Organization and Reorganization of Drainage and Sediment Routing through Time:

The Mississippi System

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University of Kansas

“big rivers are the bloodlines of continents.........”

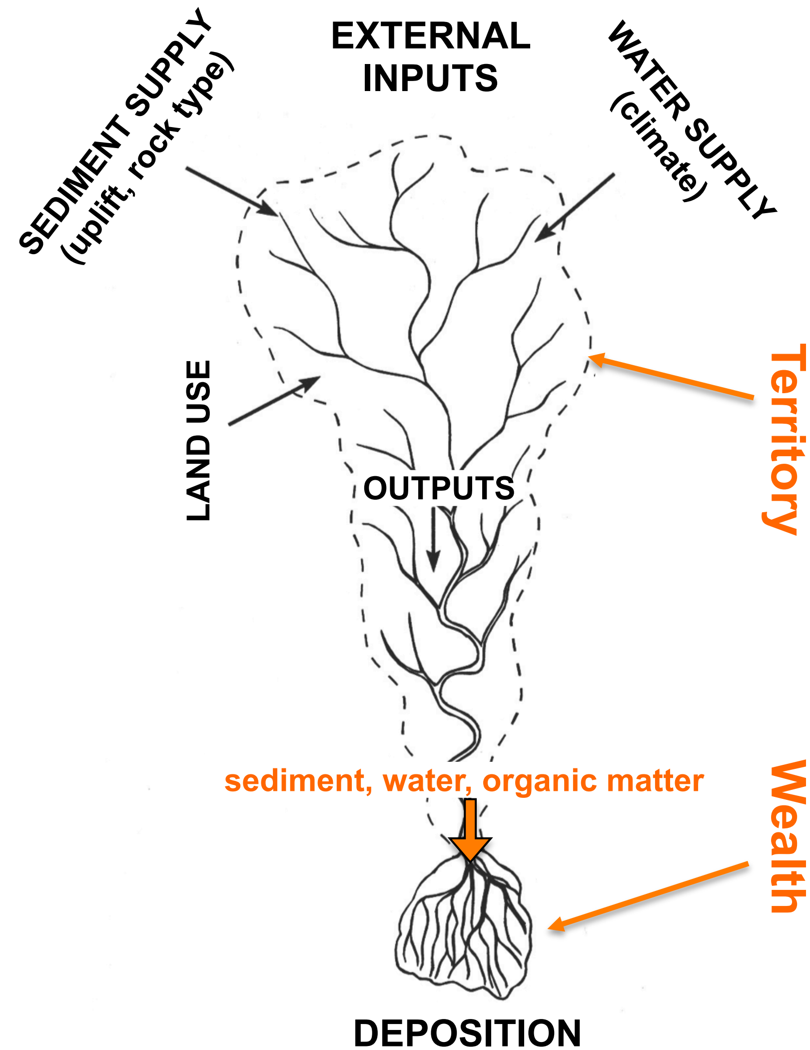
Lawton, T. (2014) Small grains, big rivers, continental concepts. *Geology* v. 42, p. 639-640.

Bloodlines.....

- Cycles of development, senescence, and decay
- Acquire, control, and lose territory
- Accumulate, control, and ultimately lose resources
- Leave behind a trail of themselves in the genetic pool

Rivers.....

- Cycles of drainage basin organization, senescence and reorganization
- Acquire and lose drainage basin area
- Accumulate and ultimately lose hydrocarbon, water, and ecological resources
- Leave behind a trail of themselves in the geologic record

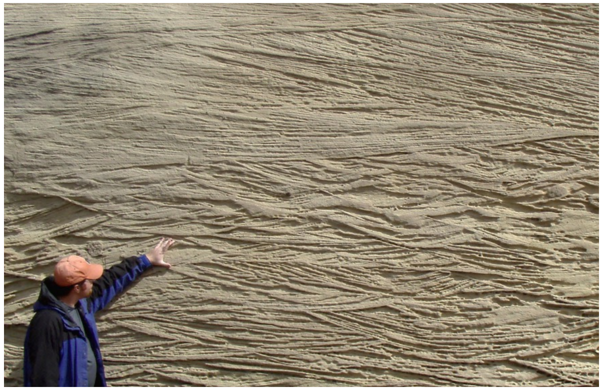


“big rivers are the bloodlines of continents.........”

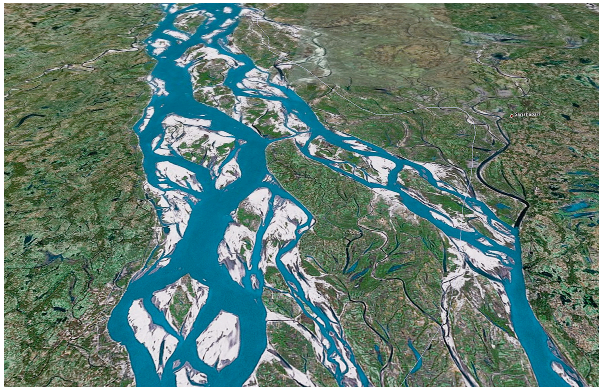
Lawton, T. (2014) Small grains, big rivers, continental concepts. *Geology* v. 42, p. 639-640.

The Record of Organization and Reorganization of Drainage and Sediment Routing through Time is Stored in……..

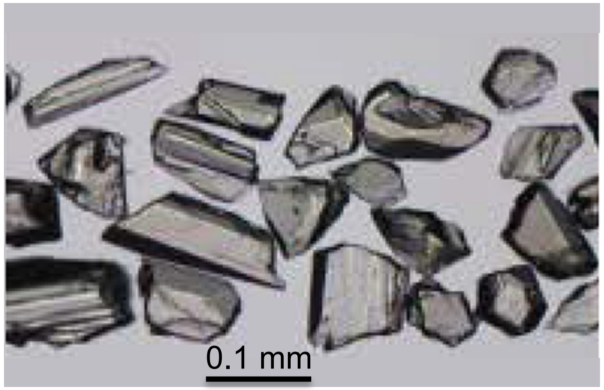
Ancient Rock Outcrops



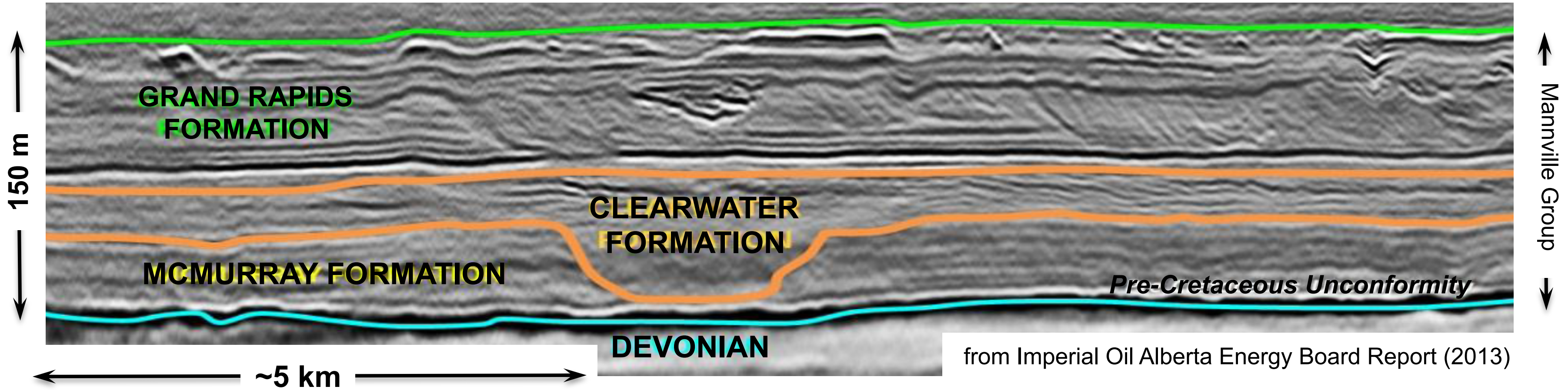
Landscape Features



Mineral Grains



Ancient Rocks in the Subsurface



from Imperial Oil Alberta Energy Board Report (2013)

FIRST PRINCIPLES

Equilibrium Response Time

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

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

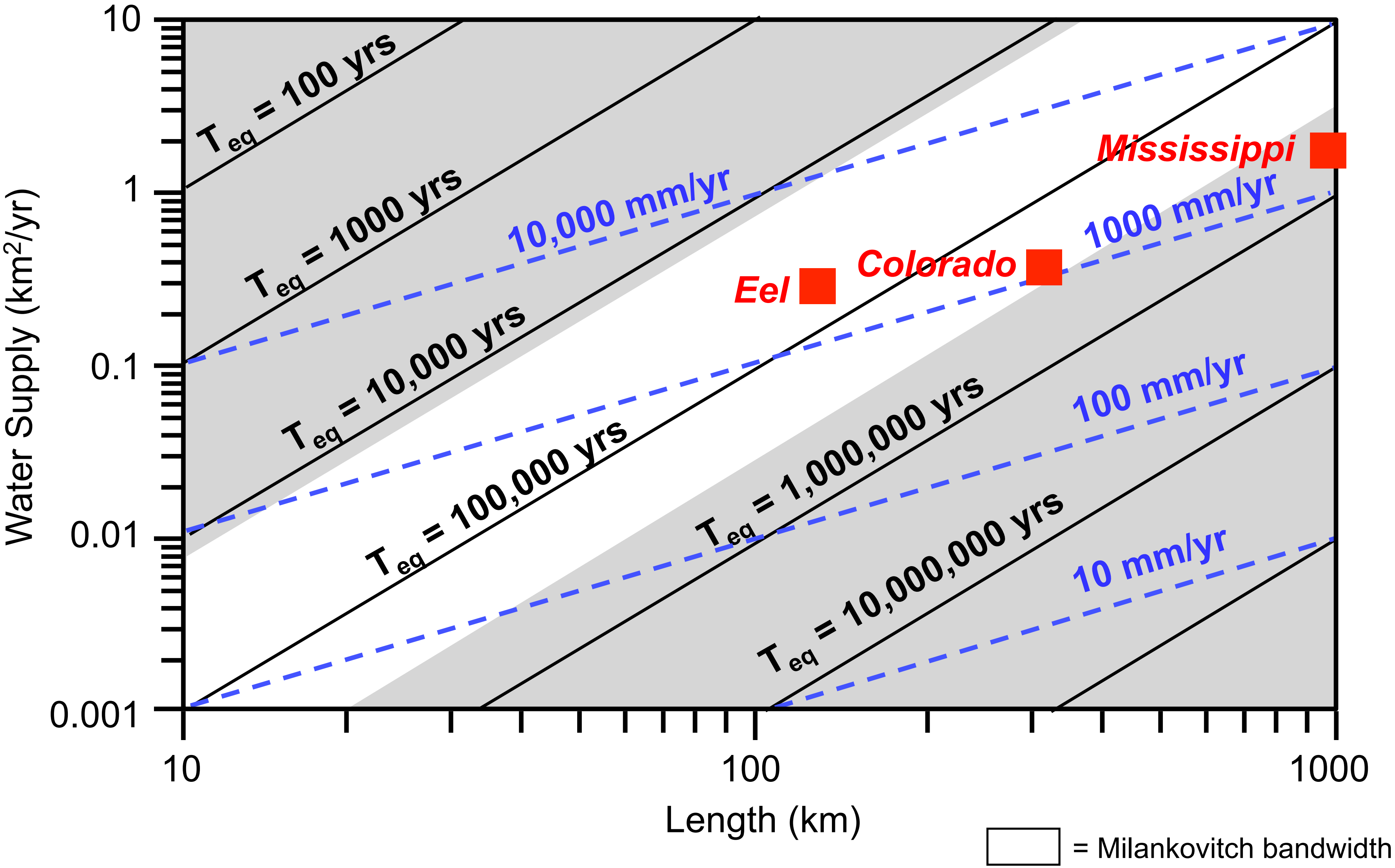
where: T_{eq} = response time (yrs)
L = length of system (km)
k = diffusivity = Q_s/W
Q_s = sediment flux (MT/yr)
W = channel or floodplain width (m)

- Response times for long profiles of most medium to large river systems 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)

FIRST PRINCIPLES

Equilibrium Response Time



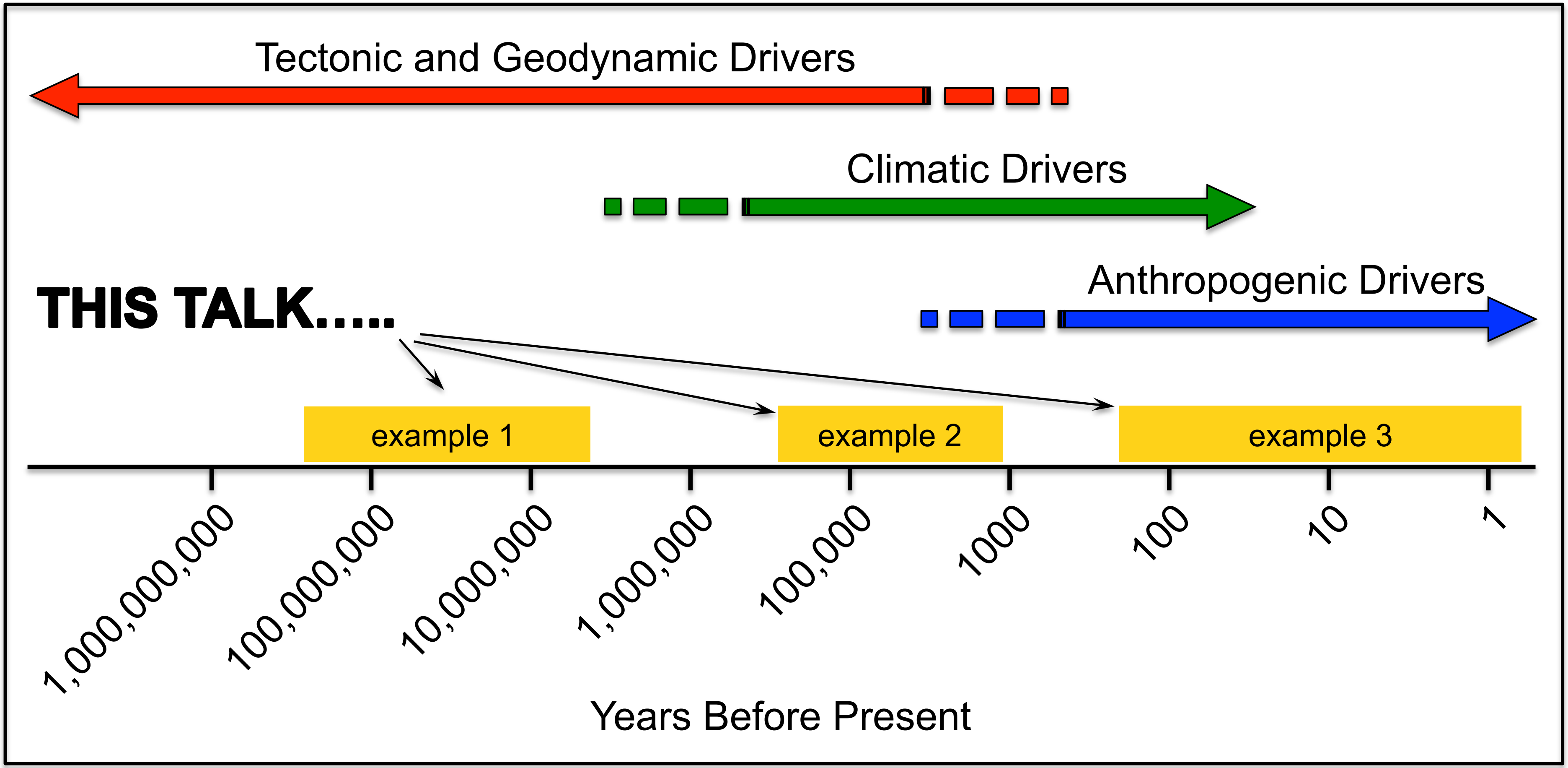
from Paola (2000)

FIRST PRINCIPLES

Drivers for Change

Organization and reorganization of drainage and sediment routing through time……..

