Balancing sediment budgets in deep time and the nature of the stratigraphic record

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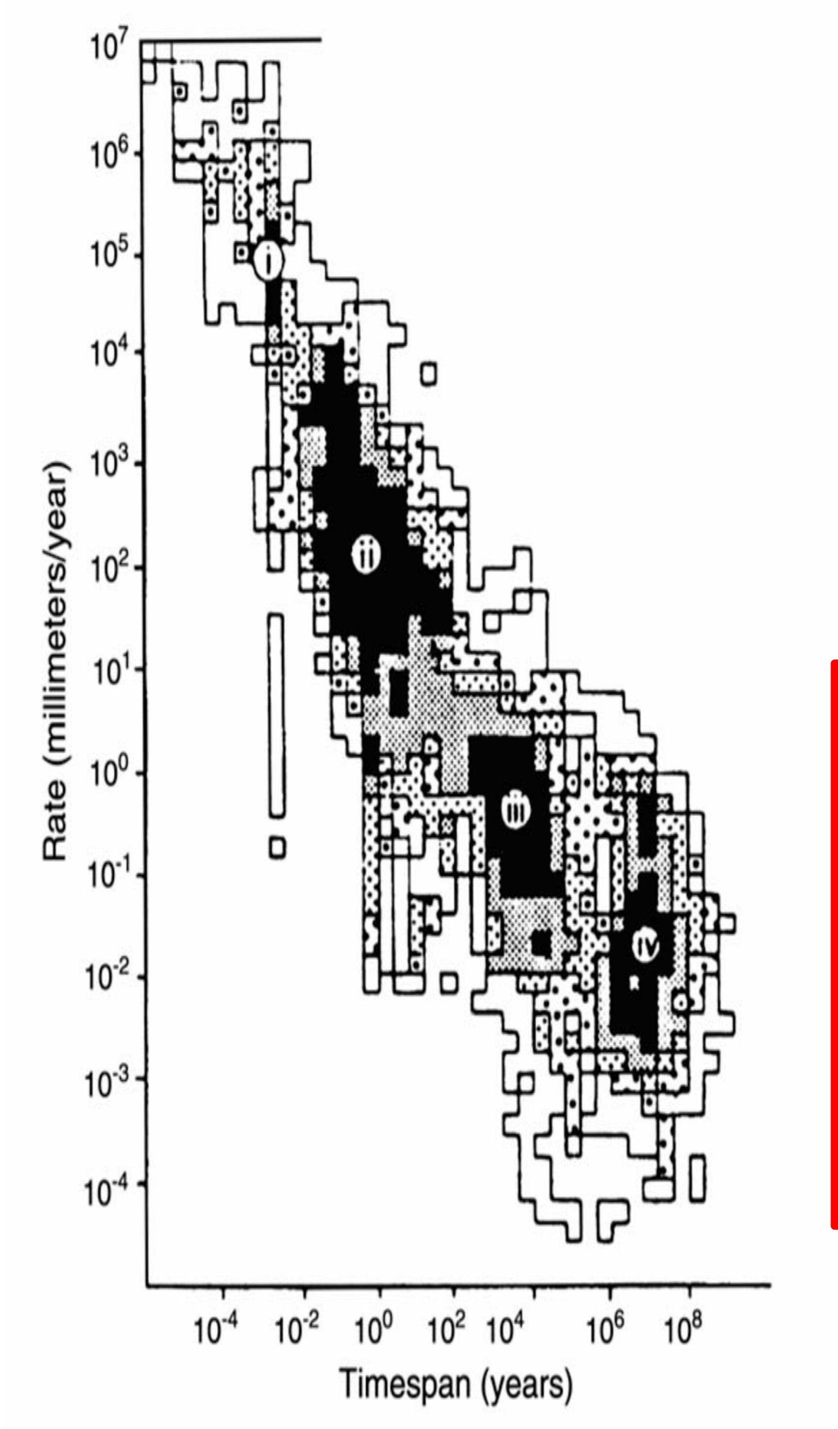
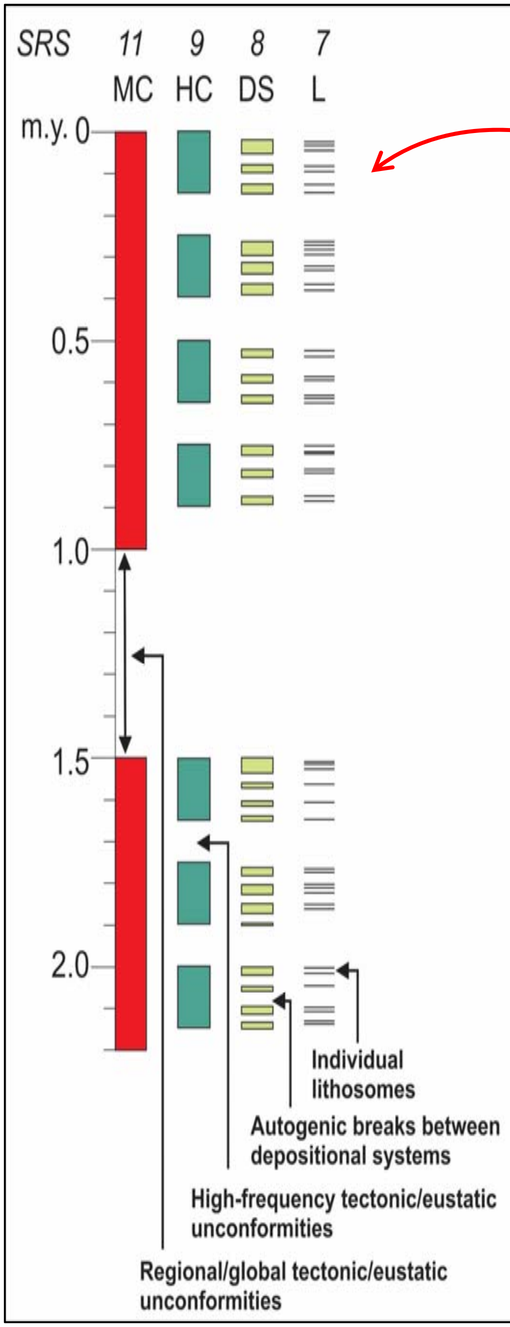
Outline

- Introduction
- GOM 3D Wheeler Analysis
- Quaternary S2S Example
- Deep Time S2S Example
- Conclusions



A plot of sedimentary accumulation rates against timespan (Sadler, 1981).

1D Sedimentation rate is inversely proportional to the time span over which it is measured: The so-called "Sadler effect"



Note: This is a 1D analysis

"more gap than record"

Derek Ager, 1973

A demonstration of the predominance of missing time in the sedimentary record.

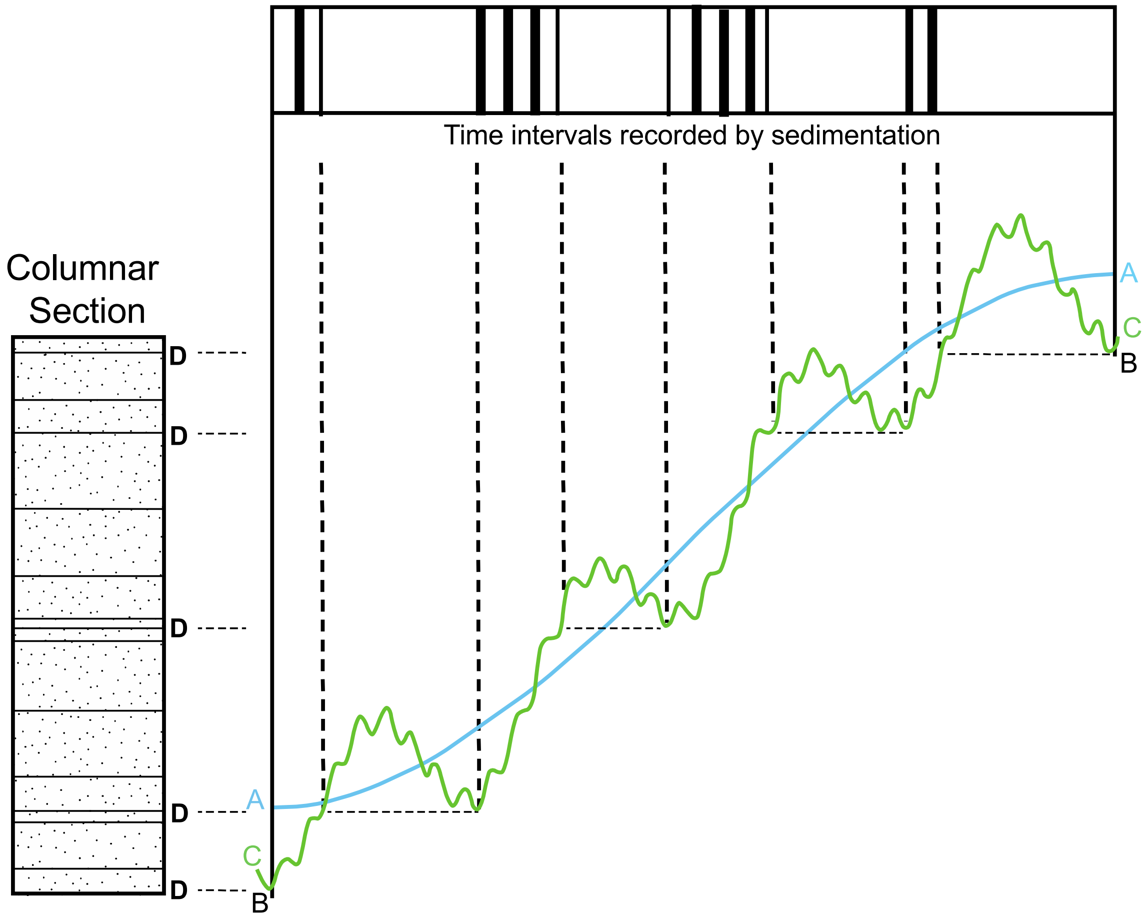
MC=million-year cycle
HC=hundred-thousand-yr cycle
DS=Depositional System
L=Lithosome

(from Miall, 1997)

Time Stratigraphy

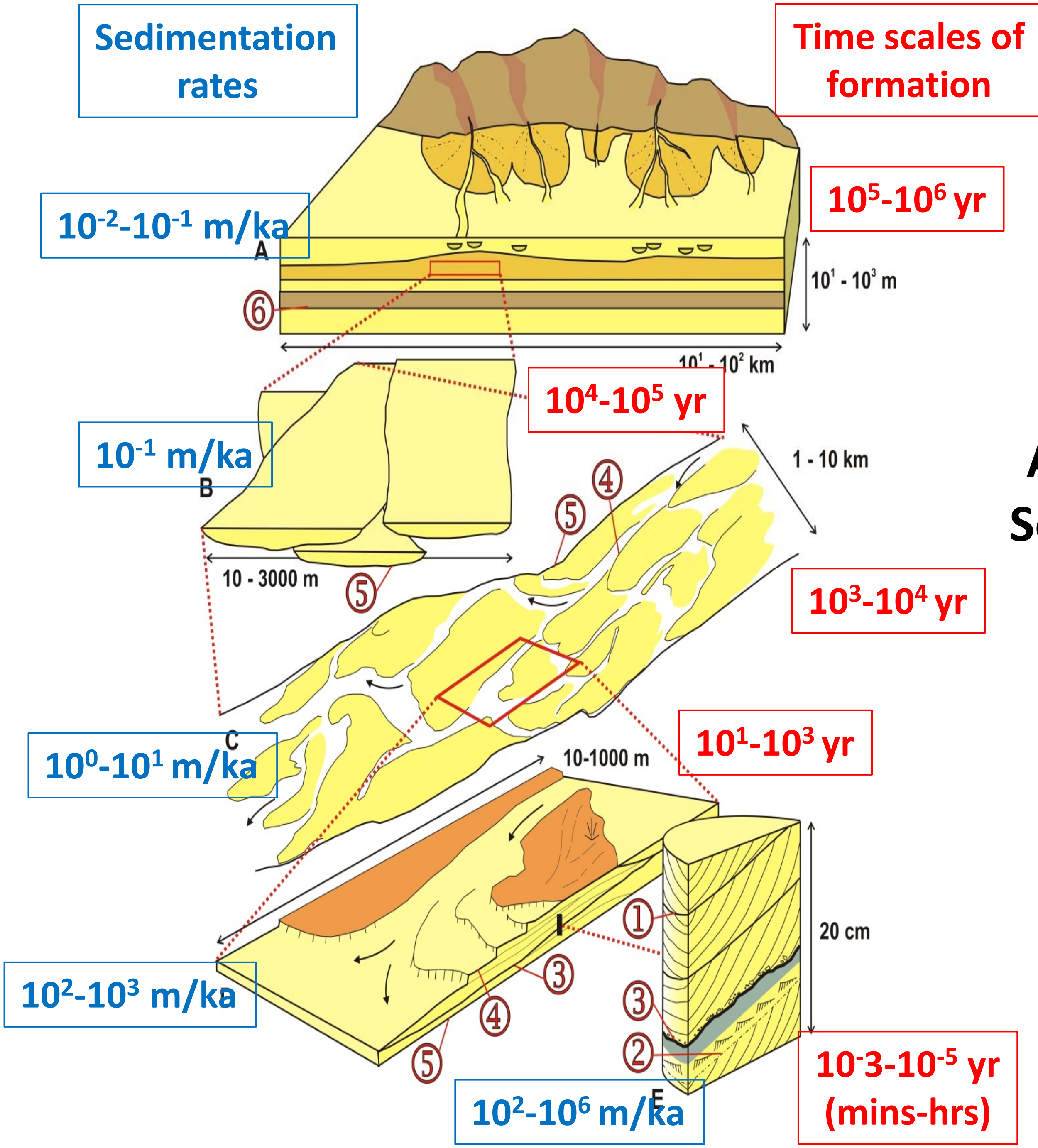
"more gap than record"

Barrell, 1917



A-A. Primary curve of rising base-level
B-B. Diastrophic oscillations giving disconformities D-D.
C-C. Minor oscillations exaggerated and simplified due largely to climatic rhythms
Equation of curve C-C: y= Sin x - 0.25 cos 8 x -0.5 cos 64 x.

