial Longitudinal Profile: Possible Implications for Icehouse vs. Greenhouse Stratigraphic Records*

Mike Blum[1]

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Abstract

This article suggests that lowstand fluvial profiles represent the first-order morphodynamic state for continental shelves, and river long profiles are graded to shelf margins. Over the last 10^6 yrs mean sea level has been -60 to 65 m, with a mode at -85 to -90: for most of this time, the majority of shelves would have been subaerial. Long profiles for river systems have equilibrium times > 10^4 to 10^5 yrs: they should be adjusted to mean states over time scales that are ≥ equilibrium times, and insensitive to the anomalous and infrequent highstands. On a global scale, shelf gradients and widths correlate to onshore fluvial gradients and drainage areas.

In an icehouse world, high-frequency climate changes are coupled to changes in ice volume, and unsteadiness of sediment supply due to climate change is modulated by the transit of river mouths across the shelf. Moreover, the transit of river mouths across a broad shelf results in the merger of river systems that discharge separately to the coastal oceans during highstand: merging of drainage basins increases the magnitude of individual point-source sediment supply, but there will be fewer river mouths and delta systems at the shelf margin than there are during highstand time. These relationships should be fundamentally different in a Greenhouse world: high frequency, long distance transit of river mouths and deltas, and merger of drainage basins should not occur to the same degree.

In an Icehouse world, then, major high-frequency (time scales < 10^6 yrs) changes in fluvial-deltaic, shelf-margin, slope, and basin-floor stratal packages will reflect fluvial responses to sea-level change. In a Greenhouse world, high-frequency stratigraphic packaging should be closely coupled to unsteadiness in sediment supply due to climate change, rather than modulated by fluvial transit of the shelf, and merging of drainages.

CONTINENTAL SHELVES AS THE LOWSTAND FLUVIAL LONG PROFILE

And Some Possible Implications for Icehouse vs. Greenhouse Stratigraphic Records

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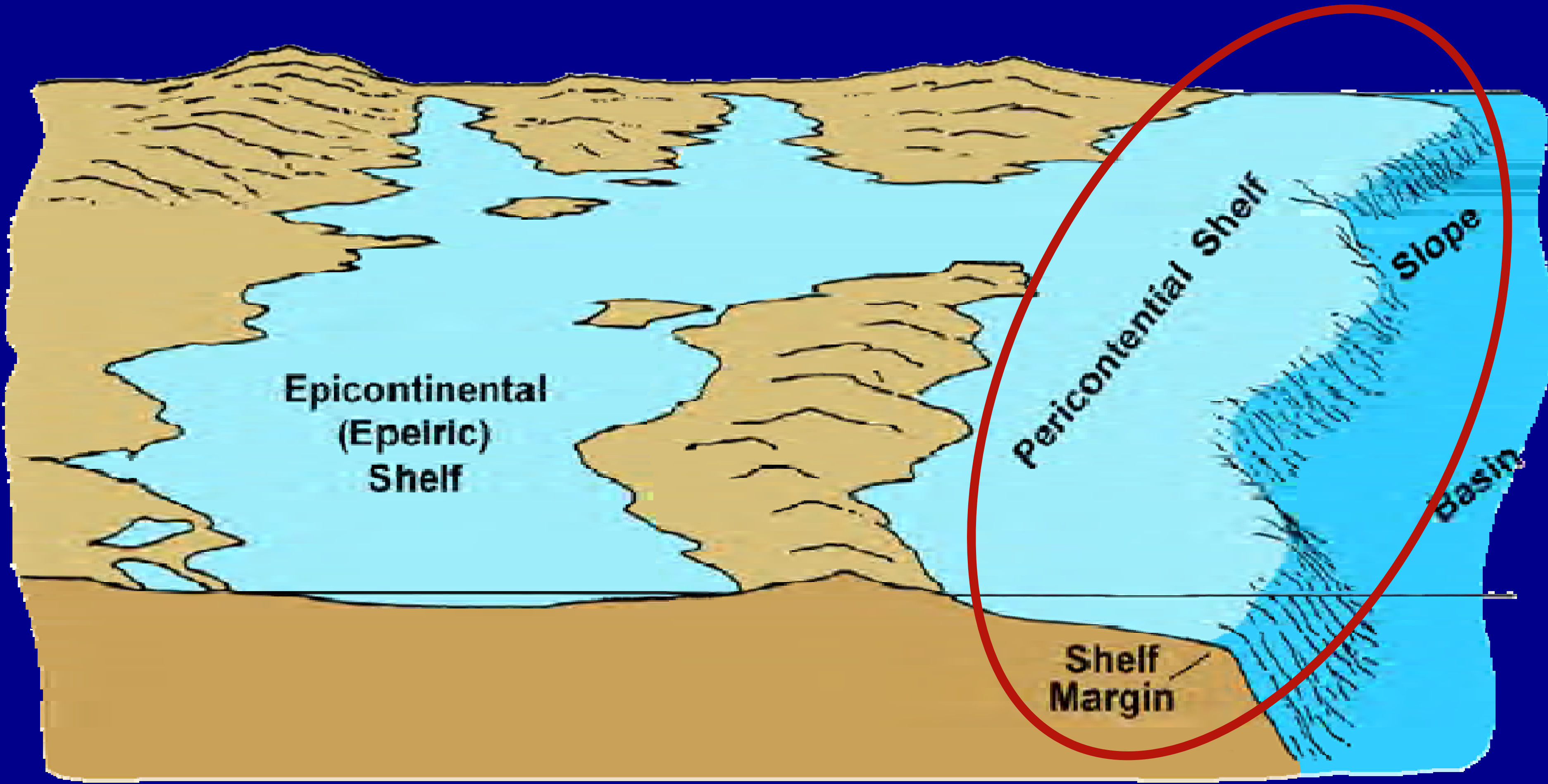
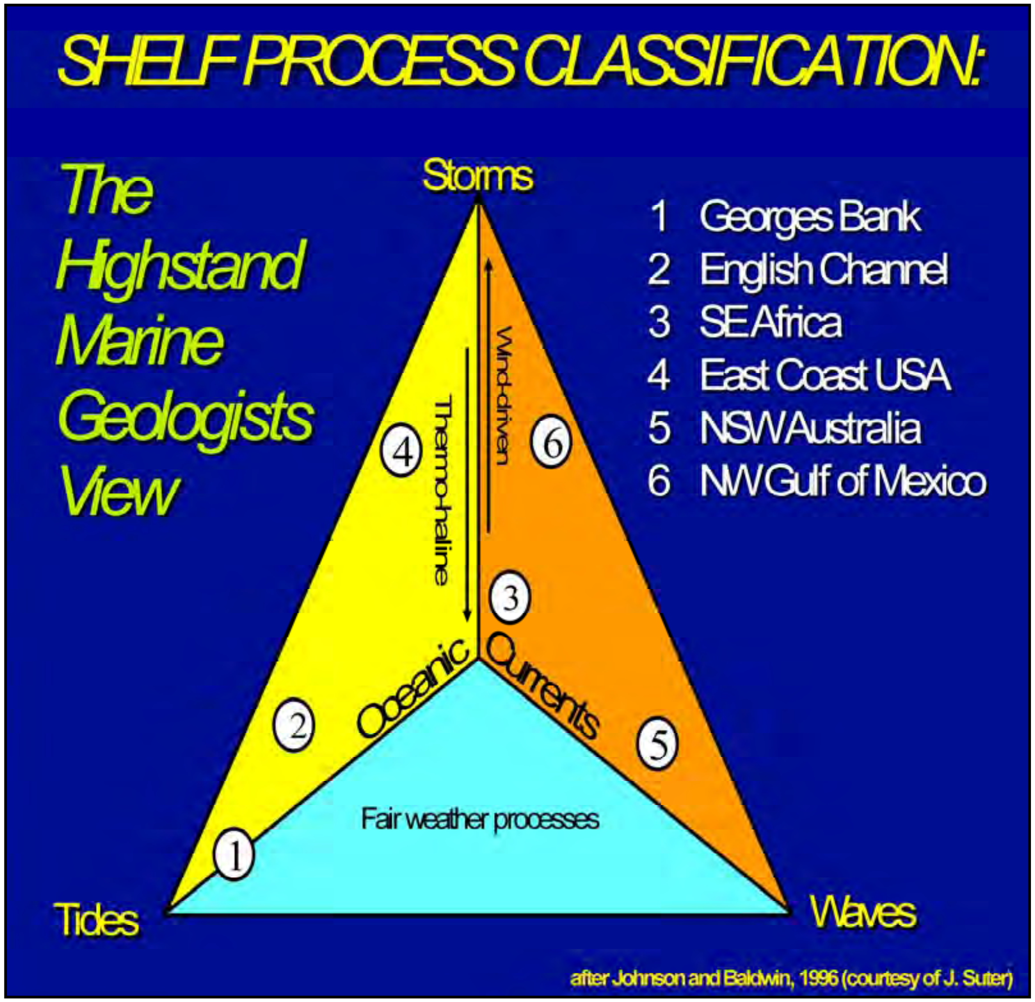
GENERAL SHELF TYPES



after Heckel, 1972; Nittrouer and Wright, 1994 (courtesy of J. Suter)



A) Process classification of continental shelves, depending on the relative balance of "fair-weather" processes (oceanic currents, tides, and waves) with storms.

Numbers refer to shelf regions discussed in this review (after Johnson and Baldwin, 1996).

A) A simplified version of the conceptual shelf process classification, which recognizes the similar depositional effects of tides and semi-permanent oceanic currents as one apex of the triangle (after Johnson and Baldwin, 1996; Galloway and Hobday, 1996). Numbers refer to shelf areas illustrated or discussed in this review.

TOPICS OF DISCUSSION

- *constructional clastic shelves as the “continental terrace”*

- *equilibrium times and mean sea-level positions*

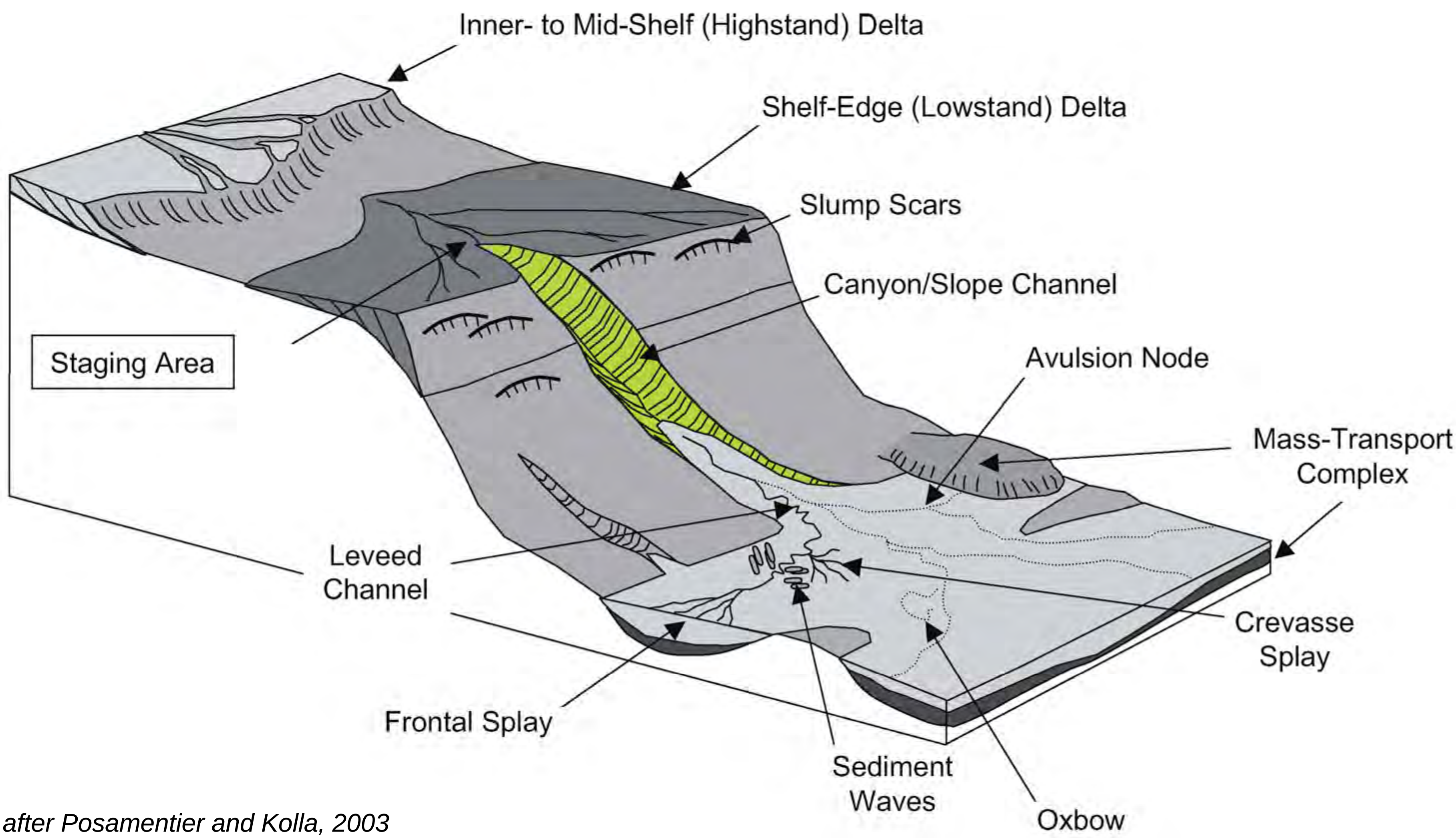
- *“graded” river long profiles and the shelf margin*

- *unsteady vs. steady sediment supply*

- *merging and unmerging of drainages during shelf transit*

- *speculations on “icehouse” vs. “greenhouse” worlds*

THE “STAGING AREA” CONCEPT

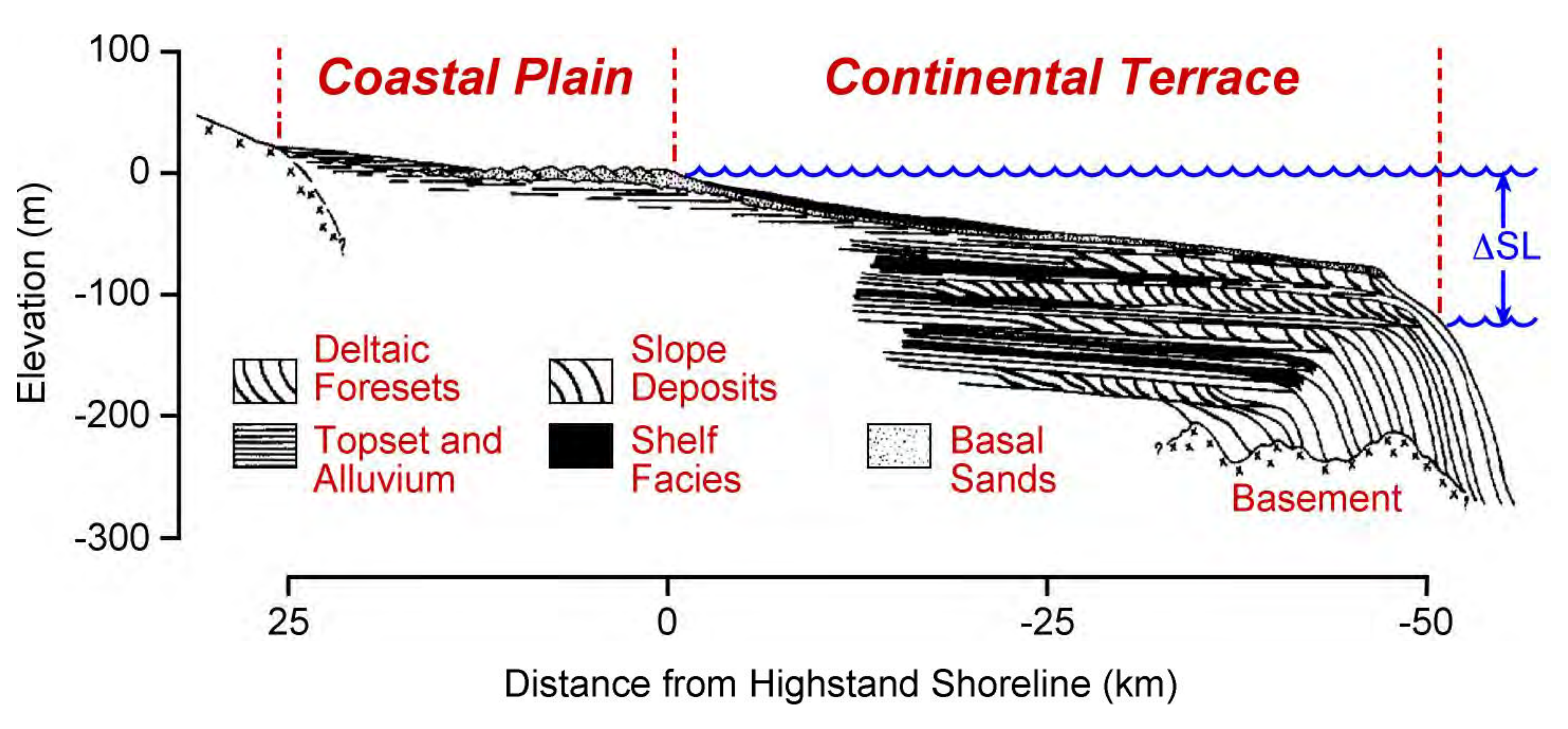


after Posamentier and Kolla, 2003

What are the source-to-sink processes and scaling relationships that control sediment dispersal to the shelf margin?