Allogenic Drivers Depend on Timescale



Key Topics

- *North American Drainage Evolution, 125-10 Million Years Ago: Senescence of One Great River, and Emergence of Another*
- *The Glacial-Interglacial Mississippi River, 125,000-1000 Years Ago: Shaping the Modern Landscape*
- *The Once and Future Mississippi Delta: Engineering a Great River and some Unintended Consequences*

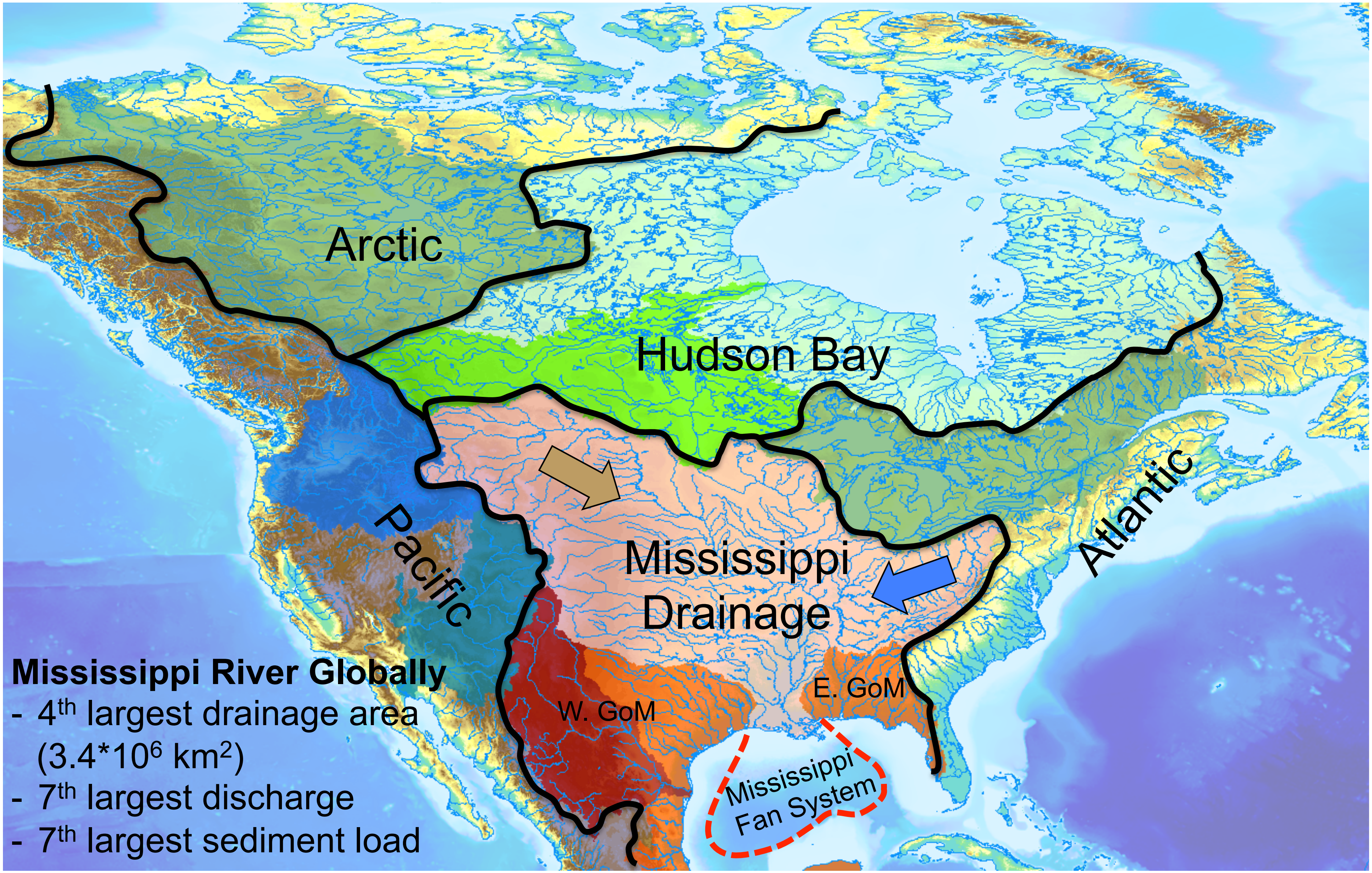
North American Drainage Evolution, 125-10 Ma

Senescence of One Great River, and Emergence of Another

special thanks to:
ExxonMobil Upstream Research, Mark Pecha (University of Arizona),
and many others……….

NORTH AMERICAN DRAINAGE EVOLUTION

Modern Drainage – Significance of Mississippi System



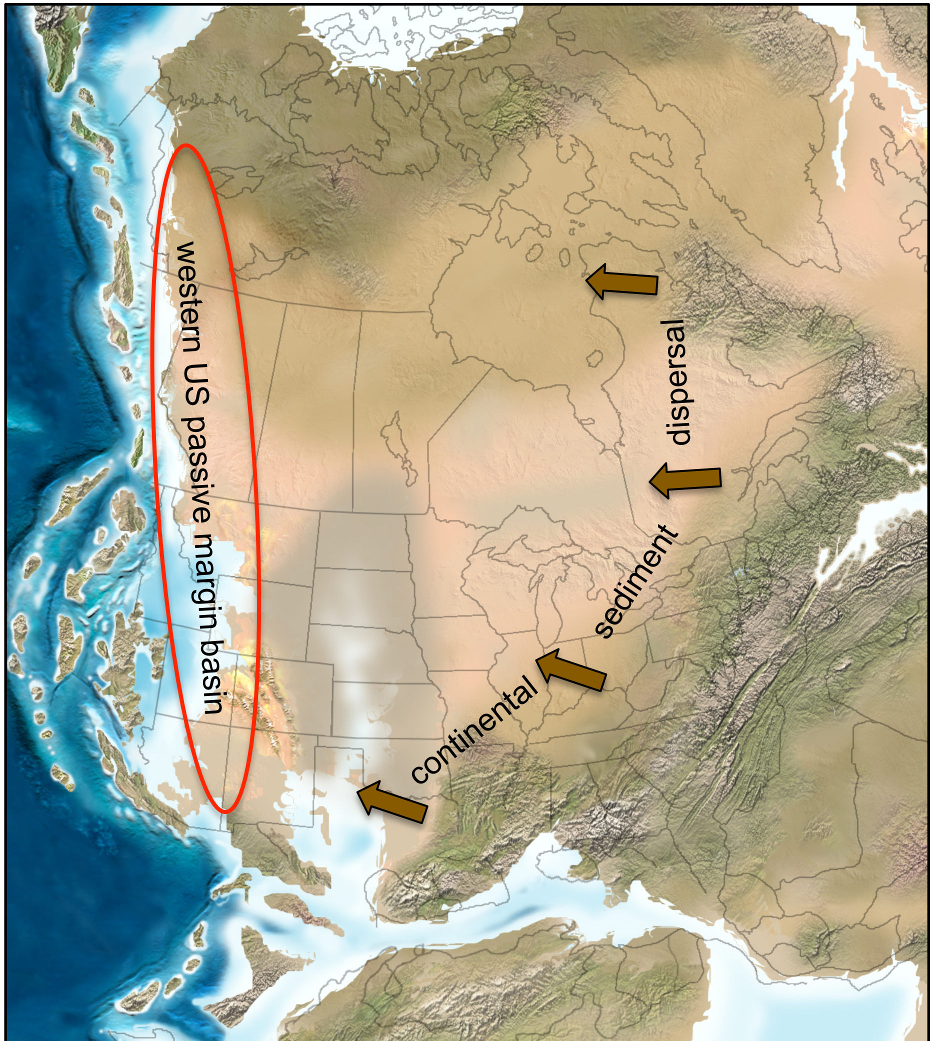
Mississippi River Globally

- 4^{th} largest drainage area ($3.4*10^6$ km^2)
- 7^{th} largest discharge
- 7^{th} largest sediment load

NORTH AMERICAN DRAINAGE EVOLUTION

Some Preliminaries - Paleogeographic Snapshots from Deep Time

Late Permian to Middle Triassic (ca. 260-230 Ma)



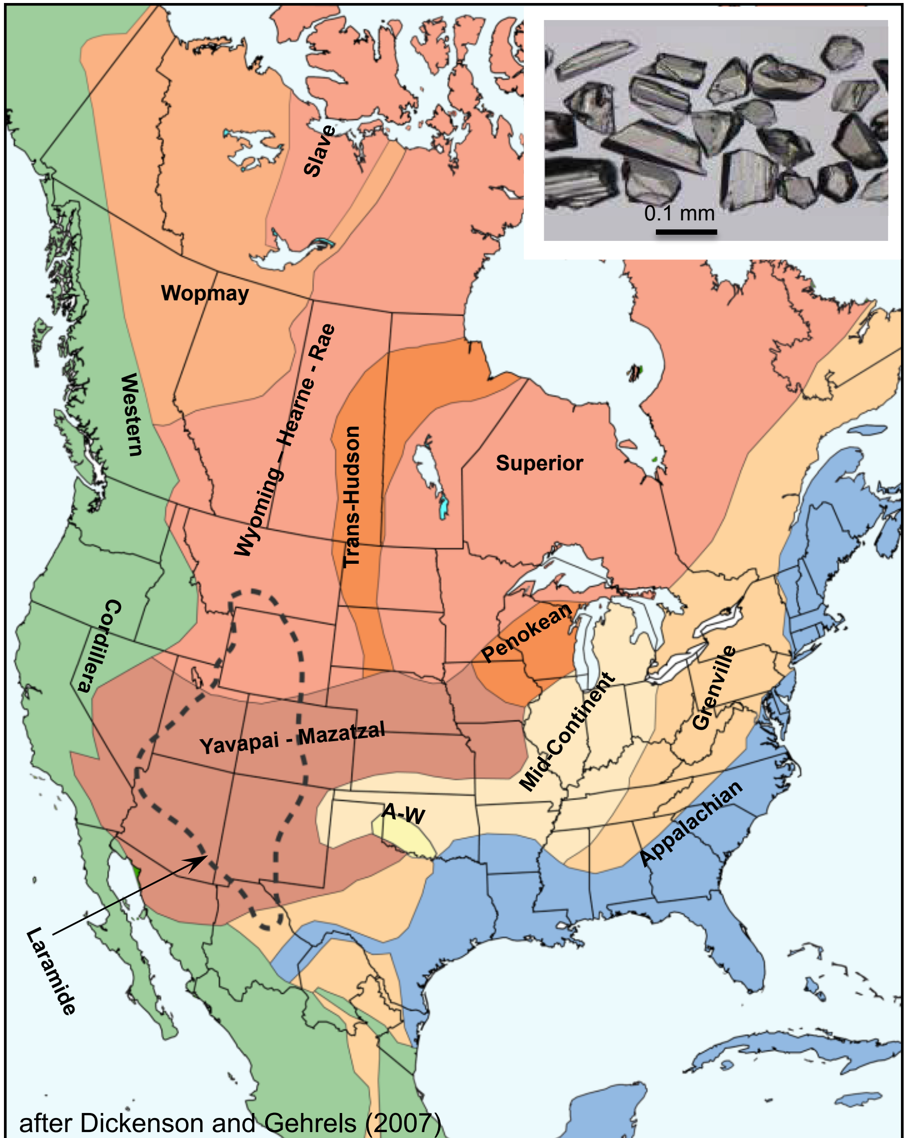
Late Jurassic to Early Cretaceous (ca. 150-140 Ma)