Time vs. Architectural Elements

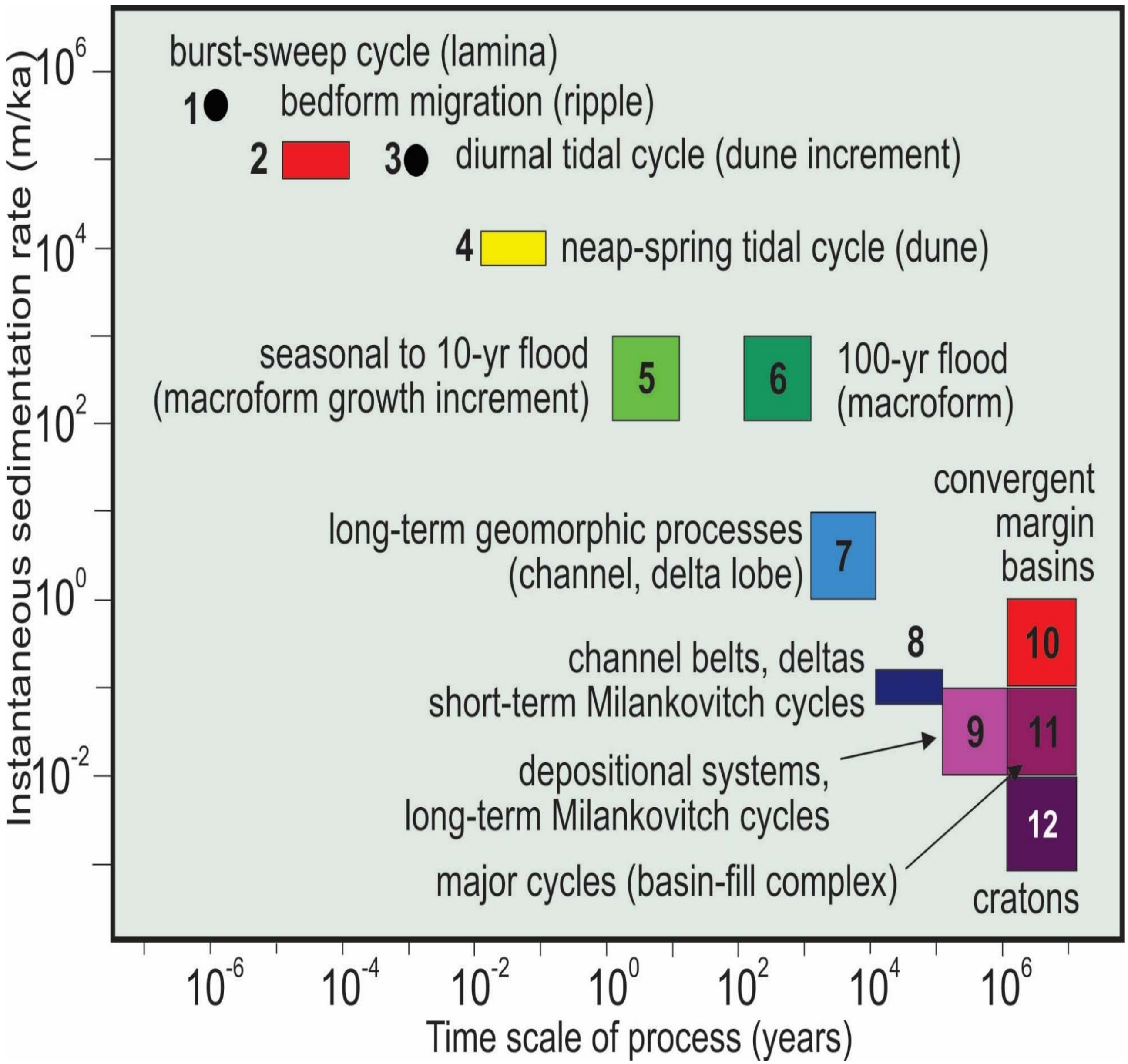


A hierarchical view of Sedimentary processes

Purple numerals refer to an hierarchy of bounding surfaces

(diagram from Miall, 1996; Rates and time scales from Miall, 2015)

Vertical sedimentation rates and time scales interpreted in terms of geological processes



Sedimentation Rate Scales 1 to 12: rates and processes Miall (2015, GSL Spec. Pub 404)

Questions

- What can 3D Wheeler Analysis tell us about how rocks are time are distributed in basin fills?
- What volumes of sediment are delivered to basins (sinks) over instantaneous to millennial time scales (source)?
- How do these compare with mapped volumes of sediment in basins (sinks)?
- How can sediment-flux analysis be applied in balancing sediment budgets in deep-time (pre-Quaternary) systems?

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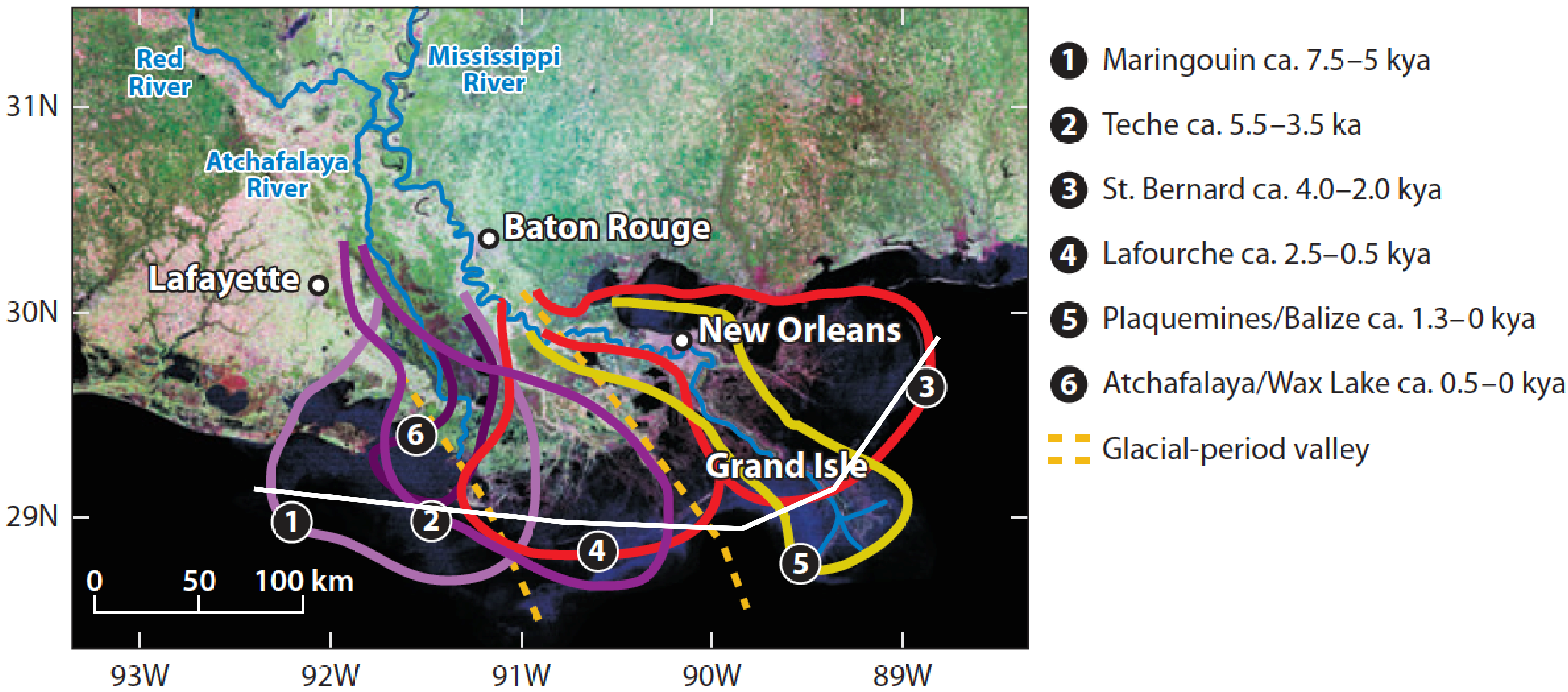
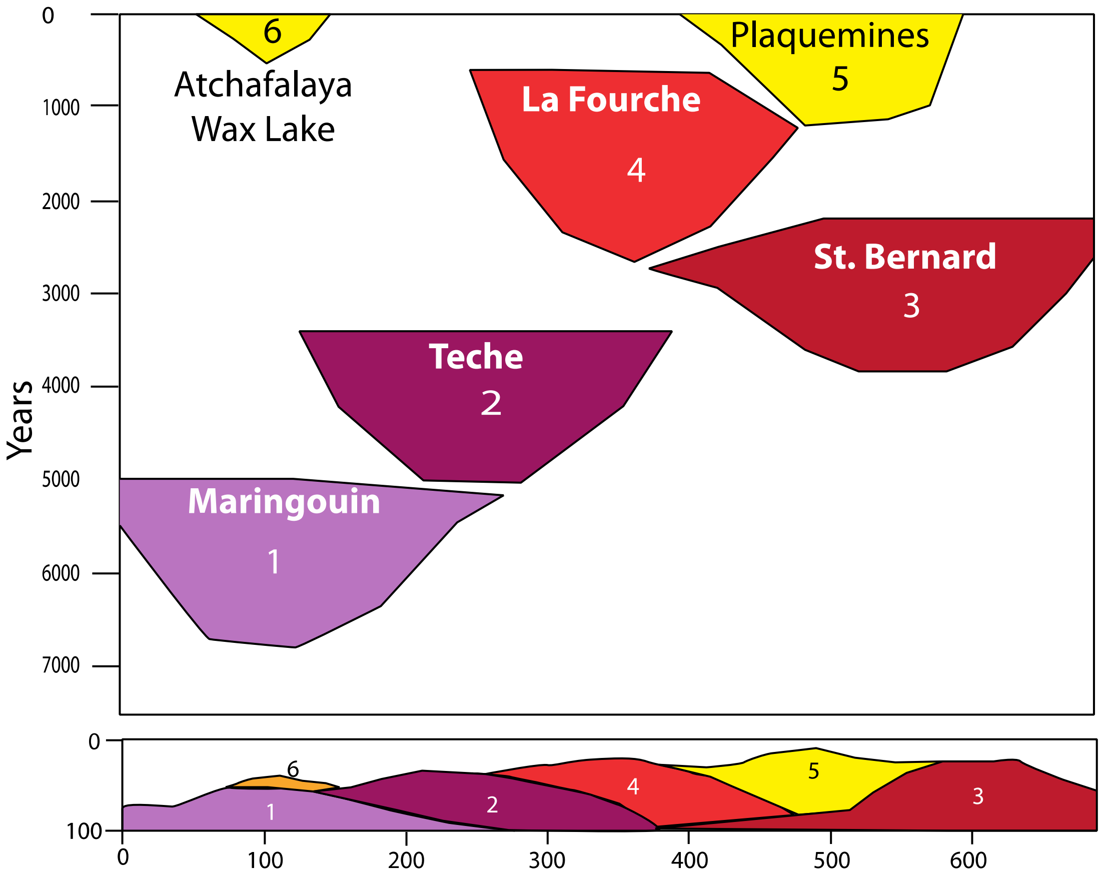
Mississippi Lobe Chronology

