

# **High Frequency Cyclical Isostatic Adjustments: Significance for Incised Valleys\***

**Mike Blum<sup>1</sup>**

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## **Abstract**

Isostatic adjustment to changes in water and sediment loads are rarely considered in high-resolution stratigraphic interpretations. This presentation uses Gulf of Mexico examples to illustrate two possible high-frequency (Milankovitch-scale) cyclical isostatic adjustments that may be intrinsic to fluvial systems and incised valleys.

First, geophysicists recognize that isostatic adjustments must accompany sea-level change. It is also known that sea-level fall forces channel extension across emergent shelves, and the formation of incised valleys, whereas sea-level rise forces river mouth backstepping, flooding of the shelf, and valley filling. New 1D steady-state modeling of the Texas Gulf of Mexico shelf illustrates that isostatic uplift in response to sea-level fall will impact river long profiles, and may serve as the driving force for incision itself. With a shelf width of ~100 km, and sea-level fall of 100 m, isostatic uplift may be 20-30 m at the shelf margin, with flexural effects extending 10's of km upstream from the highstand shoreline. Sea-level rise and flooding of the shelf will have the opposite effect.

Second, deltaic loading and subsidence are widely recognized, but development of incised valleys results in sediment unloading as well, which likely produces a cyclical pattern of isostatic uplift and subsidence. New 1D steady-state and 3D visco-elastic modeling of the Mississippi delta region indicates that sediment volumes removed and replaced were sufficient to induce >12 m of uplift in the valley center, and >9 m along valley margins, followed by subsidence of the same magnitude, with flexural effects extending ~150 km along the Gulf of Mexico coast. Cyclical uplift and subsidence should amplify valley incision and filling, whereas spatial patterns of uplift and subsidence should play a key role in development of valley fill architecture.



# *High Frequency Cyclical Isostatic Adjustments:*

## *Significance for Incised Valleys*

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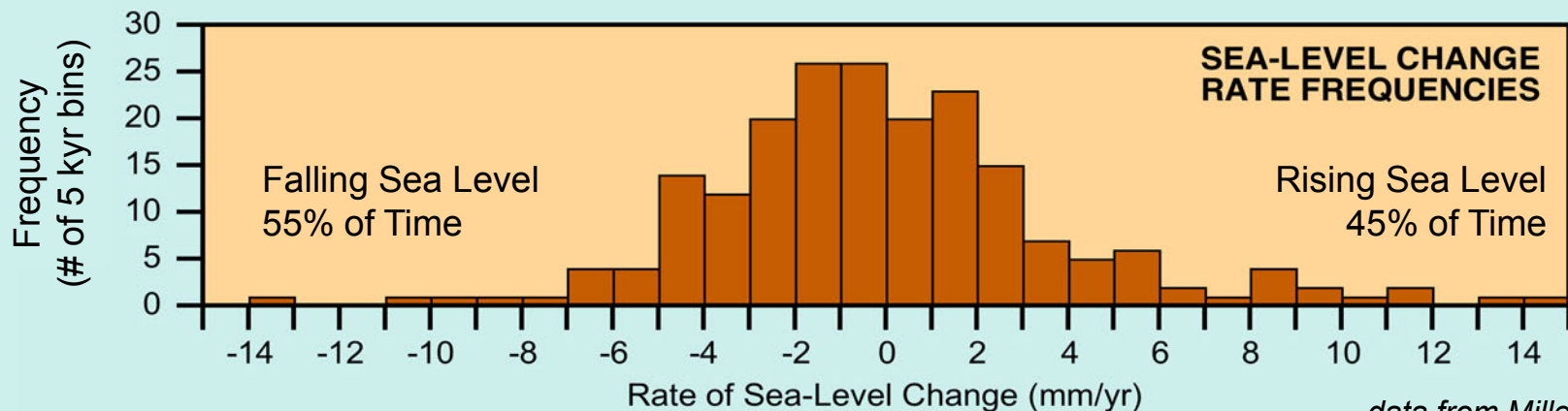
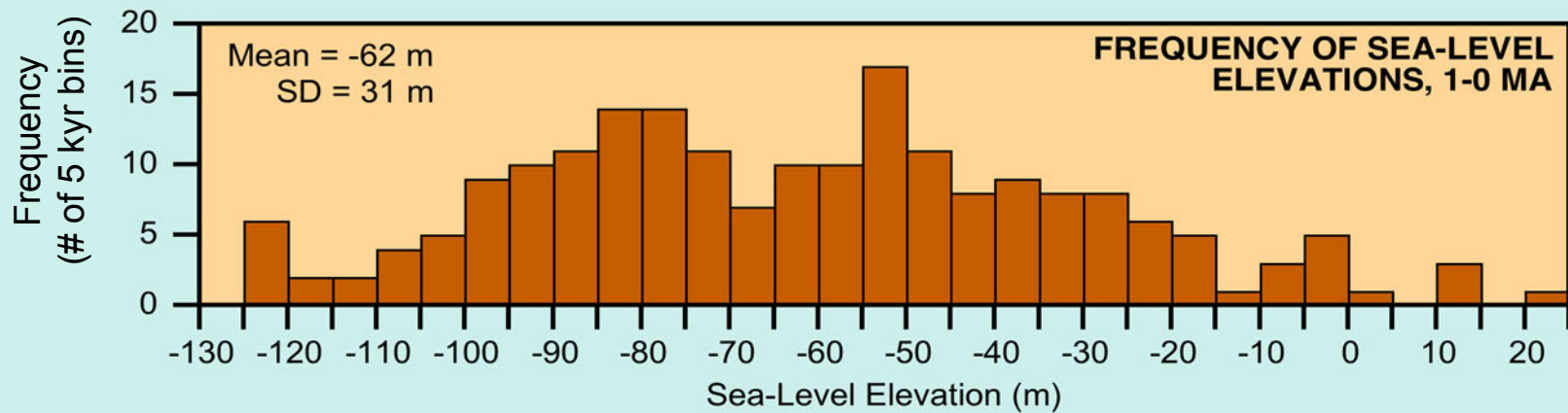
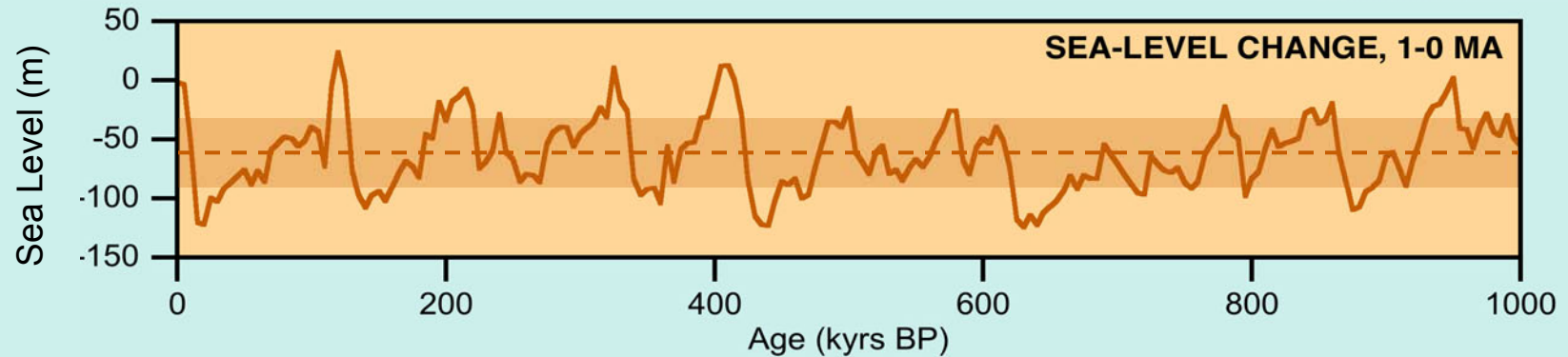
*Current address:  
ExxonMobil Upstream Research Company  
Houston, Texas*



## *Topics of Discussion:*

- *Incised-valley evolution*
- *Isostatic adjustments from sediment unloading and loading (large river phenomenon)*
- *Isostatic adjustments from sea-level change (hydroisostasy)*
- *Implications/speculation*