images courtesy of Colorado Plateau Geosystems

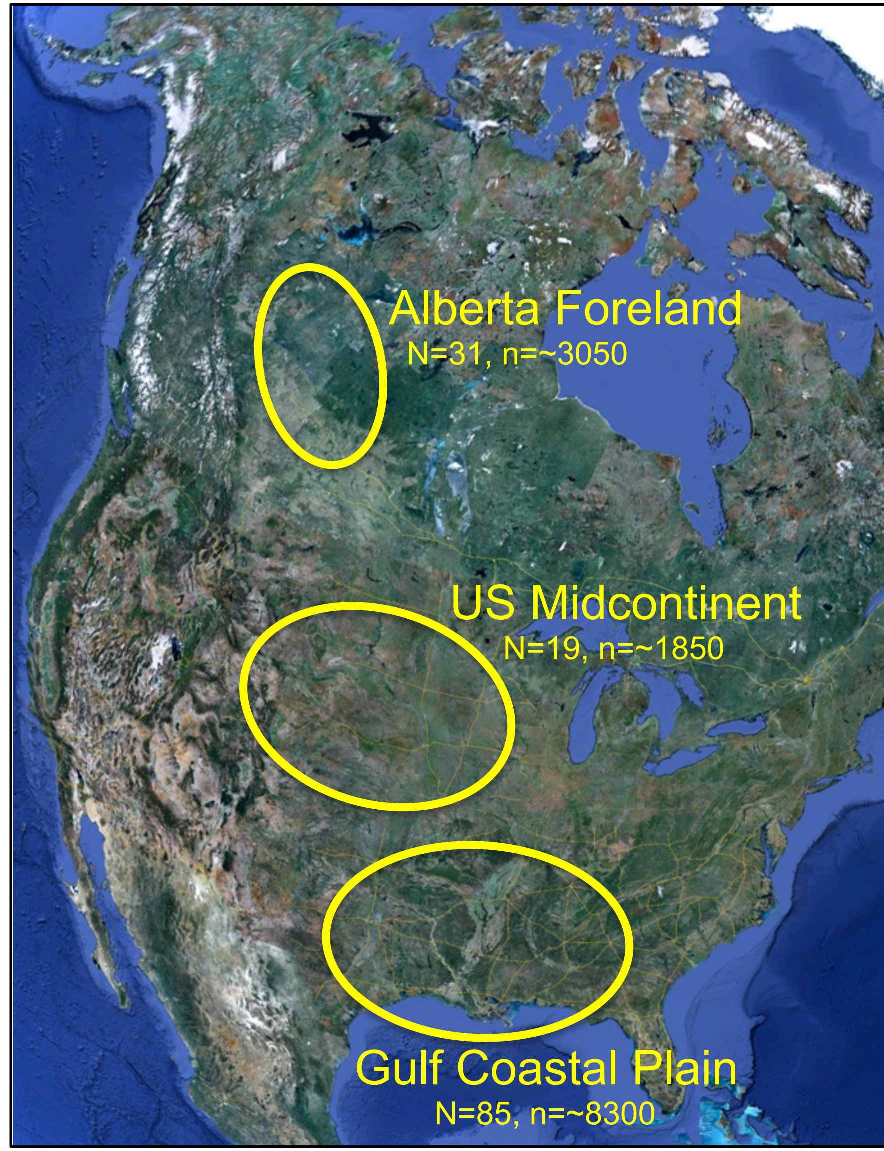
NORTH AMERICAN DRAINAGE EVOLUTION

Detrital Zircon Provenance and Geochronology Studies

North American Zircon Source Terrains



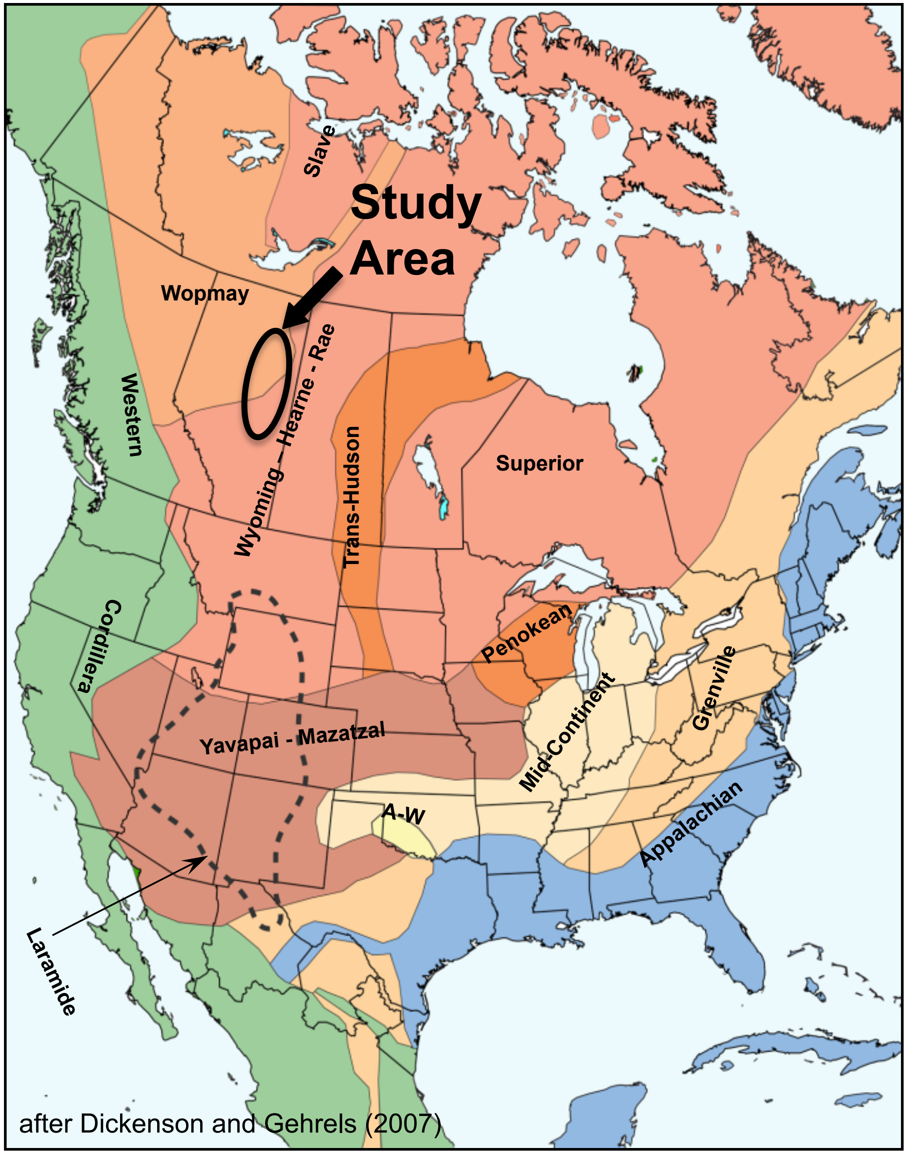
Study Areas

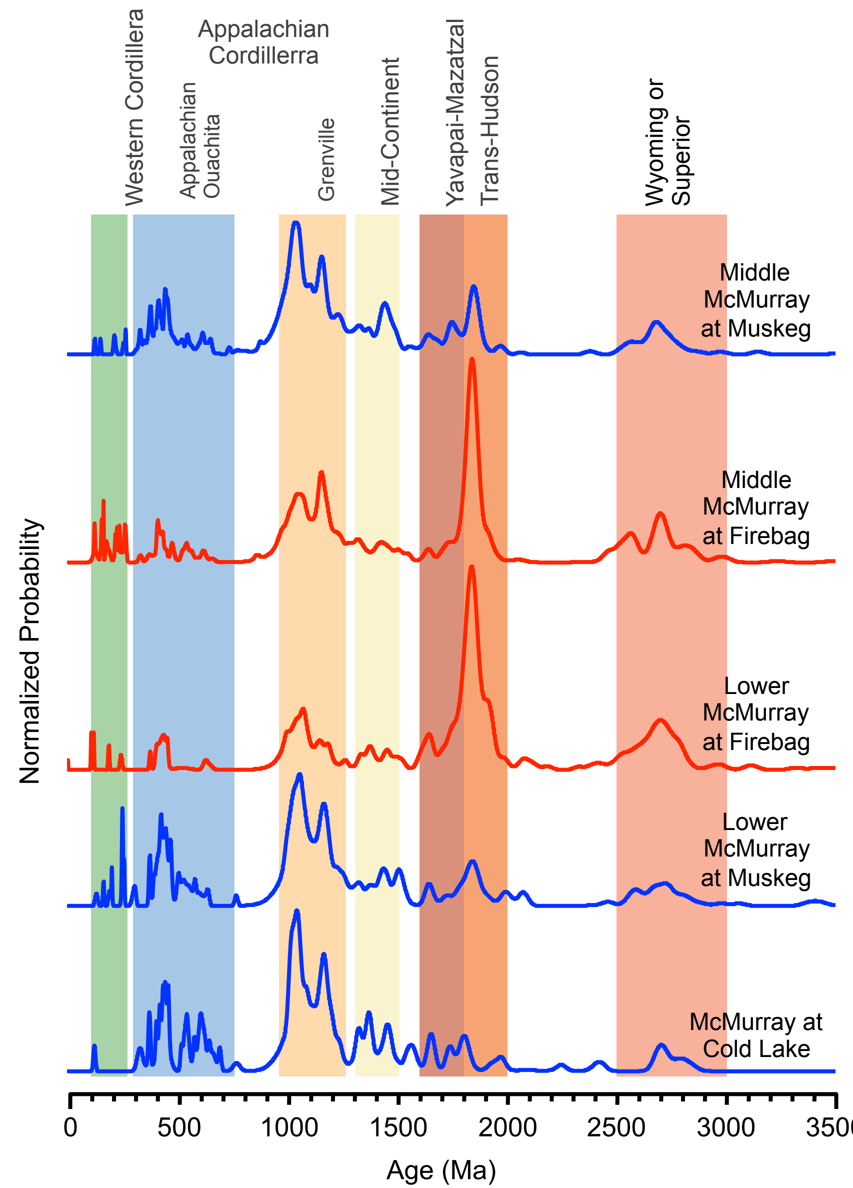


NORTH AMERICAN DRAINAGE EVOLUTION

Detrital Zircon Signature for the Cretaceous McMurray Formation

North American Zircon Source Terrains

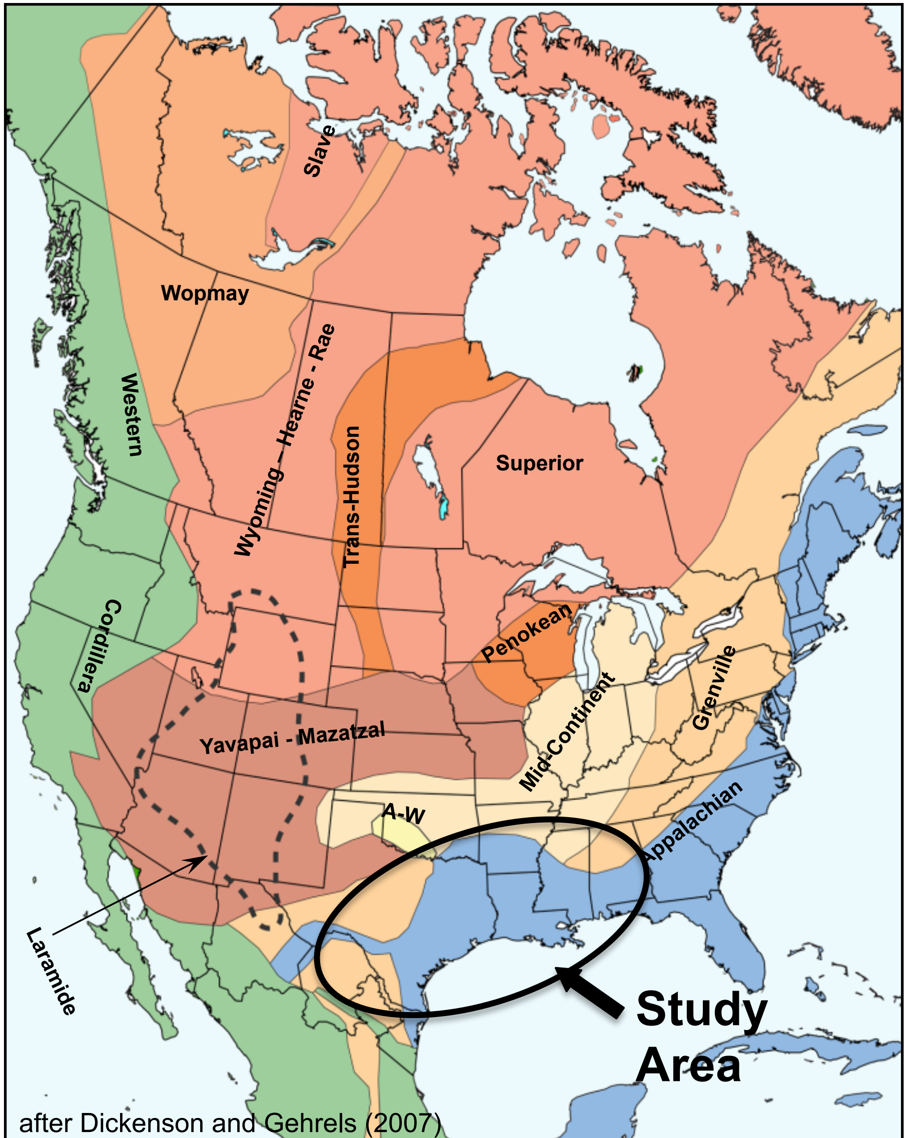


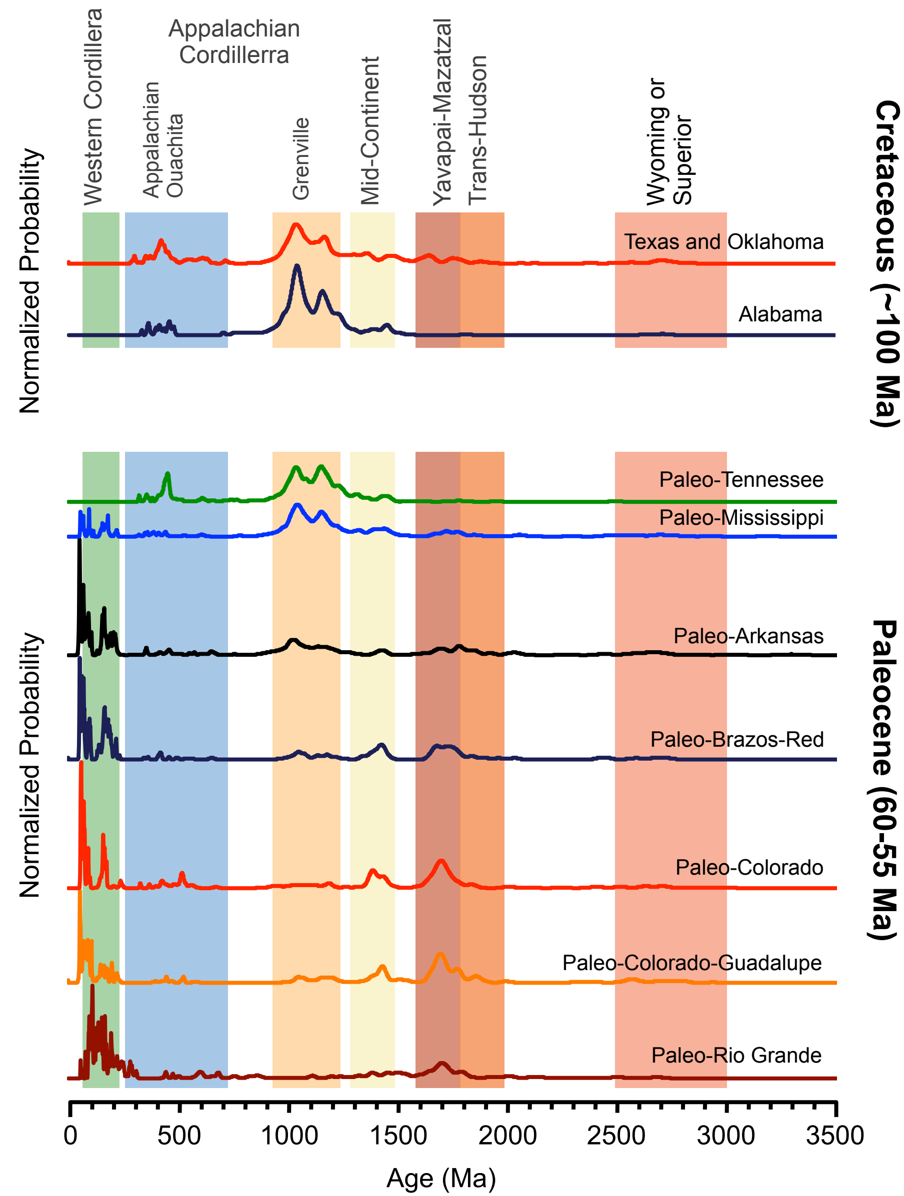


NORTH AMERICAN DRAINAGE EVOLUTION

Detrital Zircon Signature for the GoM Cretaceous and Paleocene

North American Zircon Source Terrains

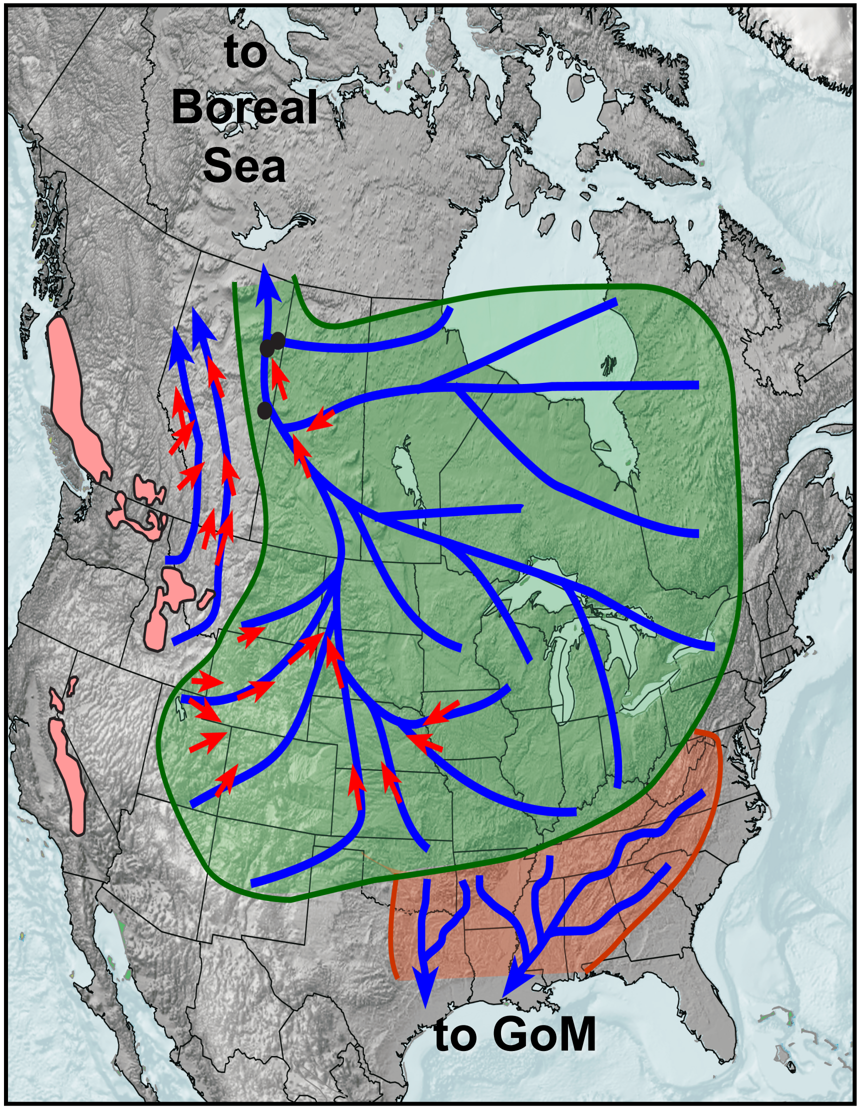




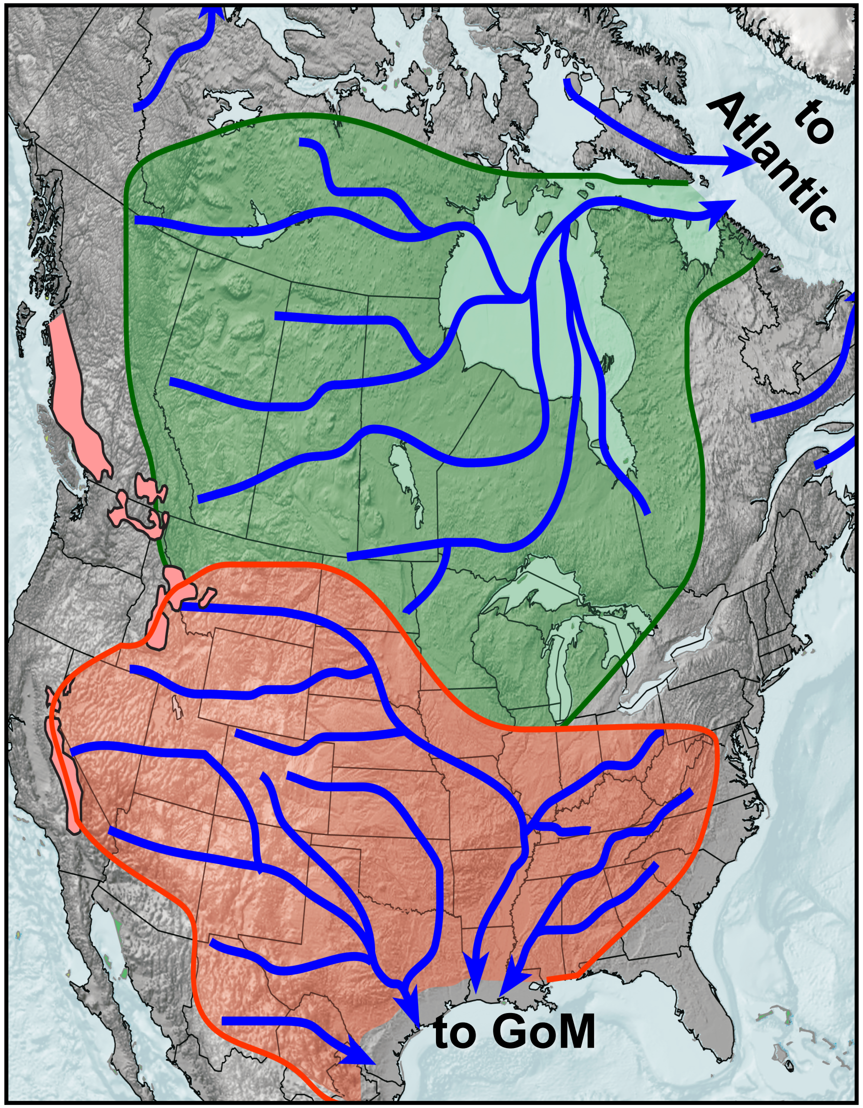
NORTH AMERICAN DRAINAGE EVOLUTION

Cretaceous to Paleocene Continental Drainage Reorganization

Mid-Cretaceous (ca. 125-100 Ma)



Paleocene (ca. 60-50 Ma)

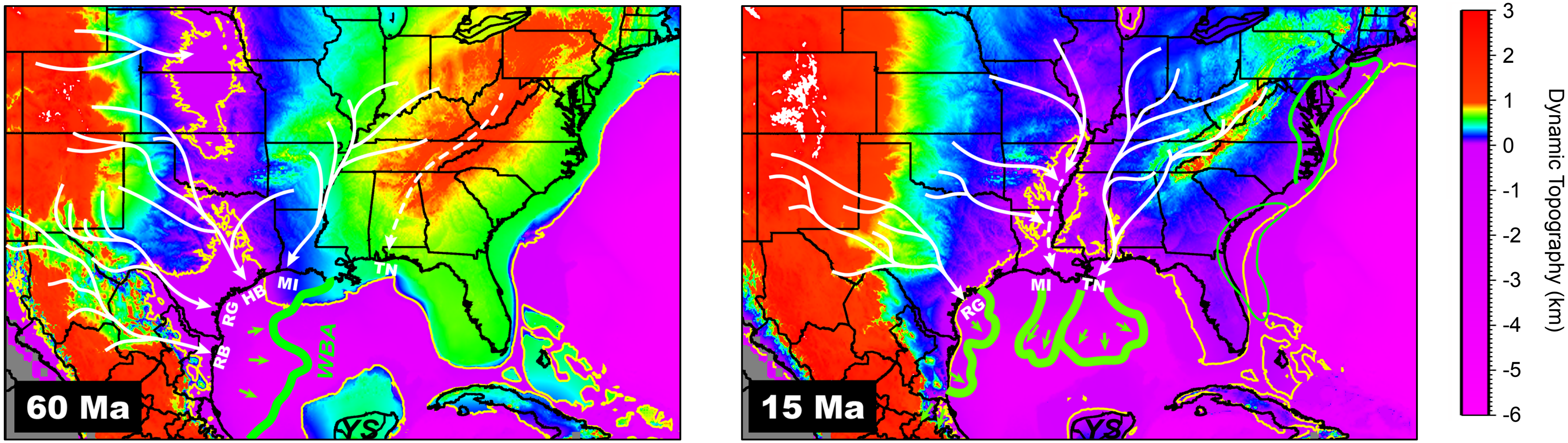


after Blum and Pecha (2014)

NORTH AMERICAN DRAINAGE EVOLUTION

Drainage Reorganization and Gulf of Mexico Depocenter Migration

Tectonic and Dynamic Topography as the Large-Scale Driver