SHELF AS THE CONTINENTAL TERRACE

from Curray's Work on the Coast of Nayarit



- *recognized that shelves were constructional, and represented repeated fluvial-deltaic progradation during sea-level fall and lowstand*
- *recognized coincidence between shelf margin depth and widely inferred Pleistocene lowstand sea levels of ~ -120 to -130 m*

after Curray and Moore (1964)

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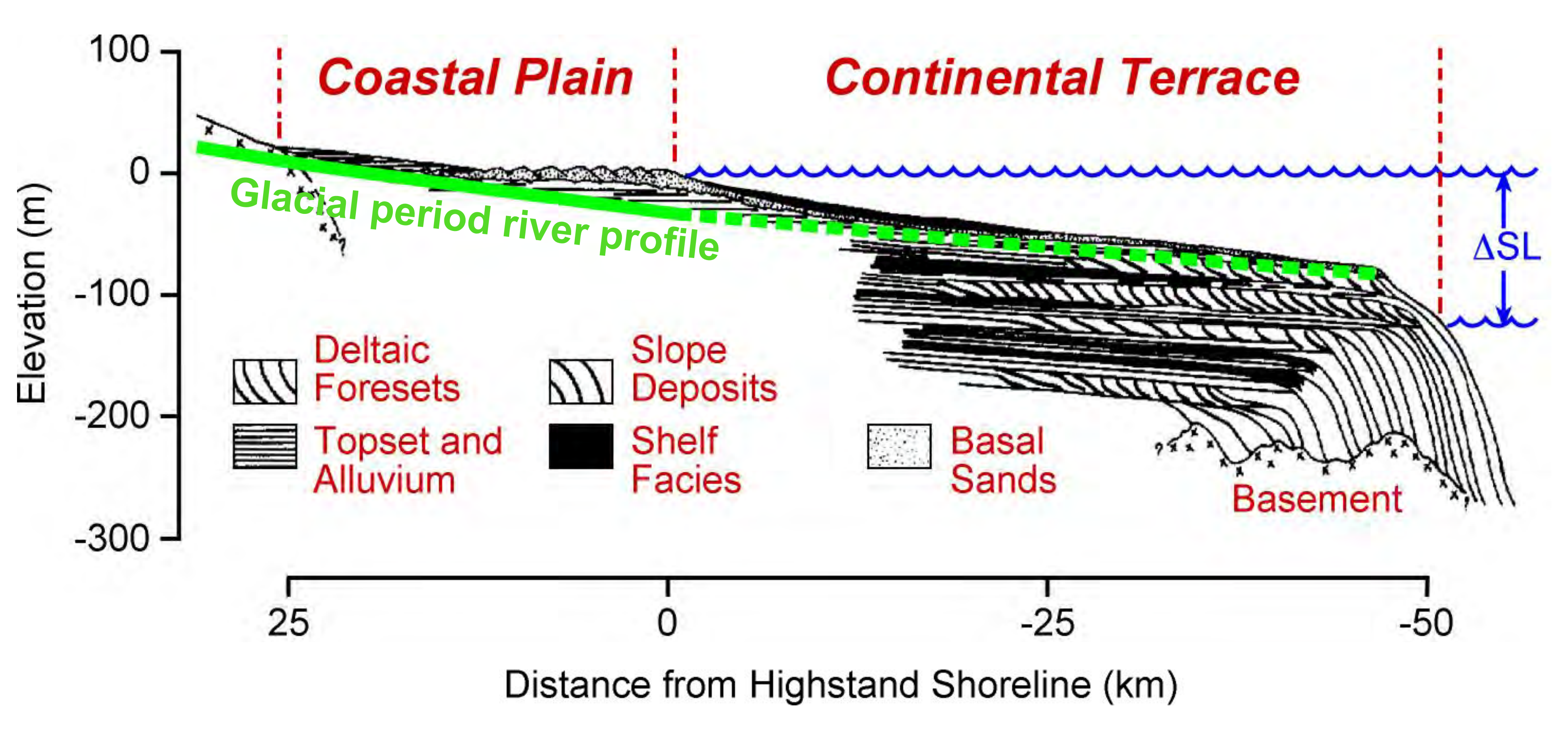

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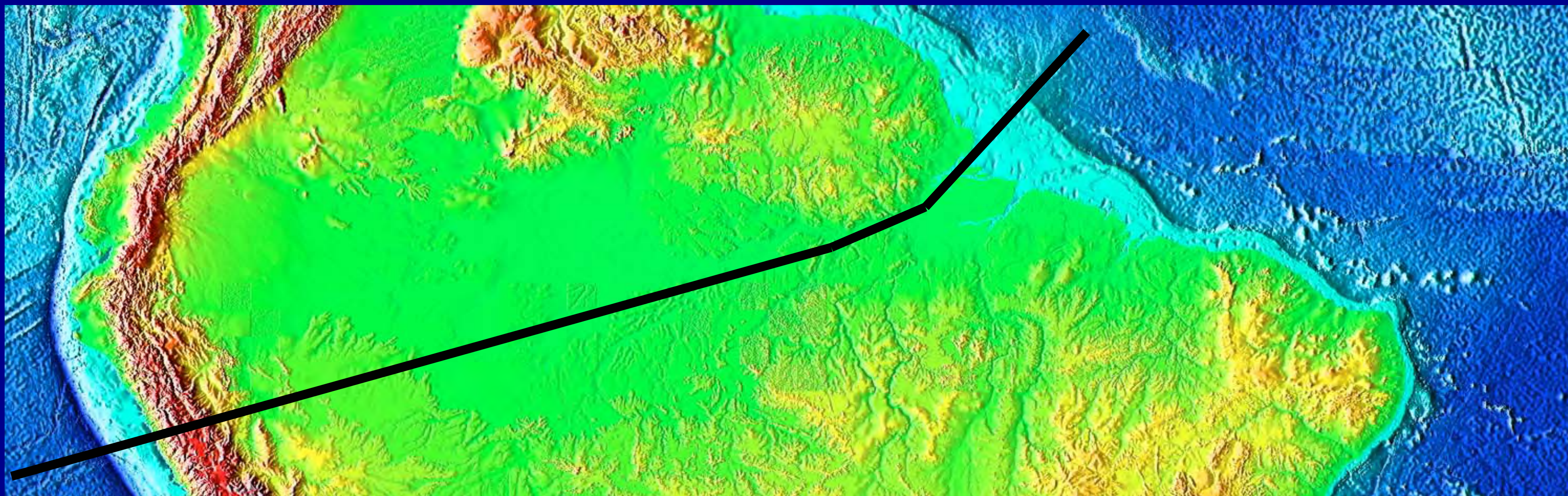
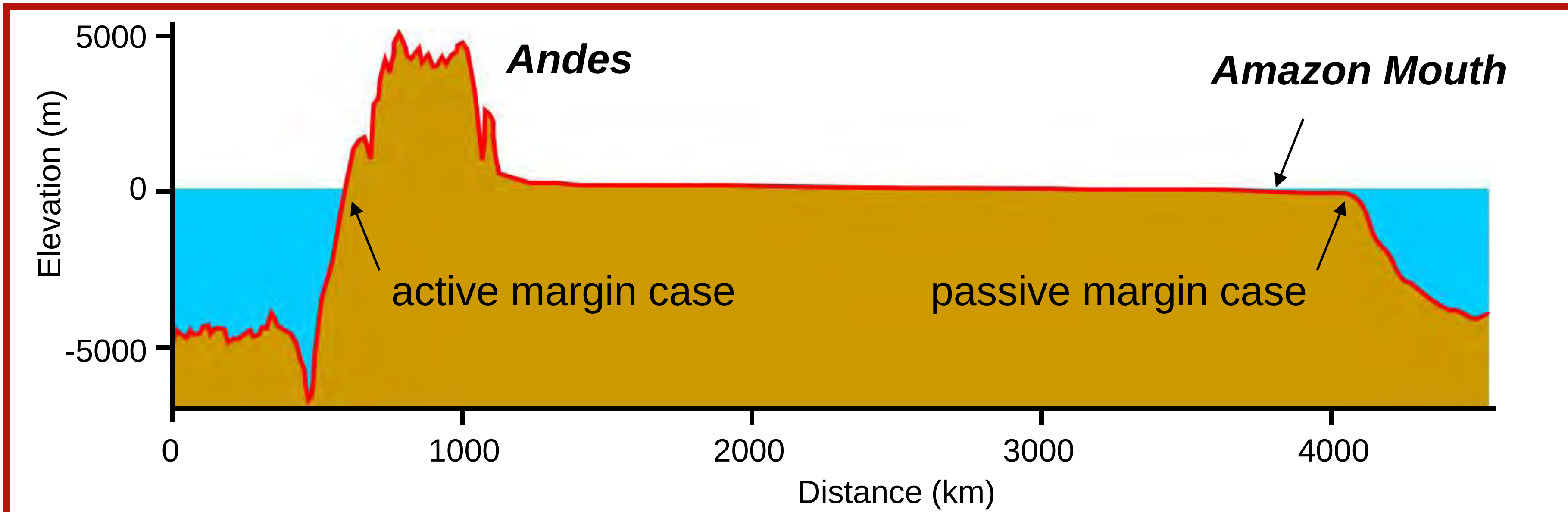
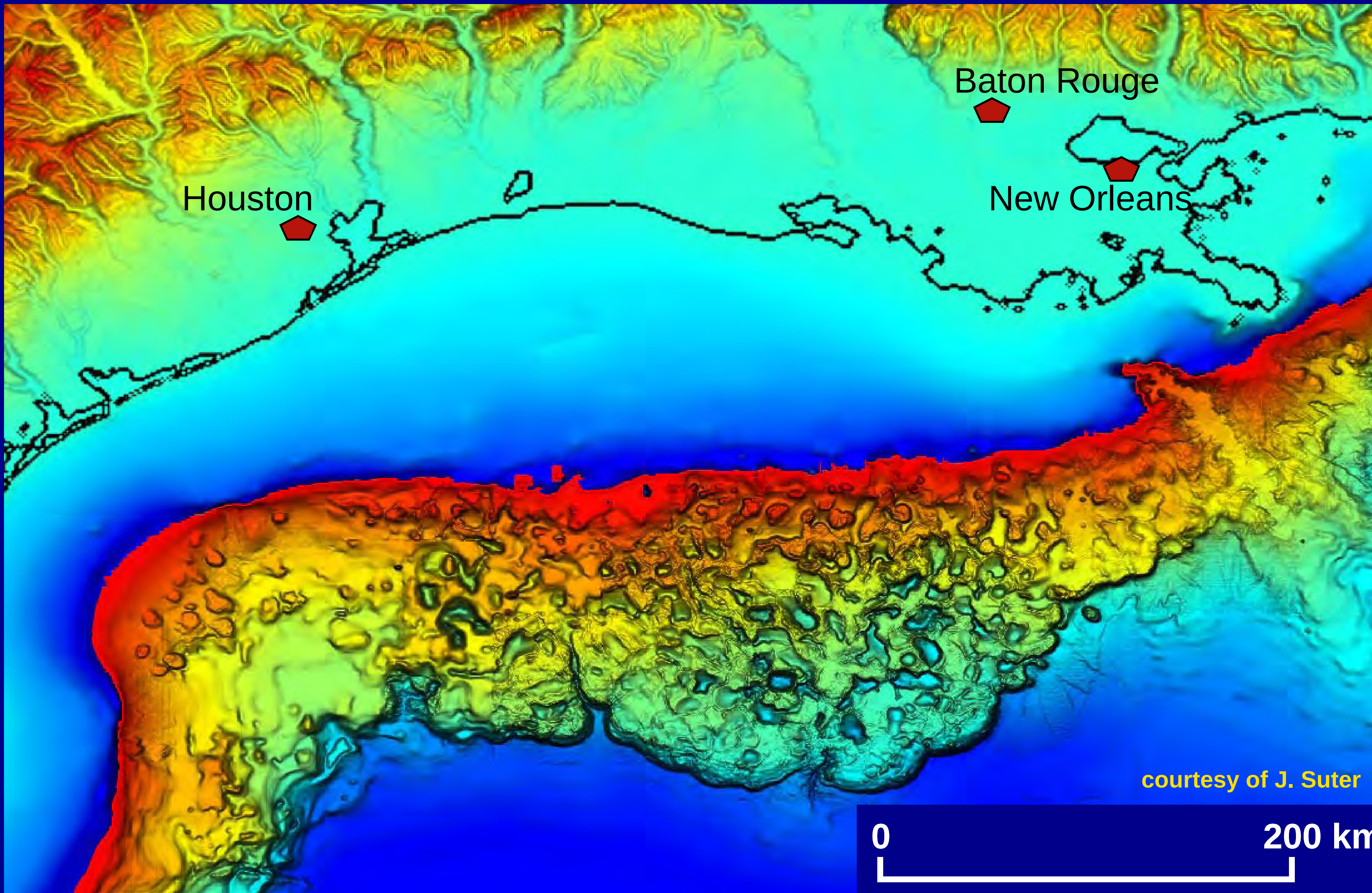
SHELVES AS THE DOWNDIP EXTENSION OF THE FLUVIAL LONG PROFILE?