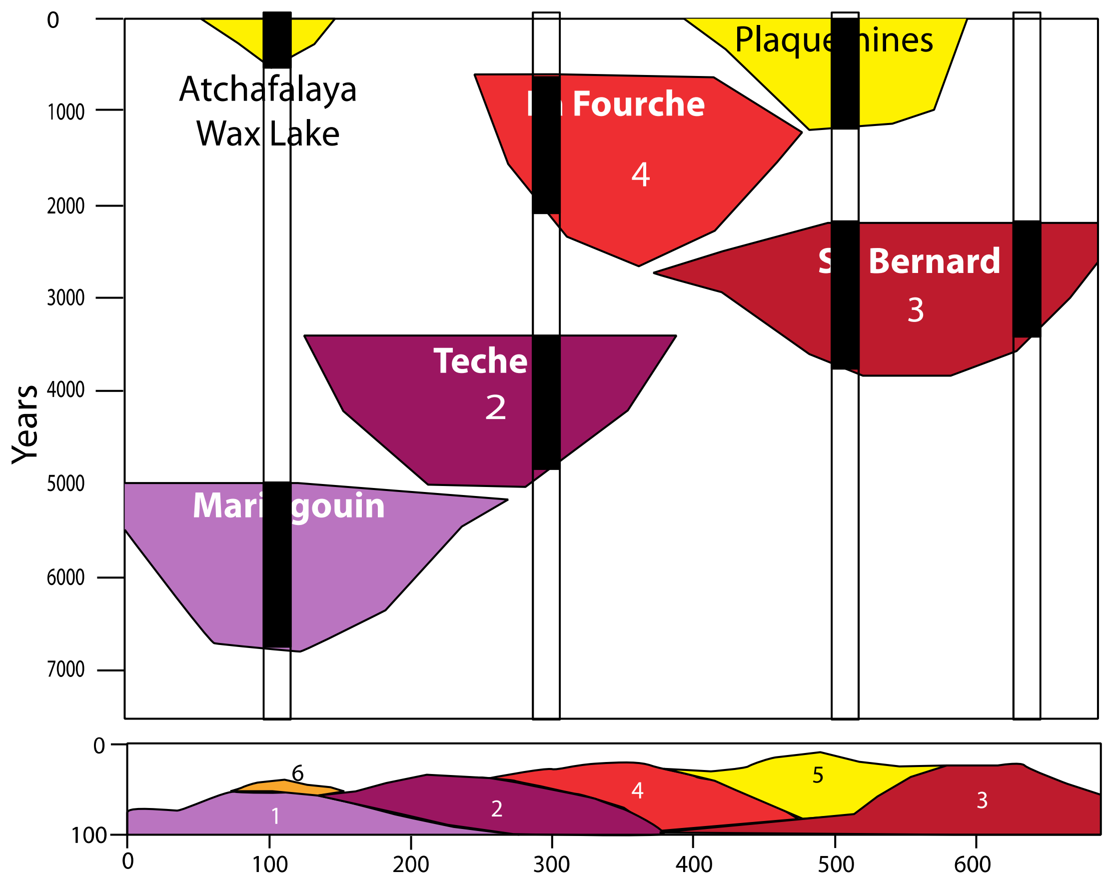


Blum and Roberts, 2012

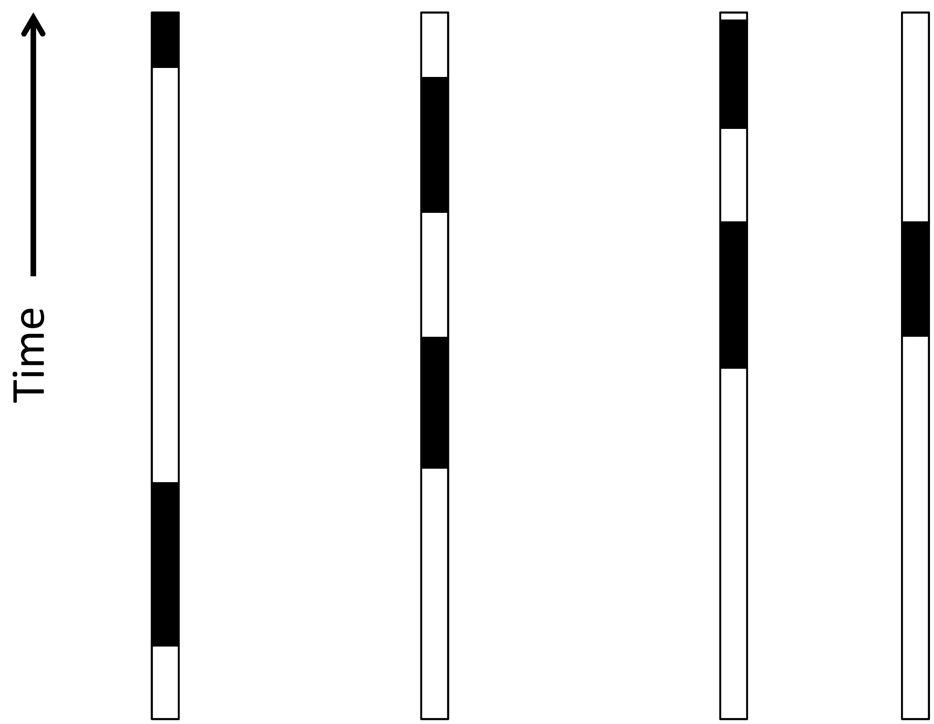
Wheeler Diagram of Mississippi Delta Lobes

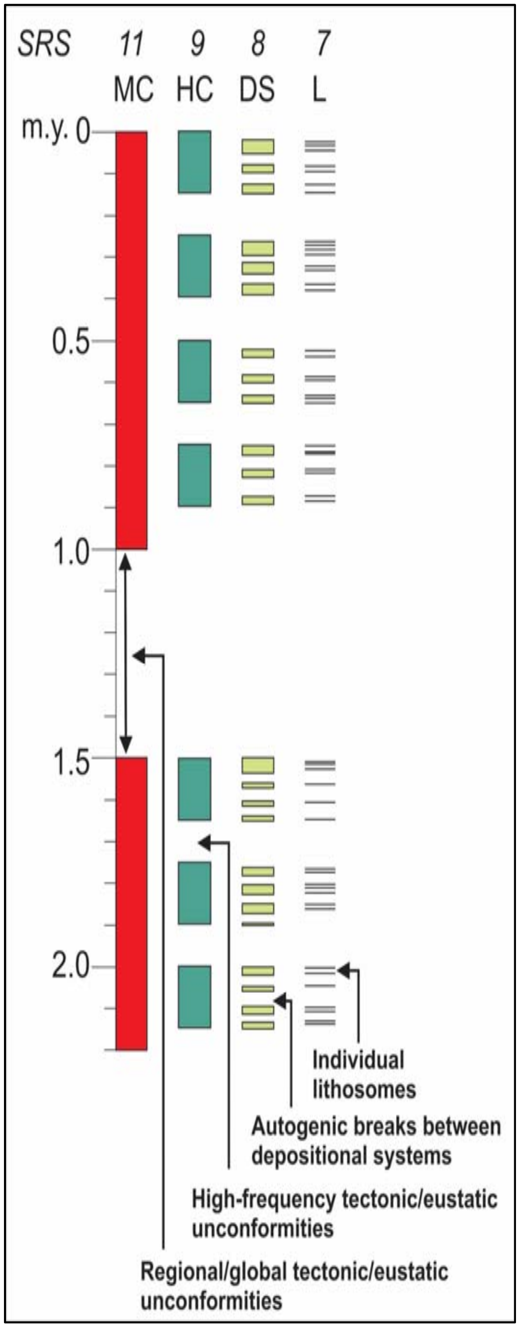


Wheeler Diagram of Mississippi Delta Lobes



1D Time Chart

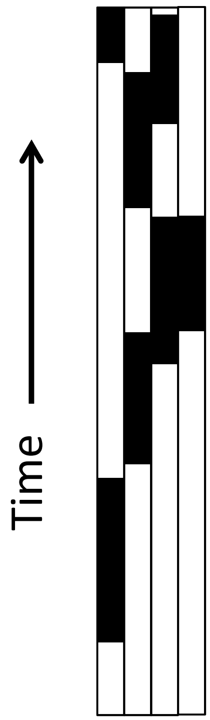




"more gap than record"

But there is sedimentation somewhere, albeit localized.

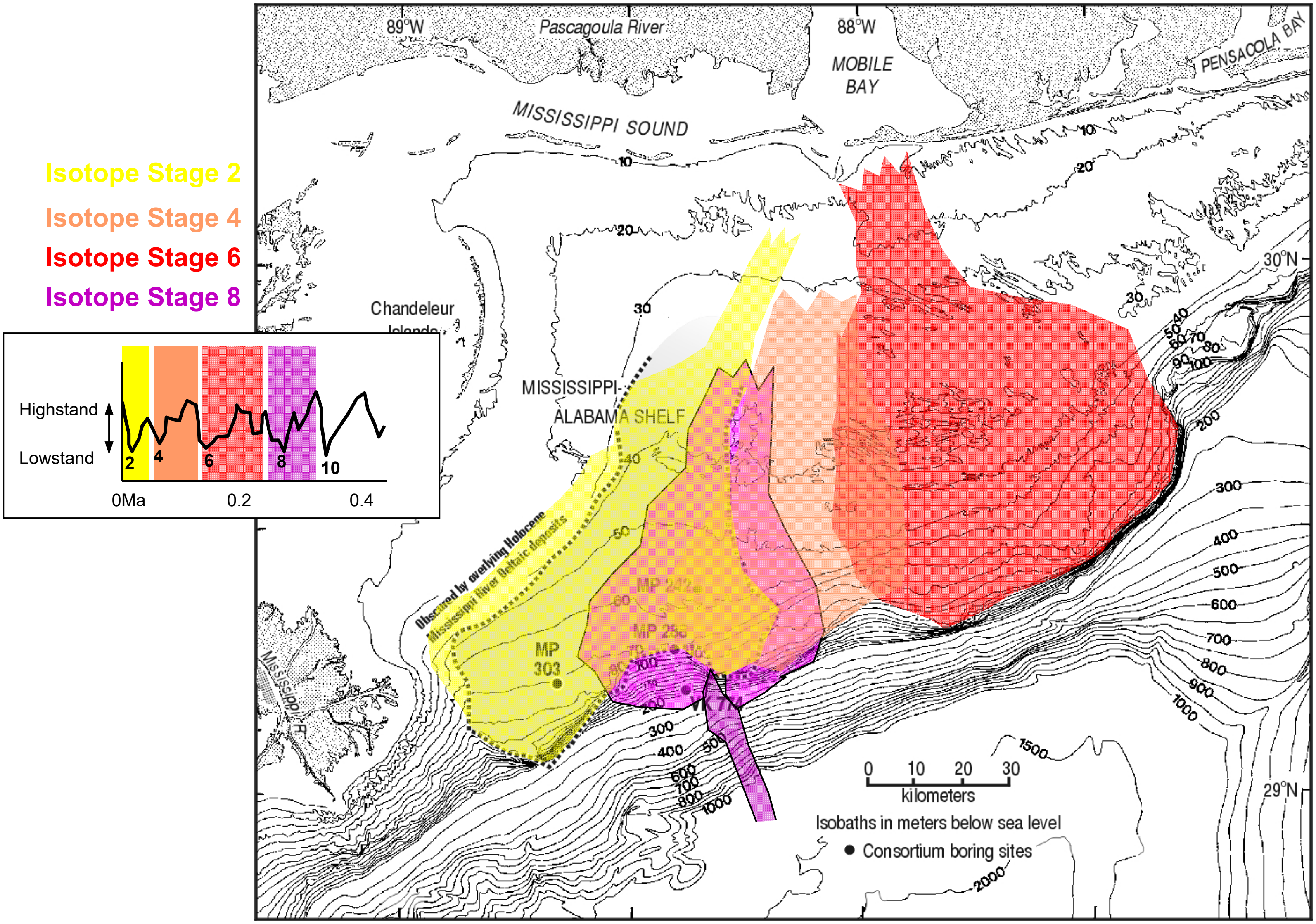
Merged 1D Time Chart



"more gap than record"

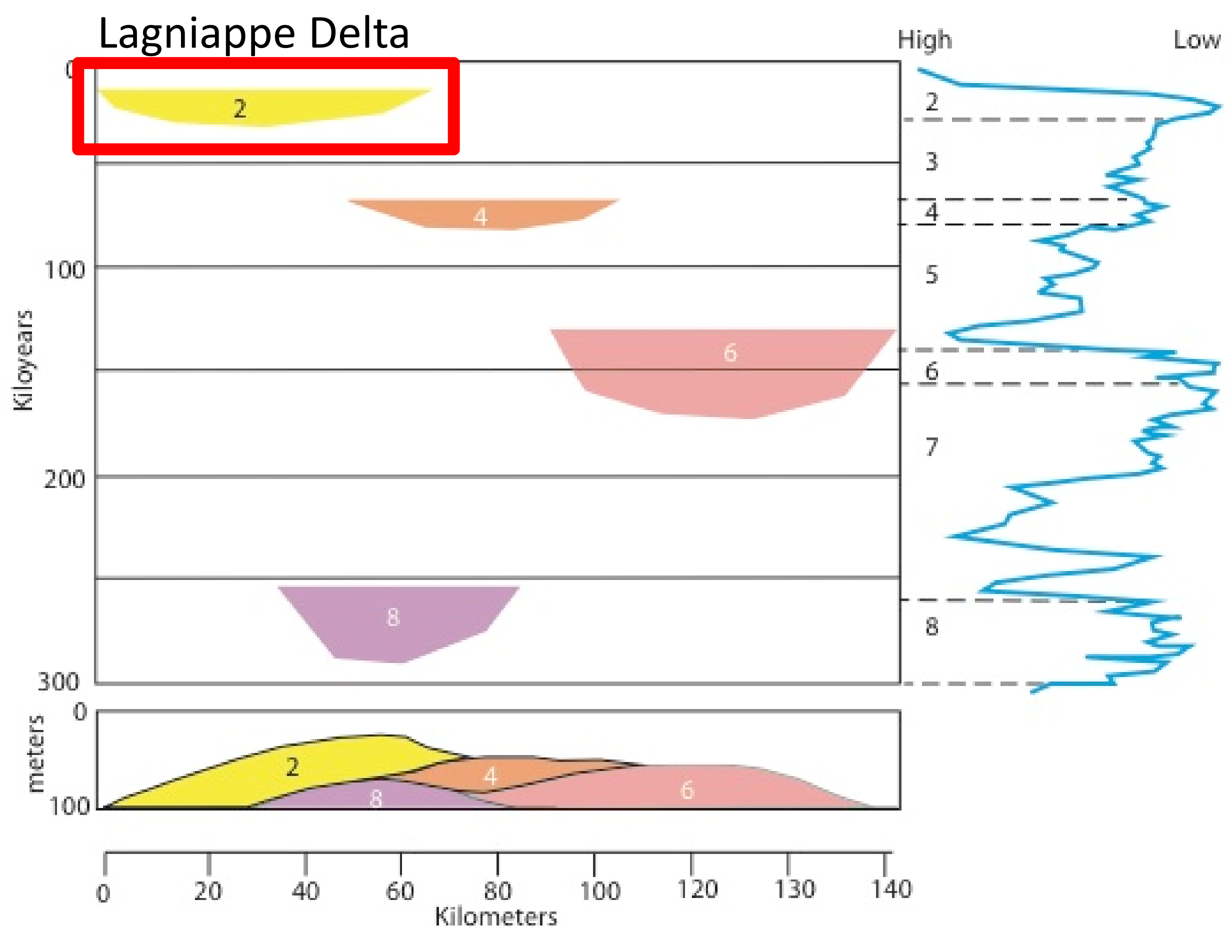
But there is sedimentation somewhere, albeit localized.