geodynamic models after Liu (2014)

Deep Gulf of Mexico Hydrocarbon Systems as the Accumulated Wealth

Sorry, image not available

CRETACEOUS TO PALEOCENE NORTH AMERICAN DRAINAGE REORGANIZATION

- Early to Mid Cretaceous North America drained north to the Boreal Sea, and the Gulf of Mexico was fed by small fluvial systems only. This continental-scale drainage, the Mississippi of its time, deposited the Mannville Group, which hosts the Alberta Oil Sands

- Western US tectonics and geodynamics, and flooding of the Western Interior Seaway, drove continental-scale drainage reorganization, such that by the Paleocene, the southern half of North America drained to the Gulf of Mexico

- This drainage reorganization resulted in the emergence of the Mississippi as a continental-scale system, and created the GoM as a major depocenter and world-class petroleum province.

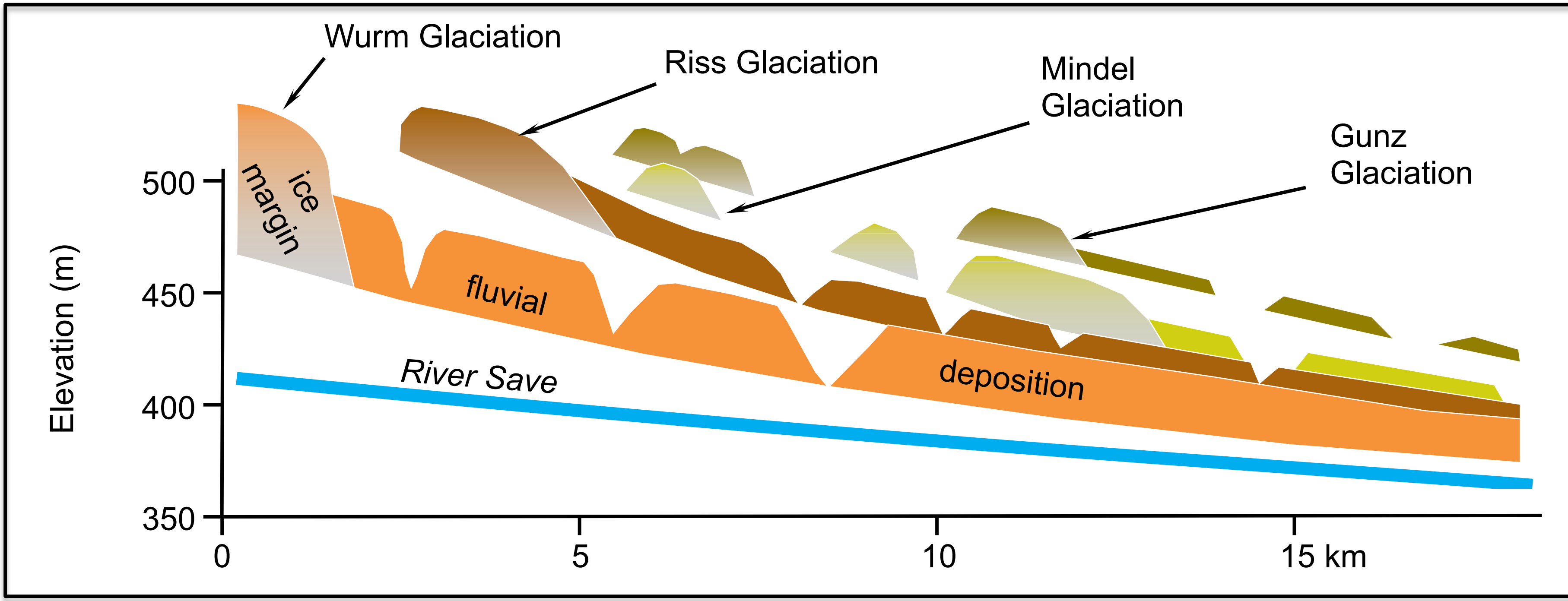
The Glacial-Interglacial Mississippi River, 125,000-500 yrs ago

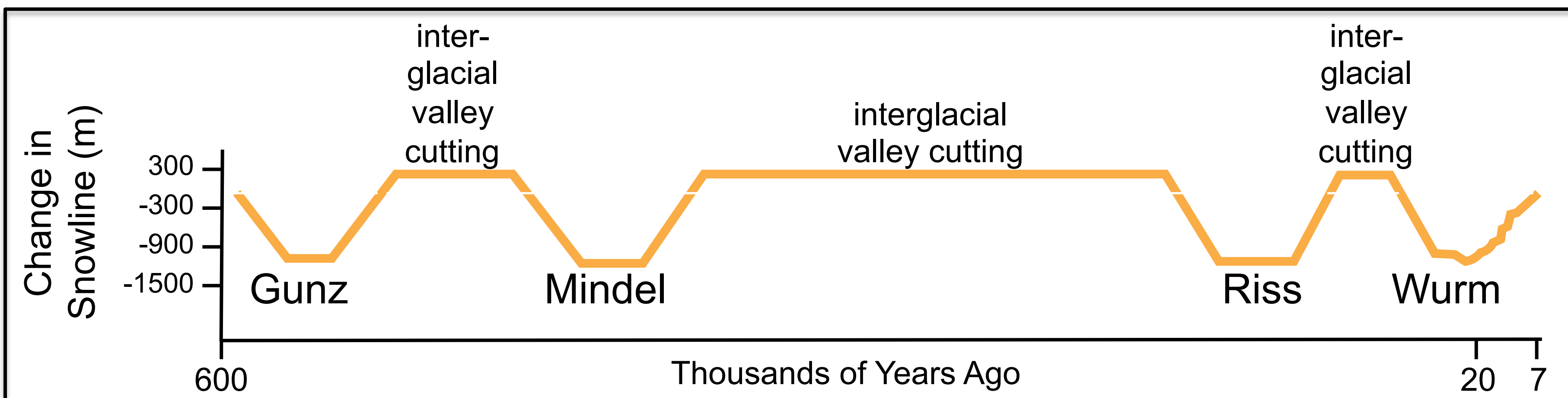
Shaping the Modern Landscape

special thanks to:
National Science Foundation and NASA, Tammy Rittenour (Utah State Geology), and many others……….