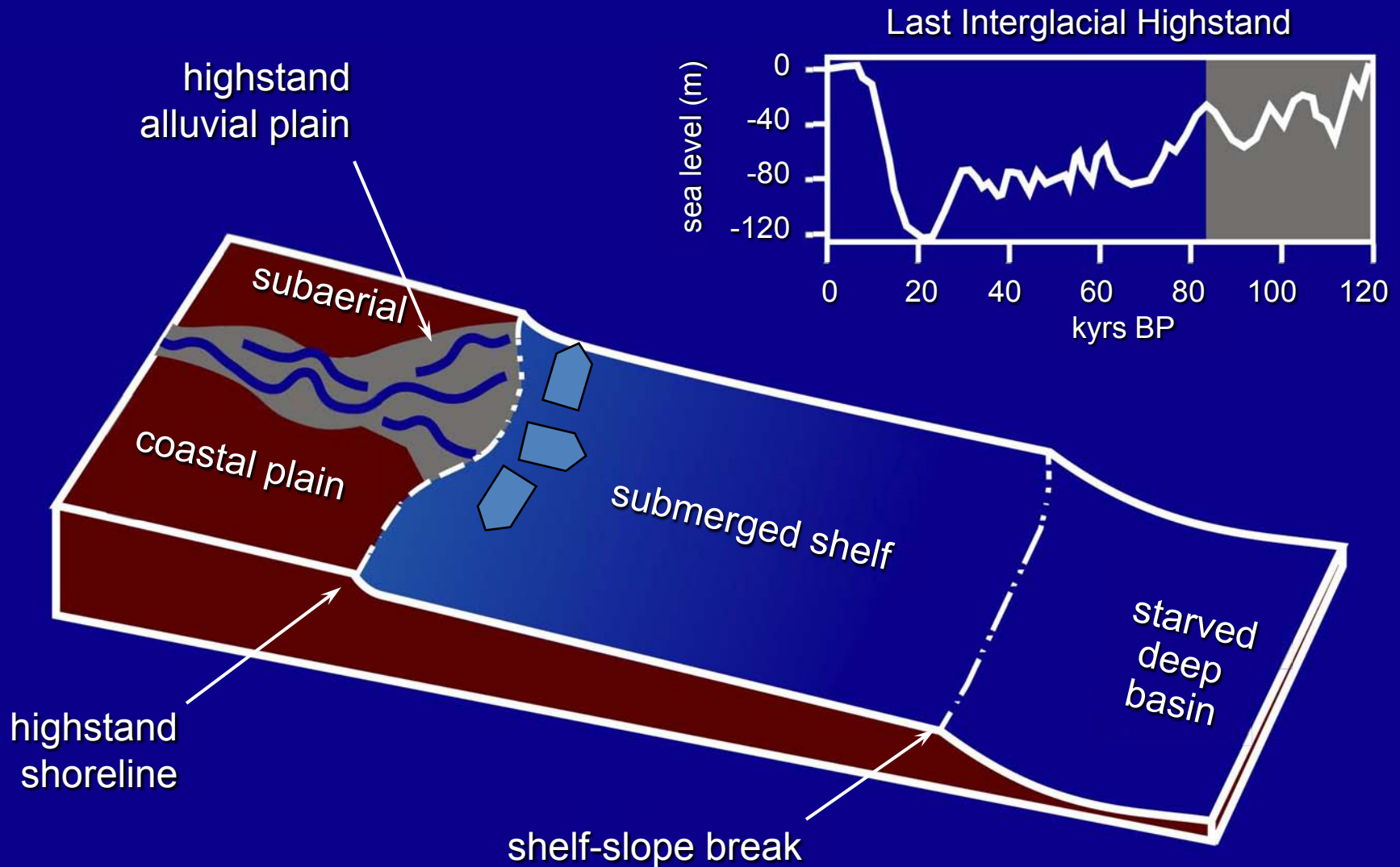
# GLOBAL SEA LEVEL CHANGE: 1-0 MA



*data from Miller et al. (2005)*

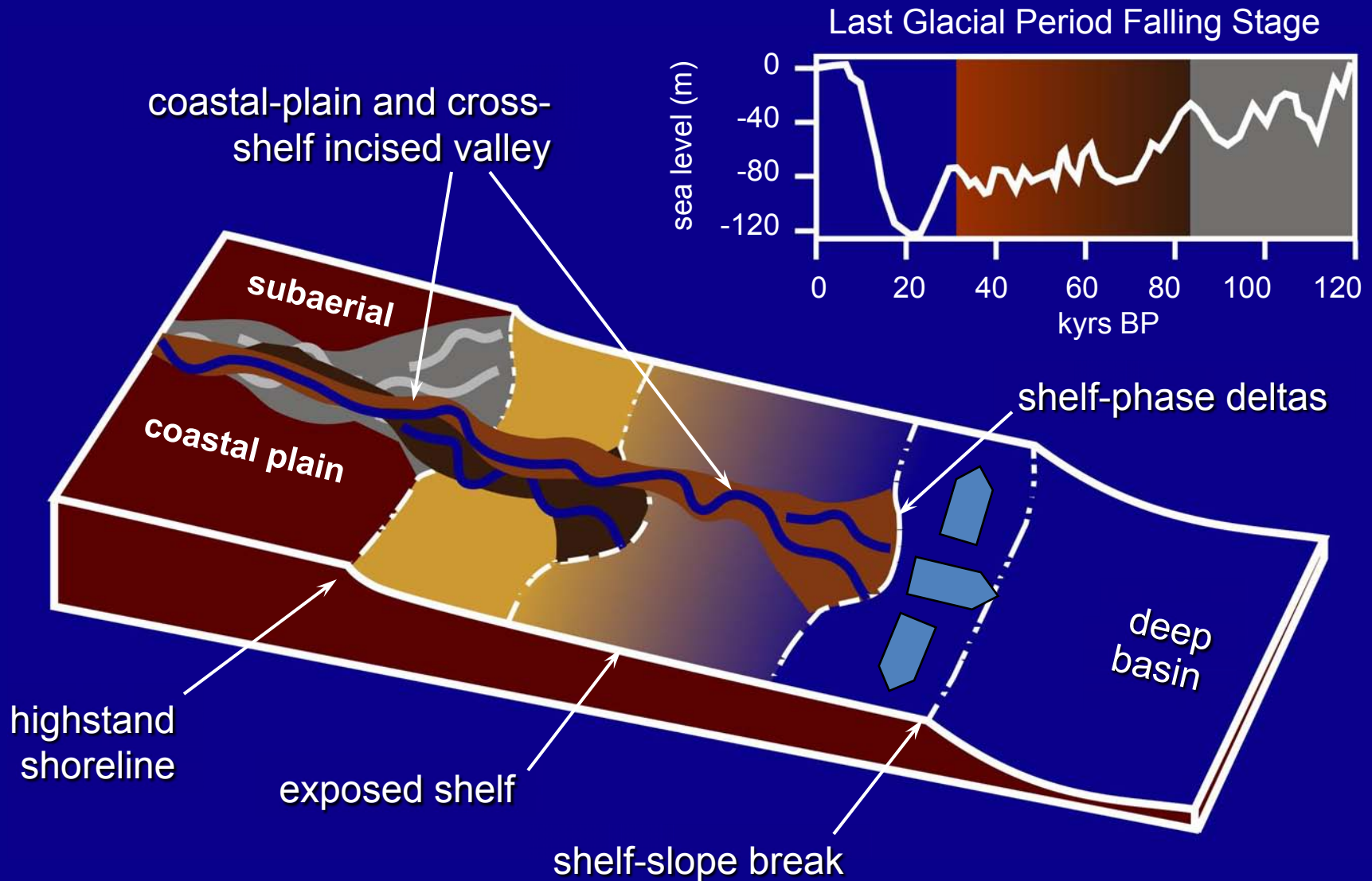
# INCISED VALLEYS AND VALLEY FILLS

*Form from Fluvial-Deltaic Transit of the Shelf*



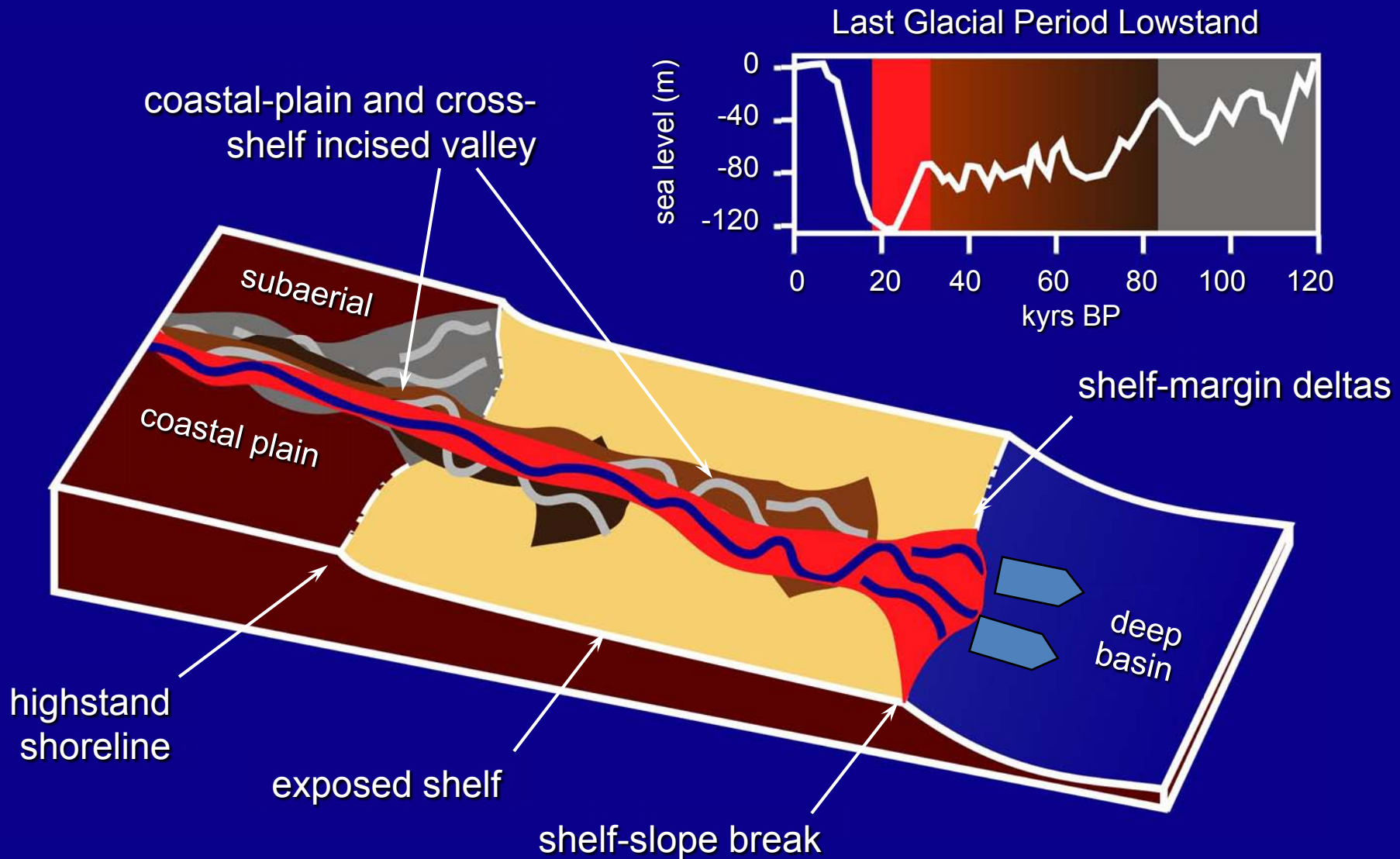
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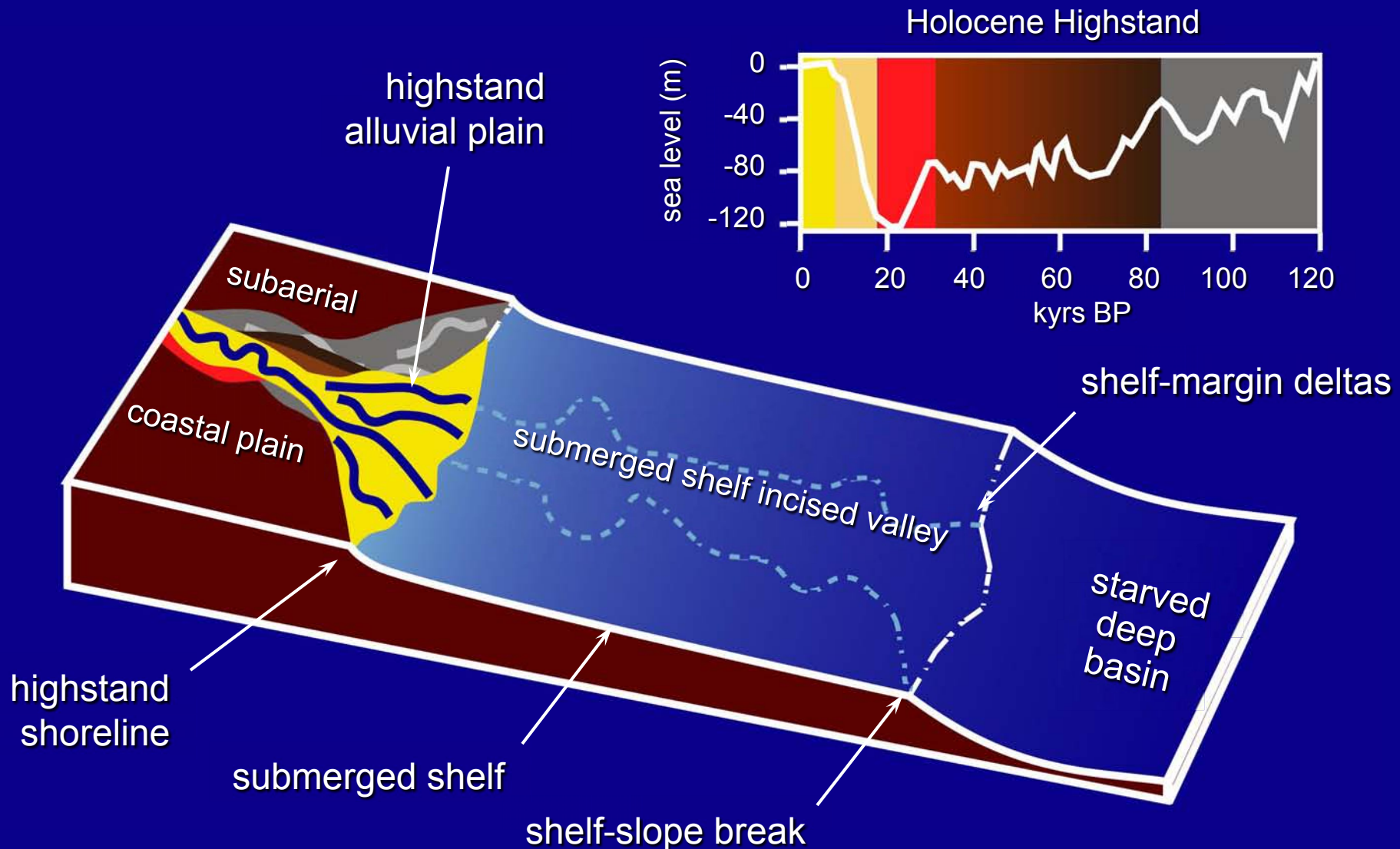
# INCISED VALLEYS AND VALLEY FILLS