Eastern GOM Lobe History



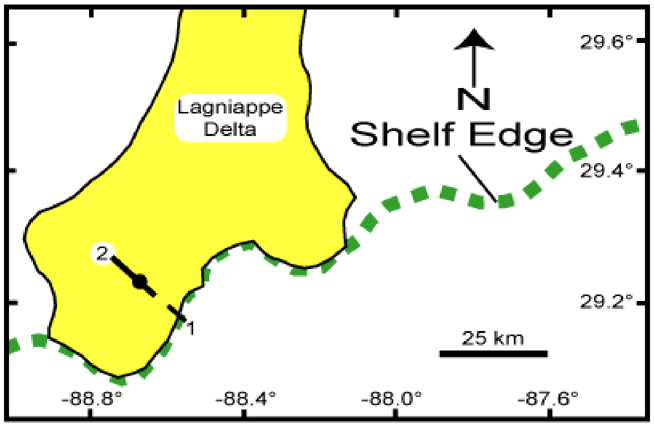
Roberts et al., 2004; Sydow, 2004

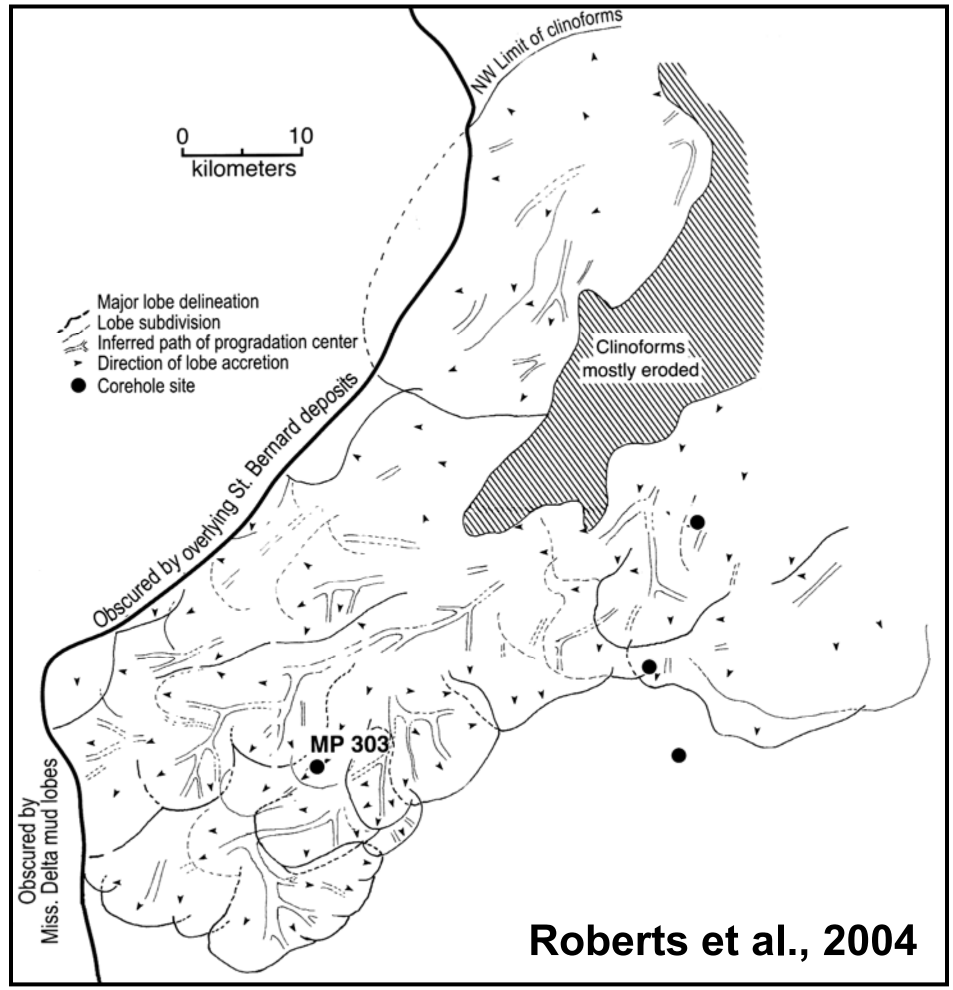
Eastern GOM Strike Wheeler Diagram



Oxygen Isotope Stages

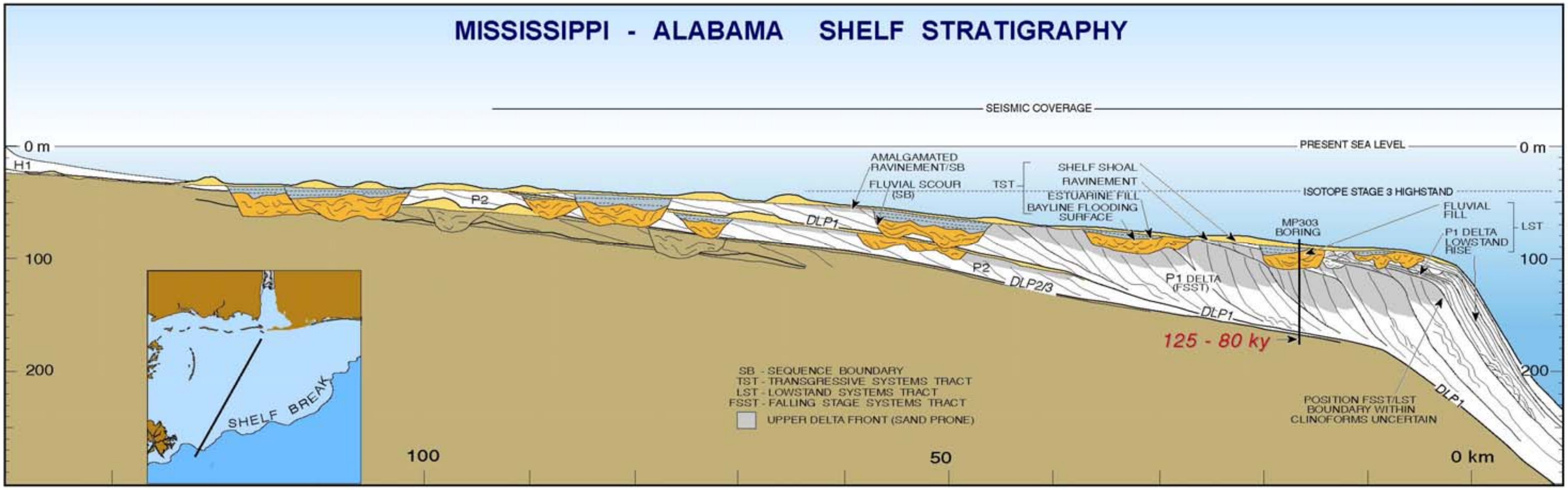
Seismic Mapping of sub-lobes in the Lagniappe Delta





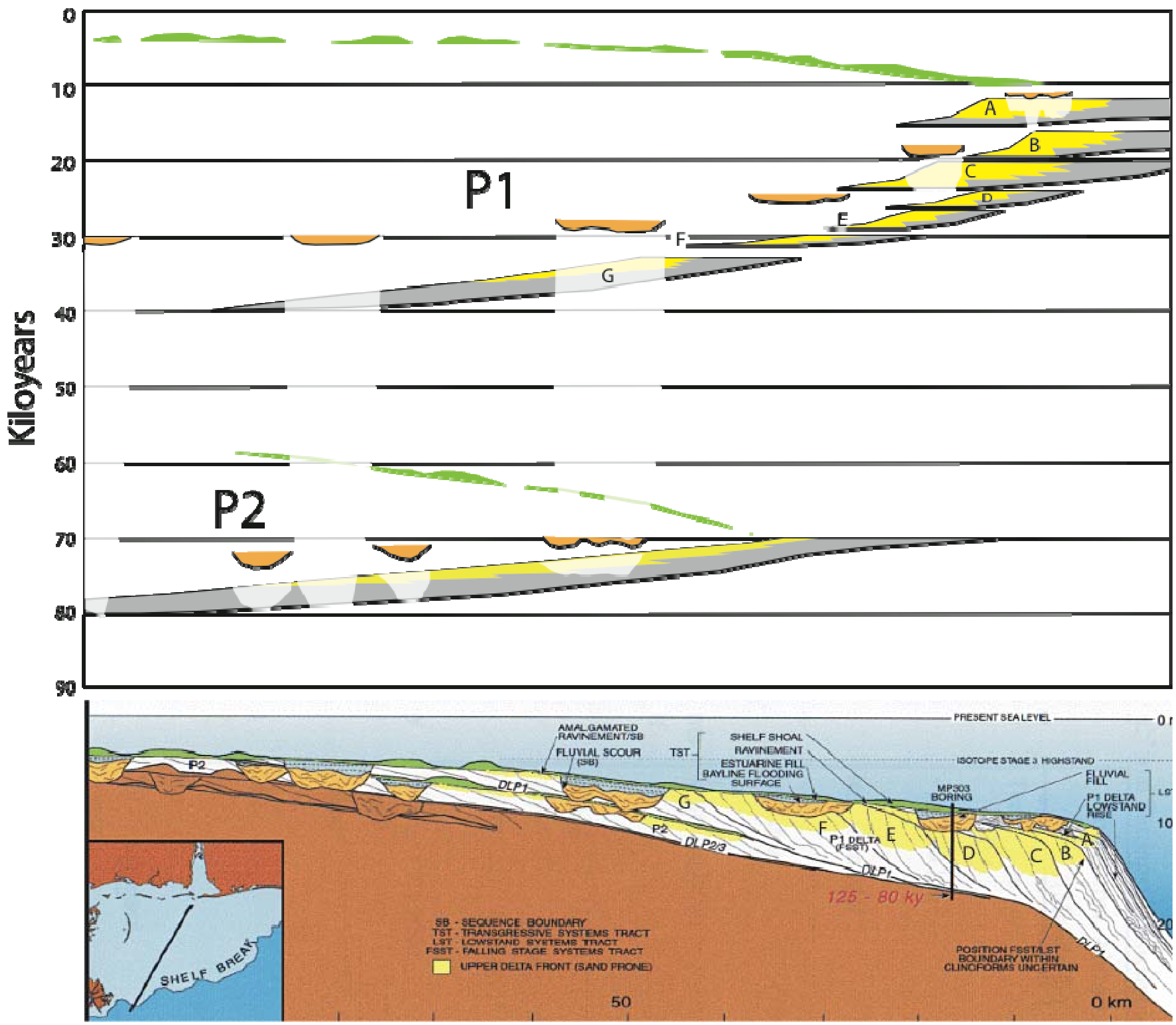
Detailed high-resolution seismic mapping reveals higher-order distributary channels and lobes within the delta.