THE ICE AGE MISSISSIPPI RIVER SYSTEM

Early Penck-Bruckner (1909) Model for Glacial-Climatic Cycles

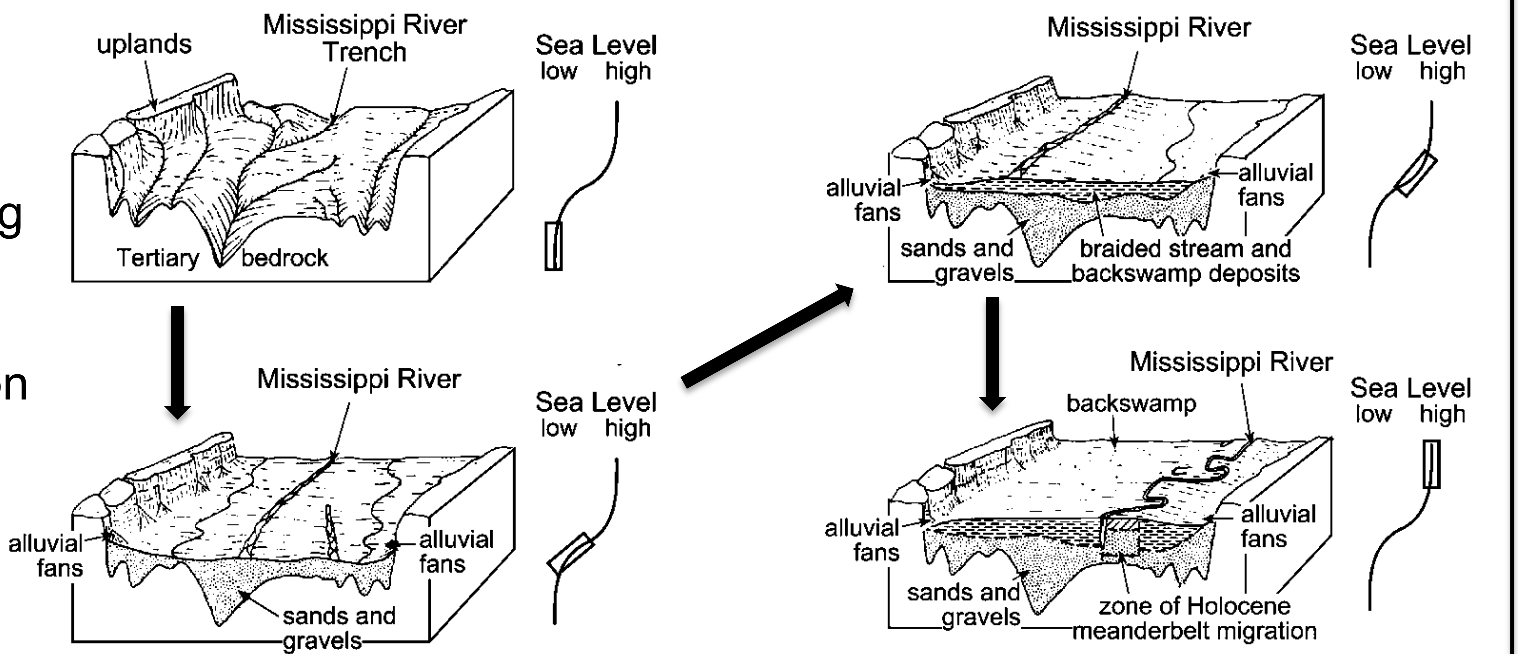


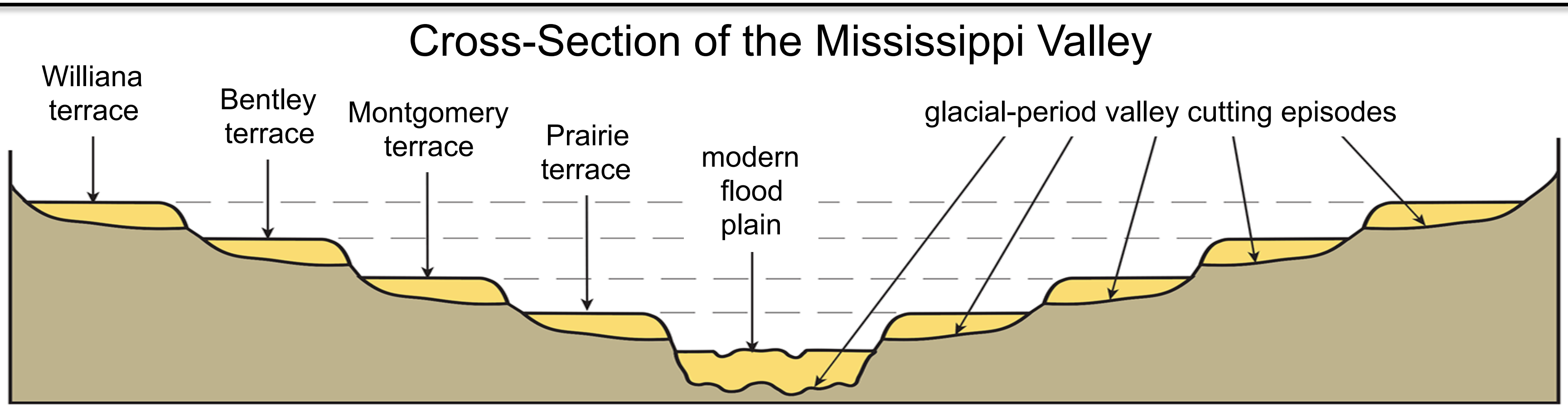


THE ICE AGE MISSISSIPPI RIVER SYSTEM

Early Fisk (1944) Model for Sea-Level Cycles

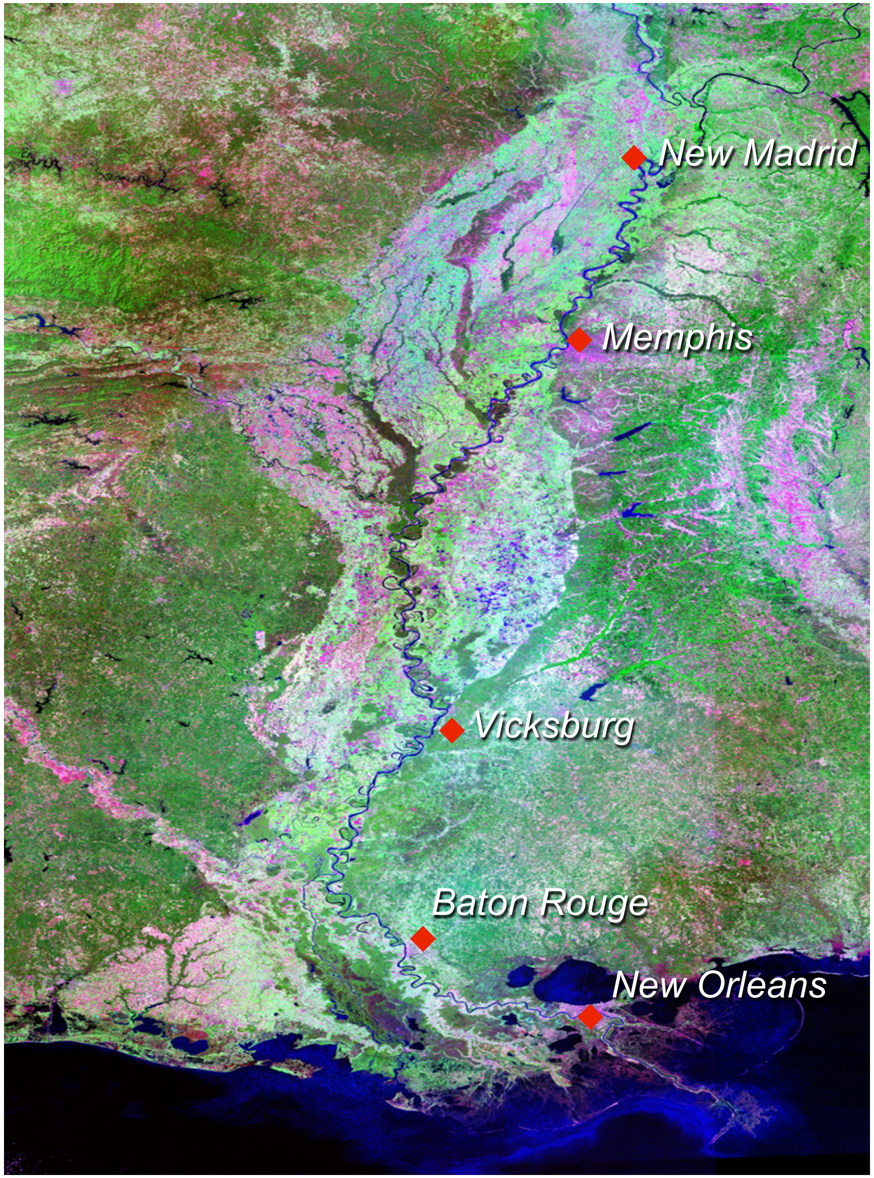
Model assumed incision during glacial period sea-level fall, and deposition during sea-level rise