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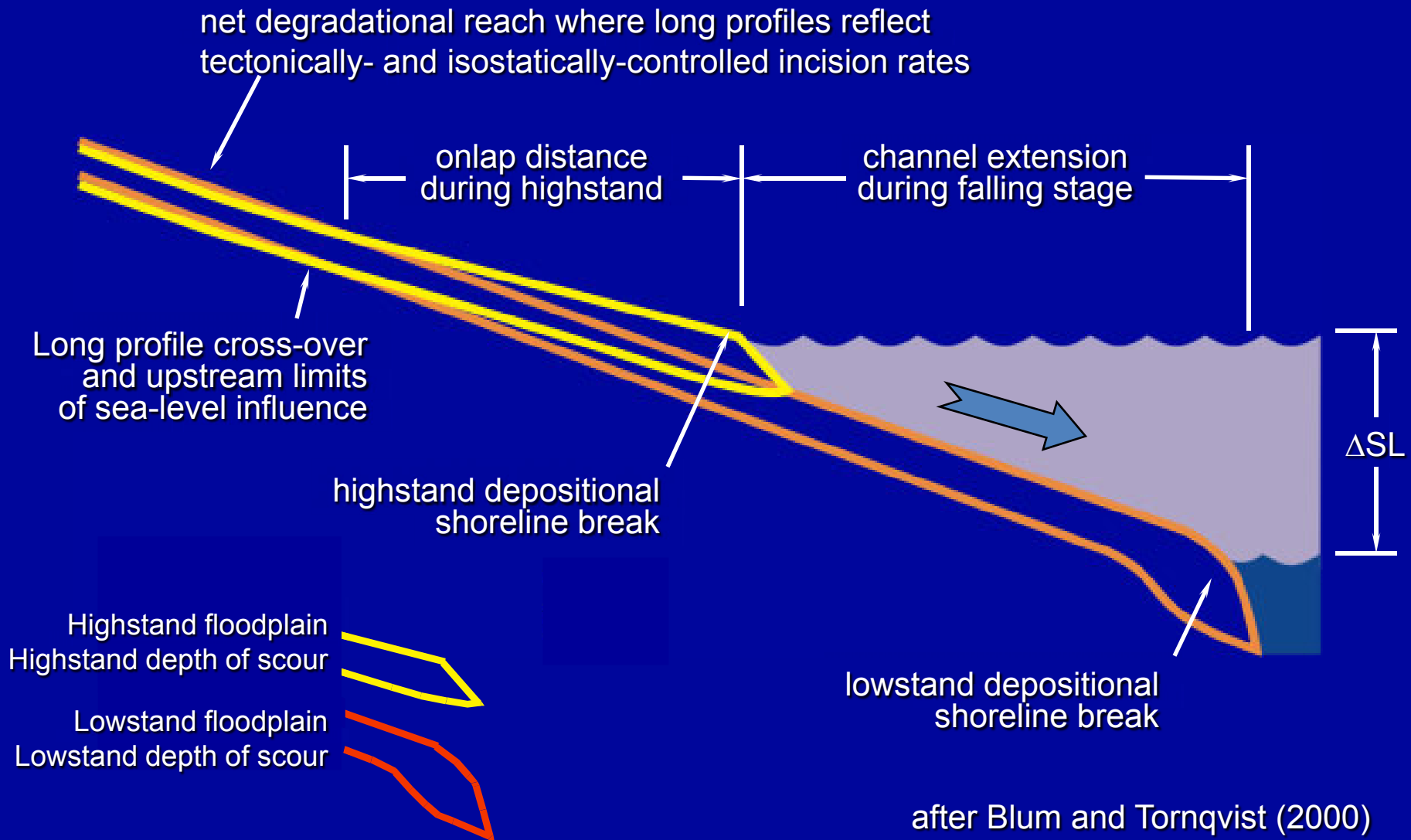


# INCISED VALLEYS AND VALLEY FILLS

*Form from Fluvial-Deltaic Transit of the Shelf*



# RIVER LONG PROFILE RESPONSES TO SEA-LEVEL CHANGE



# HOW DO YOU FORM AN INCISED VALLEY?

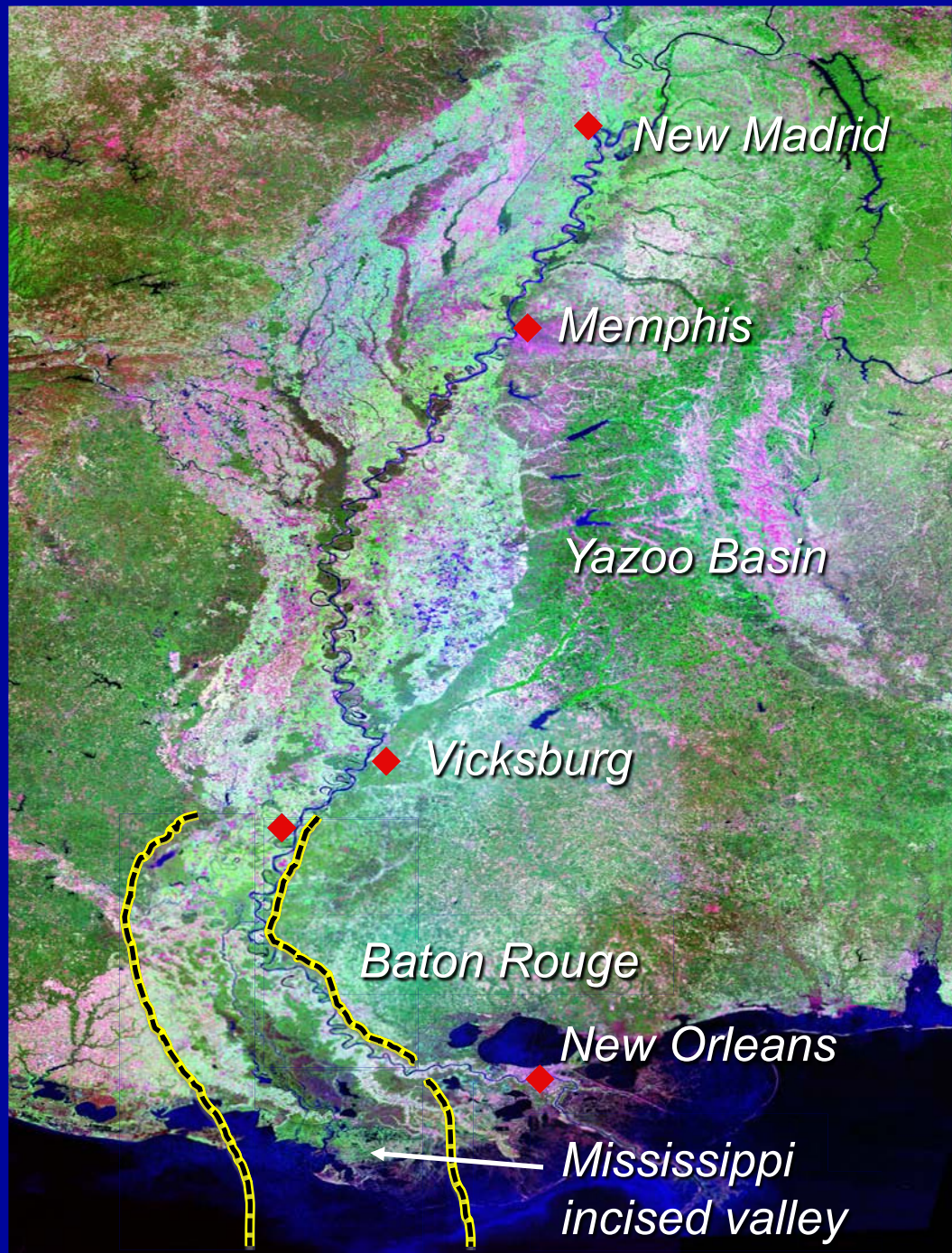
initial channel incision  
and cross-shelf extension  
with sediment bypass



lateral migration with  
contemporaneous  
channelbelt formation



- *Step-wise incision, followed by lateral migration and channelbelt construction widens the incised channel into a valley-scale feature*
- *What are the mechanisms that promote the step-wise incision?*

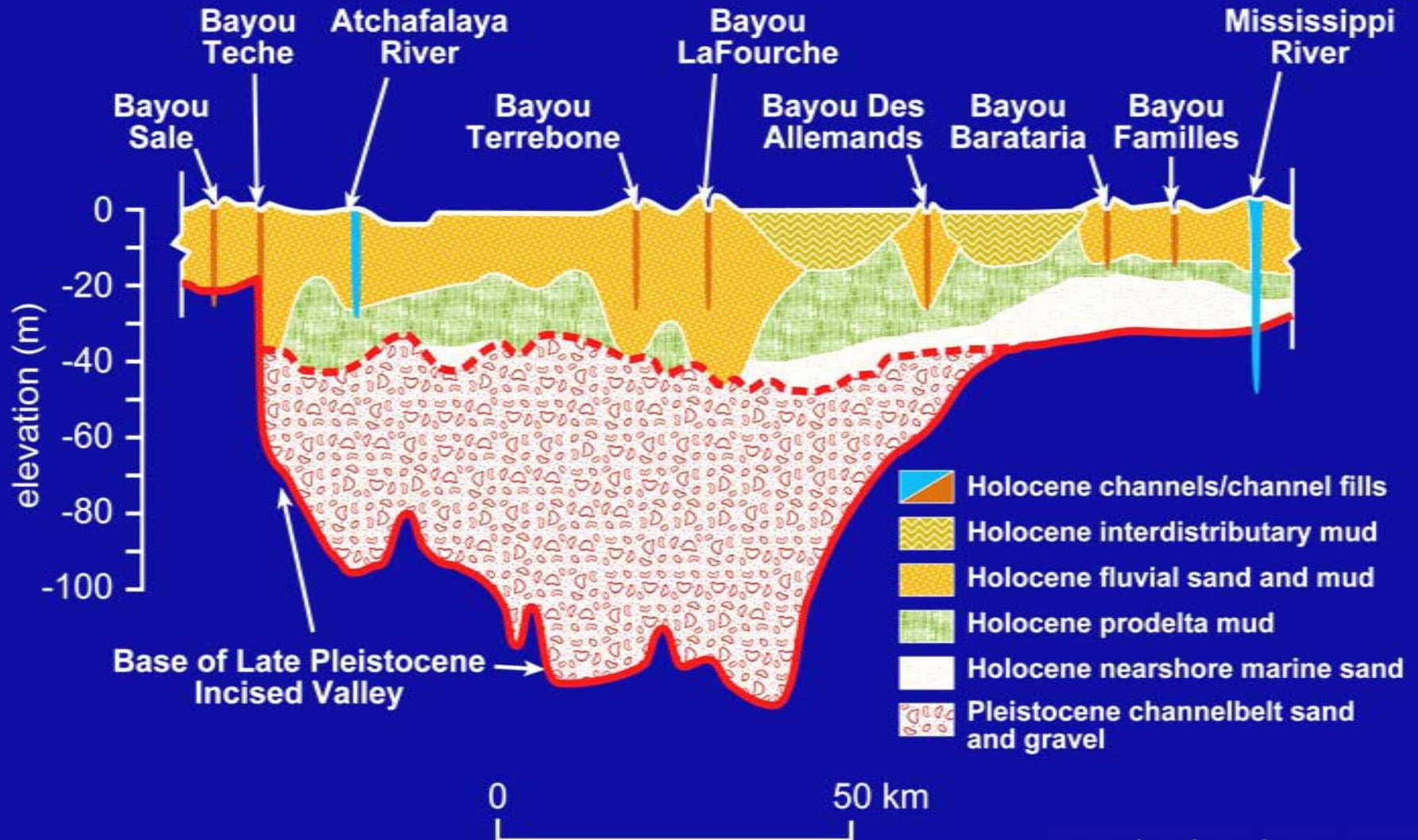


## *Isostatic Adjustments to Sediment Unloading and Loading*

- Example from the Mississippi River incised valley (a large river phenomenon)*
- Valley incision during the last glacial period sea-level fall and lowstand*
- Valley filling during the present transgression and highstand*