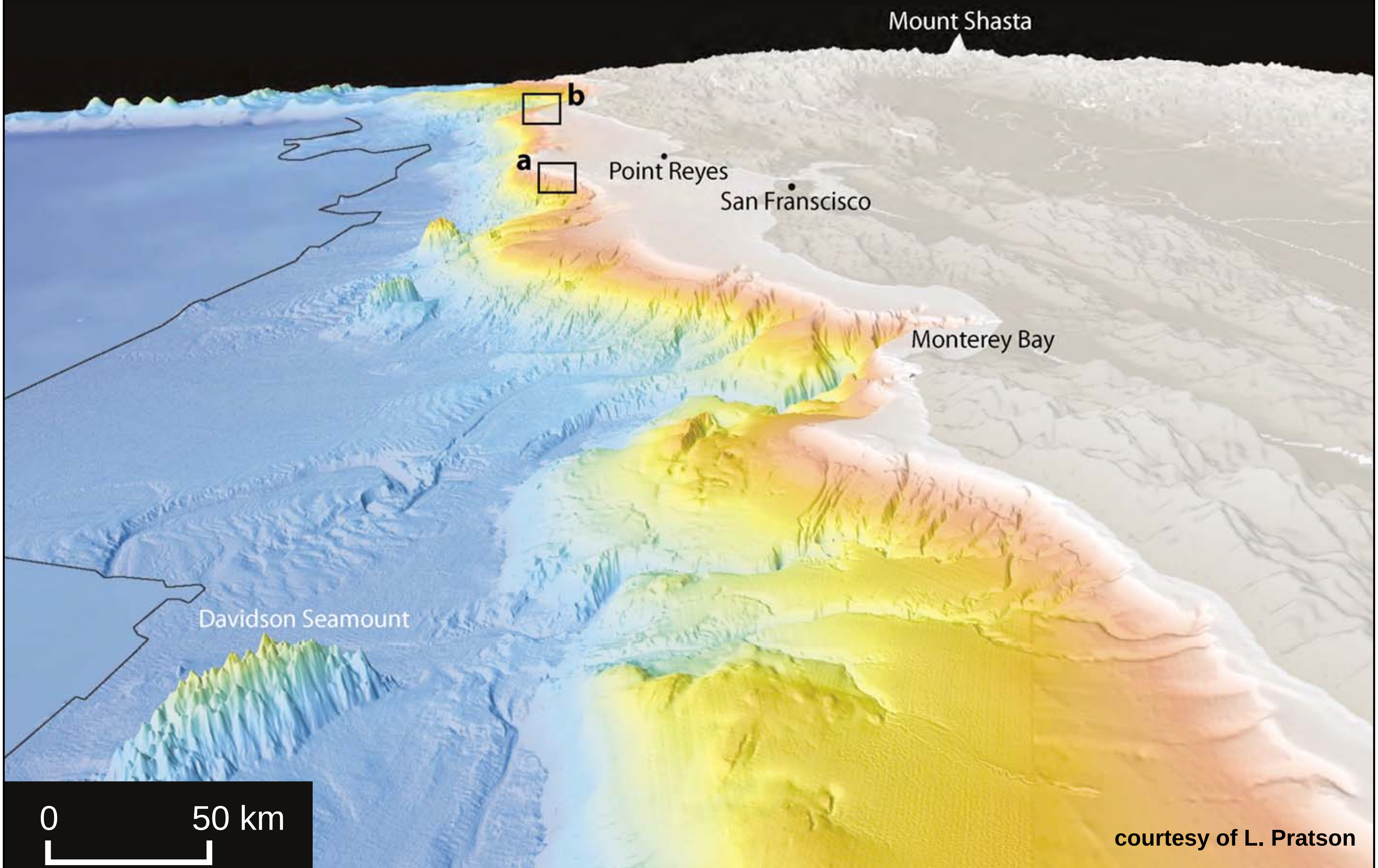


NORTHERN GULF OF MEXICO MARGIN



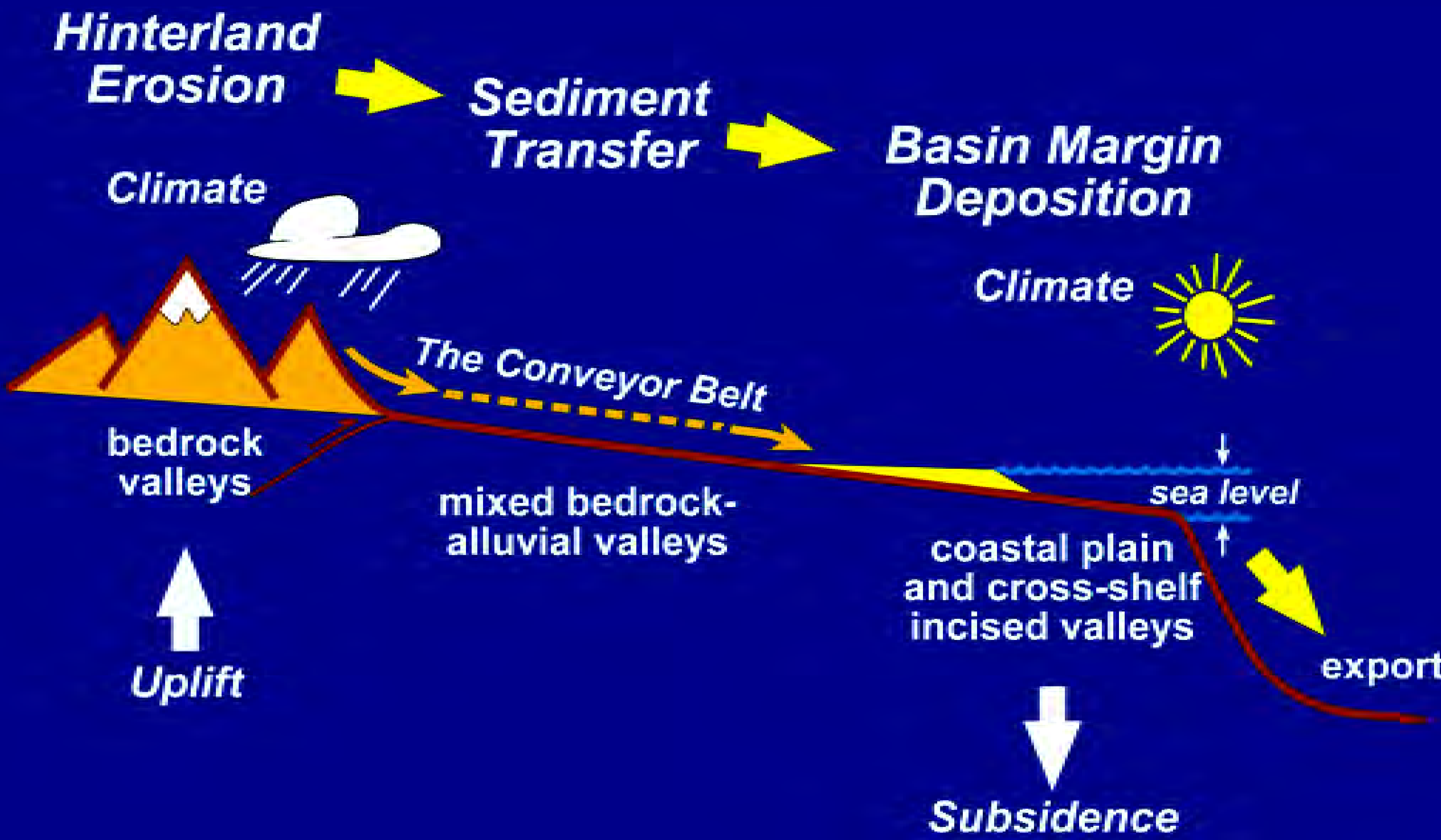
- passive margin shelf widths are usually >> 50 km

WESTERN US CALIFORNIA MARGIN



- active margin shelf widths are usually << 50 km

SOURCE-TO-SINK LONG PROFILE MODEL



TO WHAT ARE RIVER SYSTEMS GRADED?

EQUILIBRIUM RESPONSE TIMES

Diffusion-Based Characteristic Response Times
For Major Landscape/Seascape Features

$$T_{eq} = \frac{L^2}{k}$$

where:

T_{eq} = response time (yrs)

L = length of system (km)

k = diffusivity = Q_s/W

Q_s = sediment flux (MT/yr)

W = channel or floodplain width (m)

- Response times for long profiles of most river systems along constructional margins commonly exceed ~100-200 kyrs
- Long profiles for major river systems are therefore likely “graded” to mean conditions over time periods that equal or exceed characteristic response times!! Over shorter time scales, response decays with distance $L = Tk^{0.5}$

from Paola (2000)

EQUILIBRIUM RESPONSE TIMES

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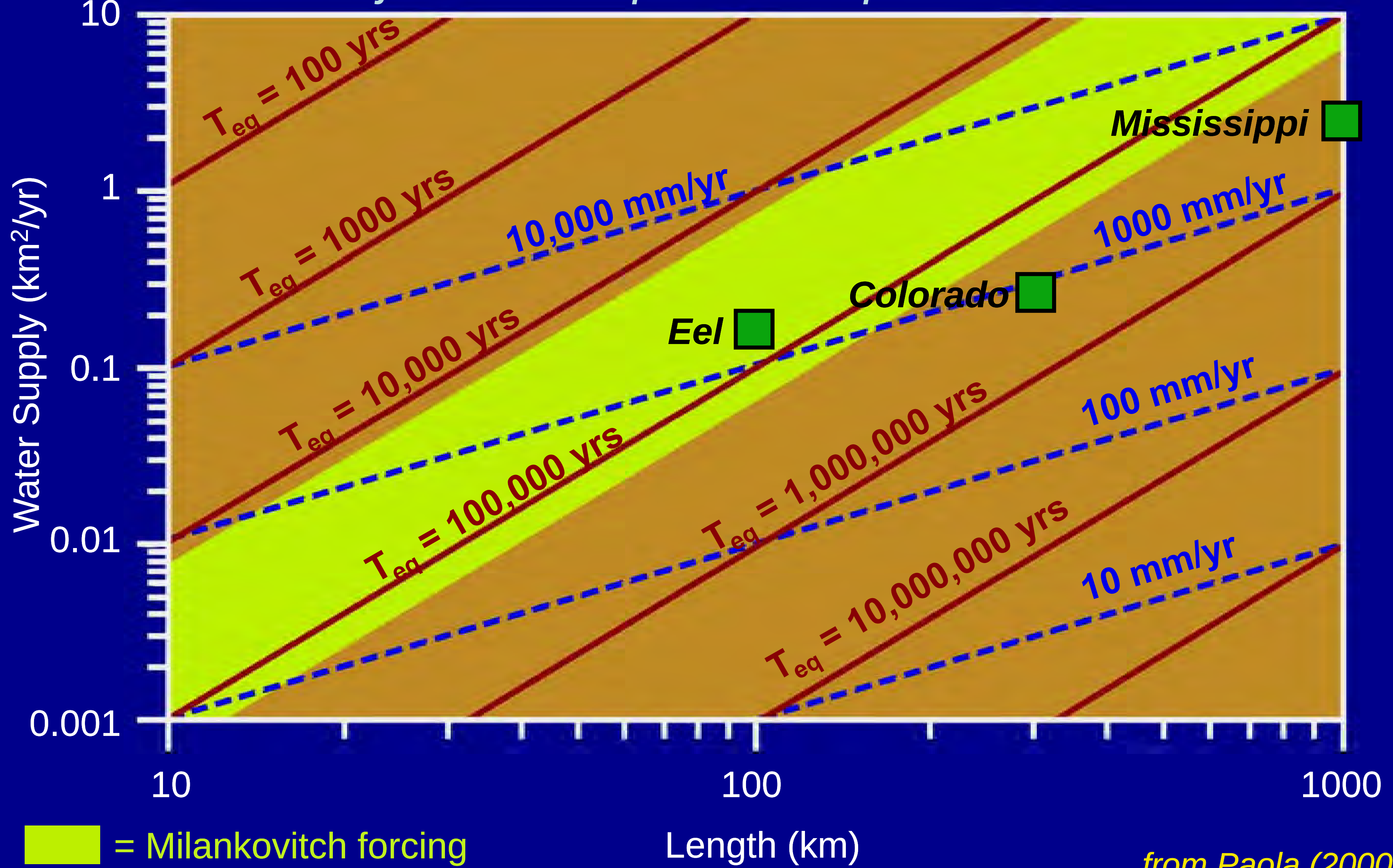
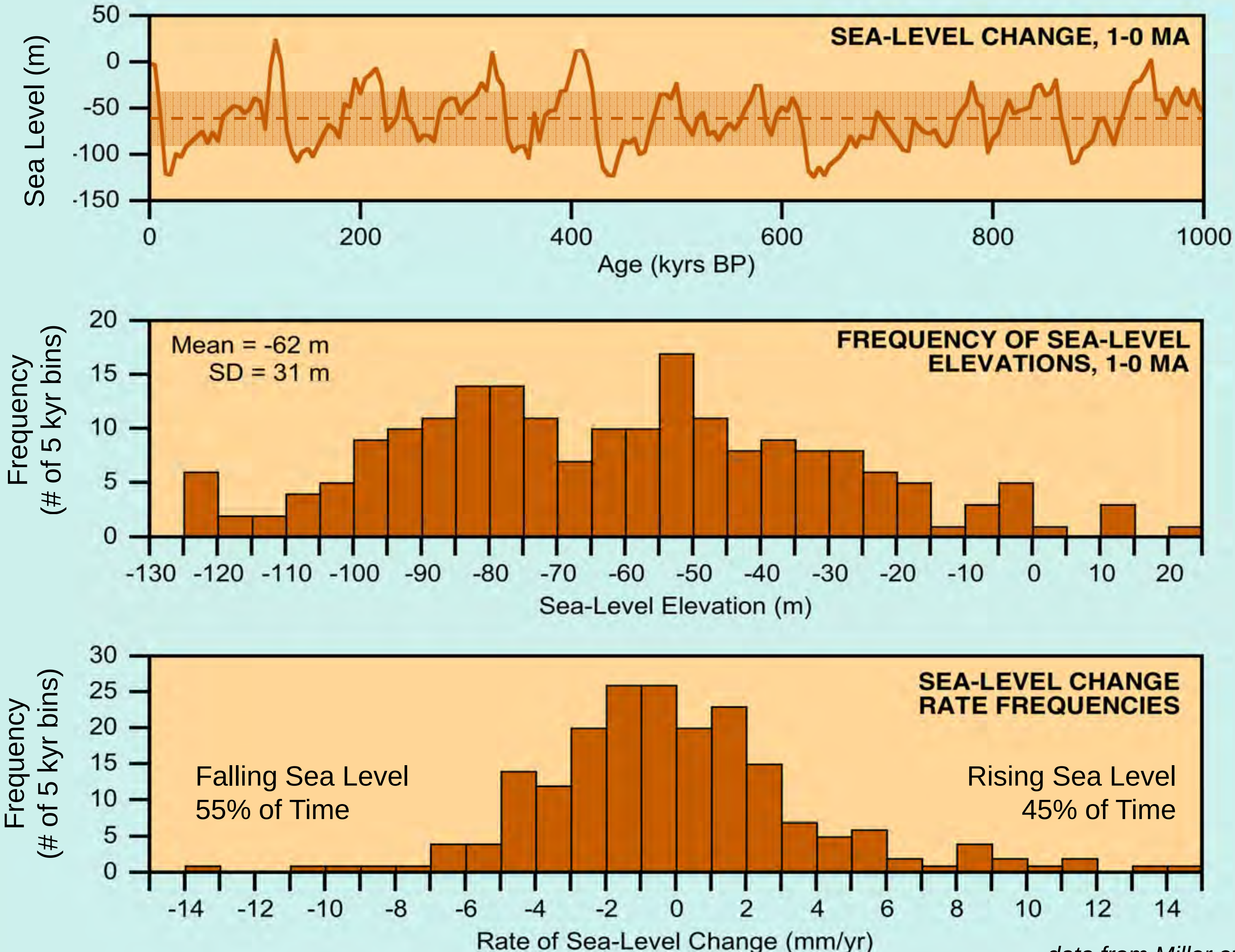