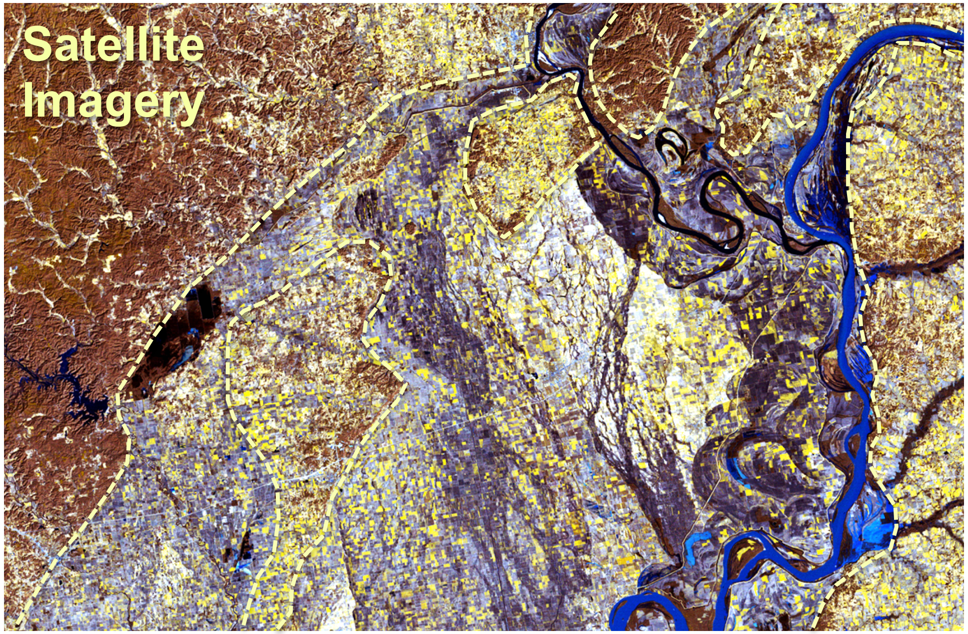




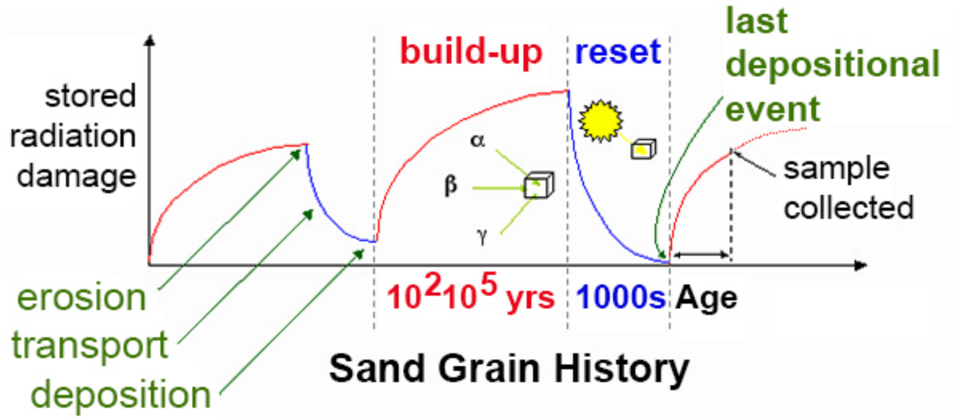
THE ICE AGE MISSISSIPPI RIVER SYSTEM

Rethinking Mississippi Valley Evolution with New Tools



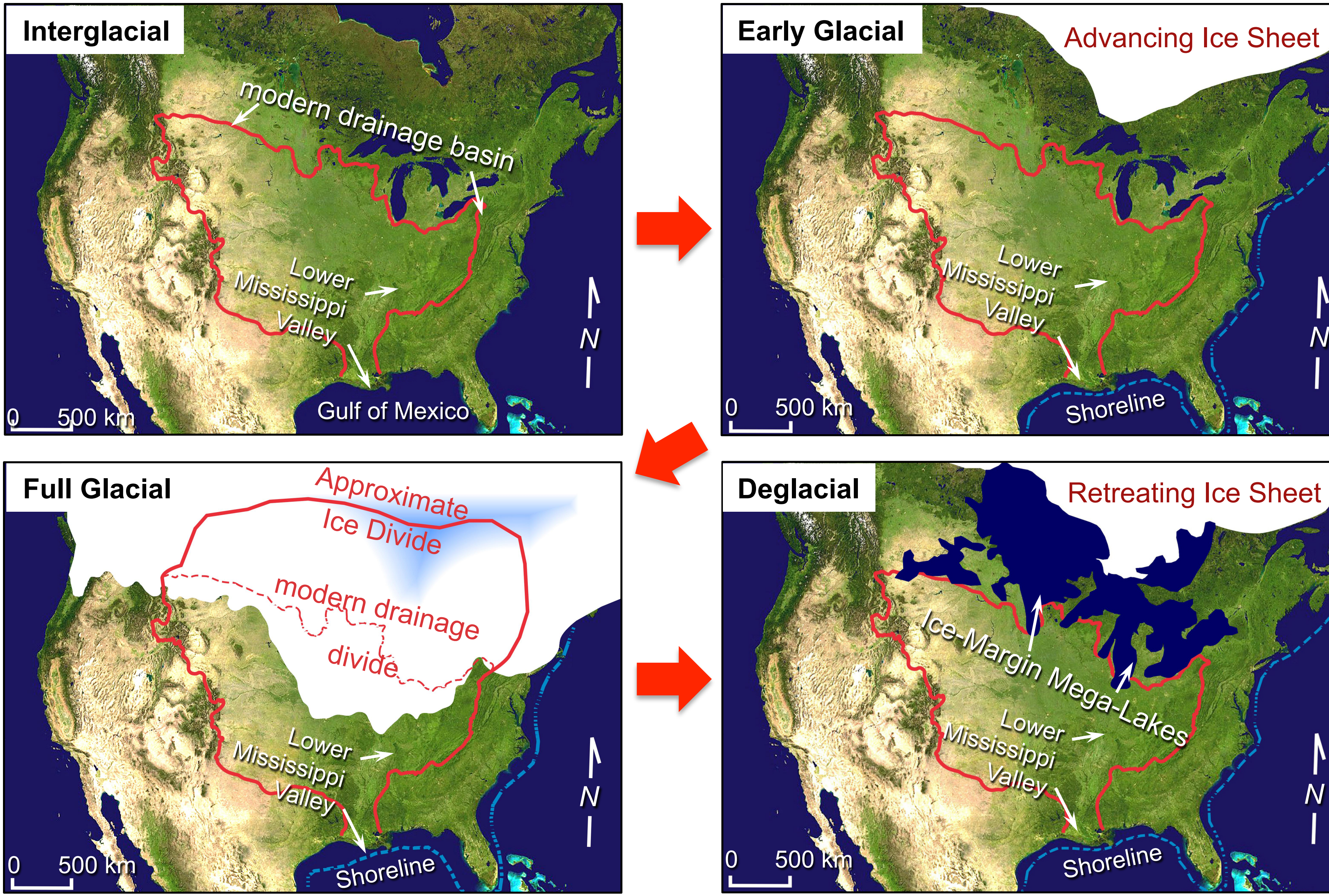


BASIC CONCEPTS OF LUMINESCENCE DATING



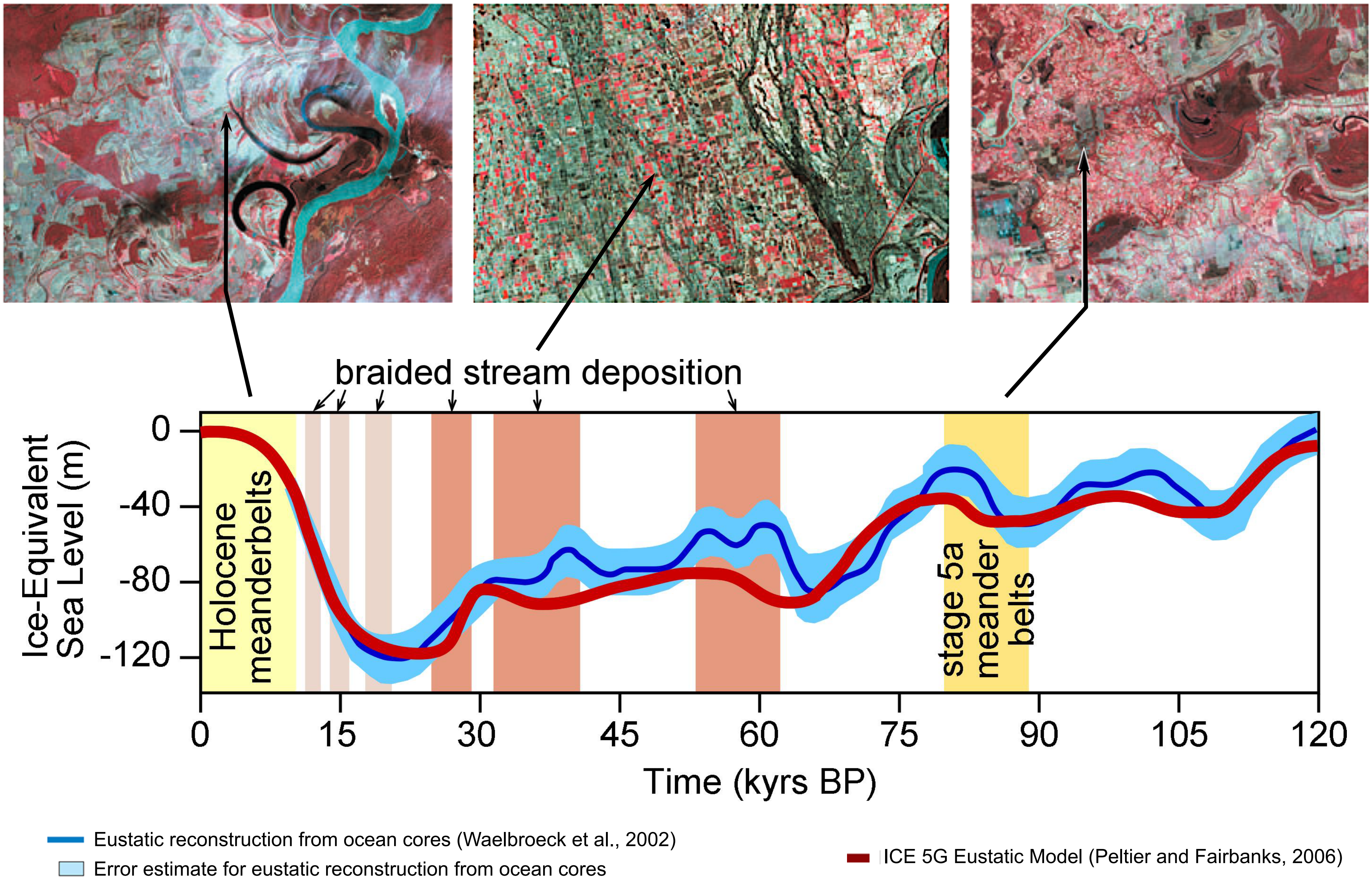
THE ICE AGE MISSISSIPPI RIVER SYSTEM

Glacial vs. Interglacial Modes of the Mississippi River System



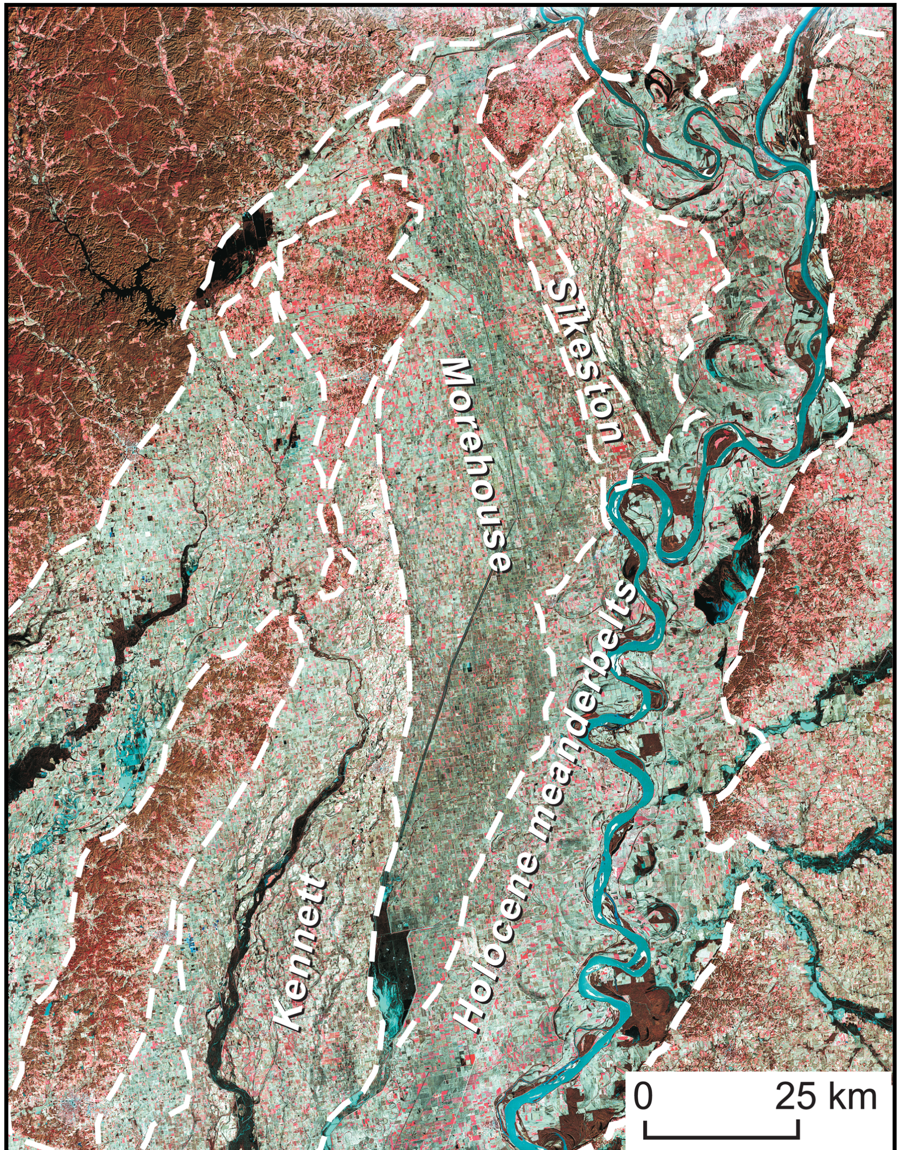
THE ICE AGE MISSISSIPPI RIVER SYSTEM

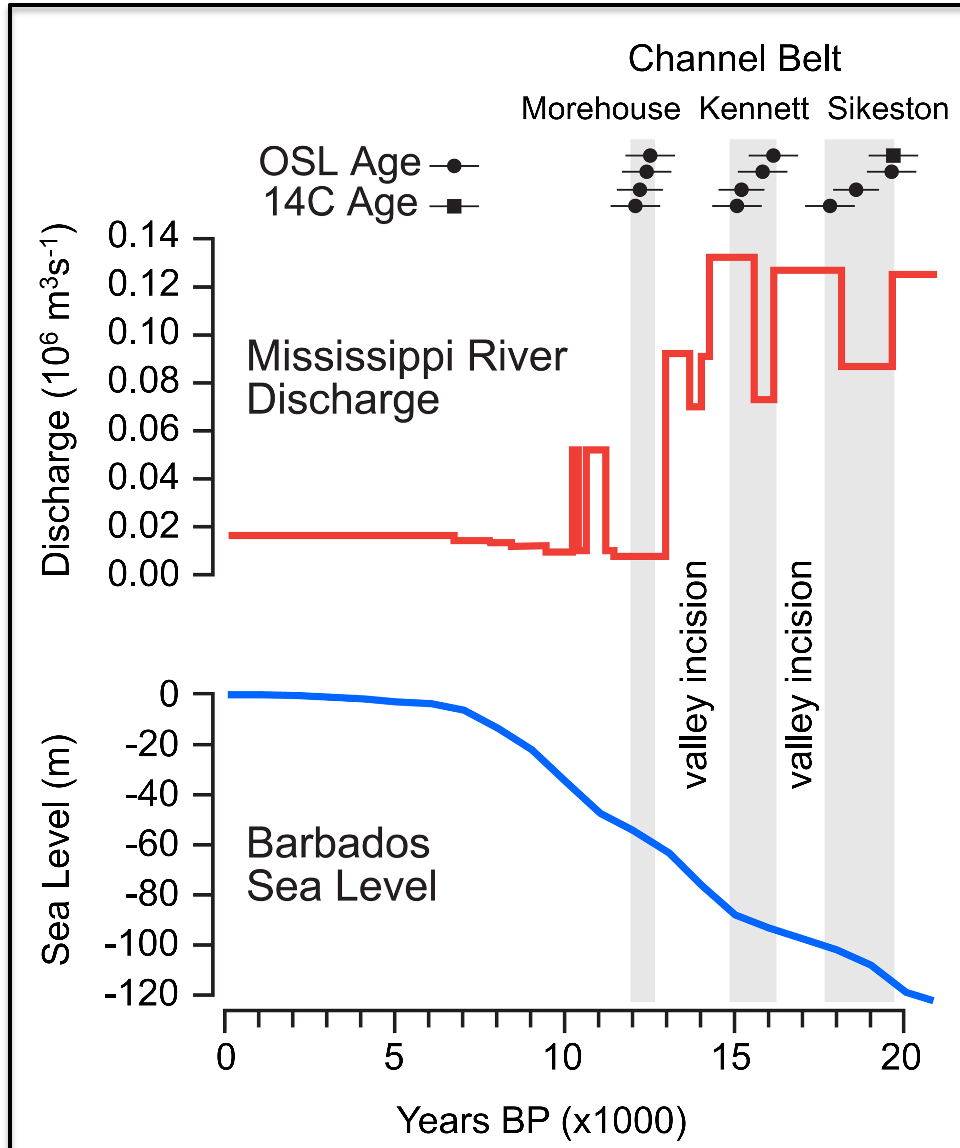
Revised Model for Mississippi River Response to Glaciation



THE ICE AGE MISSISSIPPI RIVER SYSTEM

Evolving from a Full Glacial to Deglacial to Non Glacial River

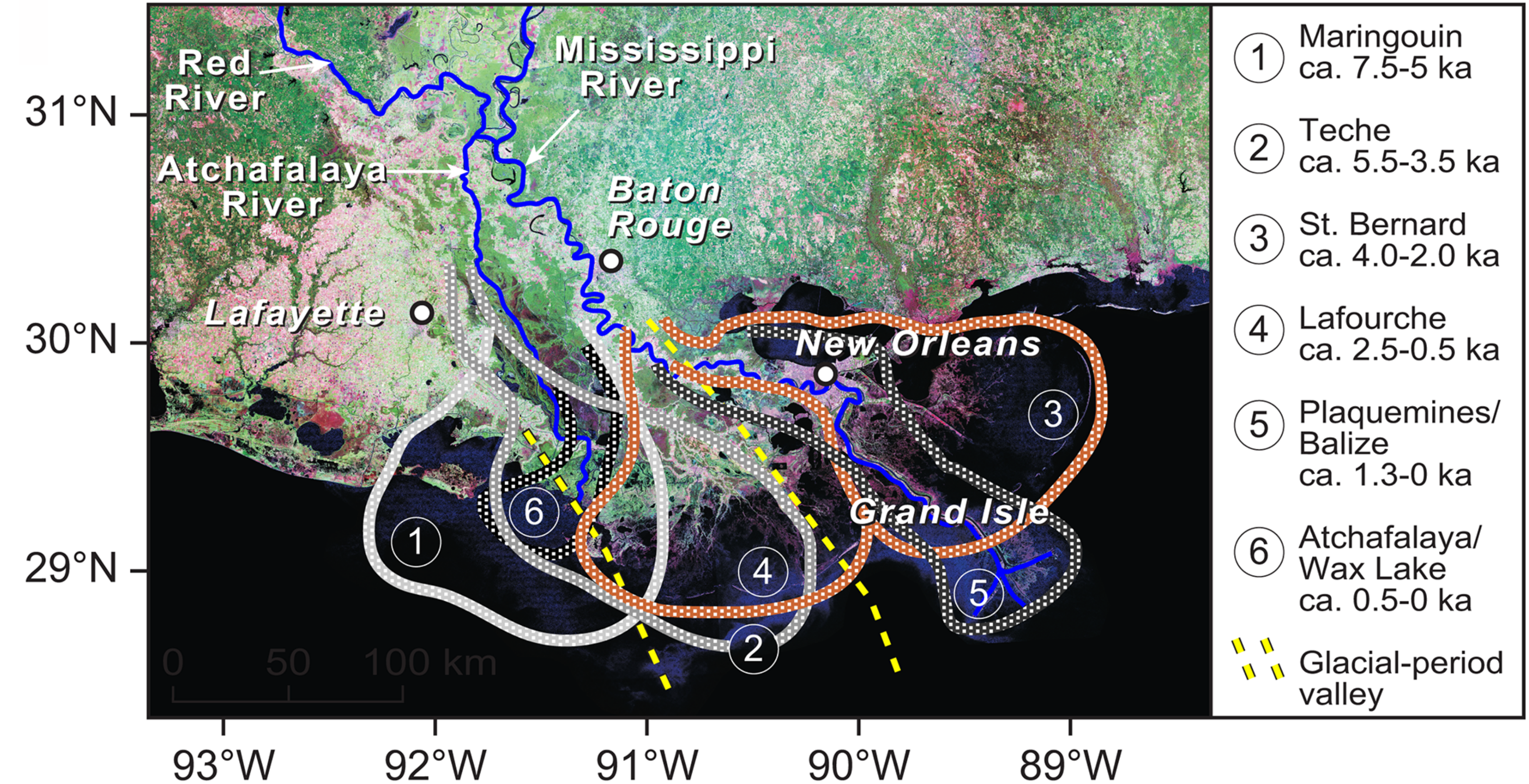




after Rittenour et al. (2007), Blum et al. (2013)

THE ONCE AND FUTURE MISSISSIPPI DELTA

History of Holocene Delta Plain Growth

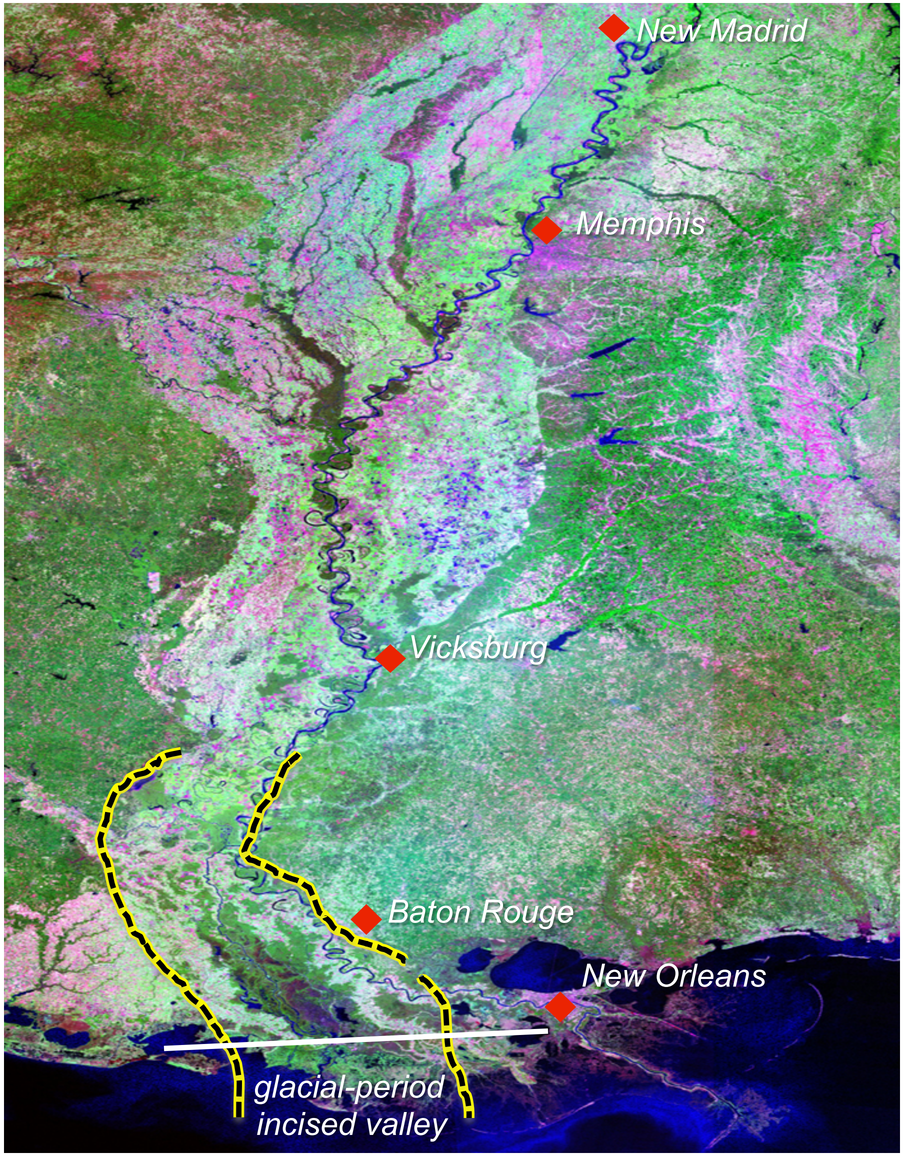


MISSISSIPPI DELTA PLAIN

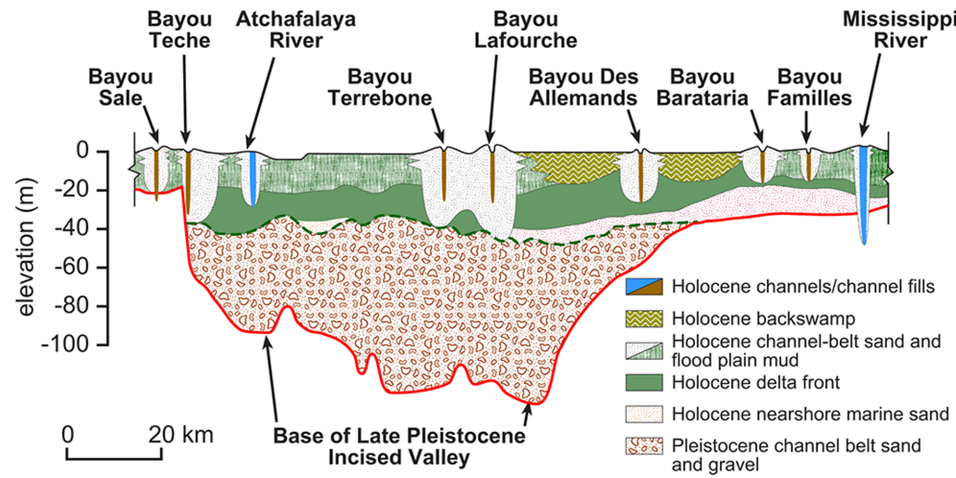
- 6 major coupled distributary channel belts and deltas
- like most major deltas, aggradation and progradation occurred after ca. 7000 yrs BP

THE ICE AGE MISSISSIPPI RIVER SYSTEM

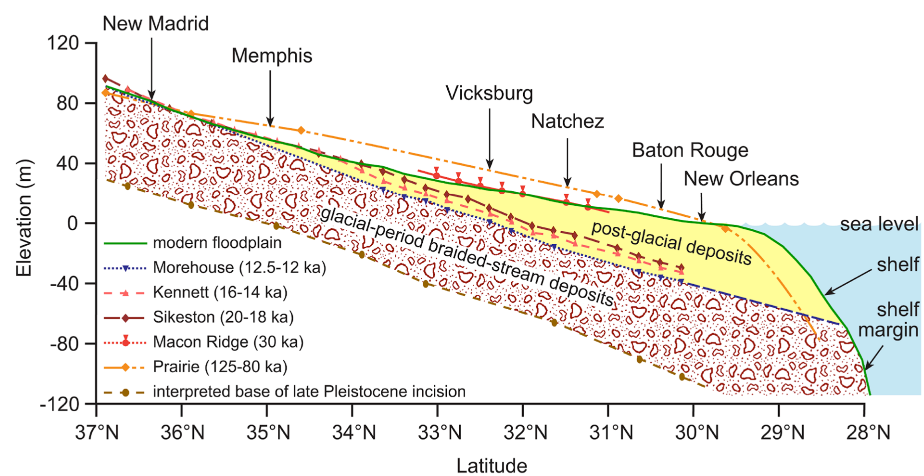
The Glacial vs. Interglacial Stratigraphic Record



Delta-Plain Stratigraphic Cross-Section



Valley-Scale Stratigraphic Dip-Section



based on Autin et al. (1991), Rittenour et al. (2007) and Blum et al. (2008).