# LOWER MISSISSIPPI INCISED VALLEY

## Valley Cross-Section at N 30°

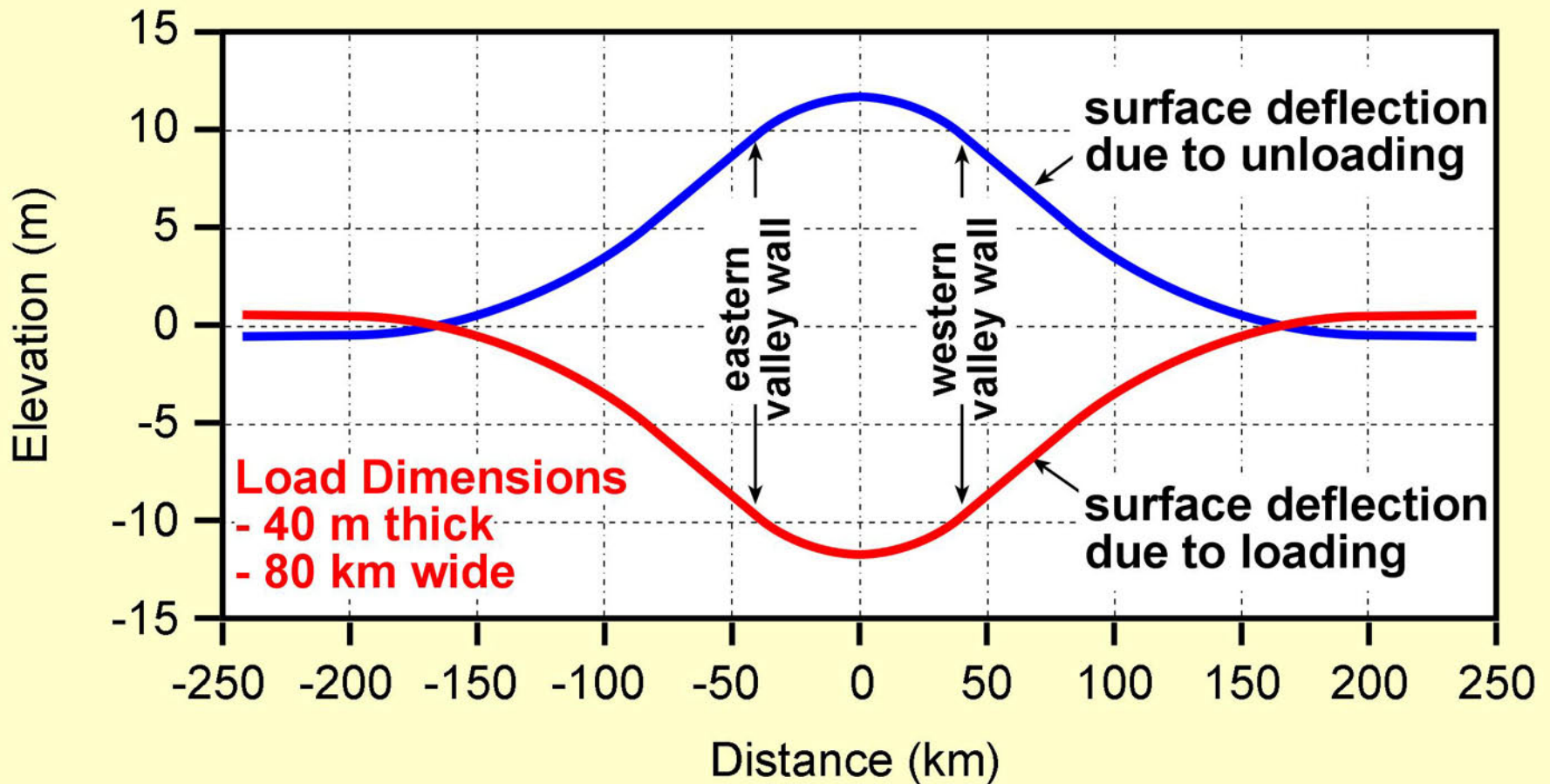


modified from Saucier (1994)

# LOWER MISSISSIPPI VALLEY AND DELTA

## *1D Isostatic Effects of Unloading and Loading at N 30°*

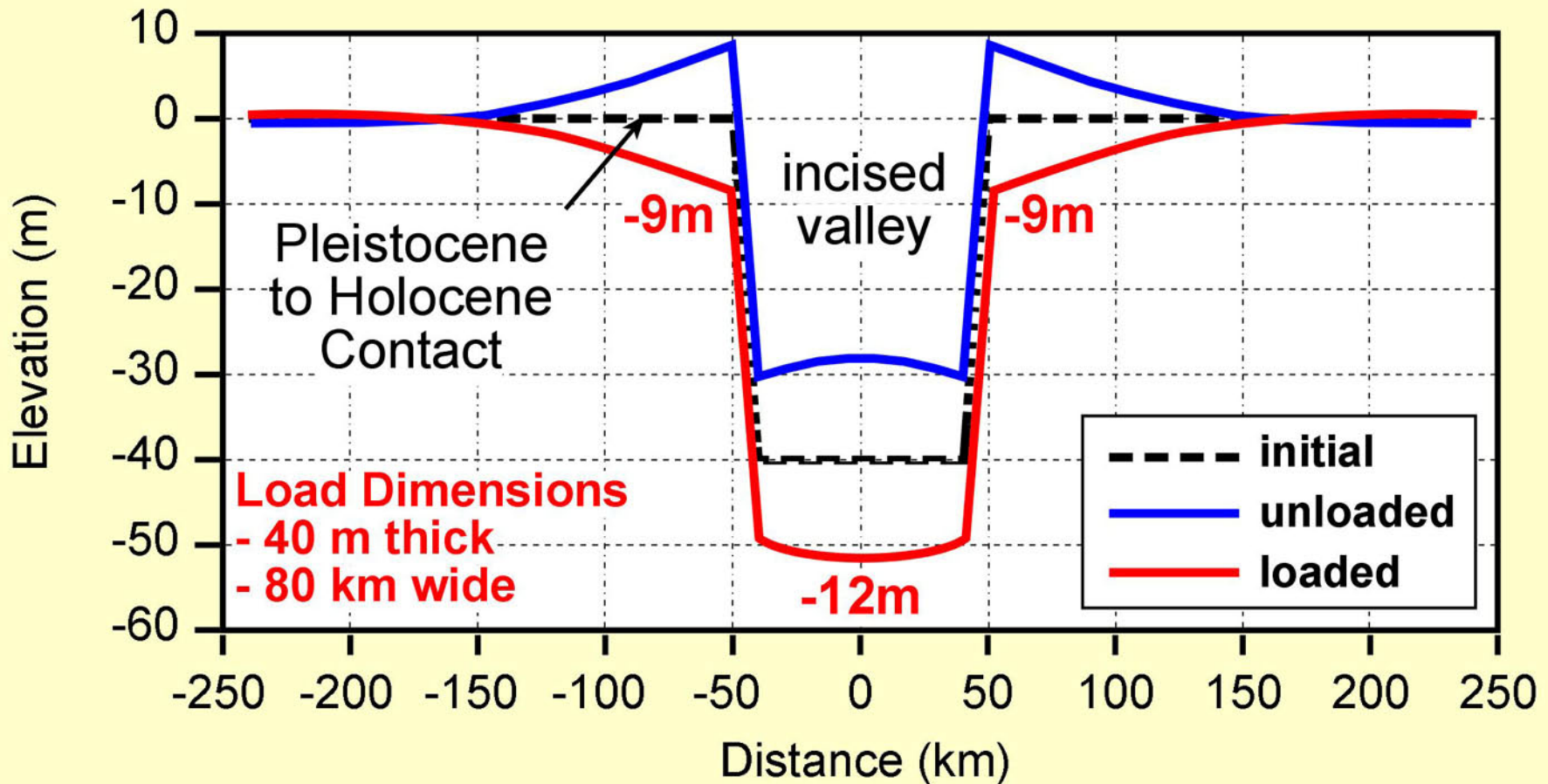
Steady-State Solution - Symmetrical Uplift and Subsidence



# LOWER MISSISSIPPI VALLEY AND DELTA

## 1D Isostatic Effects of Unloading and Loading at N 30°

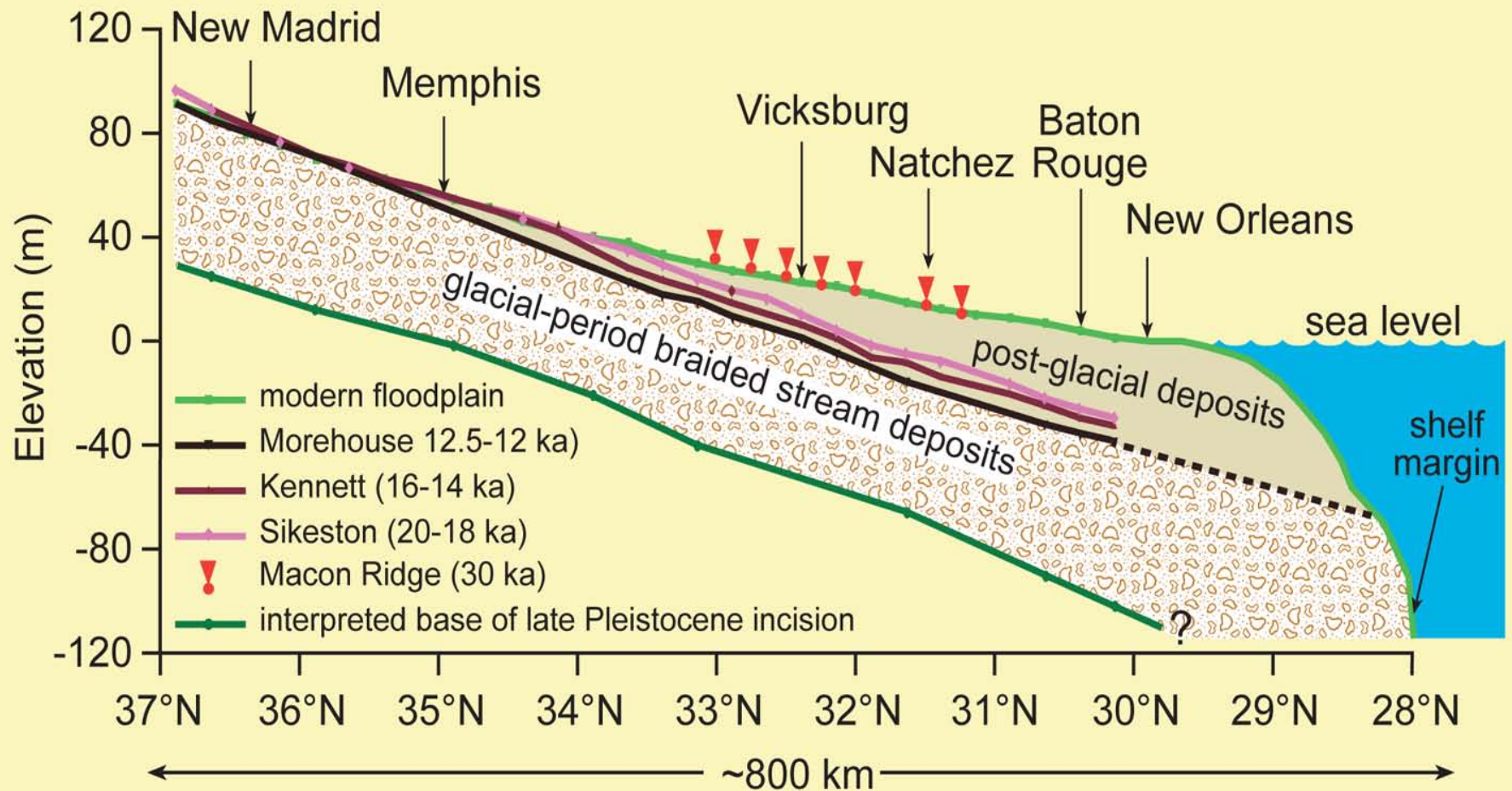
Steady-State Solution - Symmetrical Uplift and Subsidence