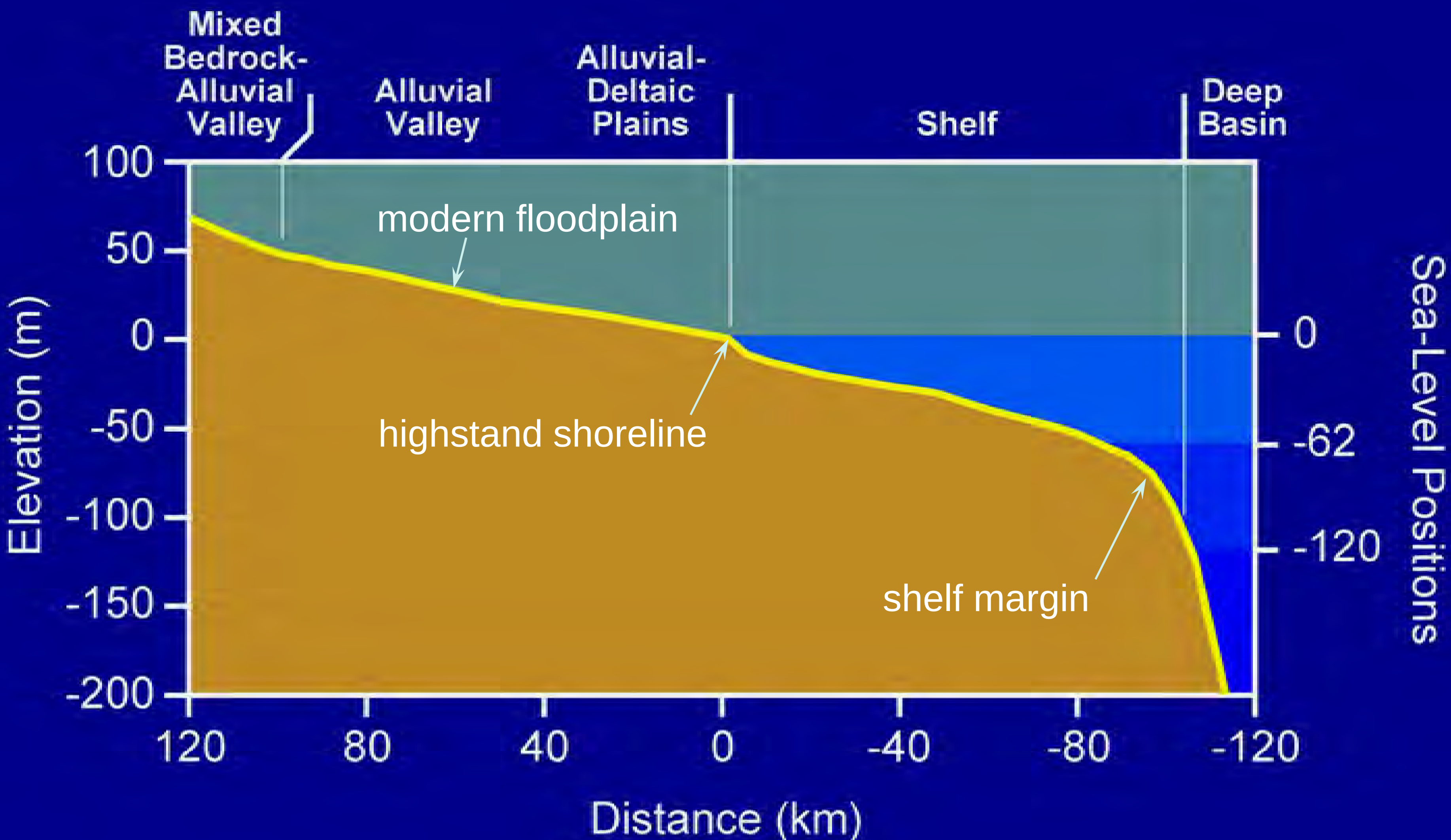
from Paola (2000)

GLOBAL SEA LEVEL CHANGE: 1-0 MA



data from Miller et al. (2005)

LONG PROFILE OF LOWER COLORADO RIVER, SHELF, AND SLOPE (TEXAS)



NGDC topographic and bathymetric data

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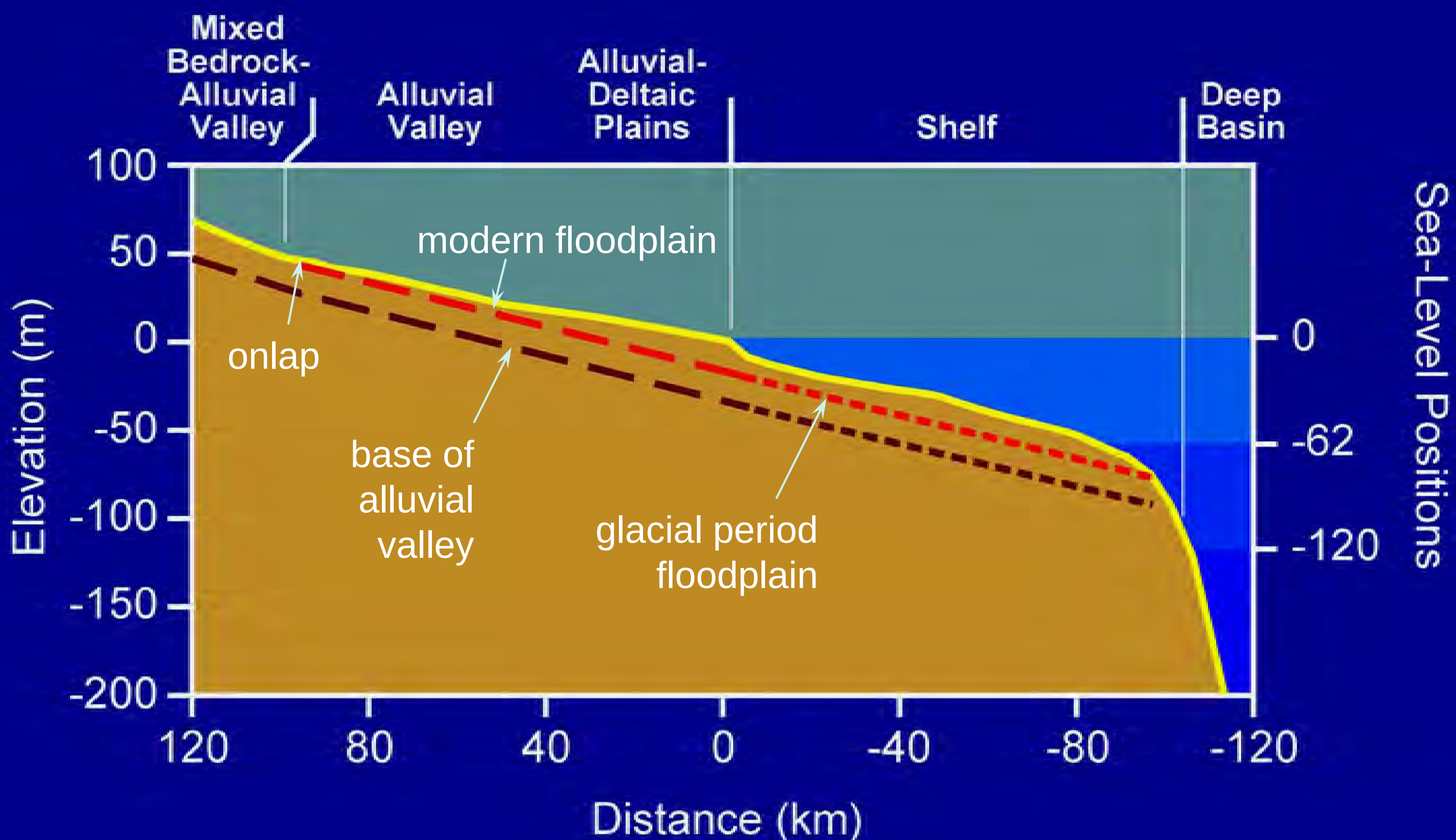

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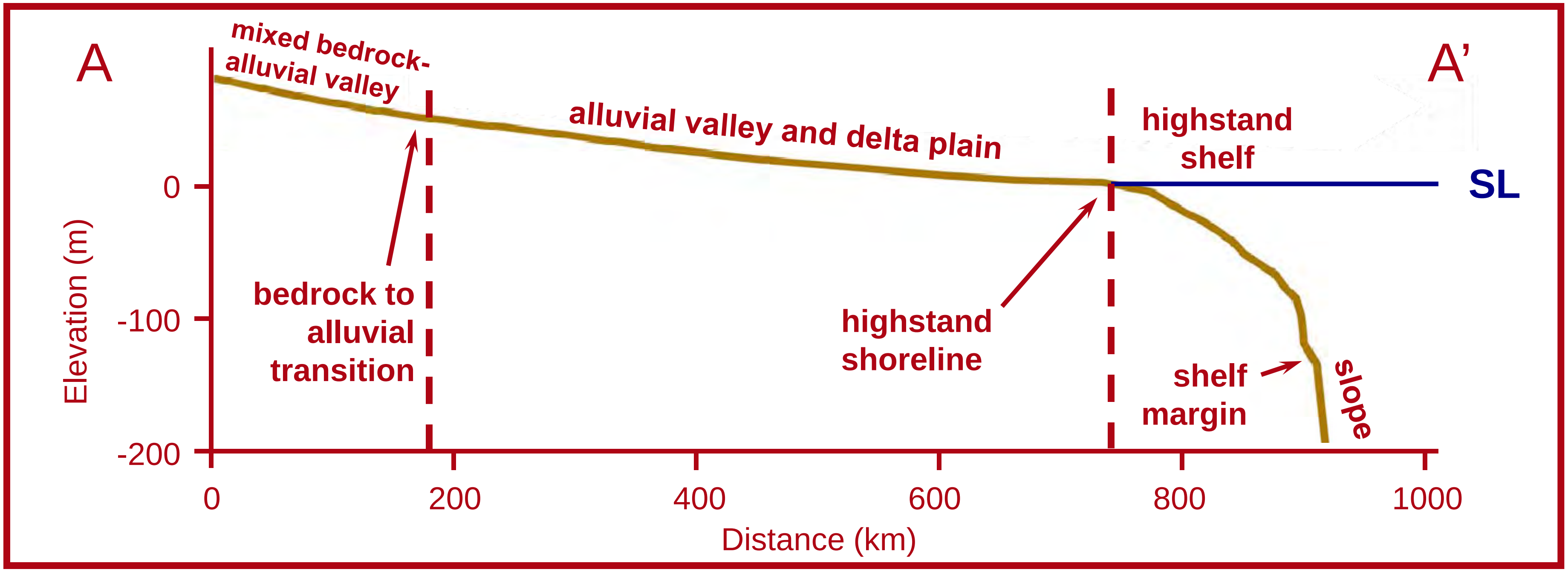
MISSISSIPPI VALLEY AND DELTA MARGIN

Topography and Bathymetry



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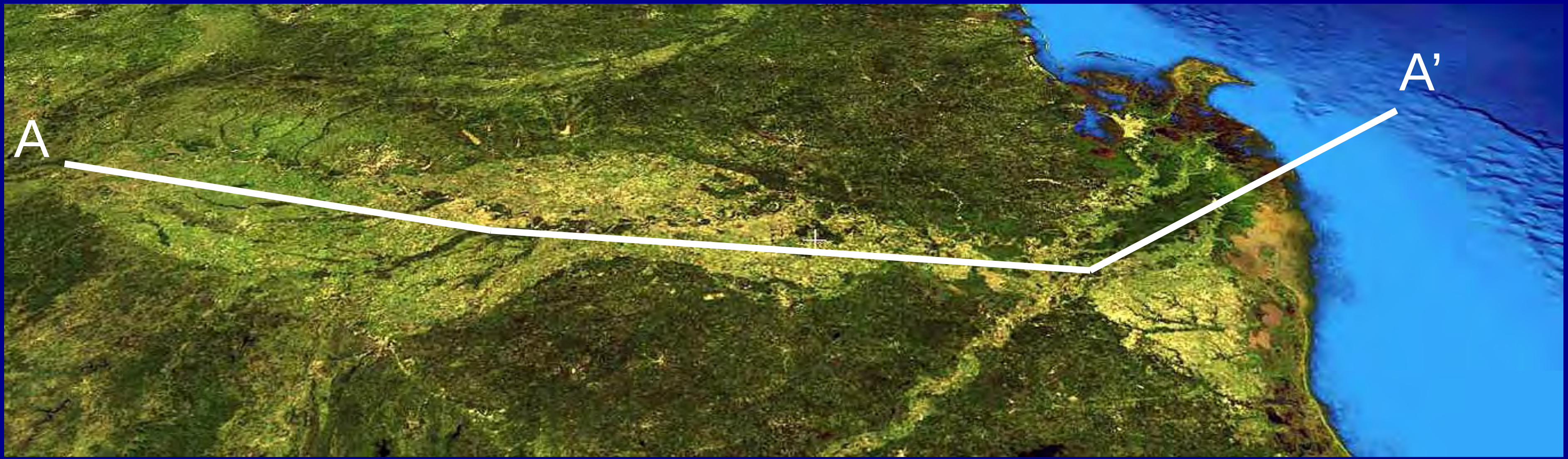
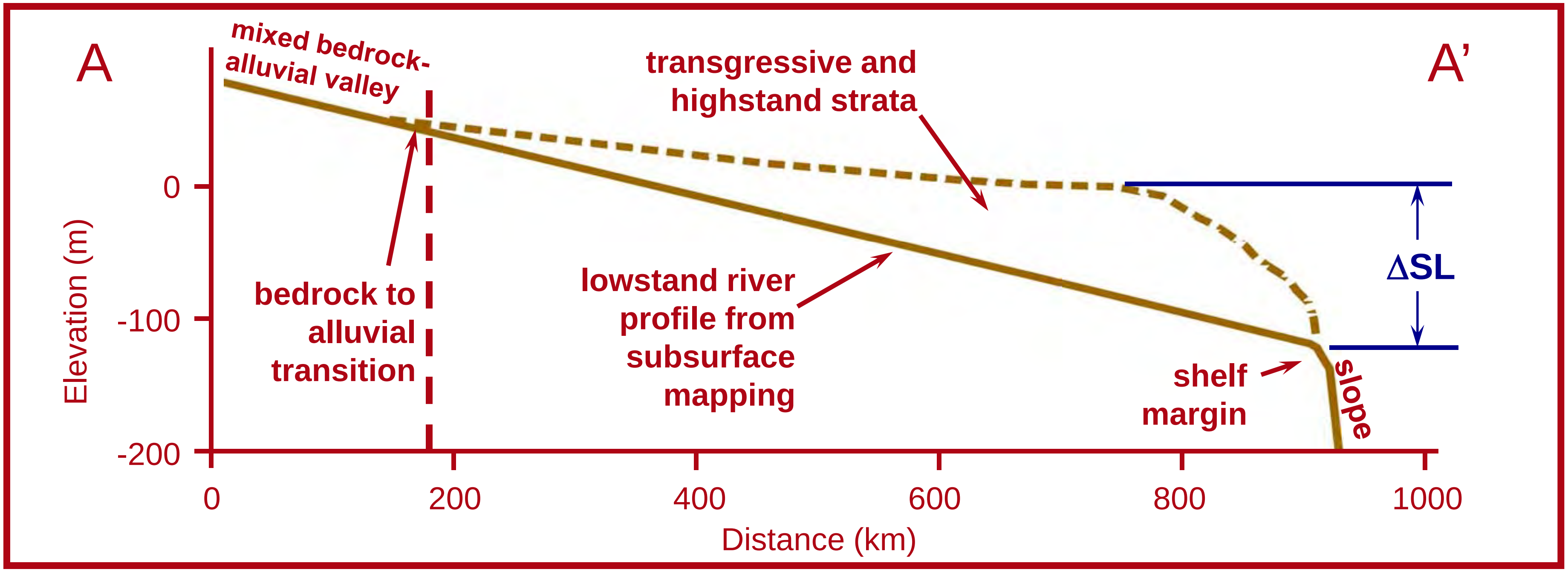
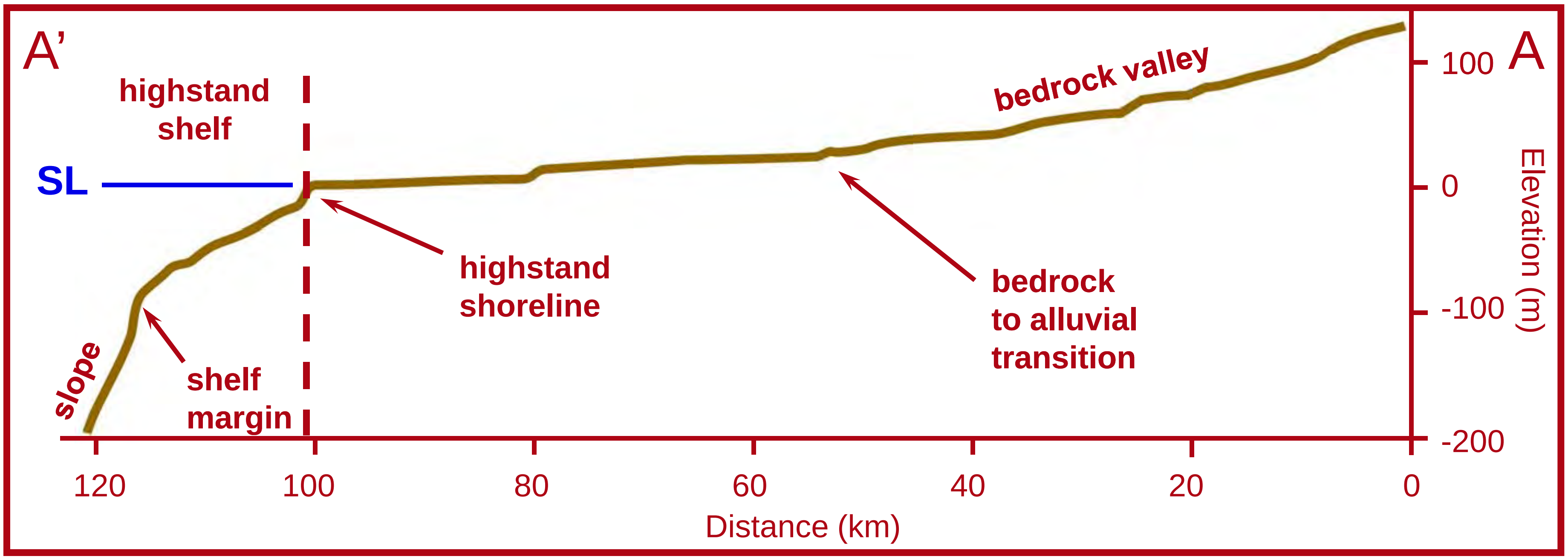