THE GLACIAL VS. INTERGLACIAL MISSISSIPPI SYSTEM

- Milankovitch-scale climate and sea-level change profoundly affected routing and storage of sediment and water, and drove the evolution of the modern landscape
- Glacial climate and ice advance into the Mississippi drainage resulted in transformation of the Mississippi into a proglacial braided river system, which, in the lower valley, was incised and extended to the shelf margin lowstand shoreline
    - Extreme high-magnitude deglacial meltwater floods had the largest lasting impact on landscape change
- Transition to an interglacial climate resulted in transformation to the well-known meandering channel, whereas global sea-level rise and highstand resulted in construction of the alluvial-deltaic plain

The Once and Future Mississippi Delta, 1900-2100 AD

Engineering a Great River with some Unintended Consequences

special thanks to:
the Harrison Professorship (LSU Geology and Geophysics), Harry Roberts (LSU Coastal Studies Institute)
and many others………..

THE ONCE AND FUTURE MISSISSIPPI DELTA

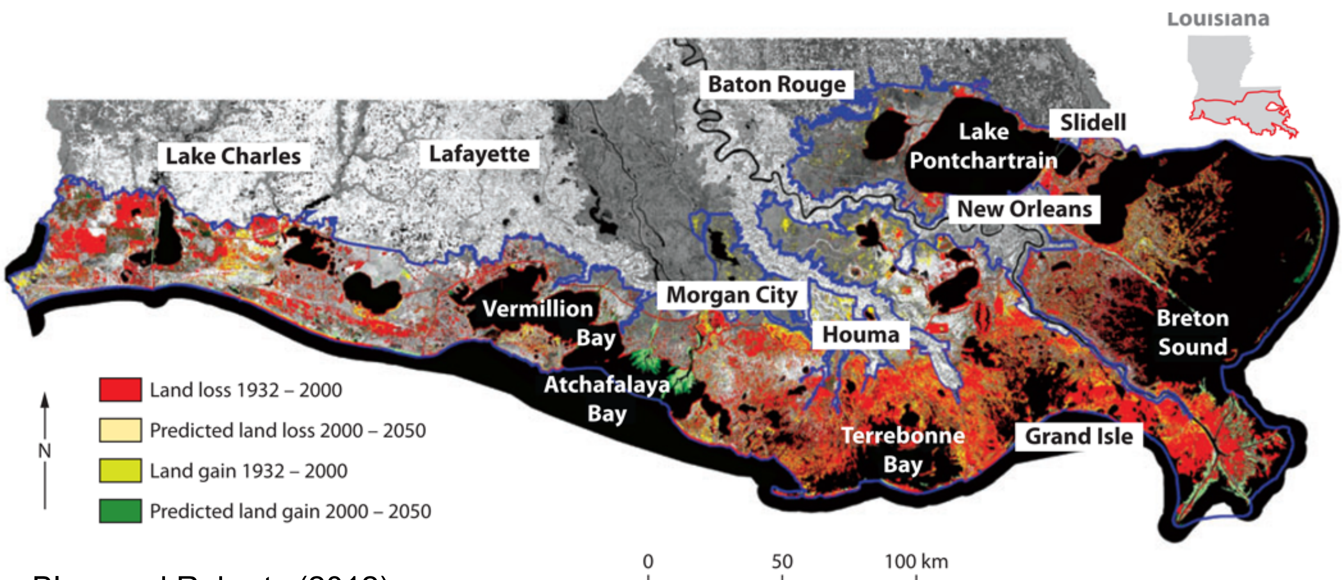
The Louisiana Coast in Year 2000

THE ONCE AND FUTURE MISSISSIPPI DELTA

Historical Trends in Delta Land-Surface Change

EARLY 1800's

- Submergence of San Bernard delta already well underway
- LaFourche delta largely intact
- Plaquemine-Balize delta emergent and growing



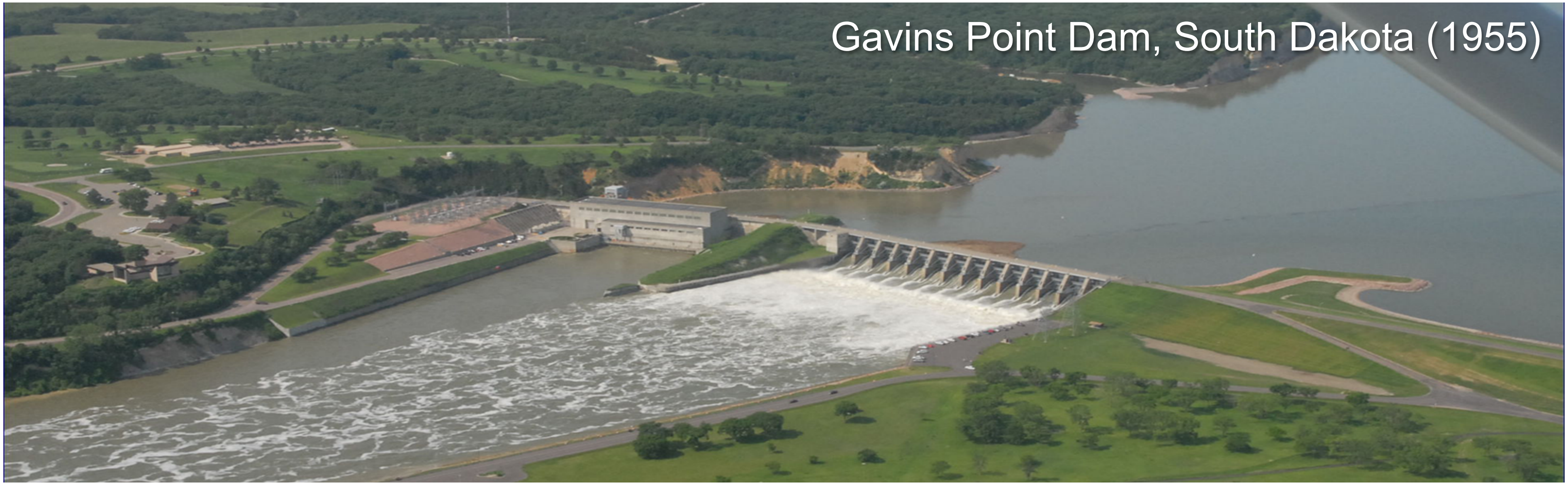
from Blum and Roberts (2012)

20th CENTURY

- Submergence of San Bernard delta continues
- LaFourche delta rapidly submerging
- Plaquemine-Balize delta mostly submerging
- Atchafalaya-Wax Lake delta becomes emergent

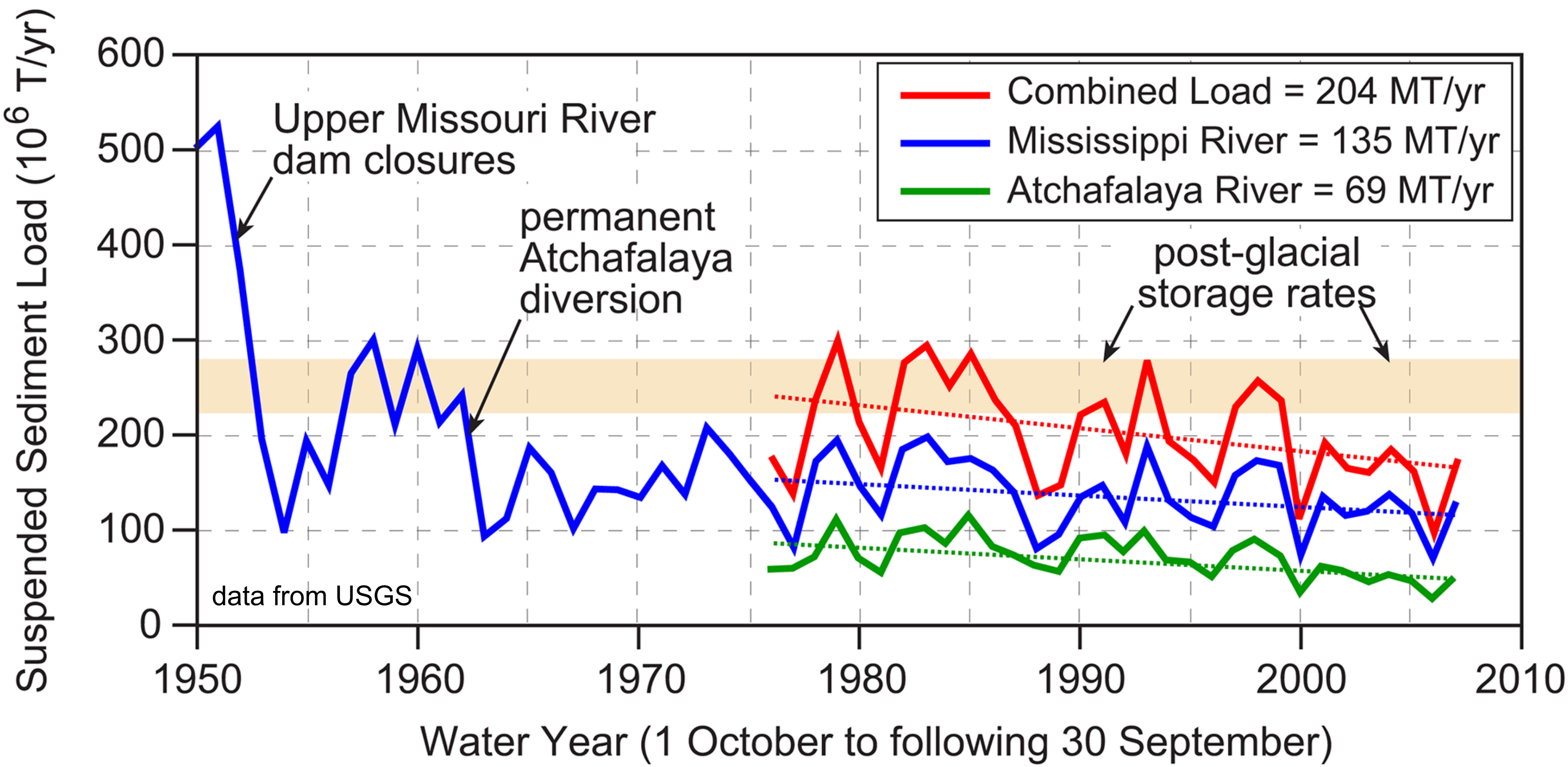
THE ONCE AND FUTURE MISSISSIPPI DELTA

Anthropogenic Drivers – A Completely Leveed and Dammed River



THE ONCE AND FUTURE MISSISSIPPI DELTA

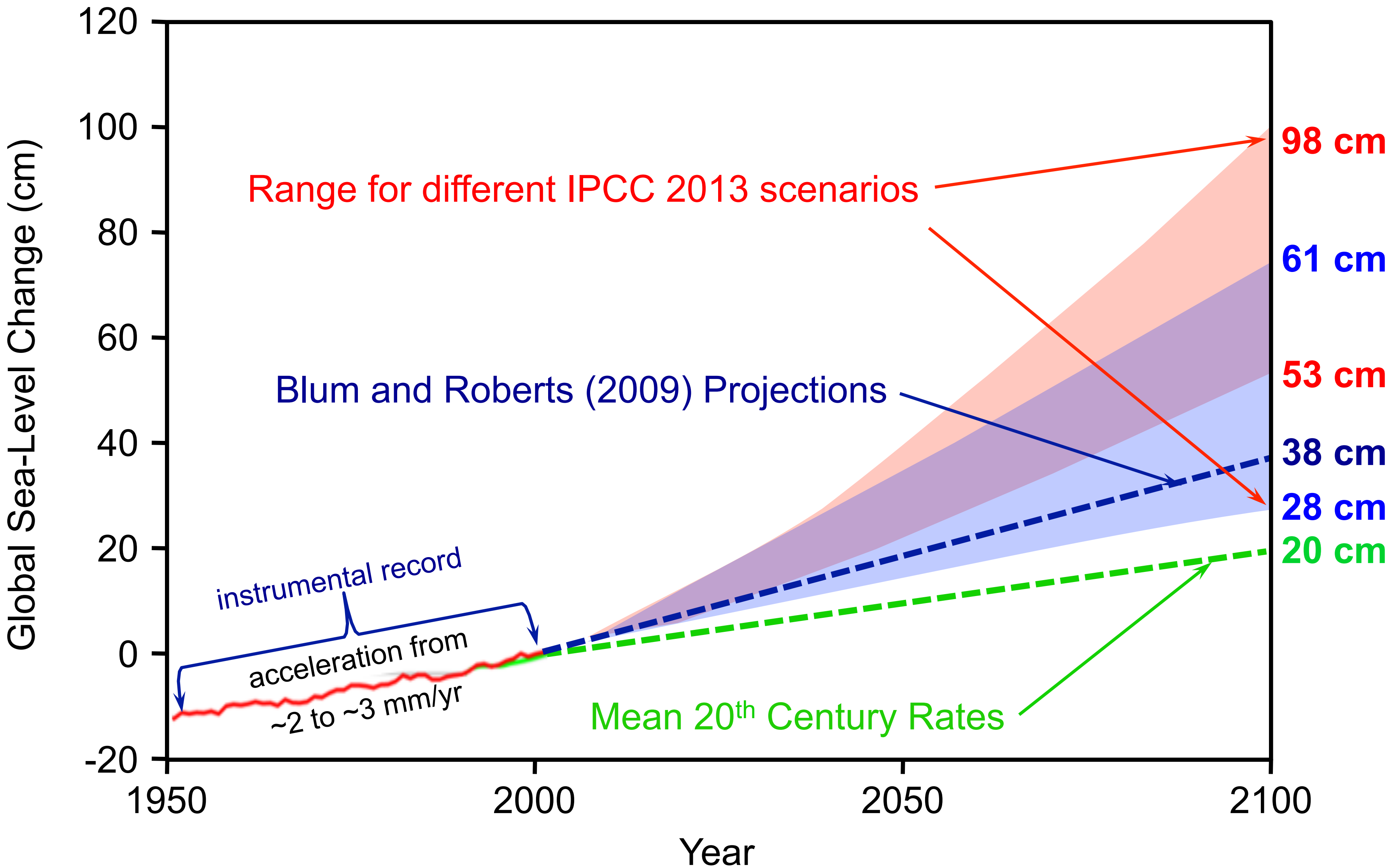
Pre- and Post-Dam Sediment Supply (more than 40,000 dams!!)



Modern post-dam sediment loads are reduced by ≥ 50% from upstream dams, and are now ≤ the long-term mean storage rate!!