*Cyclical uplift and subsidence is plausible..... what about the timing??*

# LONG PROFILE EVOLUTION, LOWER MISSISSIPPI VALLEY AND DELTA

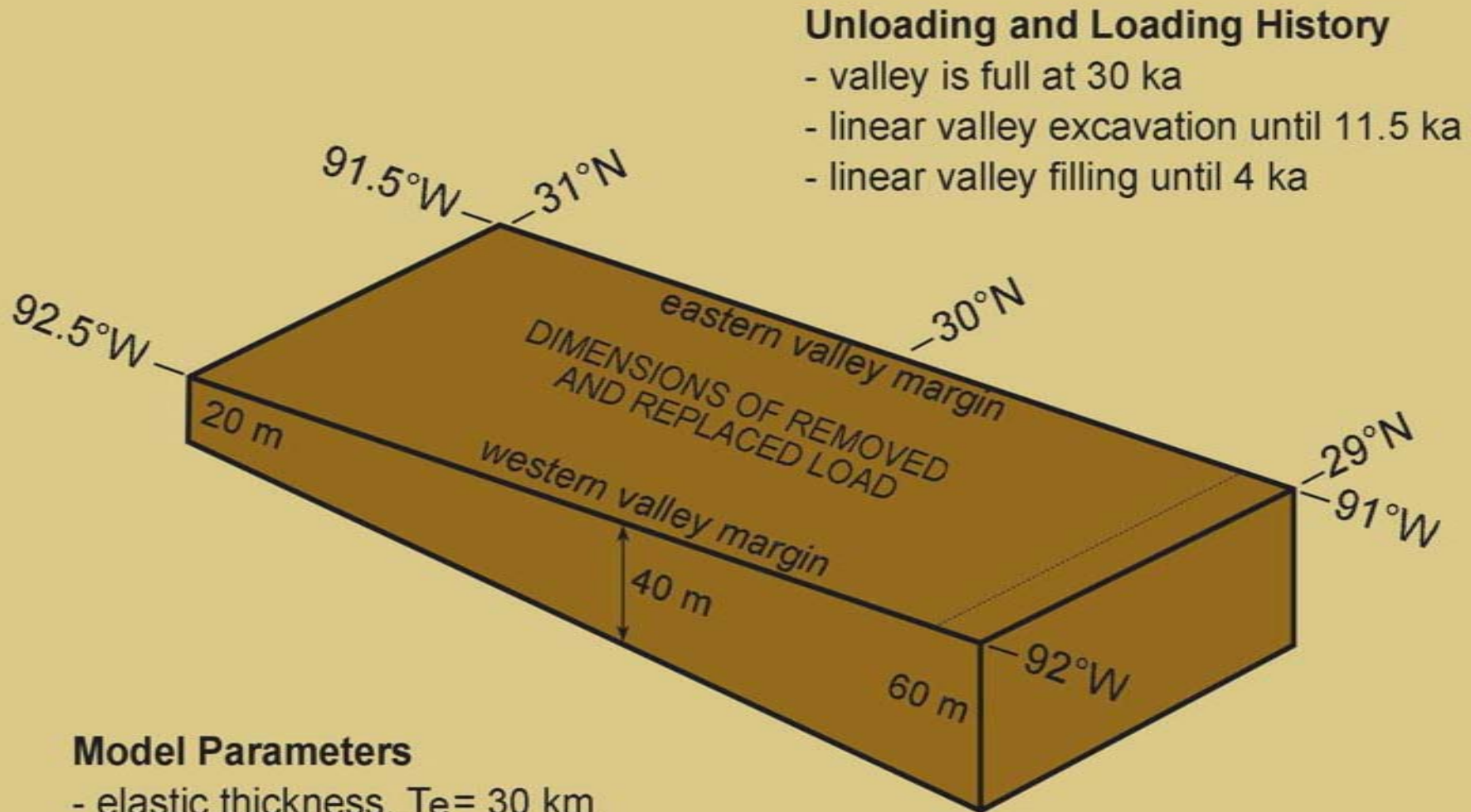
*Constrains the Magnitude and Timing of Valley Unloading and Loading*



after Blum et al. (2008)

# ***FLEXURAL MODELING PARAMETERS***

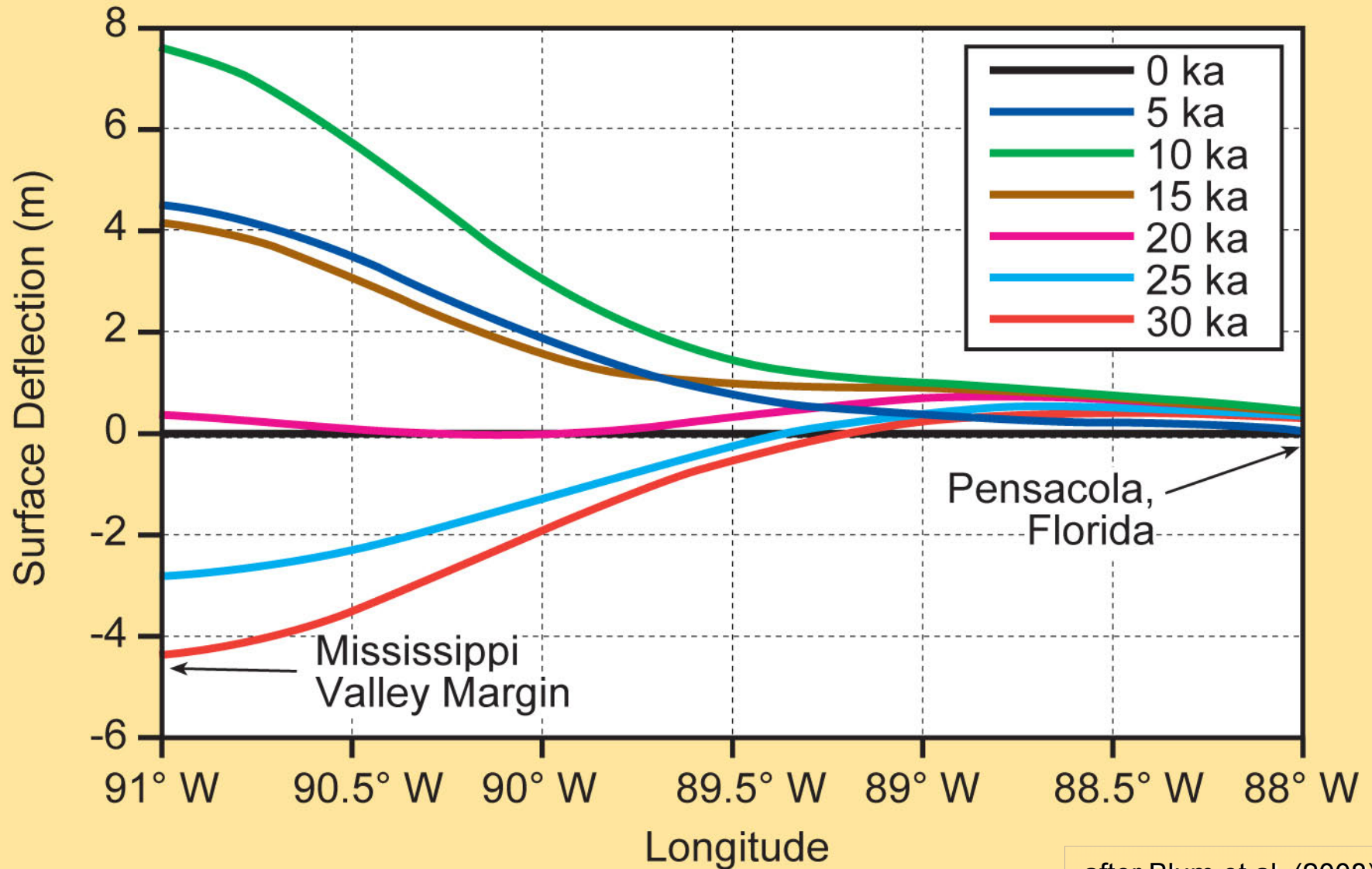
## *ANU 3d Visco-Elastic Glacial Rebound Model*



### **Model Parameters**

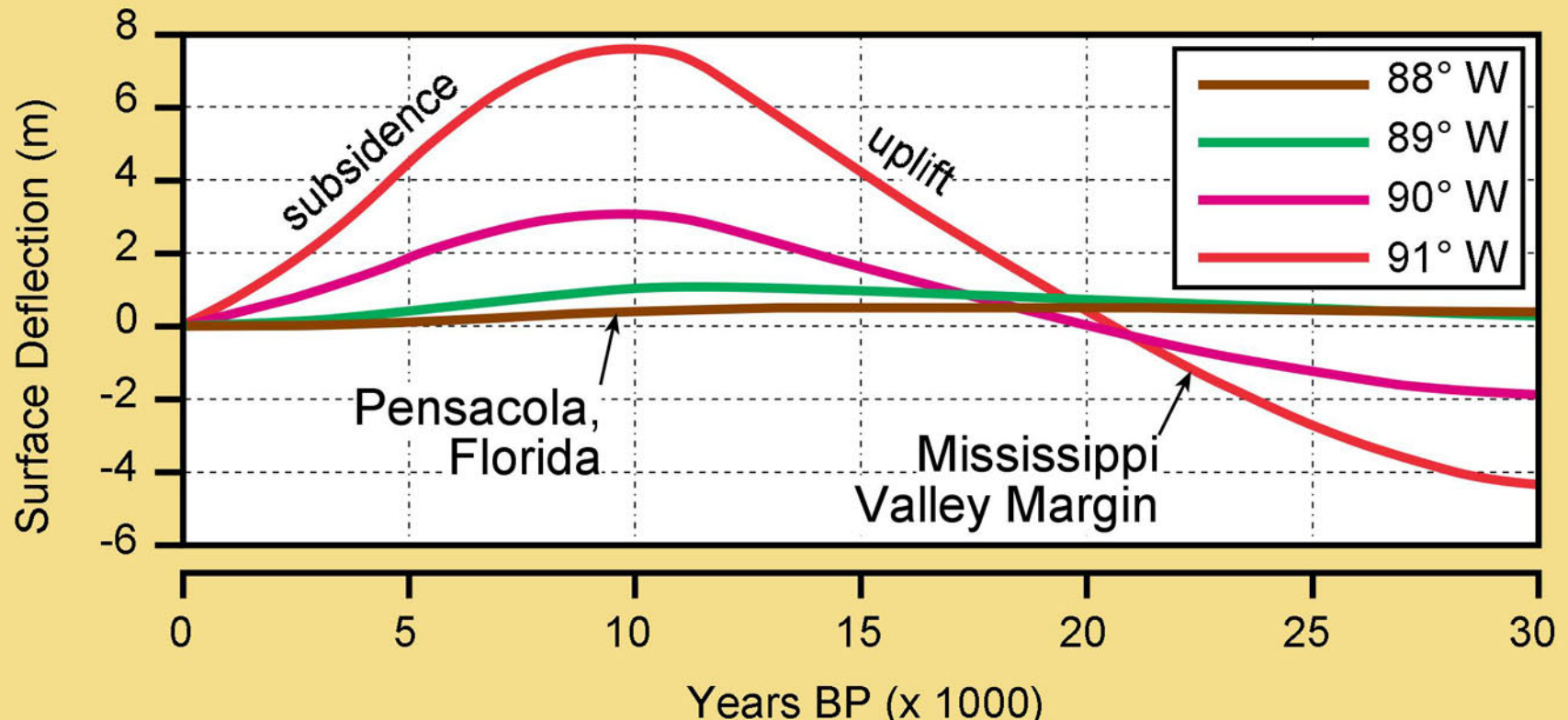
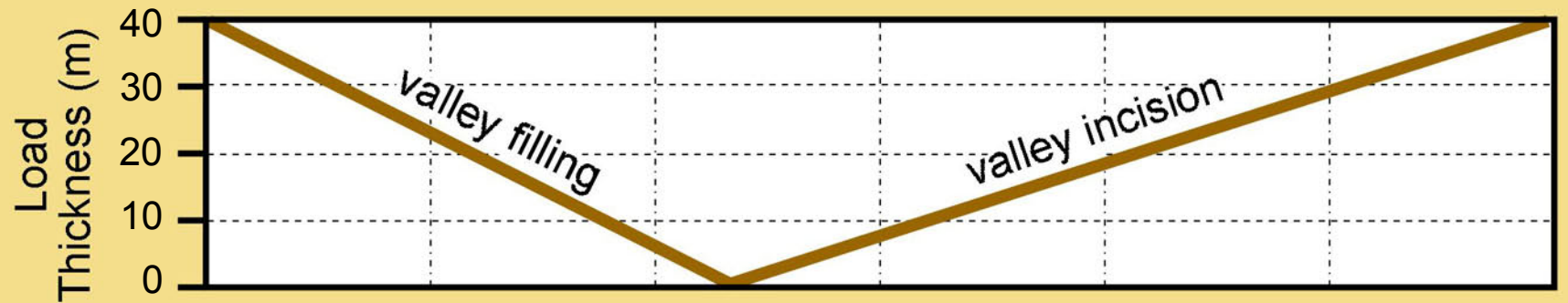
- elastic thickness,  $T_e = 30$  km
- upper mantle viscosity,  $\eta_{um} = 4 \cdot 10^{20}$  Pa