MENDOCINO TRIPLE JUNCTION: EEL RIVER
Topography and Bathymetry



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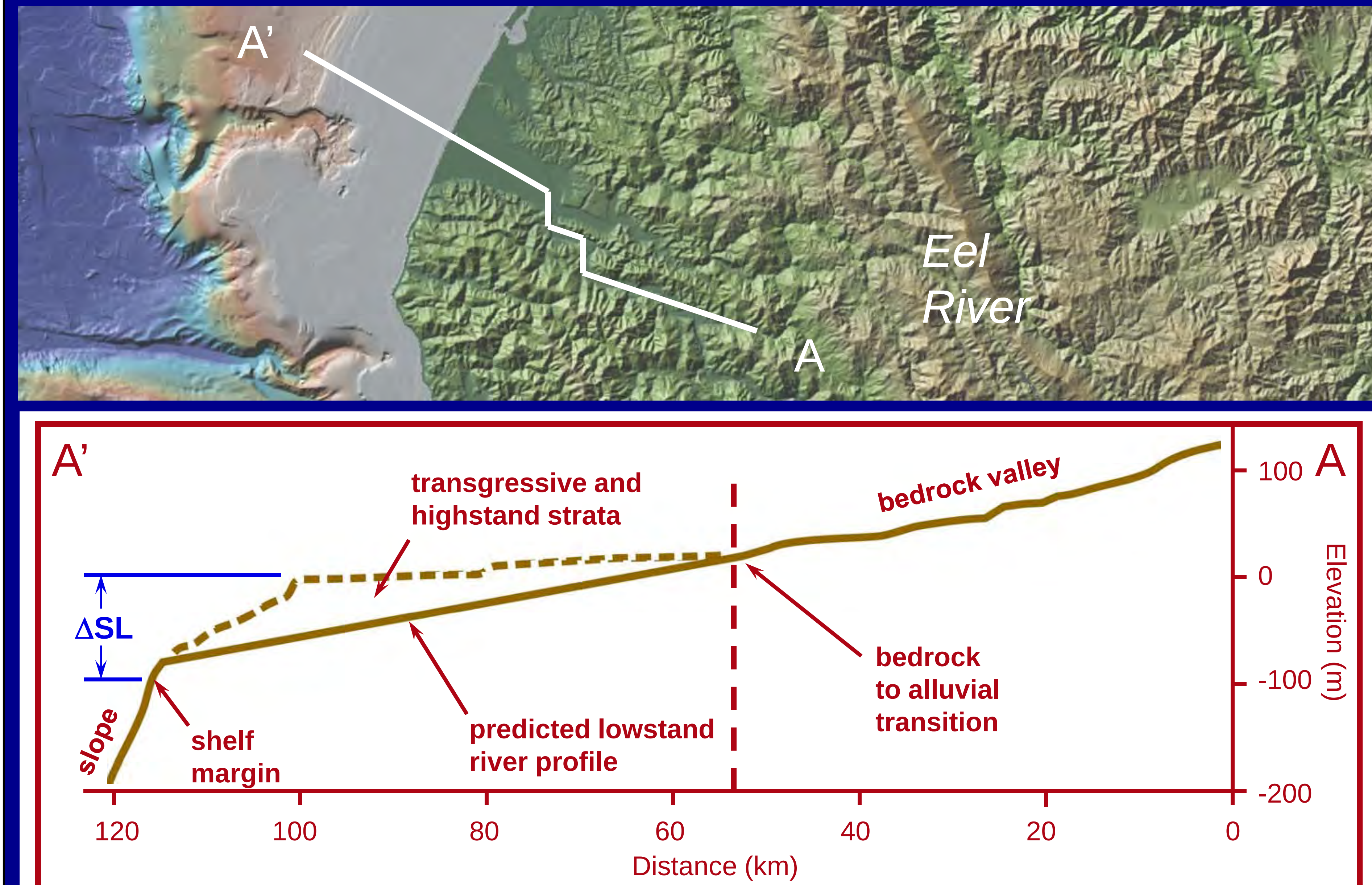
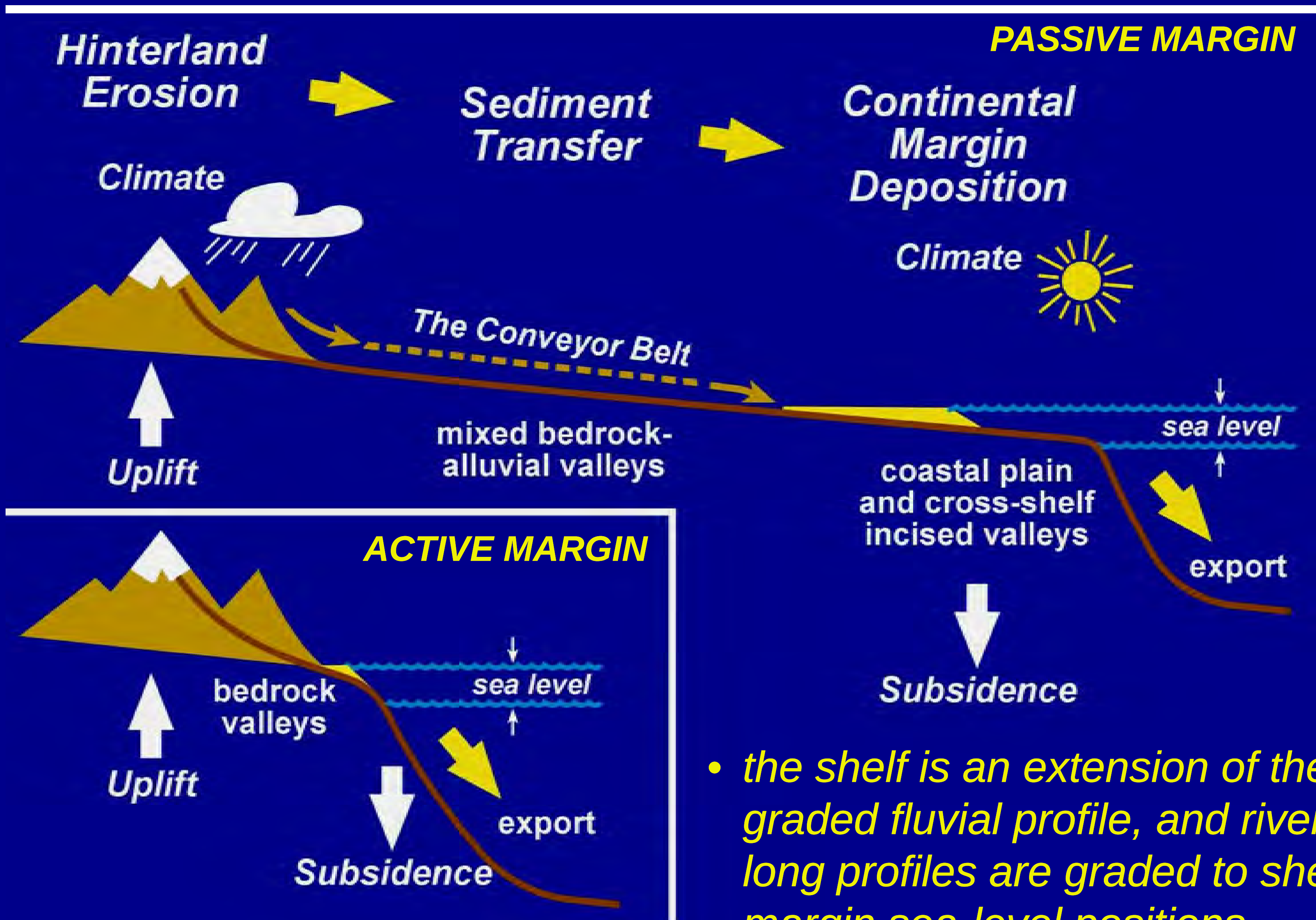
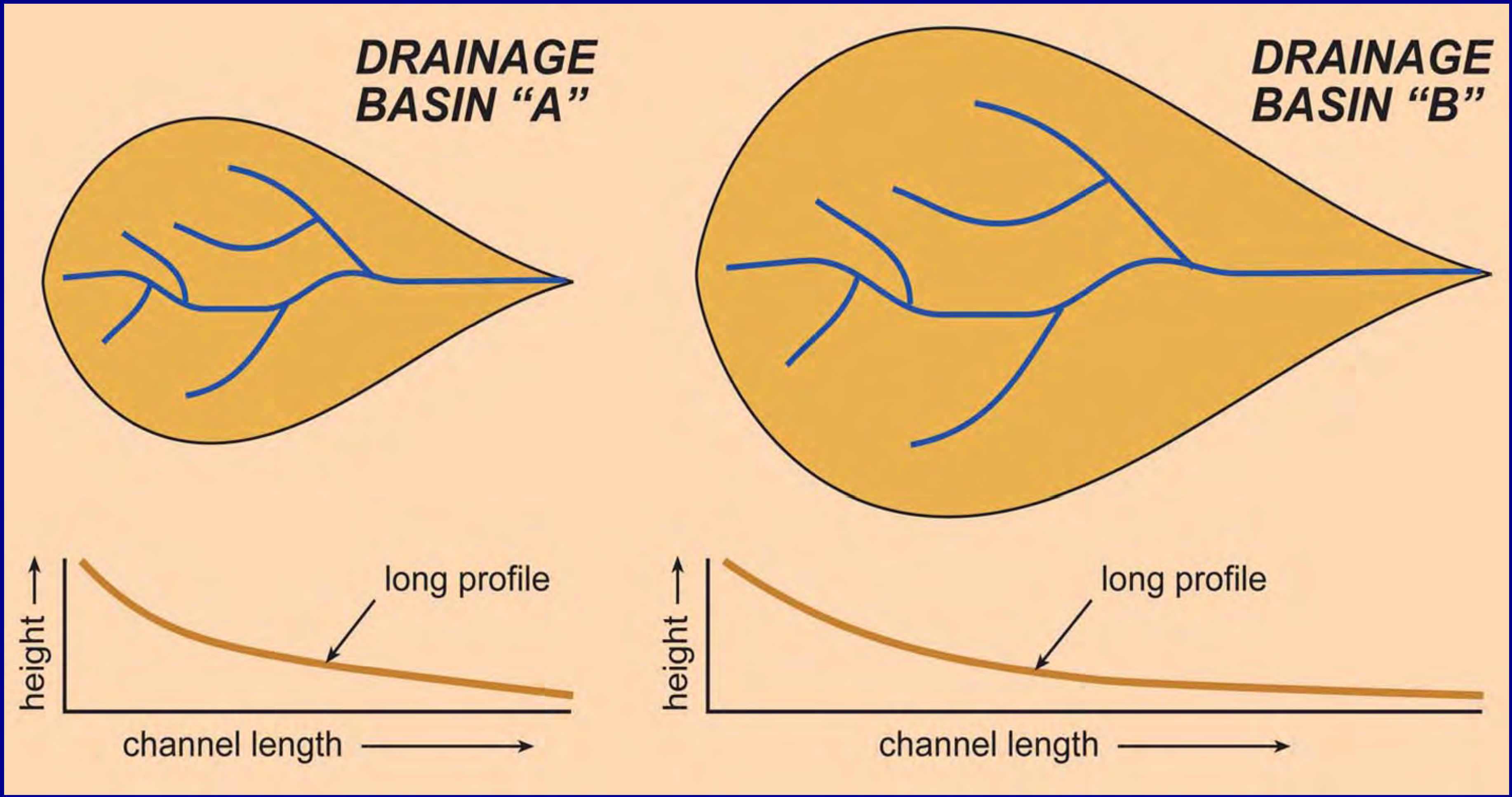