Dip Stratigraphy

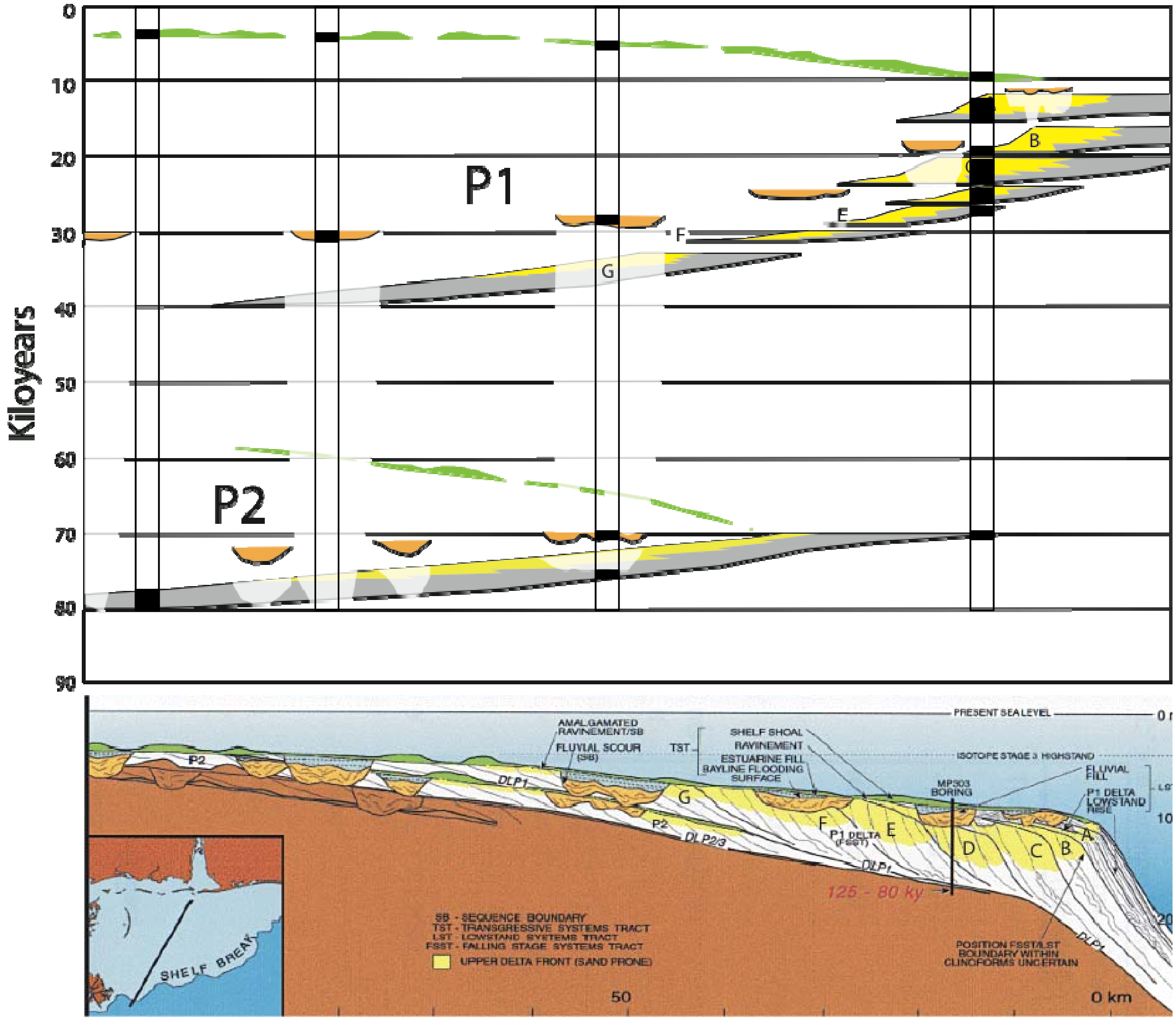


Offlapping clinoforms are eroded and interstratified with channel and valley deposits (from Roberts et al., 2000).

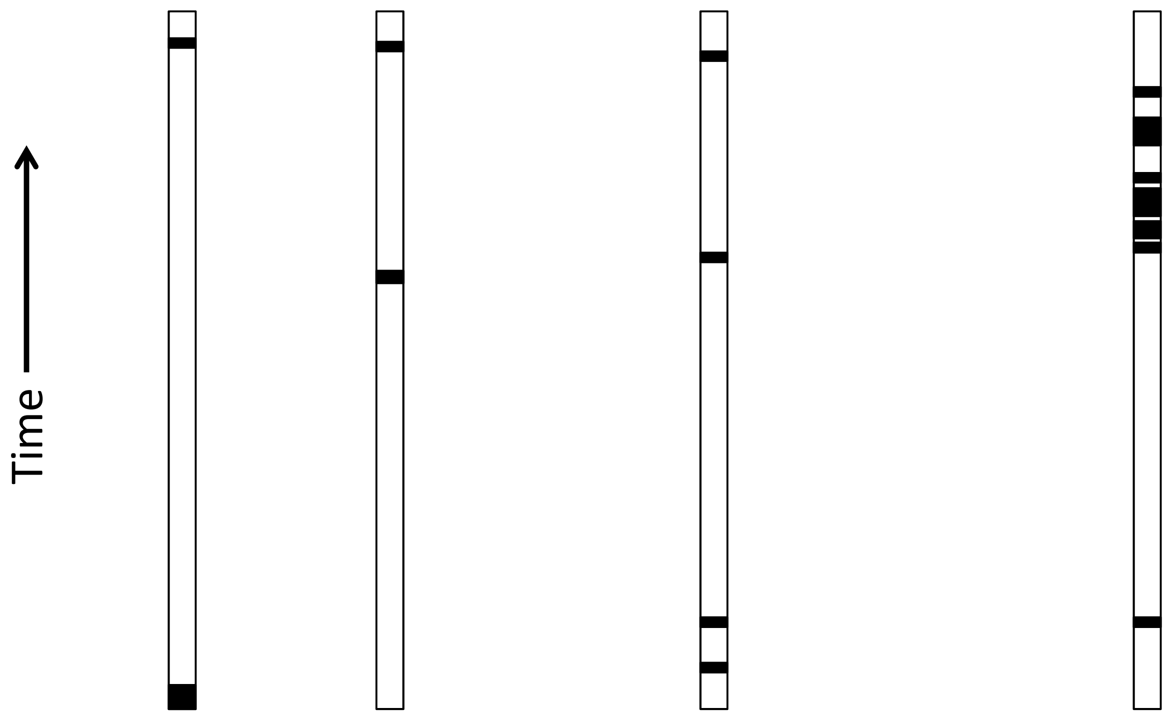
Lagniappe Delta Dip Wheeler Diagram



Lagniappe Delta Dip Wheeler Diagram

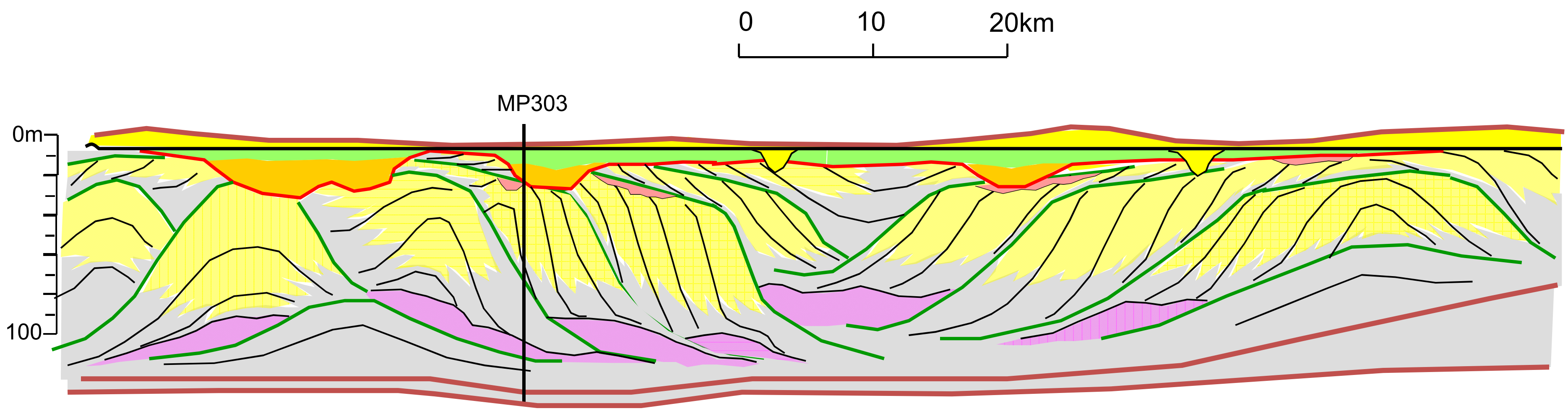


1D Wheeler Diagram



The stratigraphic record in 1D is pretty sparse, except at the shelf edge where the delta stalls out during the lowstand!

Lobes within the Lagniappe

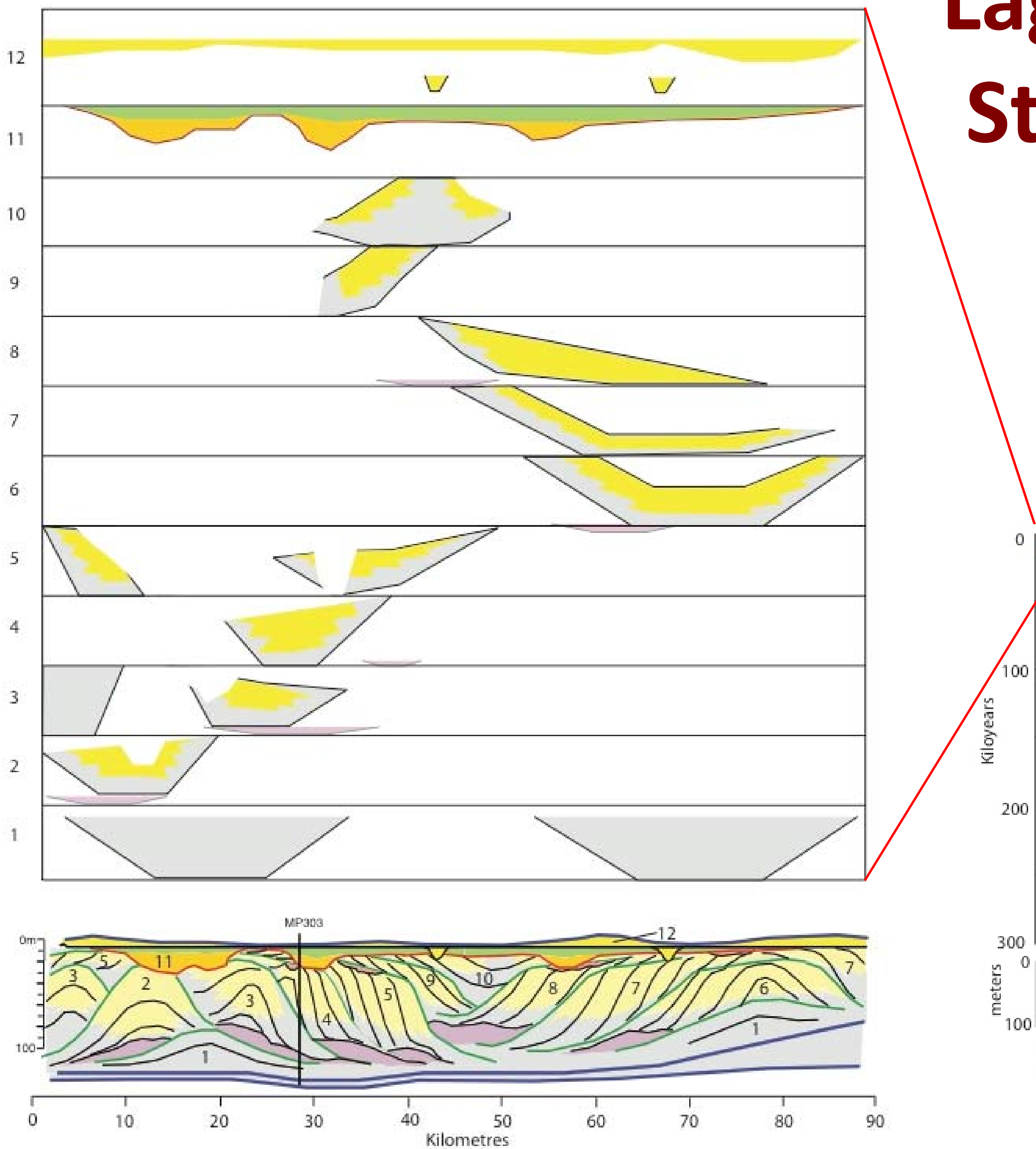


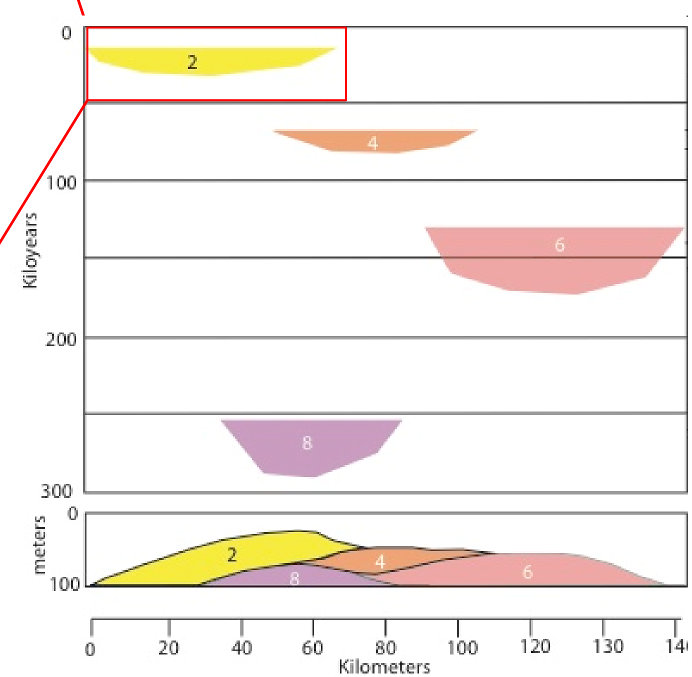
Sydow, 1992

- MFS (~Condensed Section)
- Ravinement
- SB
- Parasequence FS
- transgressive shoals, tidal inlet fills
- estuarine/lagoonal
- fluvial
- distributary channel
- delta front ss/shoreface ss
- prodelta/delta-front/offshore sh
- MTC (slump, debris flow)