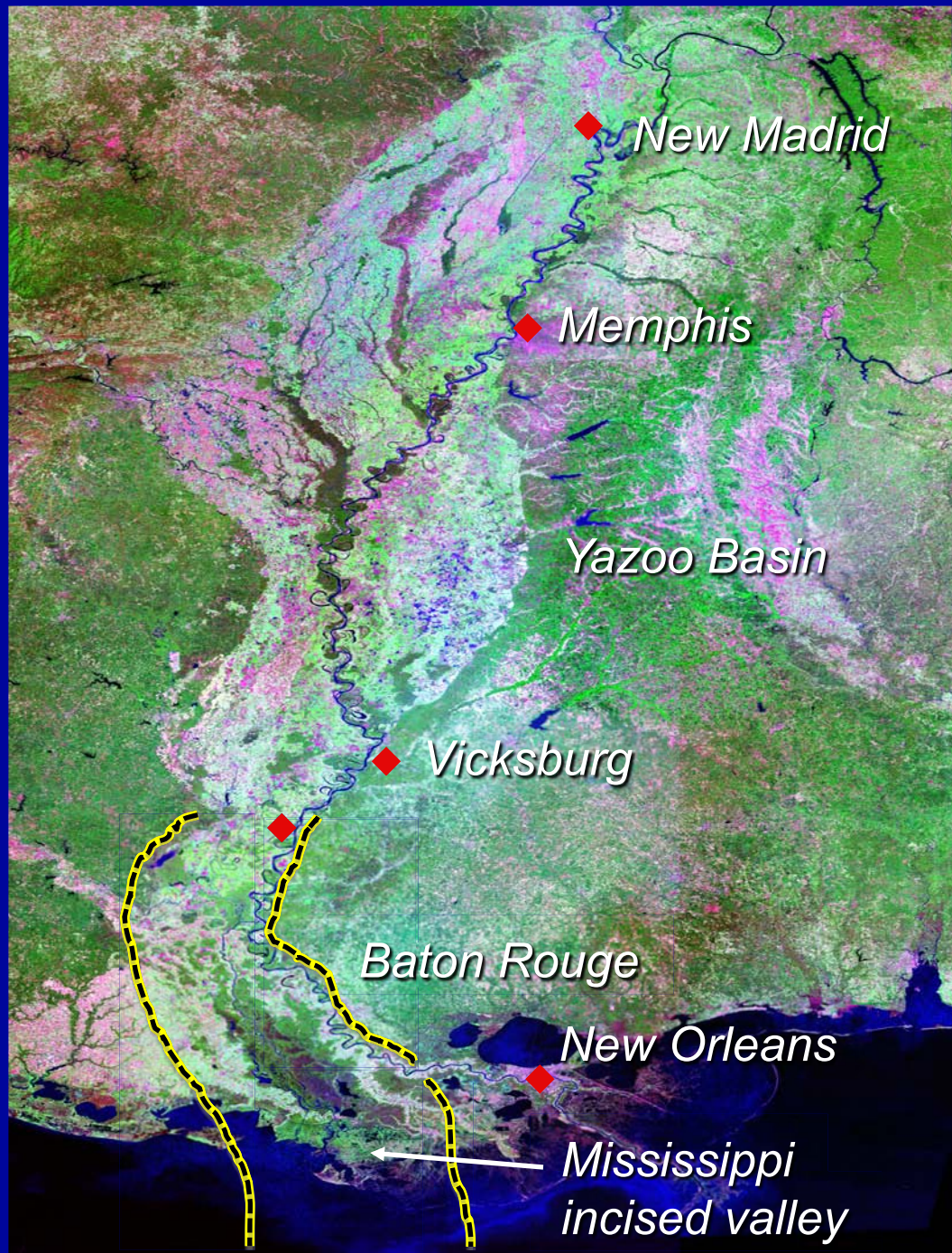
# *FLEXURAL DEFORMATION OF THE NORTHERN GULF OF MEXICO SHORELINE (LAST 30 KYRS)*



after Blum et al. (2008)

# *FLEXURAL DEFORMATION OF THE NORTHERN GULF OF MEXICO SHORELINE (LAST 30 KYRS)*





## *Isostatic Adjustments to Sediment Unloading and Loading*

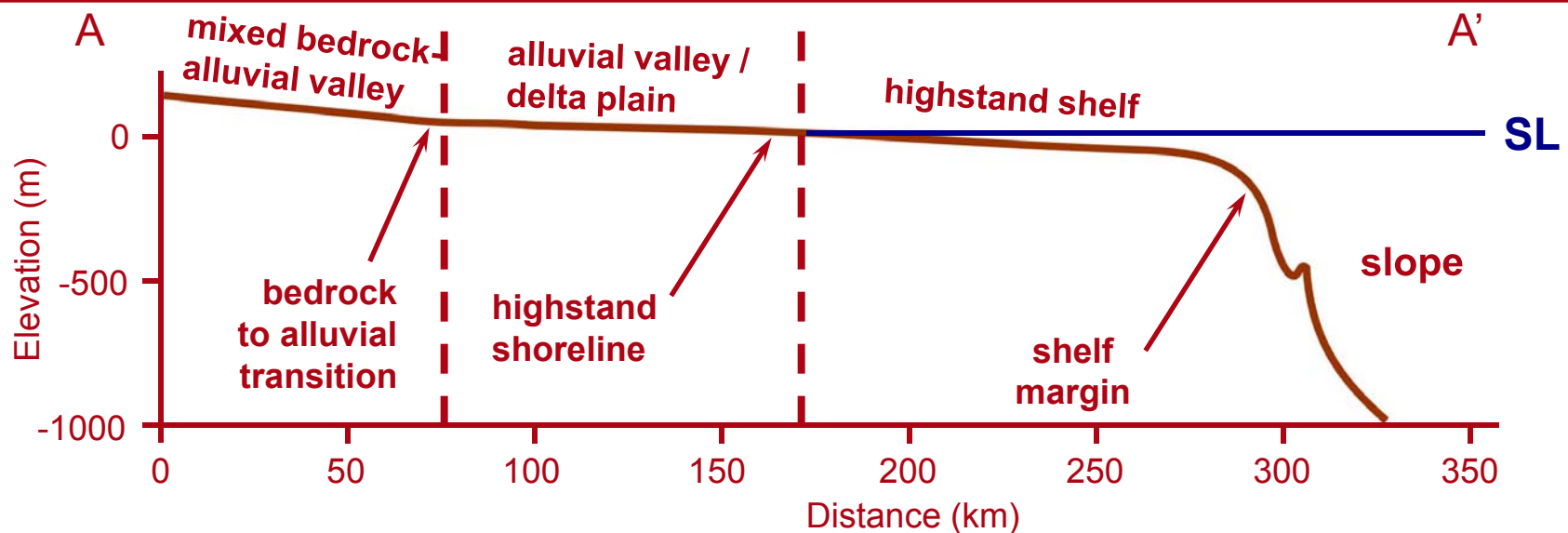
- Large-scale cyclical uplift and subsidence in response to valley incision and valley filling for mega river systems*
- Isostatic response is rapid, with less than 2000 yrs lag between load change and response*
- Feedback process that should enhance incision and deposition*

# NORTHWEST GULF OF MEXICO MARGIN: Topography and Bathymetry

Colorado-  
Brazos Delta

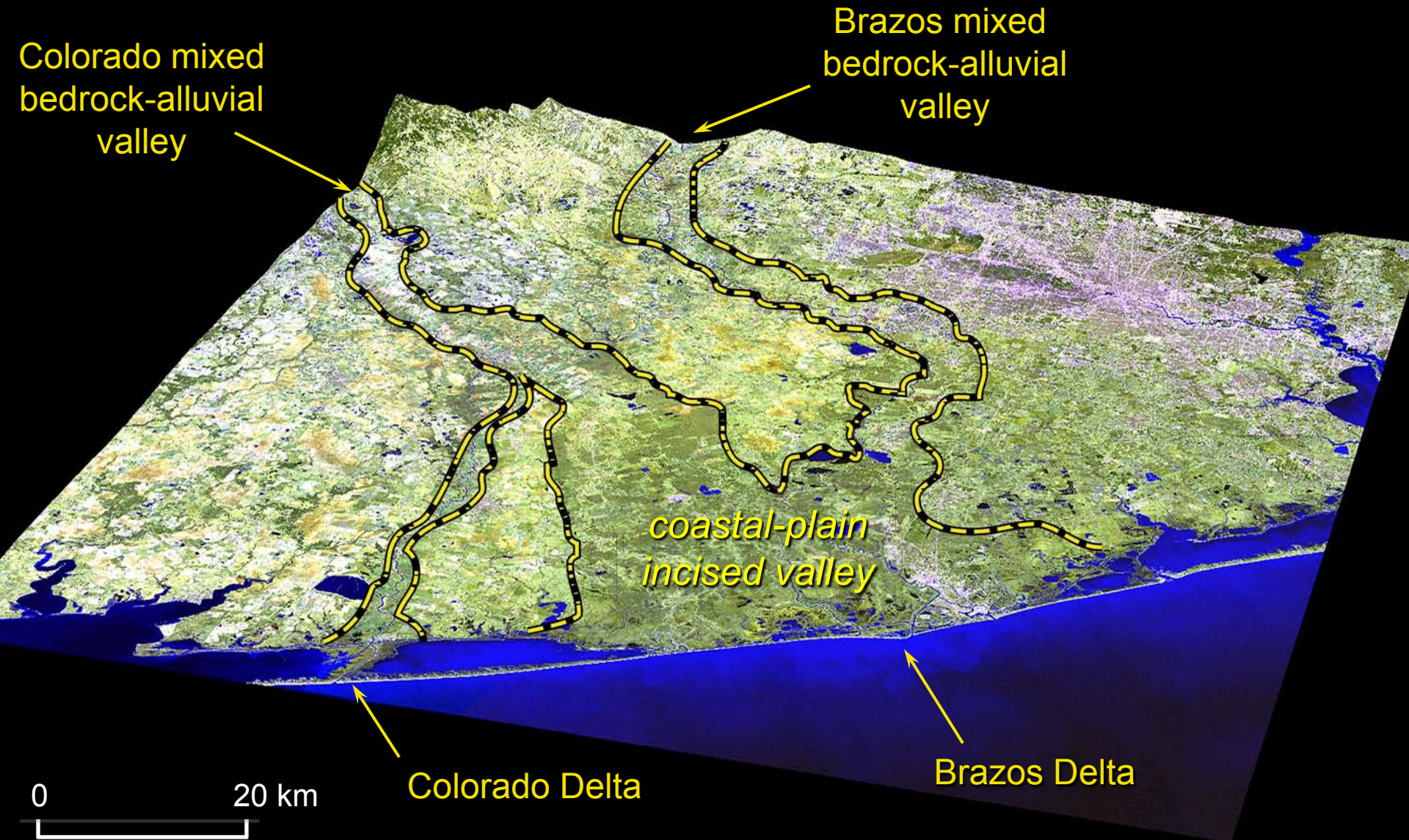
## Hydroisostatic effects?