SOURCE-TO-SINK LONG PROFILE MODELS



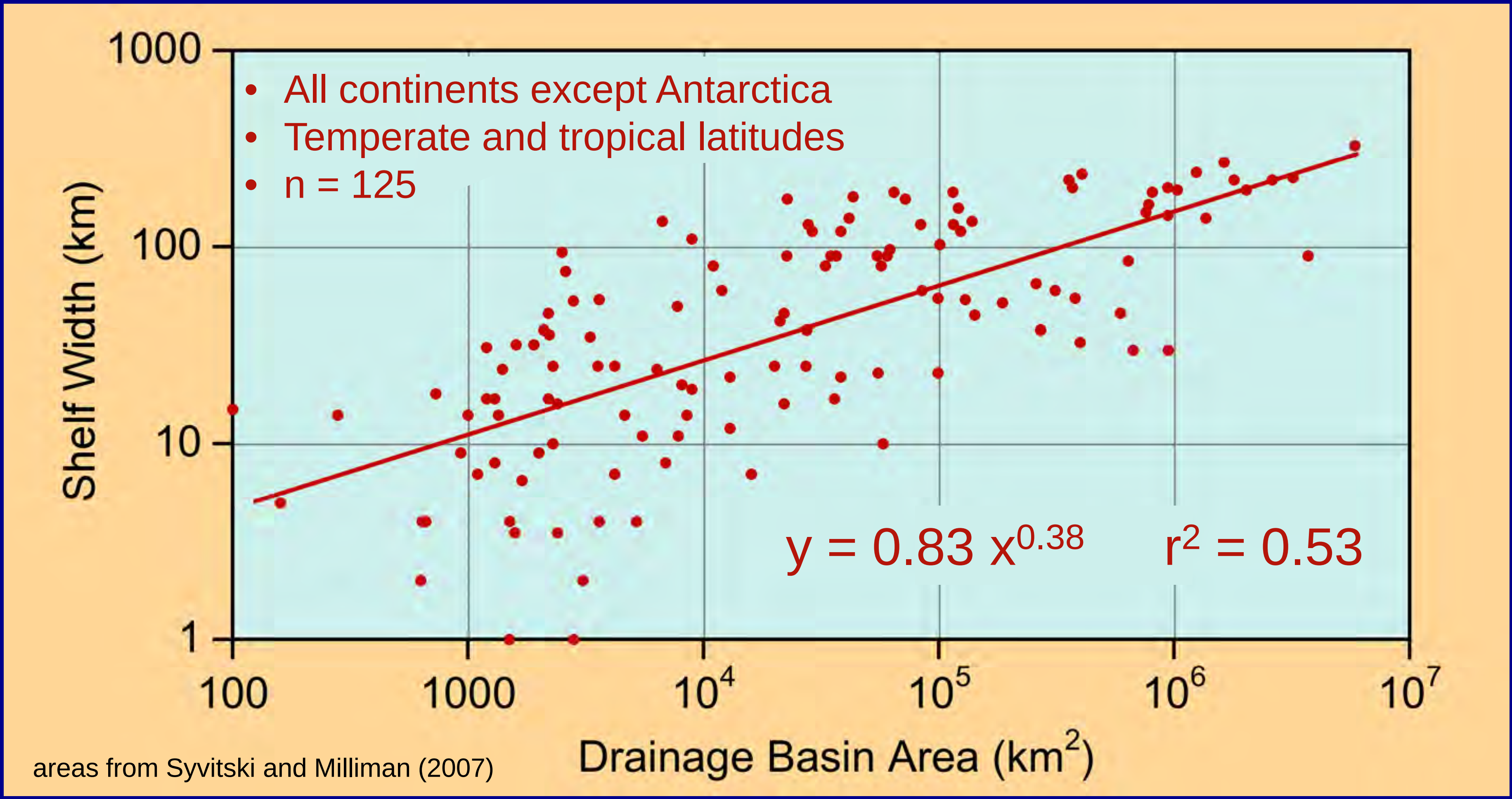
- *the shelf is an extension of the graded fluvial profile, and river long profiles are graded to shelf margin sea-level positions*

SHELVES AS THE DOWNDIP EXTENSION OF THE FLUVIAL LONG PROFILE?



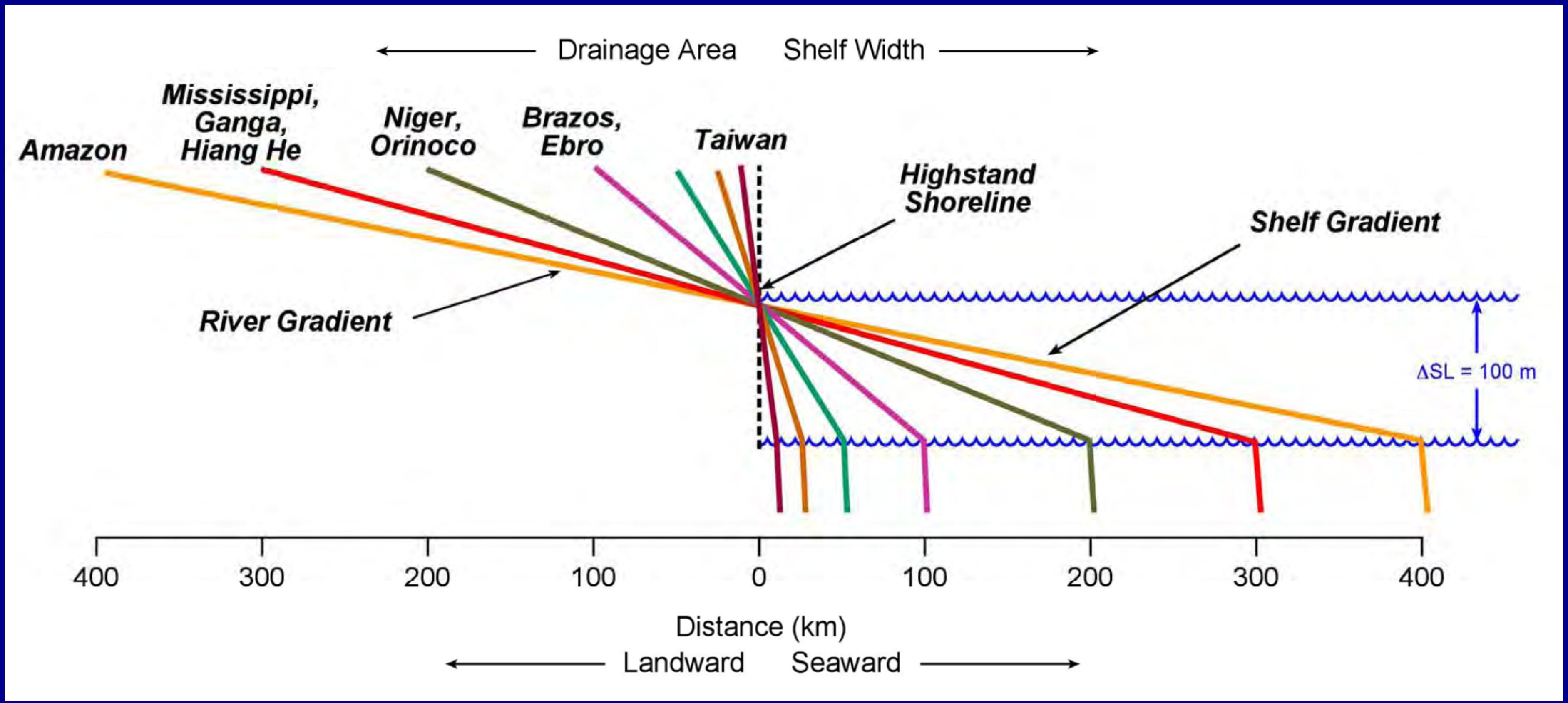
- *"Flint Law" ($S = -kA^y$): an inverse power law relationship between drainage area (A) and channel gradient (S)*
- *applies within (moving downstream) or between drainage basins*

SHELVES AS THE DOWNDIP EXTENSION OF THE FLUVIAL LONG PROFILE?



- *All shelf margins reside at similar depths, hence primary morphometric difference is shelf width*
- *Shelf width and gradient scales to fluvial drainage basin area*

SCALING OF SHELF WIDTH AND GRADIENT TO HINTERLAND DRAINAGE BASIN AREA



The Icehouse World -- High Amplitude, High Frequency Sea-Level Change

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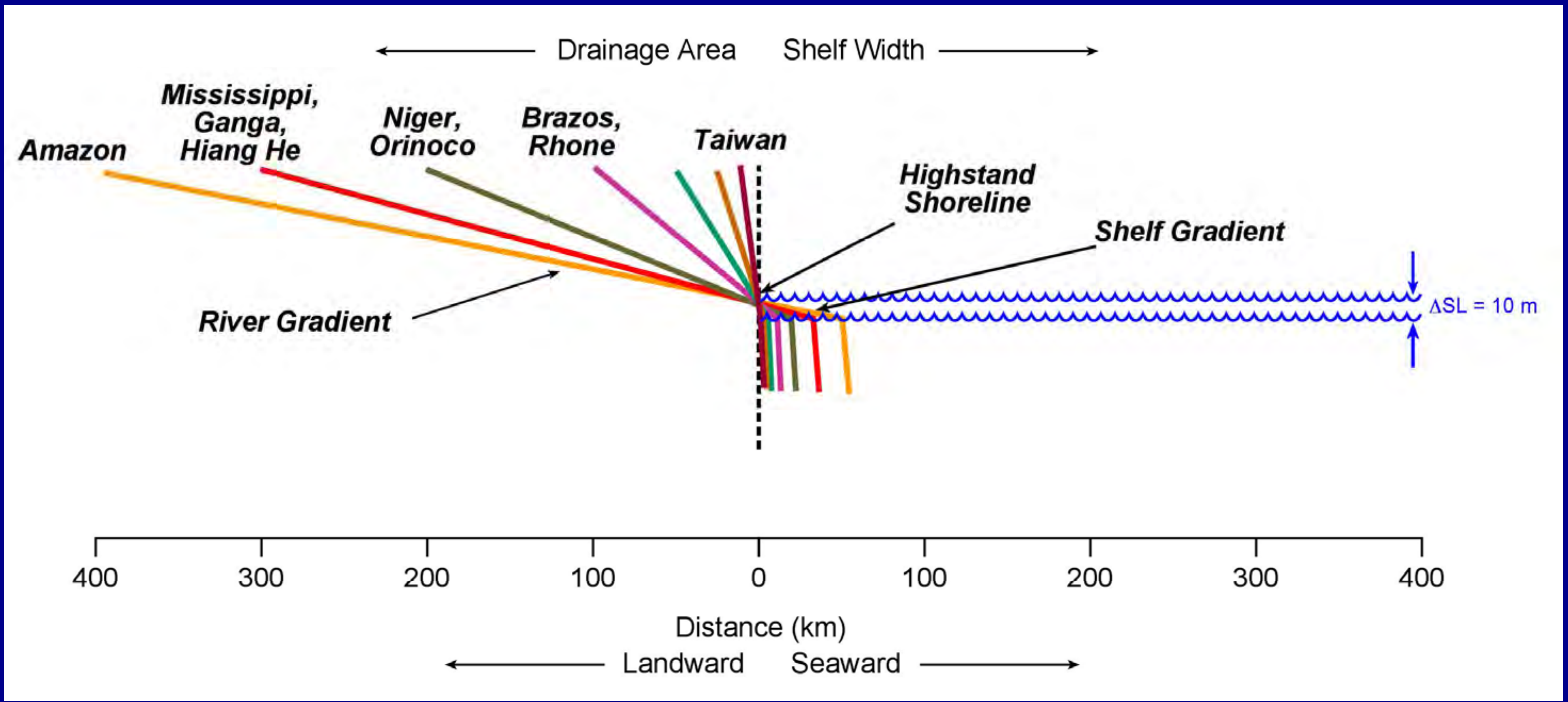
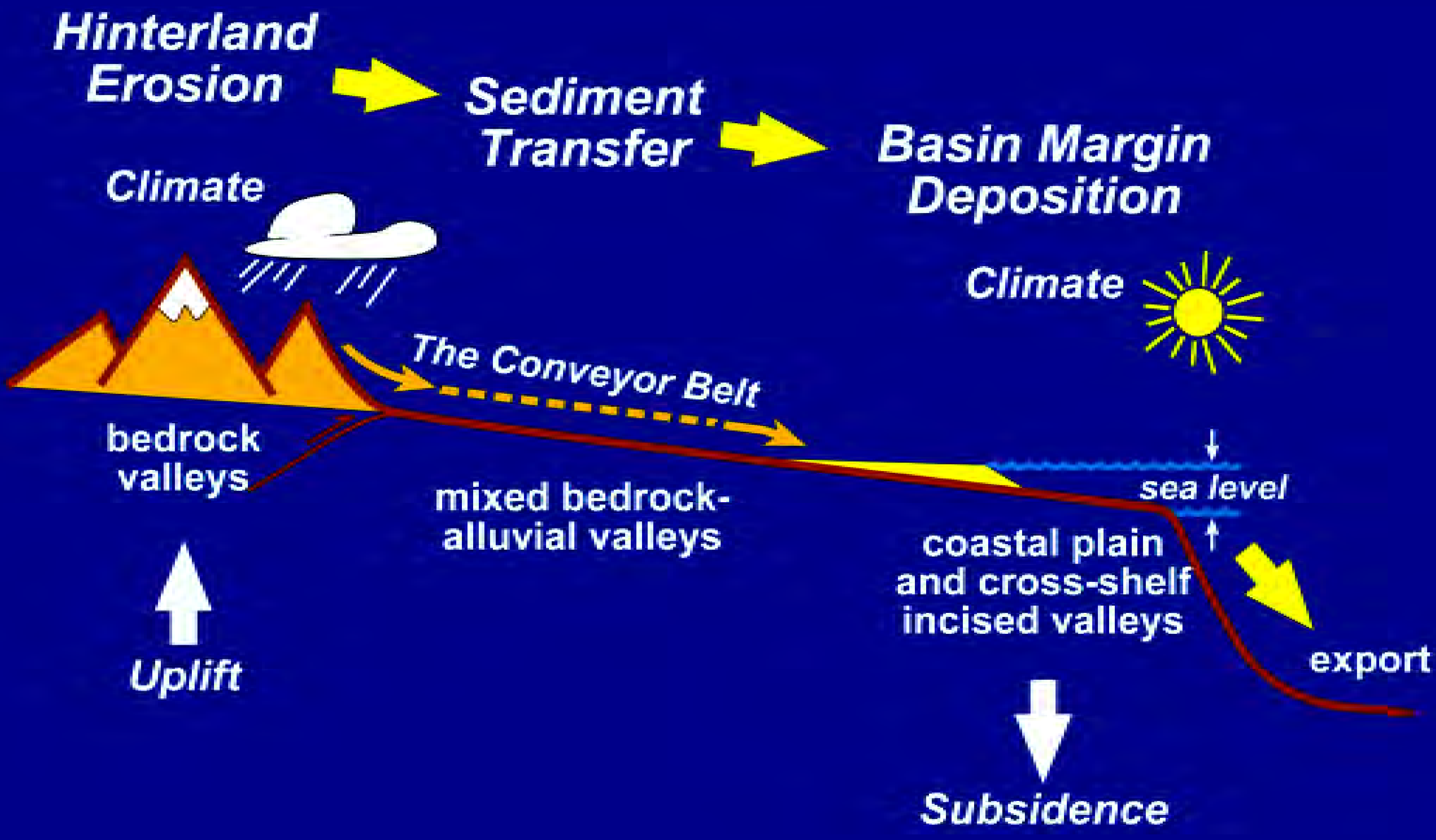