THE ONCE AND FUTURE MISSISSIPPI DELTA

Anthropogenic Drivers - Global Sea-Level Rise Projections

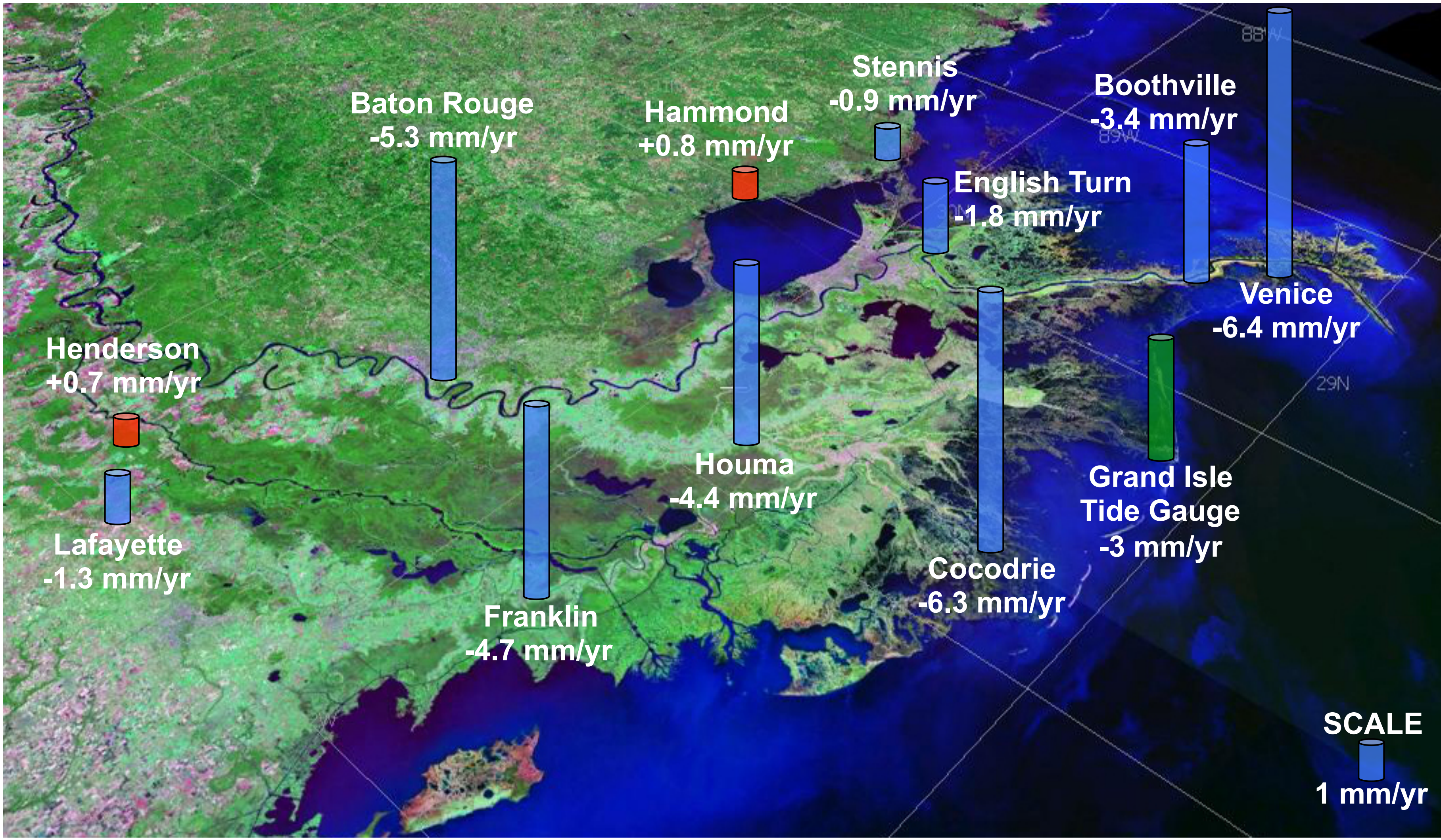


IPCC estimates from Church et al. (2013)

THE ONCE AND FUTURE MISSISSIPPI DELTA

Boundary Conditions – High Rates of Land-Surface Subsidence

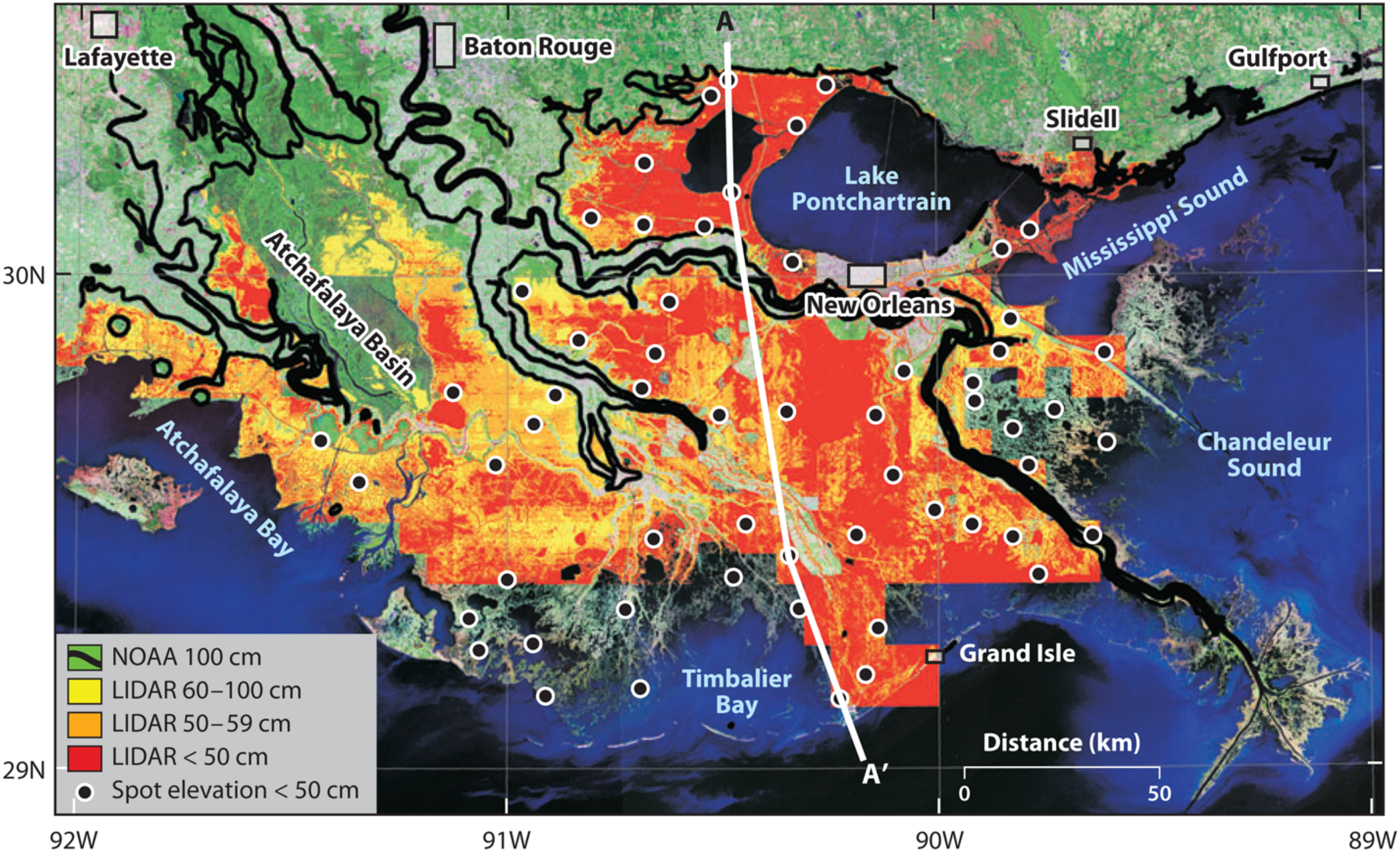
GPS Vertical Velocities



GPS data from Dokka (2006); Grand Isle tide-gauge data from NOAA online data

THE ONCE AND FUTURE MISSISSIPPI DELTA

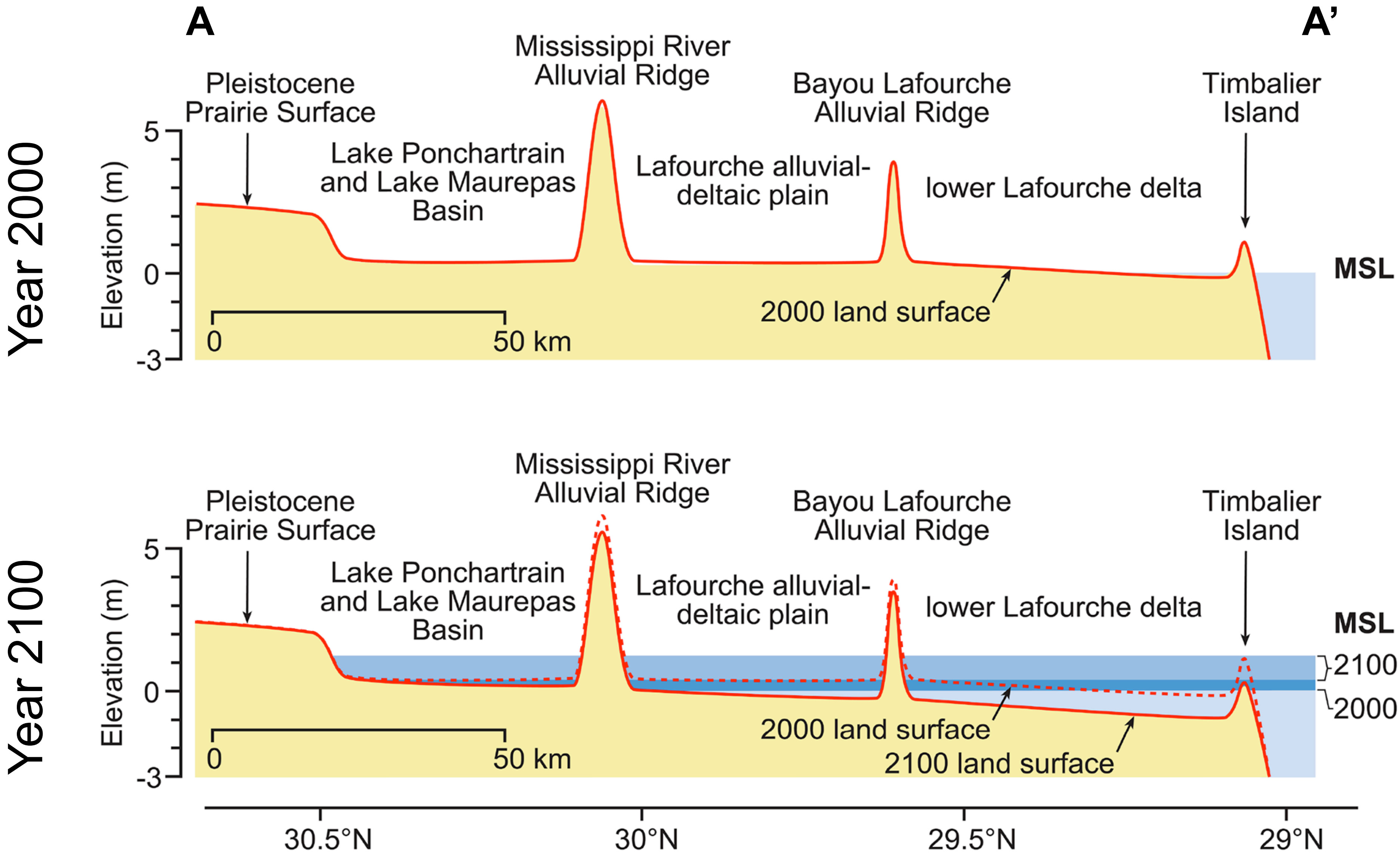
Boundary Conditions – The Delta is Really Flat and Very Low!!



- From LiDAR, >14,000 km^2 less than 1 m, and >11,000 km^2 is less than 60 cm
- Mean elevation for all 62 spot elevations ~ 40 cm!!

STATIC SUBMERGENCE MODEL: 2000 vs. 2100

Relative Sea-Level Rise with Sediment Input = 0



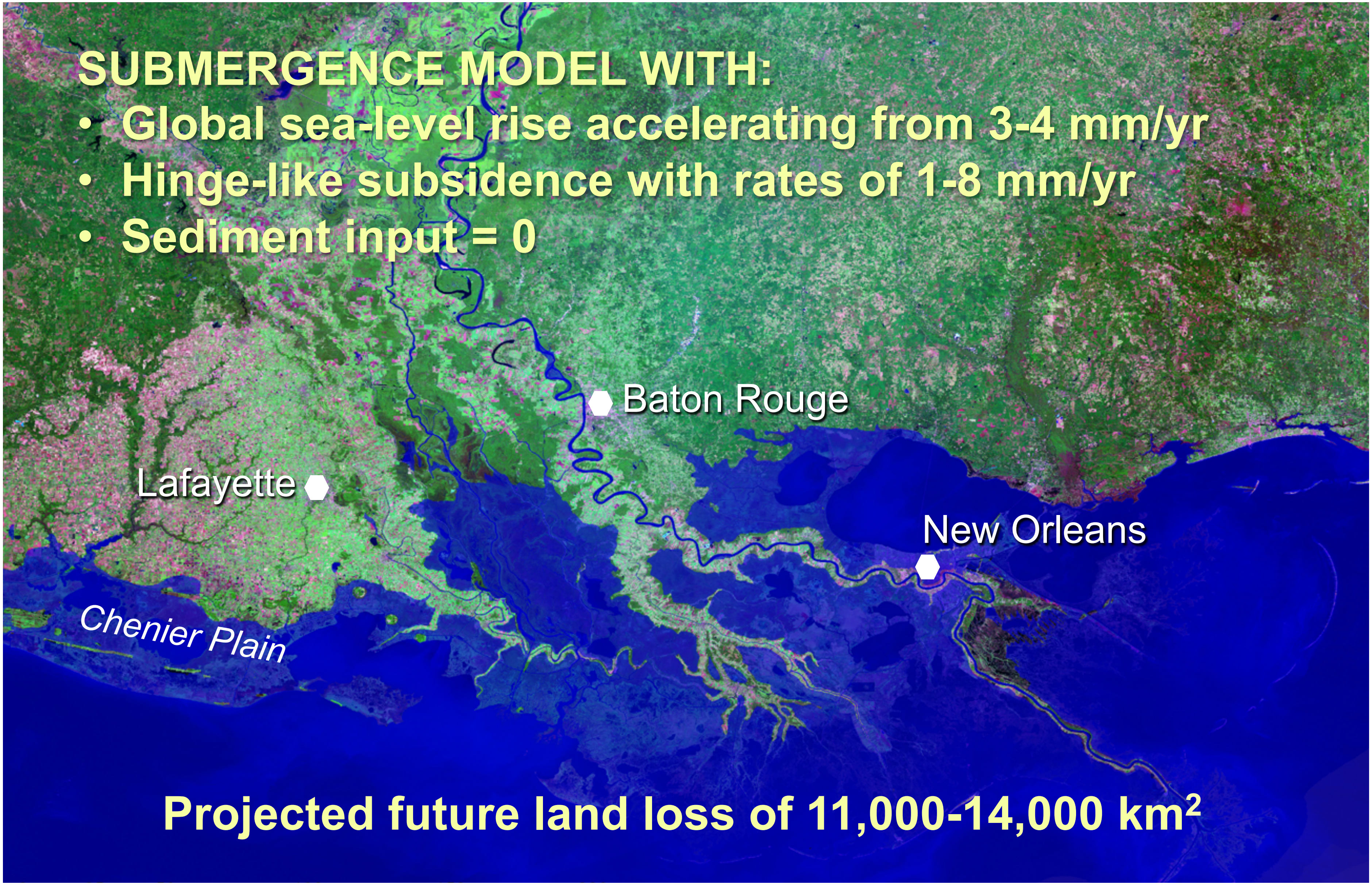
after Blum and Roberts (2012)

THE ONCE AND FUTURE MISSISSIPPI DELTA

The Louisiana Coast in the Year 2000

THE ONCE AND FUTURE MISSISSIPPI DELTA

The Louisiana Coast in the Year 2100?



THE ONCE AND FUTURE MISSISSIPPI DELTA

The Louisiana Coast in the Year 2100?

THE ONCE AND FUTURE DELTA

- The Holocene to modern Mississippi delta was constructed by aggradation and progradation over a period of 7000 yrs, as global sea-level rise decelerated and reached present highstand positions

- Land gain and land loss is natural in deltaic systems, but loss rates accelerated in the last century due to (a) acceleration of global sea-level rise, (b) dam construction that reduced sediment load (supply limited), and (c) a continuous levee system that limits dispersal to the delta plain (transport-limited)

- More than 11,000 km^2 of the Mississippi delta region is less than 0.5 m elevation, and will drown by 2100 - there is only enough sediment to sustain <25% of delta surface area