- Magnitude of uplift that results from sea-level fall to the shelf margin
- High-amplitude sea-level change with a broad shelf



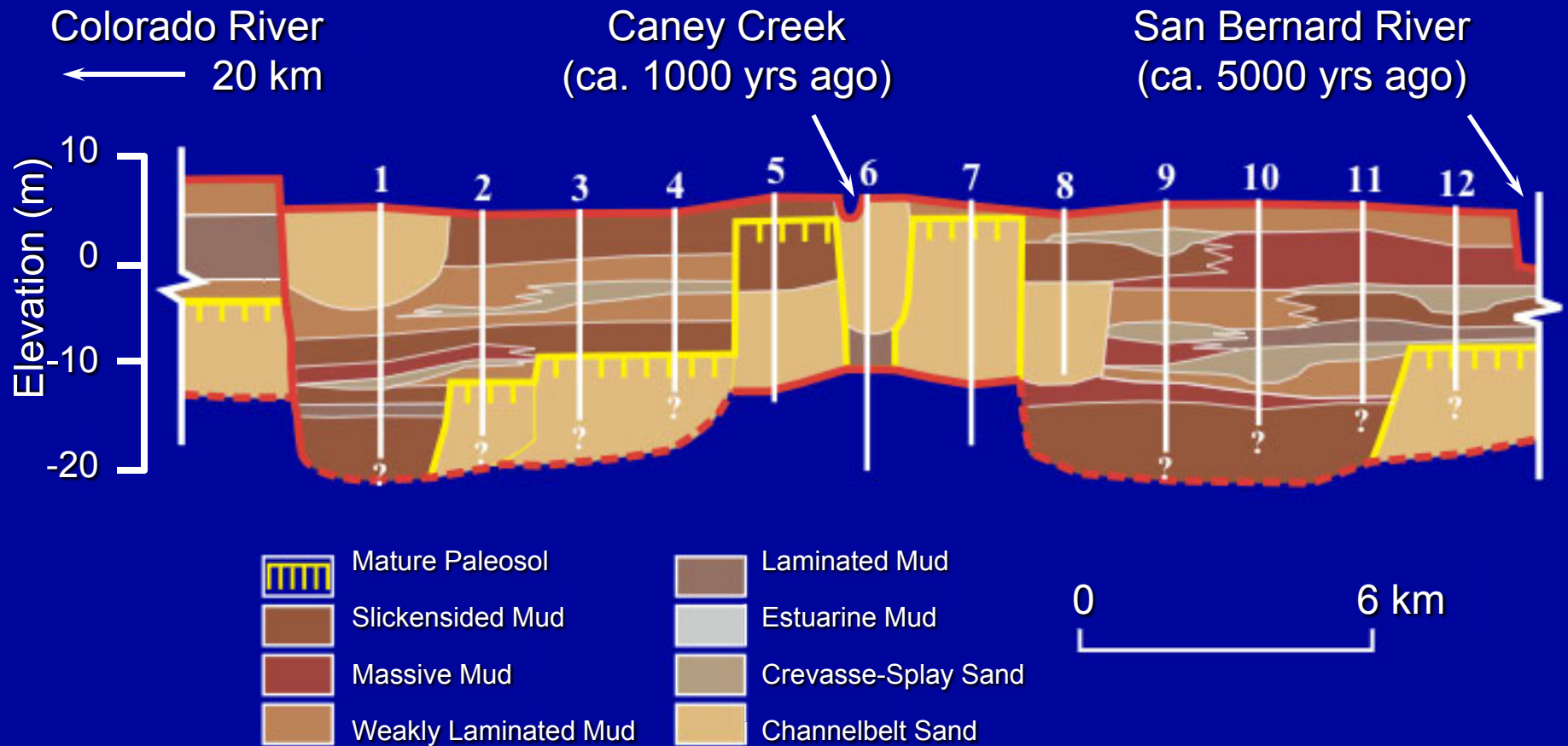
# *COLORADO-BRAZOS INCISED VALLEY*

*Last 100 kyr Glacial-Interglacial Cycle*



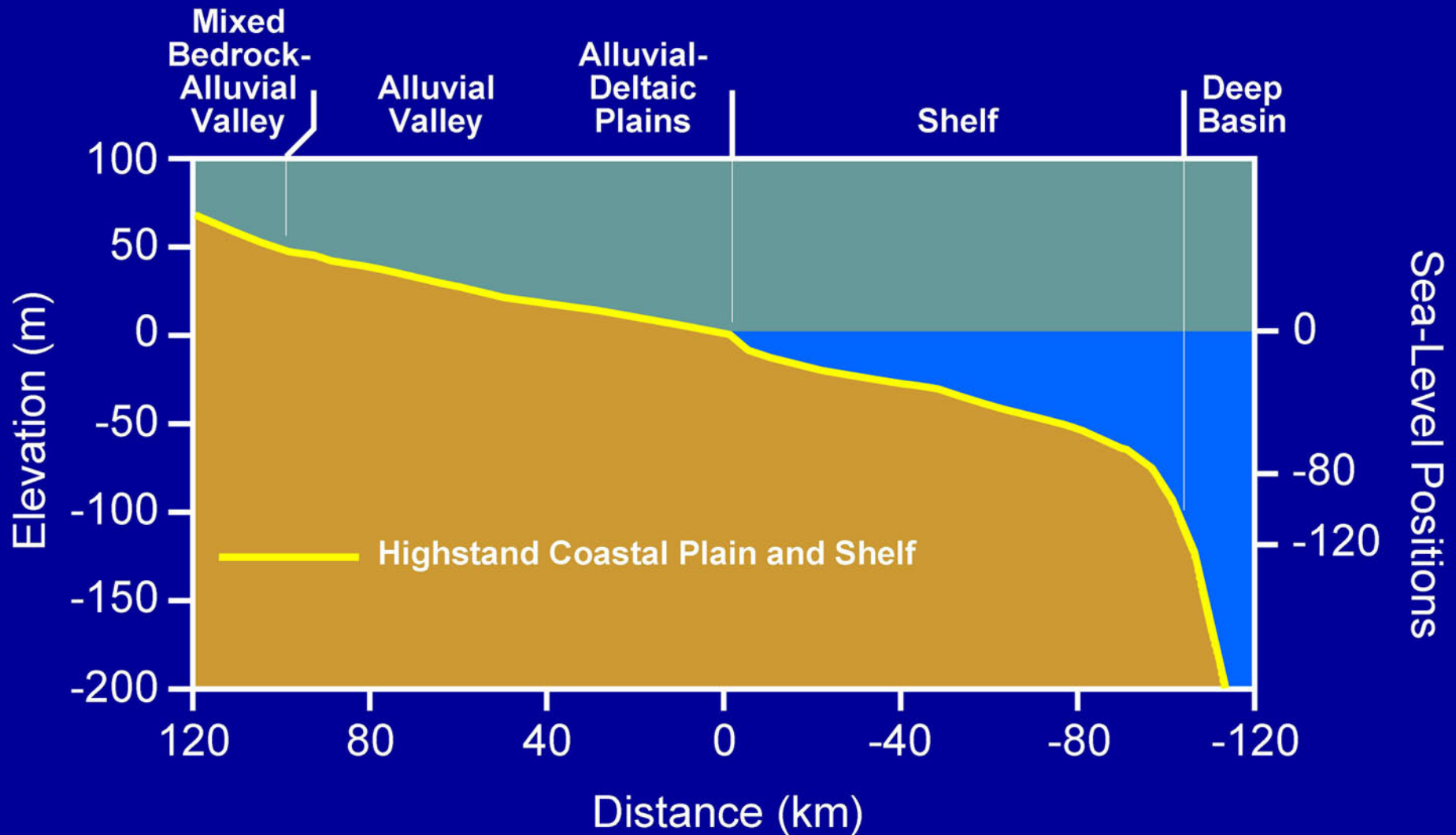
# INCISED-VALLEY FILL ARCHITECTURE

# Colorado River, Texas Coastal Plain

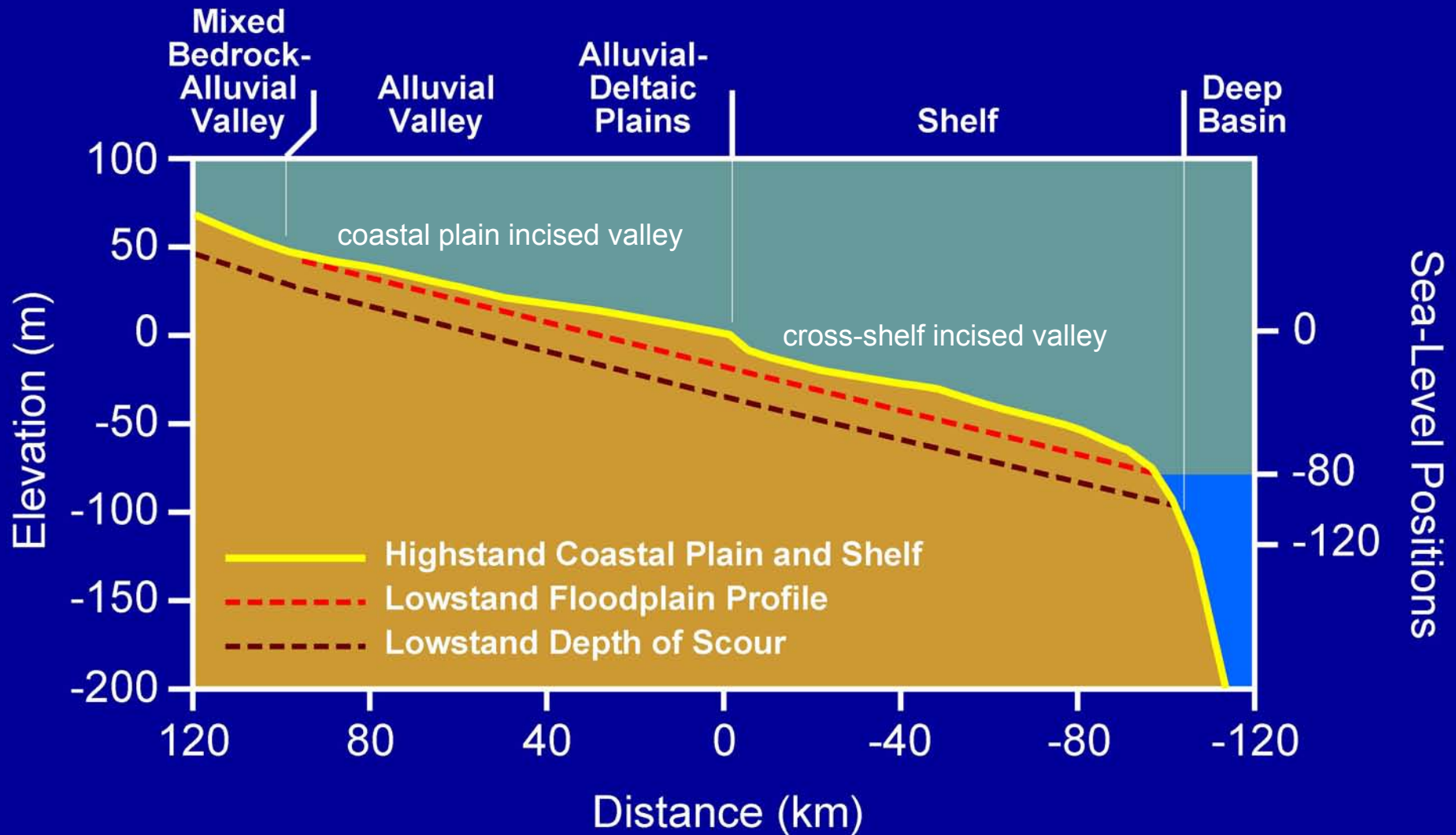


after Blum and Aslan (2006)