The Greenhouse World -- Very Low Amplitude, Low Frequency Sea-Level Change

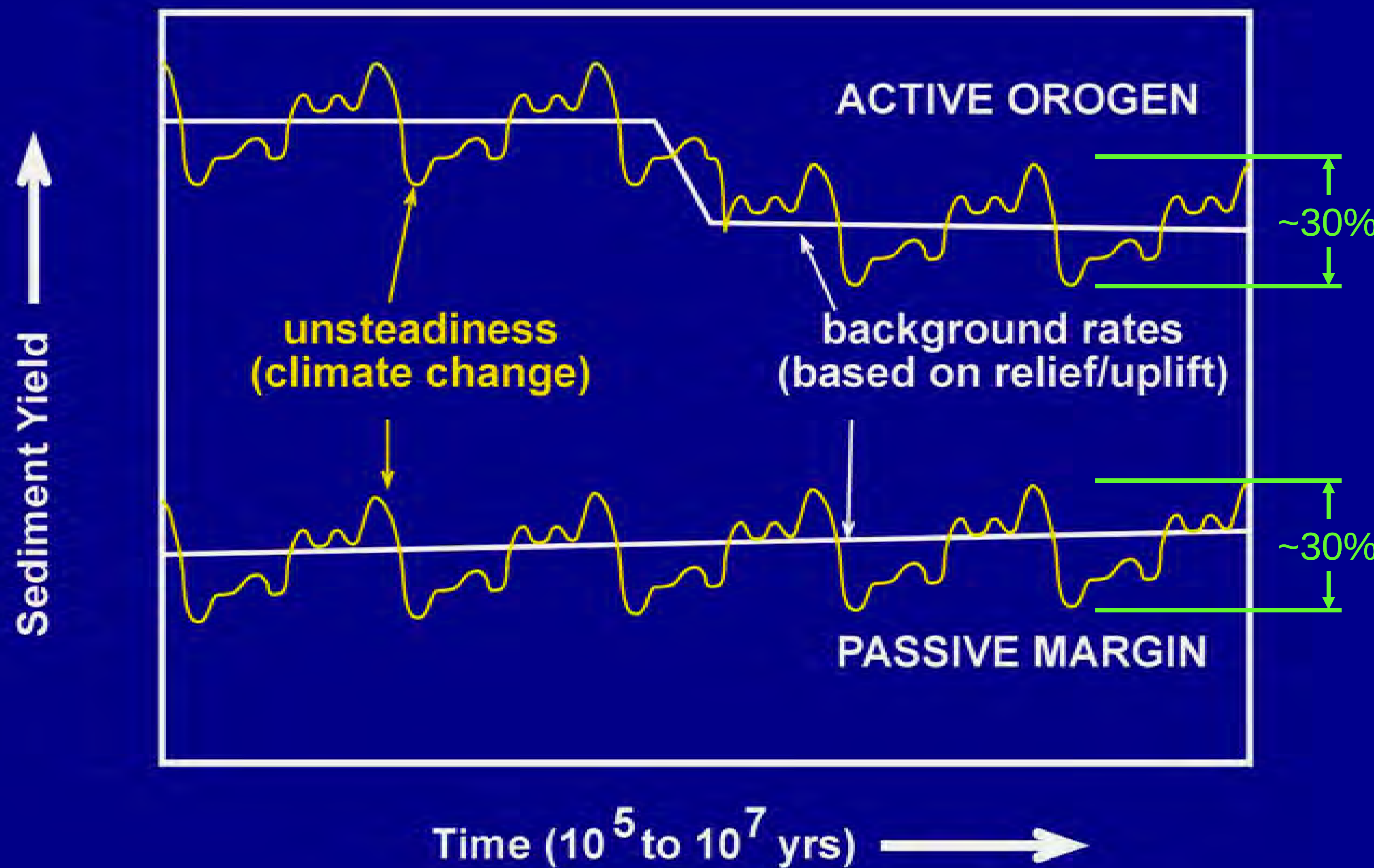
SOURCE-TO-SINK LONG PROFILE MODEL



WHAT ABOUT SEDIMENT SUPPLY AND ROUTING?