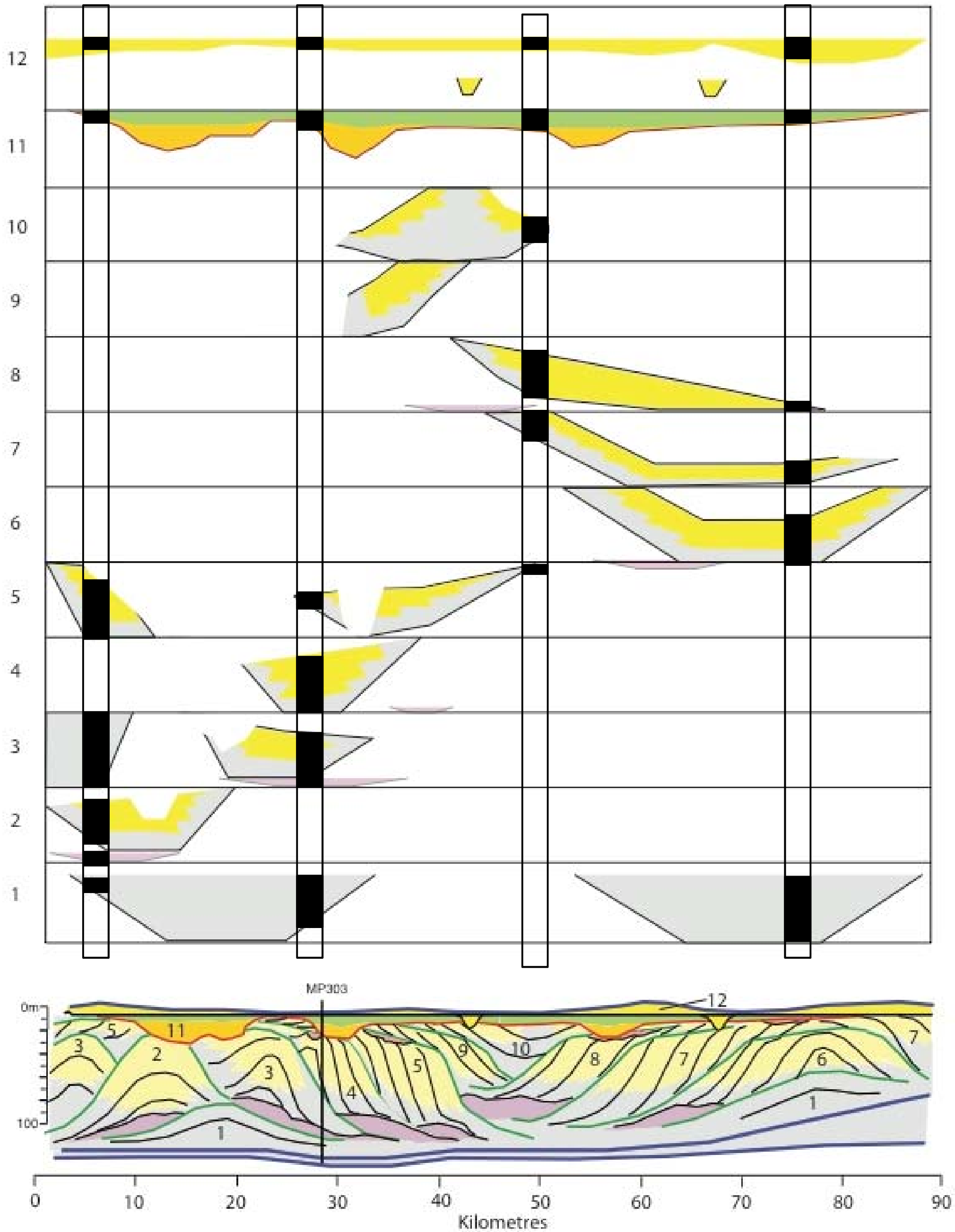
Strike section shows complexity of compensationally-stacked delta lobes.

Lagniappe Delta Strike Wheeler Diagram (40 Ka)

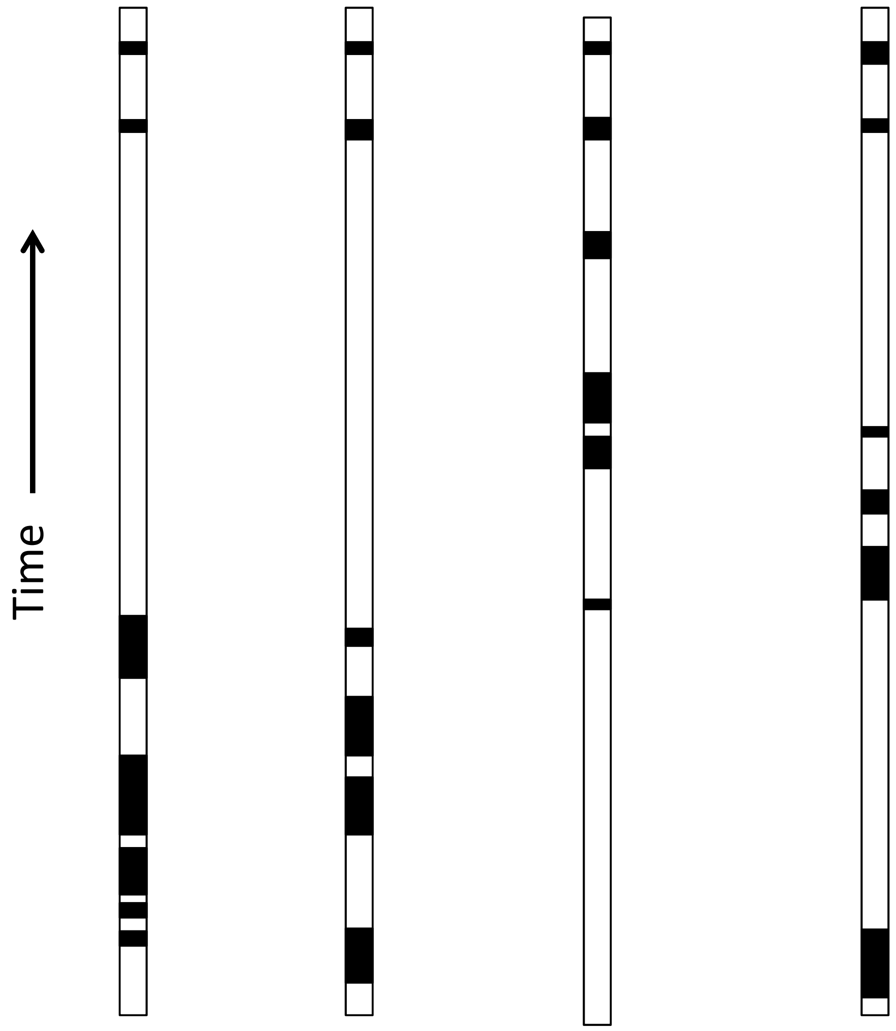




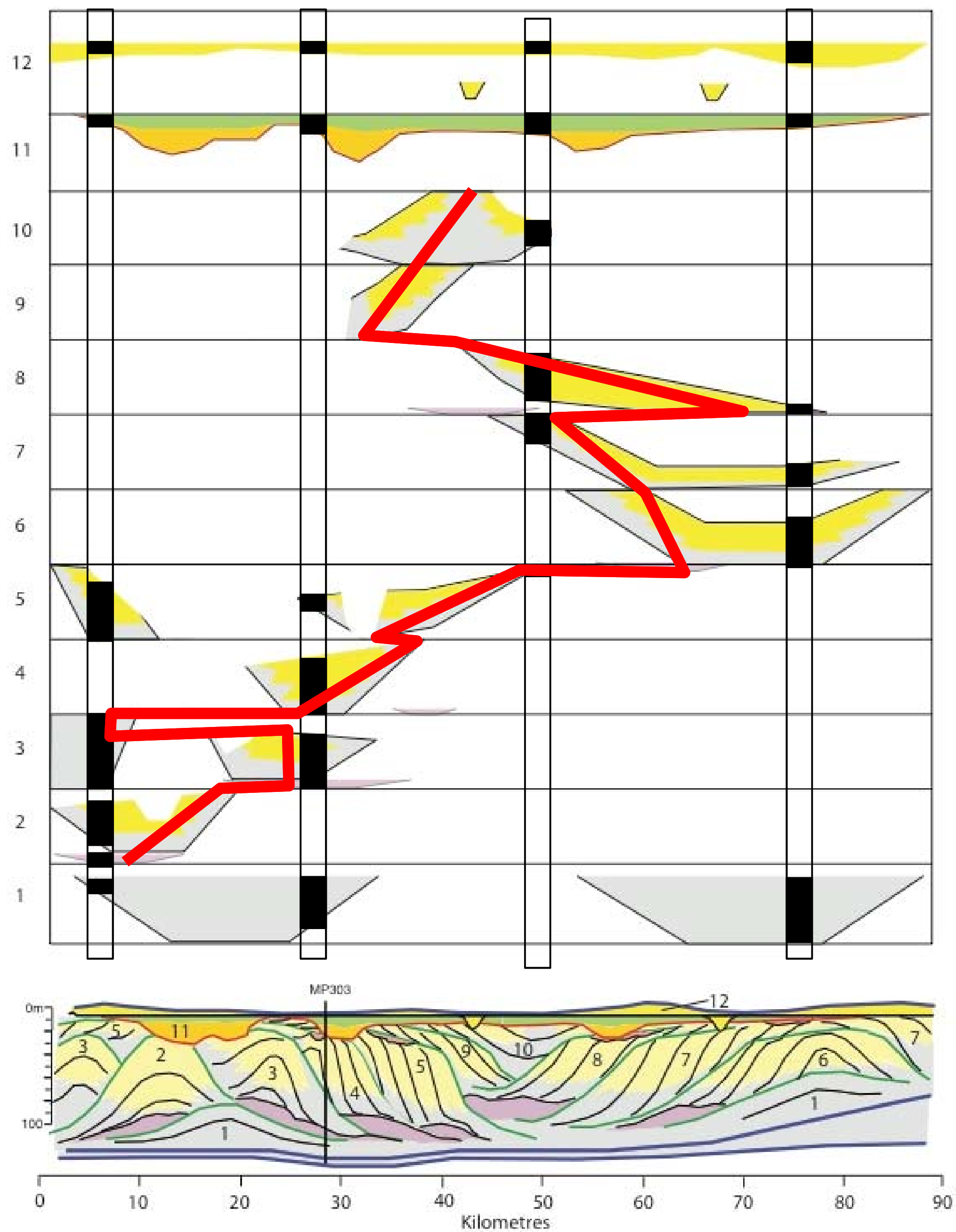
Lagniappe Delta Strike Wheeler Diagram (40 Ka)



Lagniappe Delta 1D Wheeler Diagrams



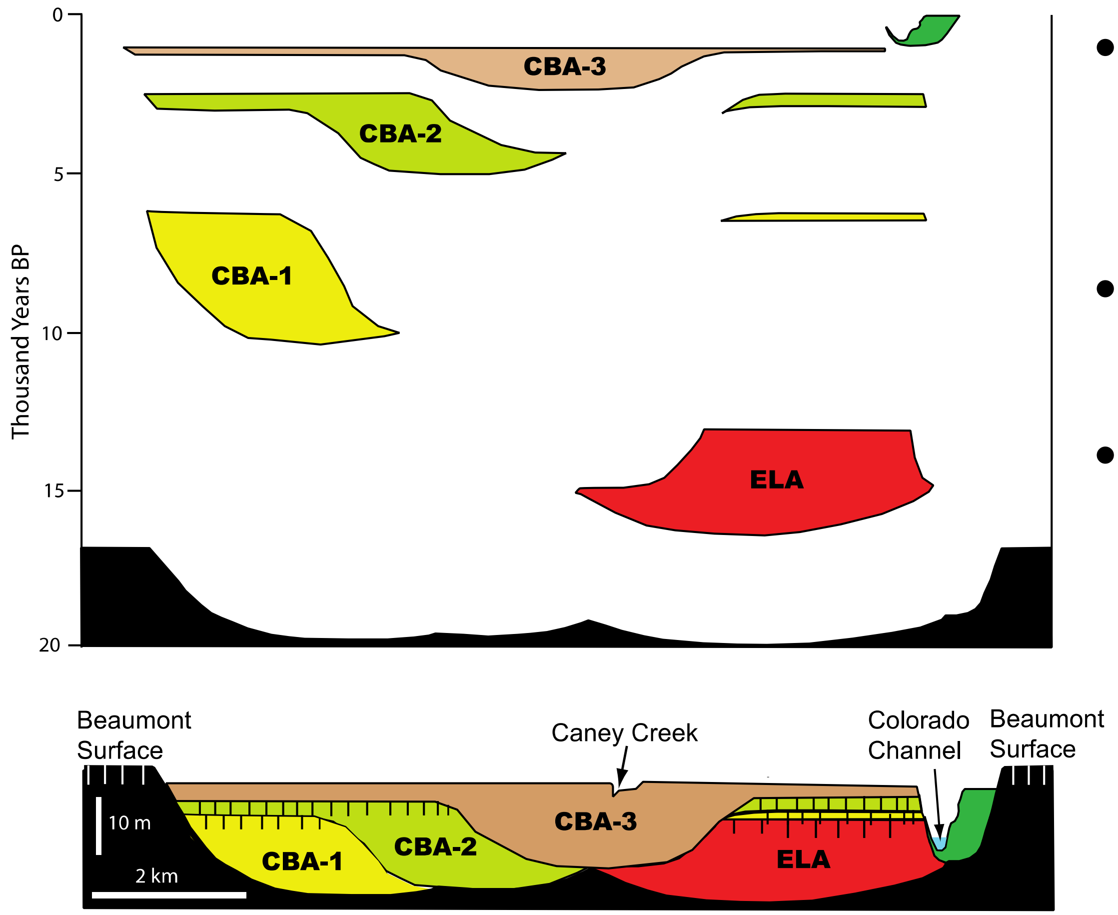
1D records are incomplete, but there is some sedimentation somewhere, even if not sampled in 1D.