# *LONG PROFILE, LOWER COLORADO RIVER, TEXAS COASTAL PLAIN AND SHELF*

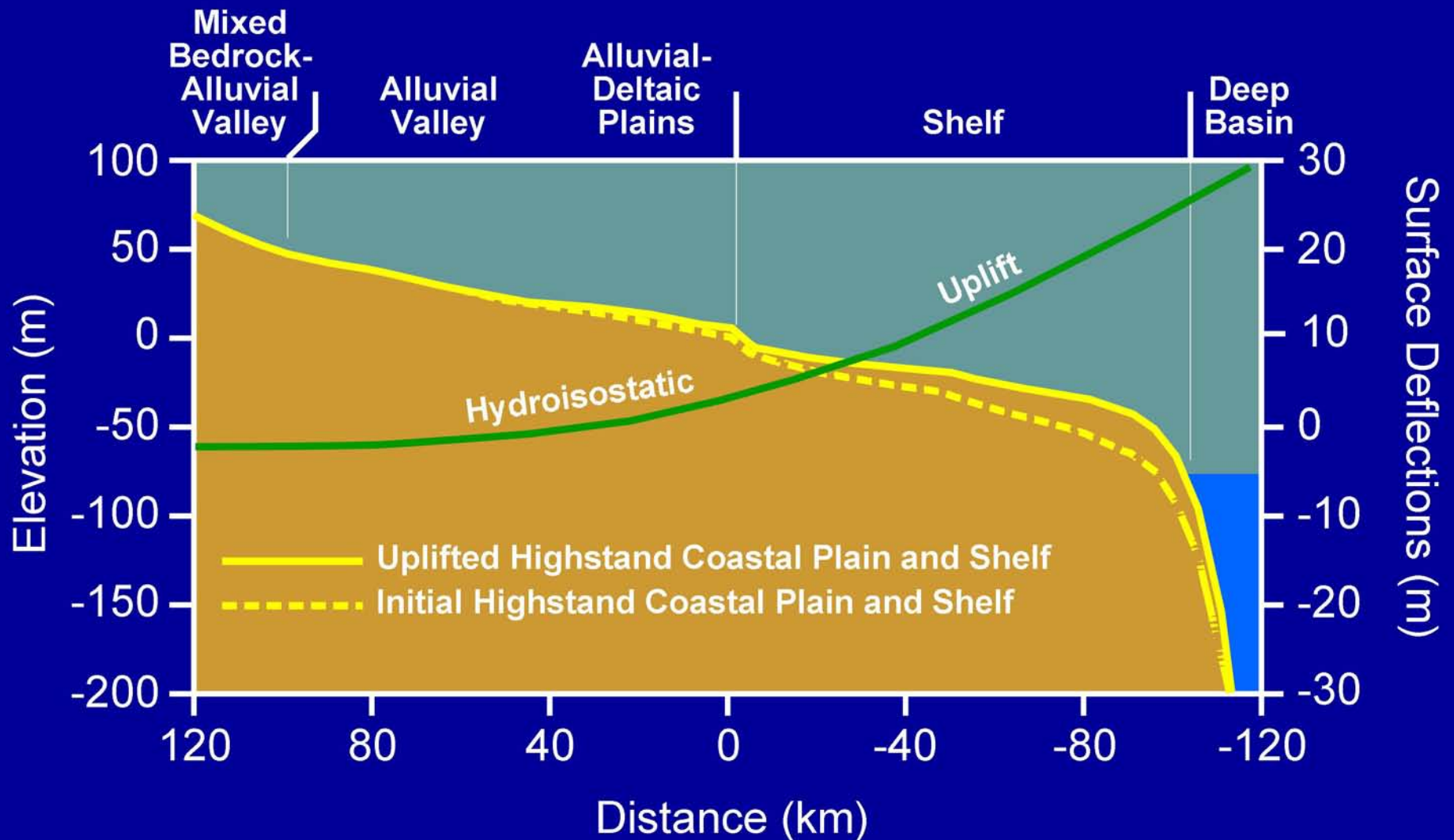


# *LONG PROFILE, LOWER COLORADO RIVER, TEXAS COASTAL PLAIN AND SHELF*

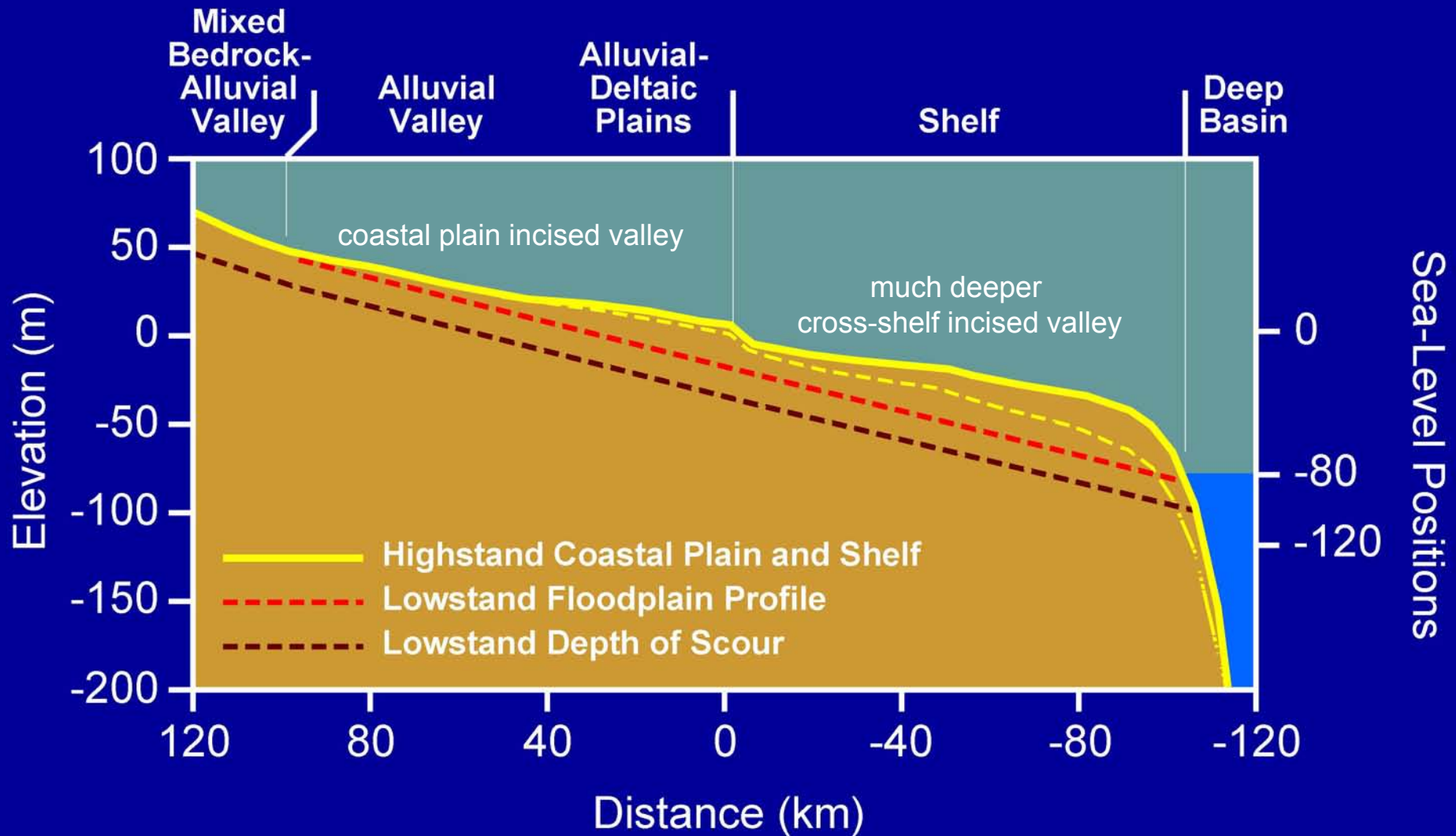


# *LONG PROFILE, LOWER COLORADO RIVER, TEXAS COASTAL PLAIN AND SHELF*

Steady-State Solution - Hydroisostatic Uplift from Sea-Level Fall



# *LONG PROFILE, LOWER COLORADO RIVER, TEXAS COASTAL PLAIN AND SHELF*



# HOW DO YOU FORM AN INCISED VALLEY?

initial channel incision  
and cross-shelf extension  
with sediment bypass



lateral migration with  
contemporaneous  
channelbelt formation



- *Large-scale cyclical uplift and subsidence from unloading and loading of shelves in response to sea-level change*
- *In regional-scale rivers, step-wise incision may reflect hydroisostatic uplift in response to sea-level fall !!*

# CONCLUSIONS

- *Evolution of incised valley systems very likely co-occurs with 2 distinct types of large-scale cyclical isostatic adjustments.*
- *For large river systems, large-scale flexural uplift and subsidence results from evolution of the incised valley itself, and the change in mass distribution from sediment unloading and loading.*
  - *Magnitude of uplift and subsidence will correlate to scale of river system and incised valley.*
  - *Timing of uplift and subsidence will reflect the forcing mechanisms that drive incision and filling, and need not correlate from system to system*
- *For river systems that discharge to broad shelves, large-scale flexural uplift and subsidence results from hydroisostatic effects that accompany sea-level change.*
  - *Magnitude will correlate to shelf width and amplitude of SL change.*
  - *Timing of effects will correlate to SL change.....regional signal*
- *Isostatic effects should be incorporated in models for incised-valley evolution, and variability in likely isostatic effects should be explored (low vs. high gradient systems, greenhouse vs. icehouse worlds).*

## References

- Blum, M.D., H. Jonathan, A. Purcell, and R.R. Lancaster, 2008, Ups and downs of the Mississippi Delta: *Geology Boulder*, v. 36/9, p. 675-678.
- Blum, M.D. and A. Aslan, 2006, Signatures of climate vs. sea-level change within incised valley-fill successions; Quaternary examples from the Texas Gulf Coast: *Sedimentary Geology*, v. 190/1-4, p. 177-211.
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- Miller, K.G., J.D. Wright, and J.V. Browning, 2005, Visions of ice sheets in a greenhouse world, *in* *Ocean chemistry over the Phanerozoic and its links to geological processes*, v. 217/3-4, p. 215-231.
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