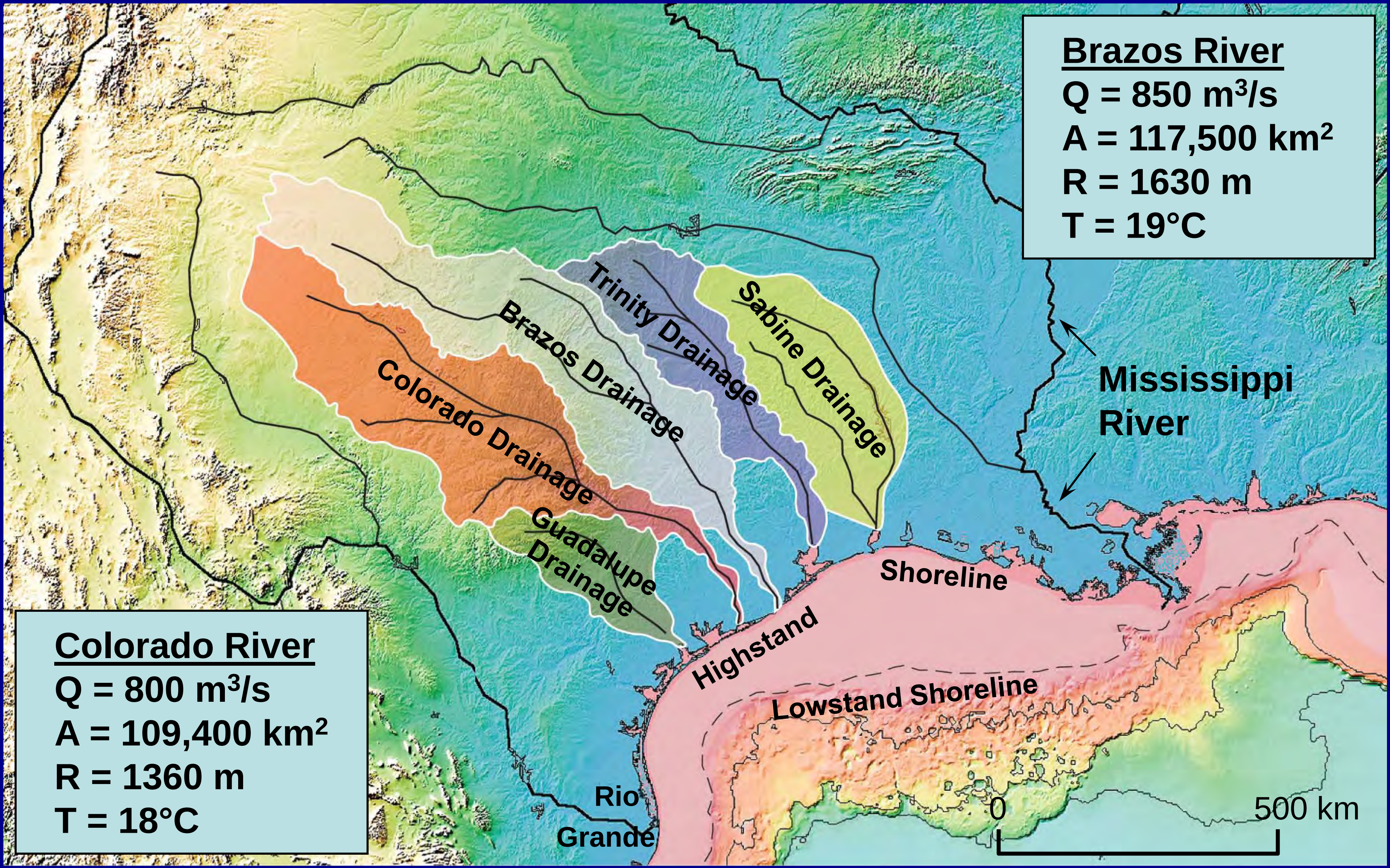
FLUVIAL SEDIMENT SUPPLY

Tectonics vs. Climate Change



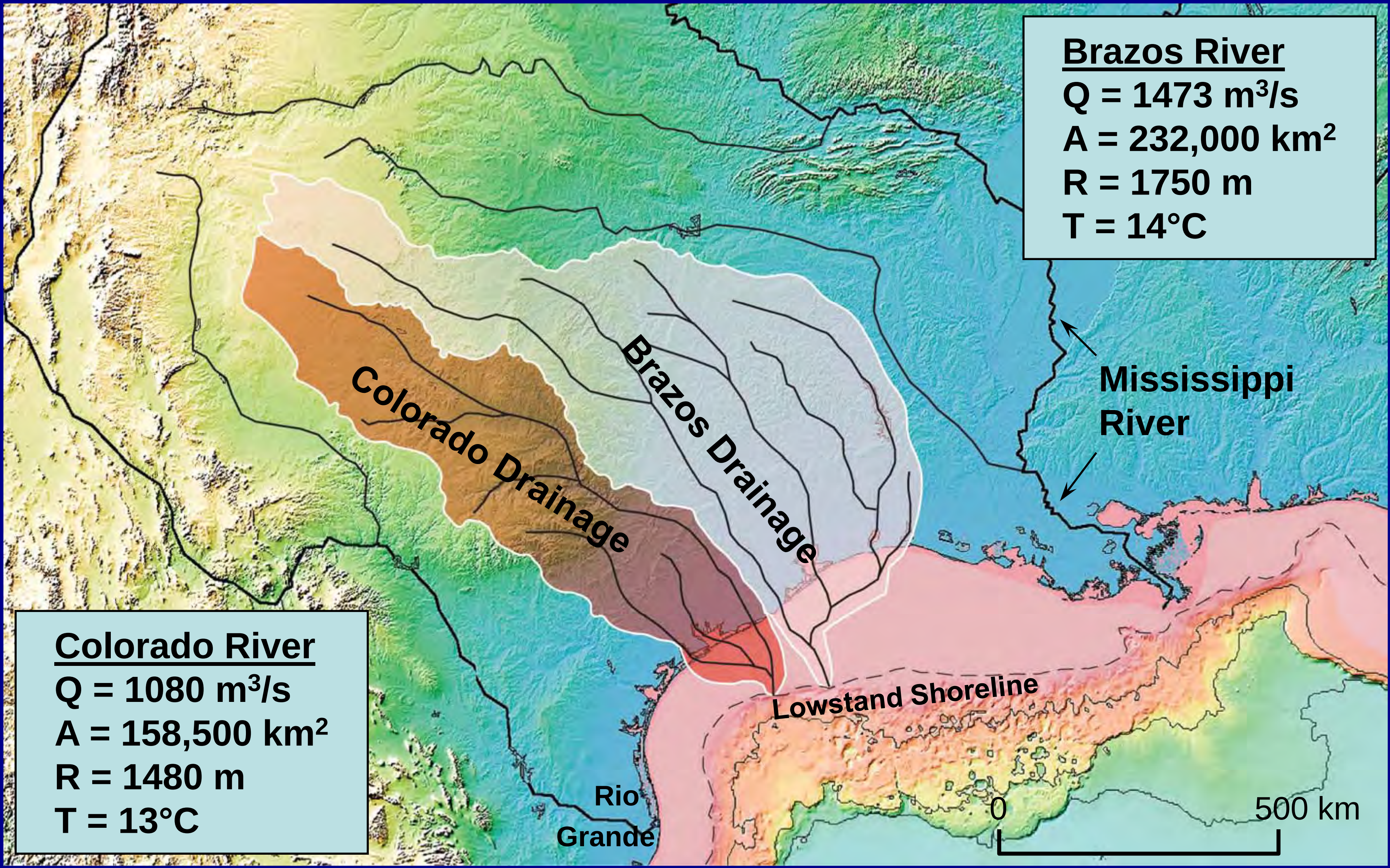
PRESENT HIGHSTAND BOUNDARY CONDITIONS

Highstand Drainage Basins

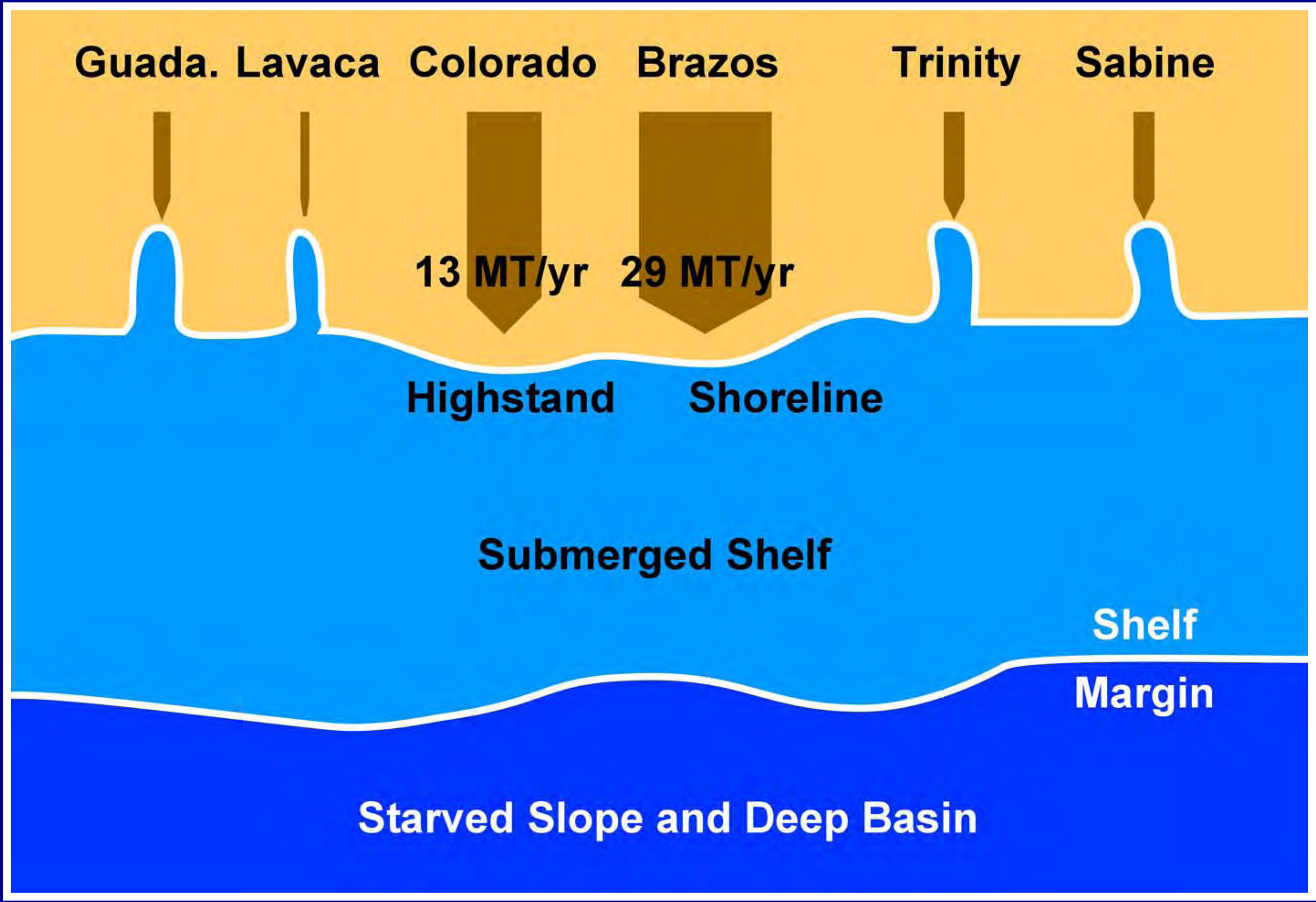


LAST GLACIAL MAXIMUM BOUNDARY CONDITIONS

Lowstand Drainage Basins



FIRST DRAFT HIGHSTAND SEDIMENT BUDGET:
Colorado and Brazos Rivers, Texas



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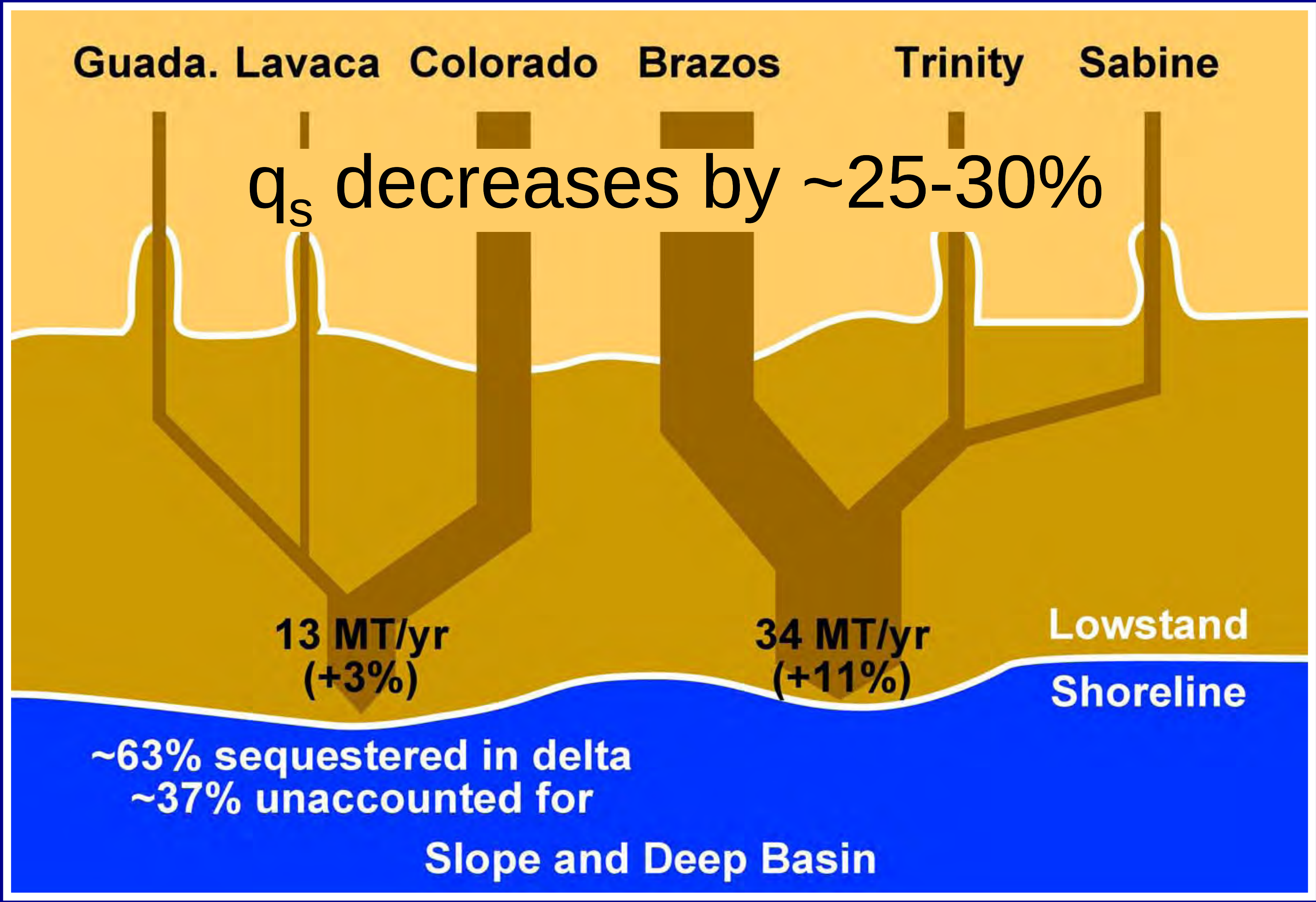
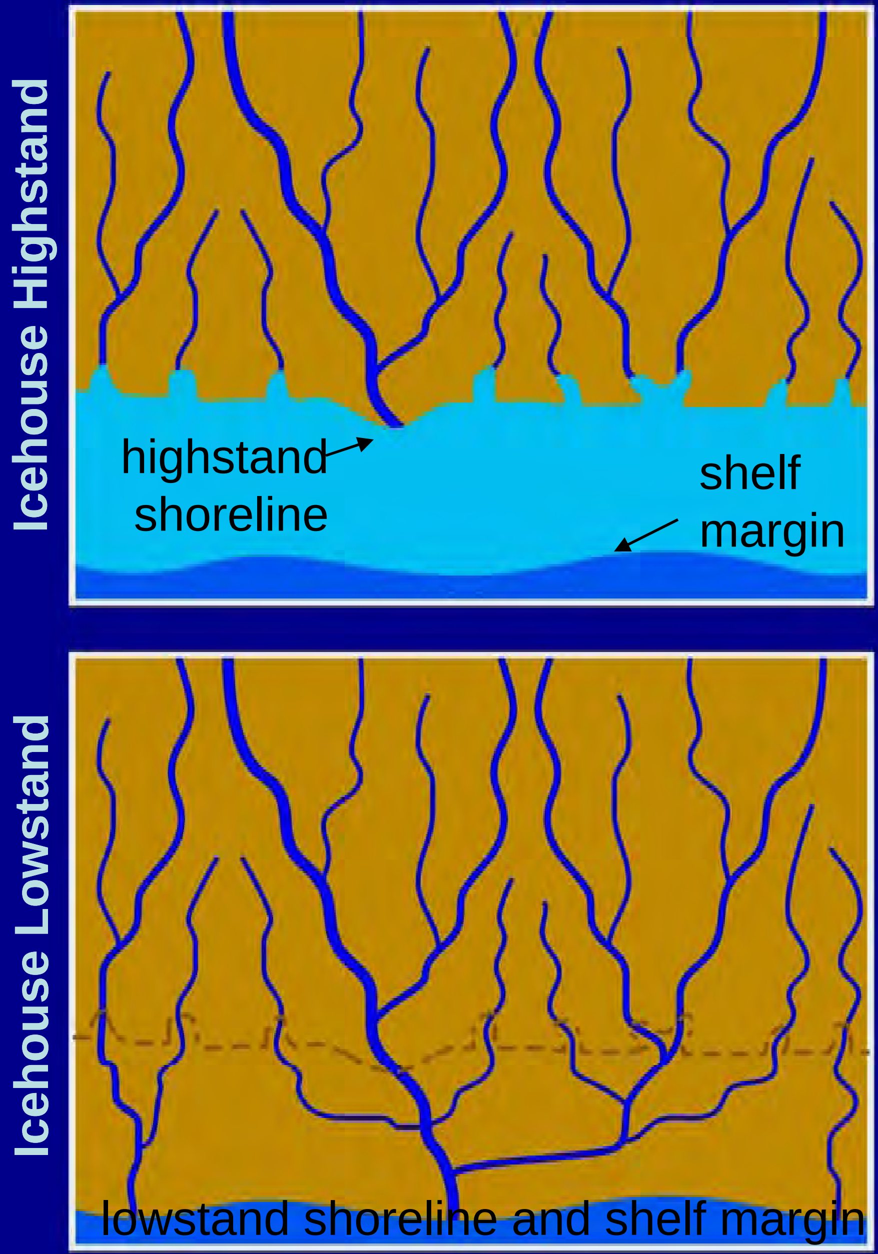


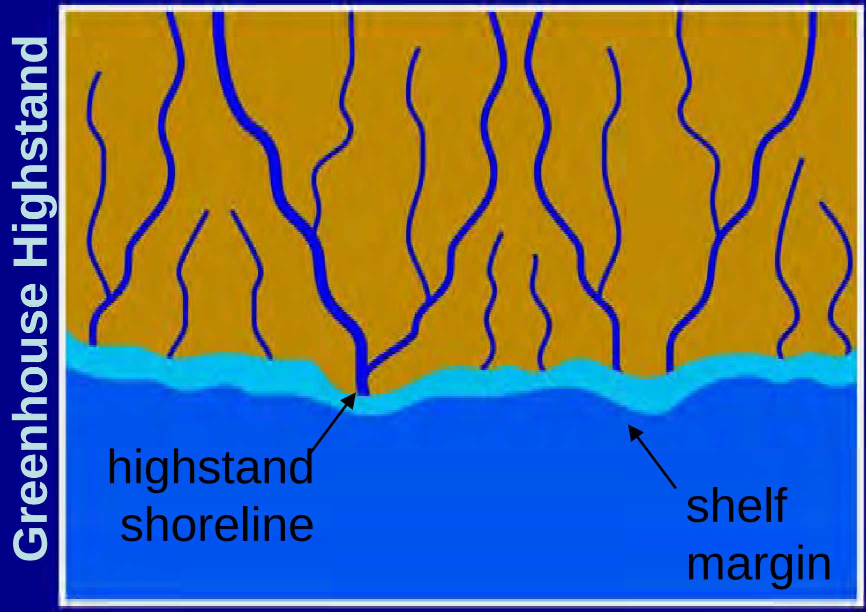
q_s decreases by ~25-30%

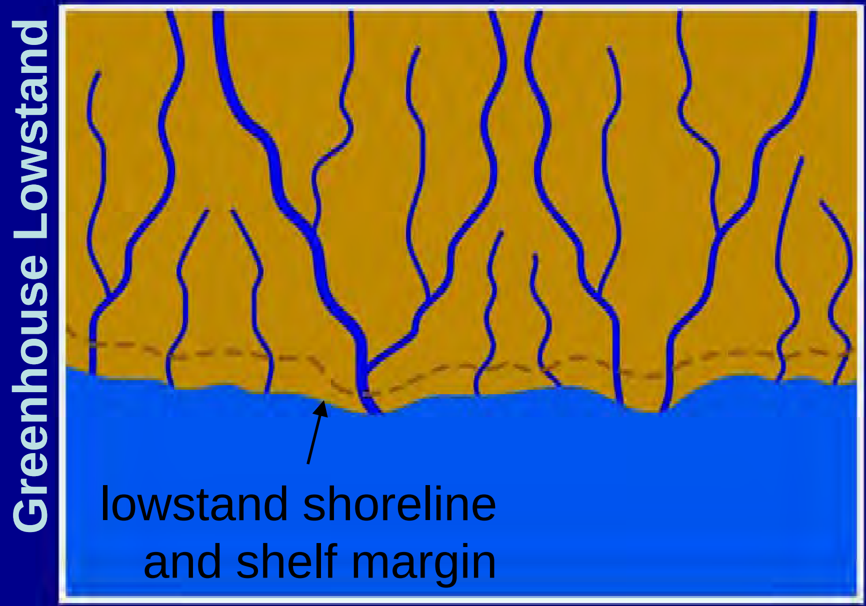
RIVER LONG PROFILES, SHELVES, AND SEDIMENT DISPERSAL: ICEHOUSE WORLD



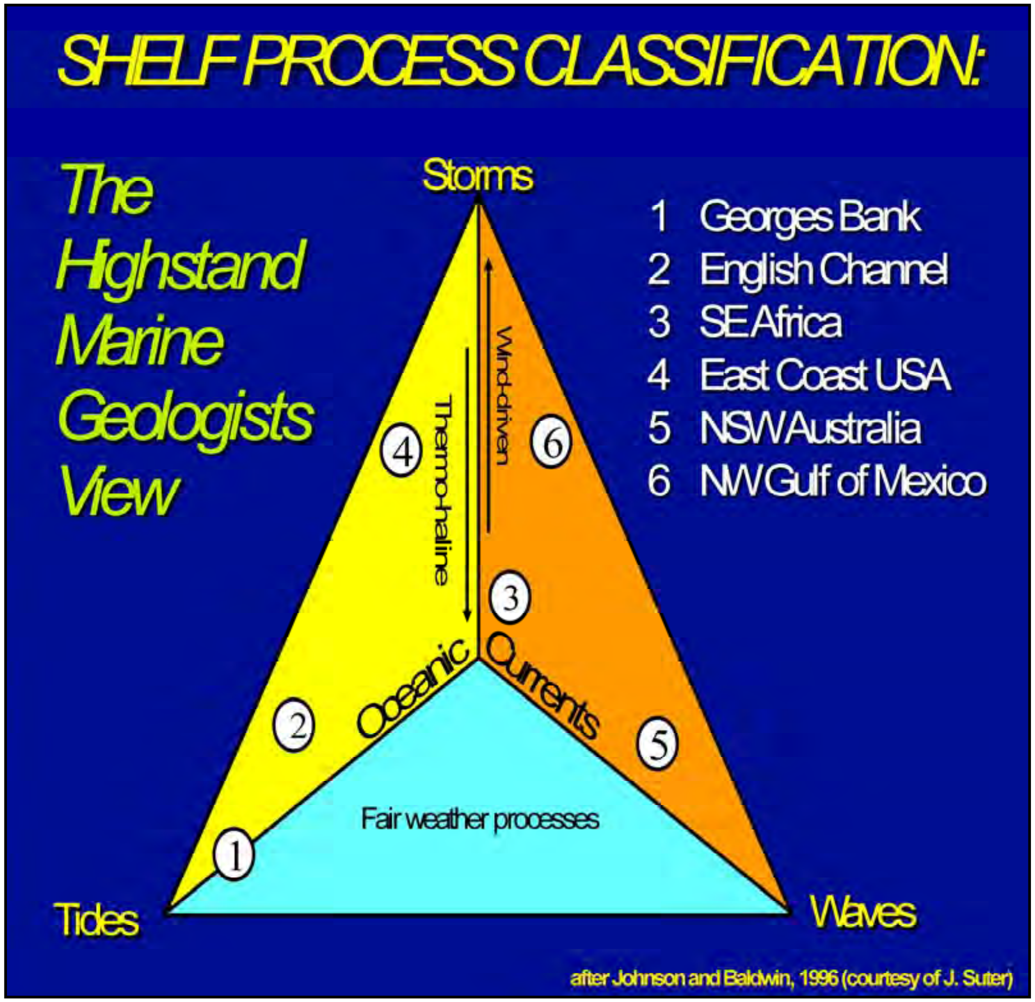
- Strong dichotomy in shelf widths. Wide shelves (>50 km) front large drainage basins, and narrow shelves (<<50 km) front small drainage basins.
- For most large river systems, shelf width limits sediment dispersal to the shelf margin during highstand. Sediment flux to the shelf margin is decoupled from climate controls, and coupled to shelf transit and SL change (also van der Zwan, 2002).
- Merging of drainages during lowstand increases point source sediment supply, but decreases number of point sources.
- Sediment supply to the shelf margin reflects how river systems respond to SL change in the lower part of their long profile

RIVER LONG PROFILES, SHELVES, AND SEDIMENT DISPERSAL: GREENHOUSE WORLD





- Most constructional shelves are inherently very narrow, even during highstands.
- Inherently narrow shelf widths will not limit sediment dispersal to the shelf margin during highstand
- For most systems, sediment flux to the shelf margin should be directly coupled to climate change (van der Zwan, 2002). The best explanation for “high-frequency” sequences?
- Merging of drainages during lowstand does not seem likely due to limited high-frequency transit. More discrete point sources, but fewer “mega rivers”



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