Lagniappe Delta Strike Wheeler Diagram (40 Ka)

- Line of "continuous" recorded sediment.
  - Recall that record will be more fragmented at finer time scales.

How about the GOM Fluvial Systems?



- GOM valley terraces are laterally offset, and cannibalized.
- 1D record is, again, incomplete.
- Lateral shifting of valleys, and rivers, results in downstream localization of sediment in the sink.

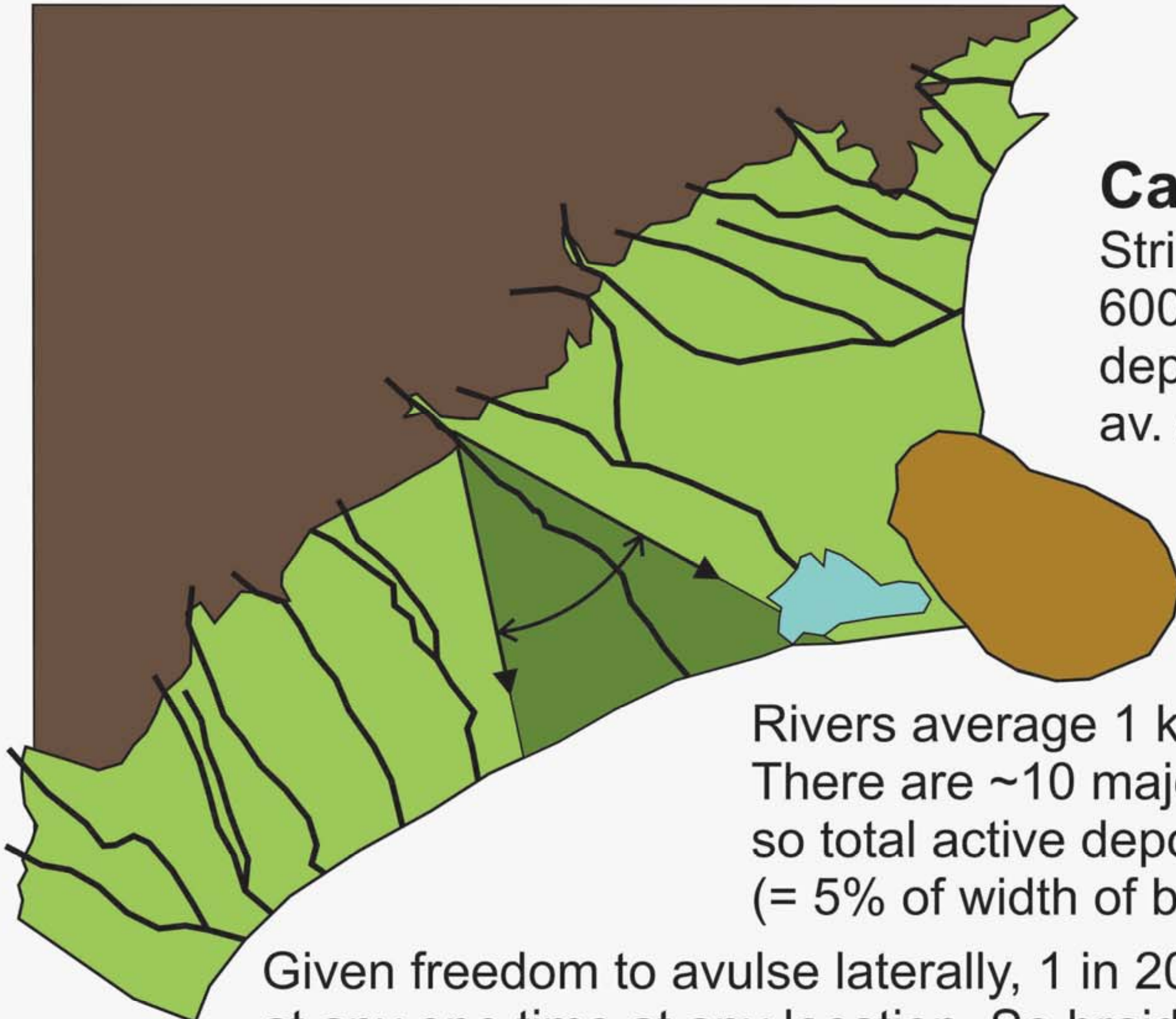
Wheeler diagram of Quaternary valleys, GOM (stratigraphy from Blum, 1993)

Canterbury Plains
South Island, N.Z.

A gravel-bed braided river draining the Alpine Mountains of the South Island

Canterbury Plains

Strike width: 200 km
600 m of gravel/sand
deposited in 700 ka
av. sed. rate 0.86 m/ka



0 40 km

Rivers average 1 km width.
There are ~10 major rivers
so total active depositional width = 10 km
(= 5% of width of braidplain).

Given freedom to avulse laterally, 1 in 20 chance of active channel at any one time at any location. So braidplain is undergoing active sedimentation at any location **only 5% of the time** = 35 ka.

600 m of sediment in 35 ka = sed. rate of 17.1 m/ka
which is consistent with rate for “long-term geomorphic processes”

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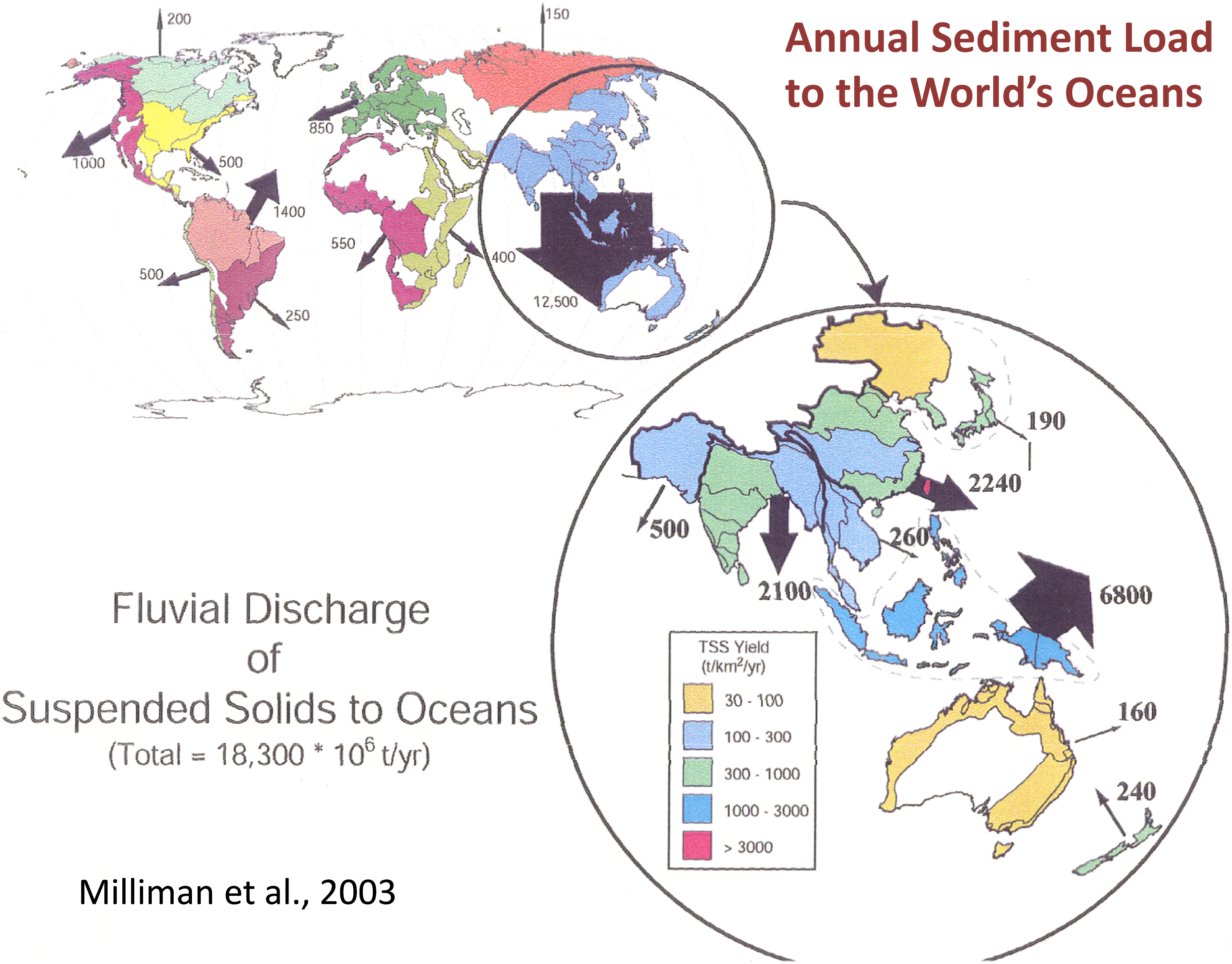
Annual Sediment Load to the World's Oceans



Fluvial Discharge
of
Suspended Solids to Oceans
(Total = 18,300 * 10^6 t/yr)

Milliman et al., 2003

Annual River Sediment Discharge

- Method:
  - Convert yearly sediment discharge (t/year) to sediment volume
  - 1 t = 1000 kg
  - assume density (ρ) of 2000kg/m^3.
- Mississippi Example:
  - 400 x 10^6 t/year = 400 x 10^9 kg/yr
  - 400 x 10^9 kg/yr ÷ 2000 kg/m^3 = 0.2 x 10^9 m^3/yr

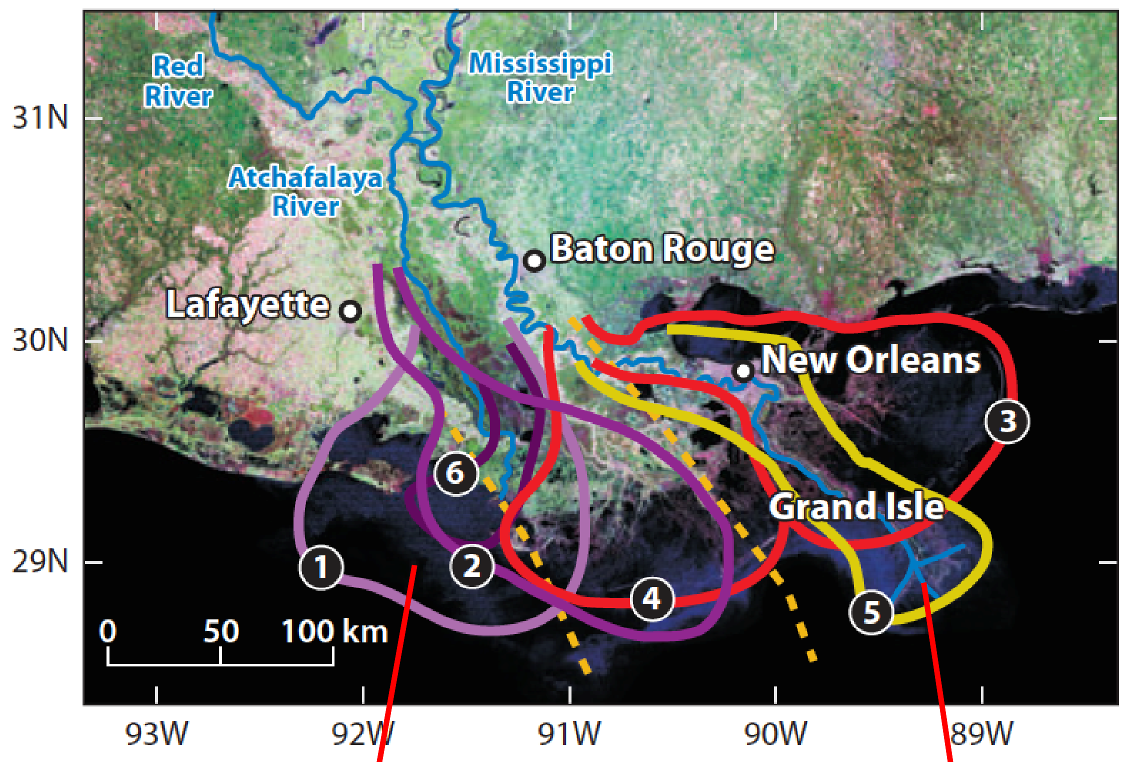
  = 0.2 km^3/yr

Longer River Sediment Discharge

- If the Mississippi delivers 0.2 km^3/yr, how much of the Gulf of Mexico can it fill in 1500 or 7000 years?
  - In 1500 years, the river delivers 300 km^3
  - In 7000 years it's 1400 km^3
- So, how much sediment is in the Holocene Mississippi system?

Longer River Sediment Discharge

- So, about how much sediment is in the Holocene Mississippi system?



<1000 km³

<750 km³

Blum and Roberts, 2012

1. Maringouin ca. 7.5–5 kya
2. Teche ca. 5.5–3.5 ka
3. St. Bernard ca. 4.0–2.0 kya
4. Lafourche ca. 2.5–0.5 kya
5. Plaquemines/Balize ca. 1.3–0 kya
6. Atchafalaya/Wax Lake ca. 0.5–0 kya

All lobes together are around 3000 km^3 versus 1400 km^3 estimated from flux considerations

Given errors, this is "very good".

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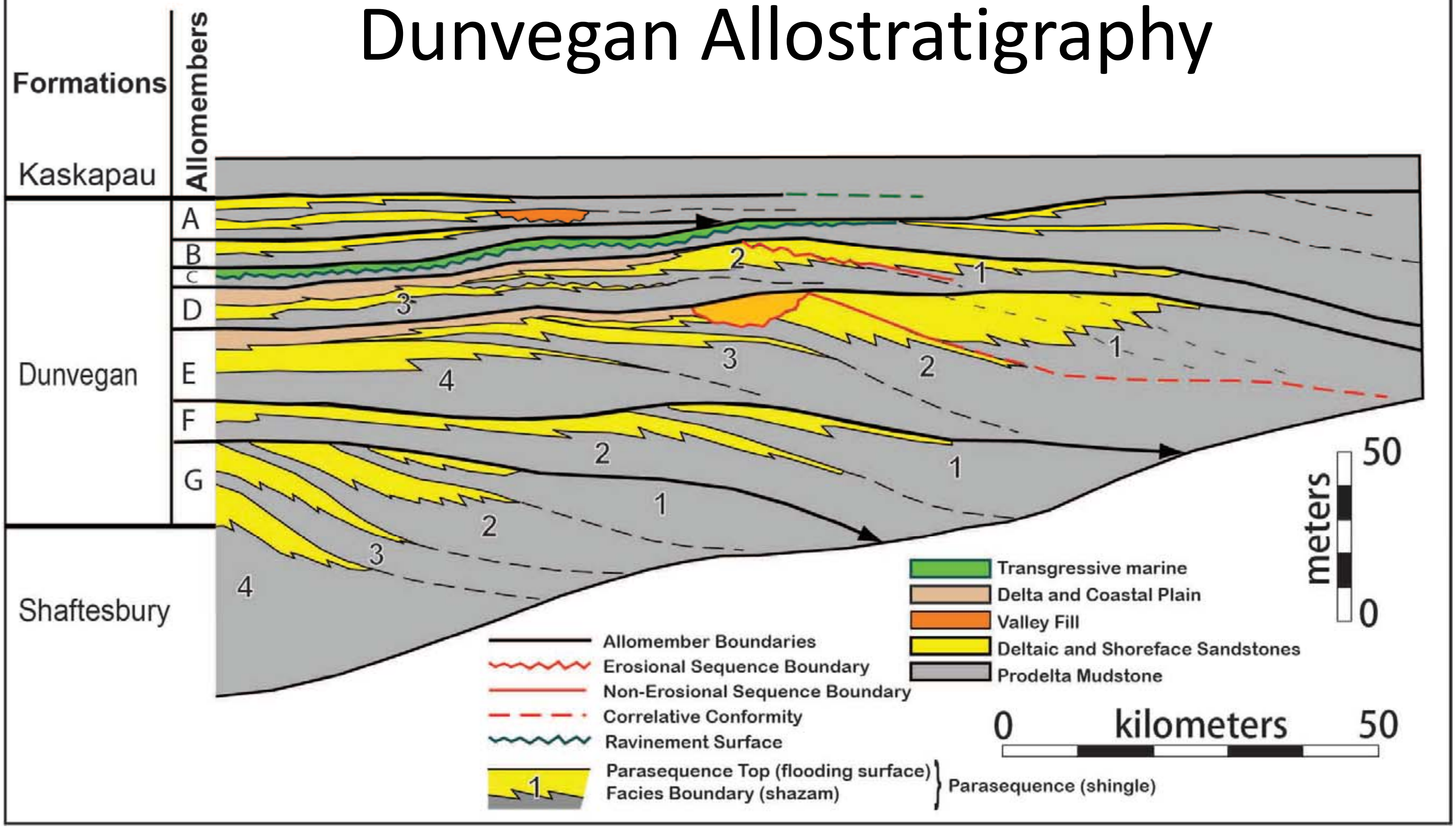
Dunvegan

- Temperate, humid climate.
- Small, high relief drainage basins linked to an active mountain chain.
- Drainage area is estimated from paleogeographic and paleotectonic reconstructions.

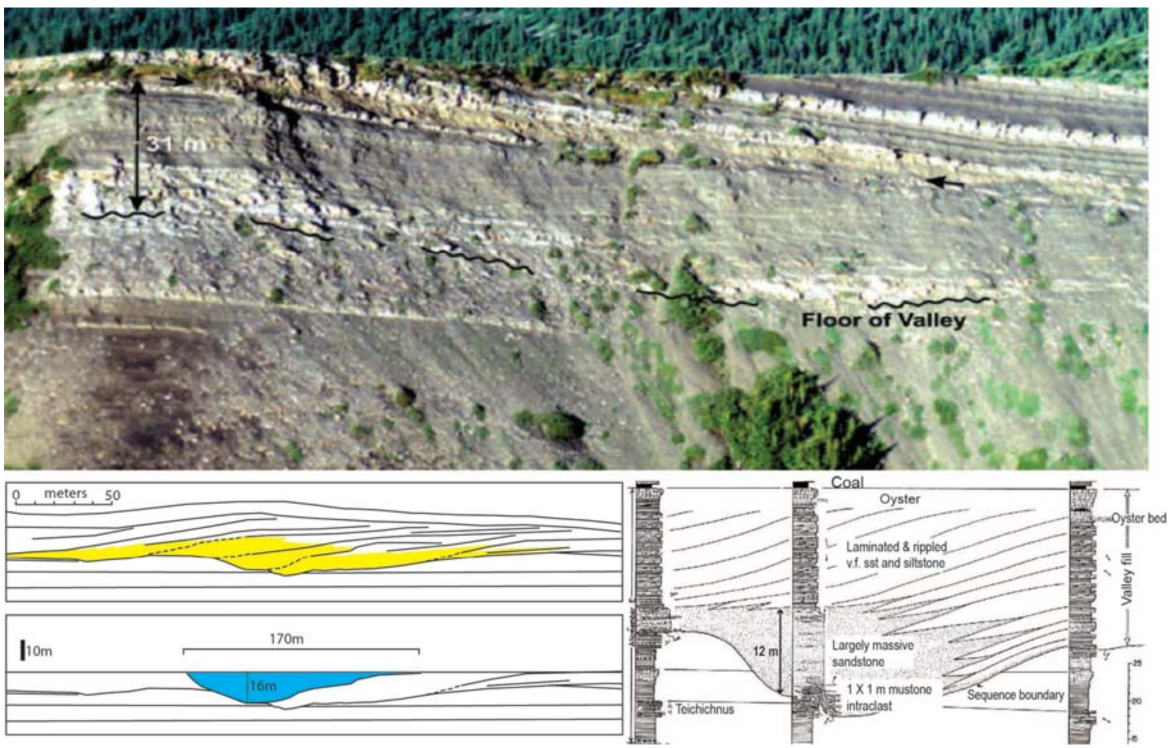
Dunvegan Allostratigraphy



- Valleys can be correlated to lowstand deltas and offshore mudstones
- Enough detail is available to estimate discharge (fulcrum analysis of Holbrook and Wanas (2014)

Paleodischarge Estimations

E1 Channel	Depth *m*	Width *m*	U *m/s*	Q_w $10^3\ m^3/s$	Q_b m^3/s	Q_s m^3/s
Min	10	150	1	1.6	0.08	2.1
Max	15	230	1	3.7	0.12	4.8



Depth, width grain size and paelohydraulics of channels can be obtained (Bhattacharya and MacEachern, 2009; Bhattacharya et al., 2015; Lin and Bhattacharya, 2017)

Outcrop data from Plint and Wadsworth, 2003

Annual to Longer Term Paleodischarge Estimations

E1 Channel	Annual bedload *10^6 m^3*	Annual suspended load *10^6 m^3*	Total Annual Load *10^6 m^3*	Total Bedload *Km^3*	Total Suspended Load *km^3*	Total Sediment Load *km^3*
Min	1.0	15	16	4.8	135	145
Max	1.5	23	25	7.4	300	307

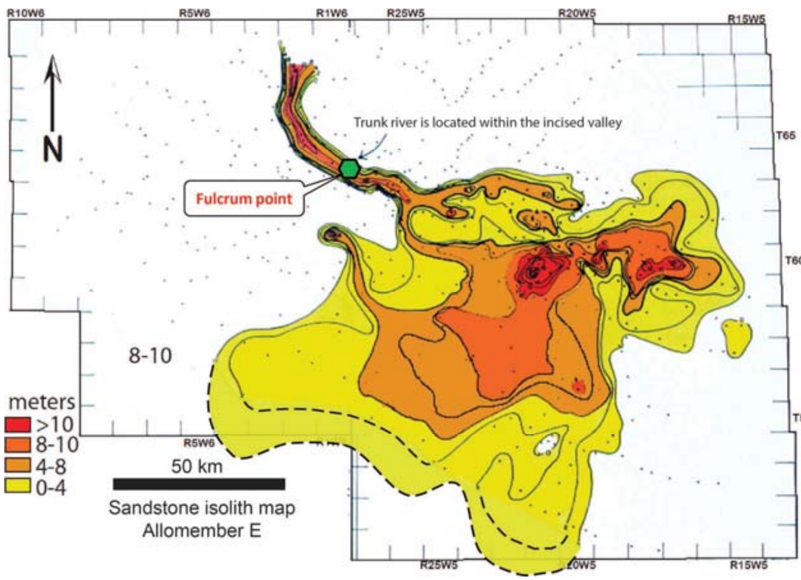
- Annual load is 0.016 – 0.025 km^3/year (1/10th of the Mississippi).
- This is 32 – 50 x 10^6 t/year
- This would be about equivalent to the Fly River in PNG or the Waiapu in New Zealand.
- Much less than continental scale rivers, such as the Mississippi (210 x 10^6 t/year) or Ganges/Brahmaputra (1670 x 10^6 t/year)

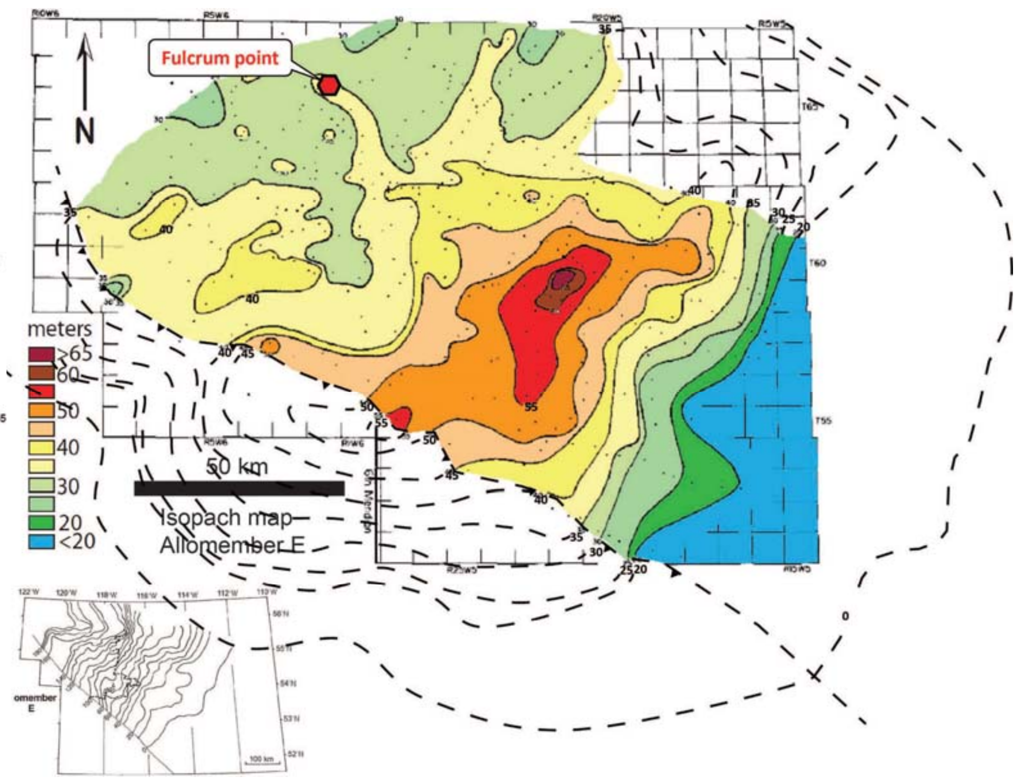
Calculations from Lin and Bhattacharya, 2017

Maps of “closed” systems can be compared to sediment discharge estimates

Sandstone Isolith

Isopach



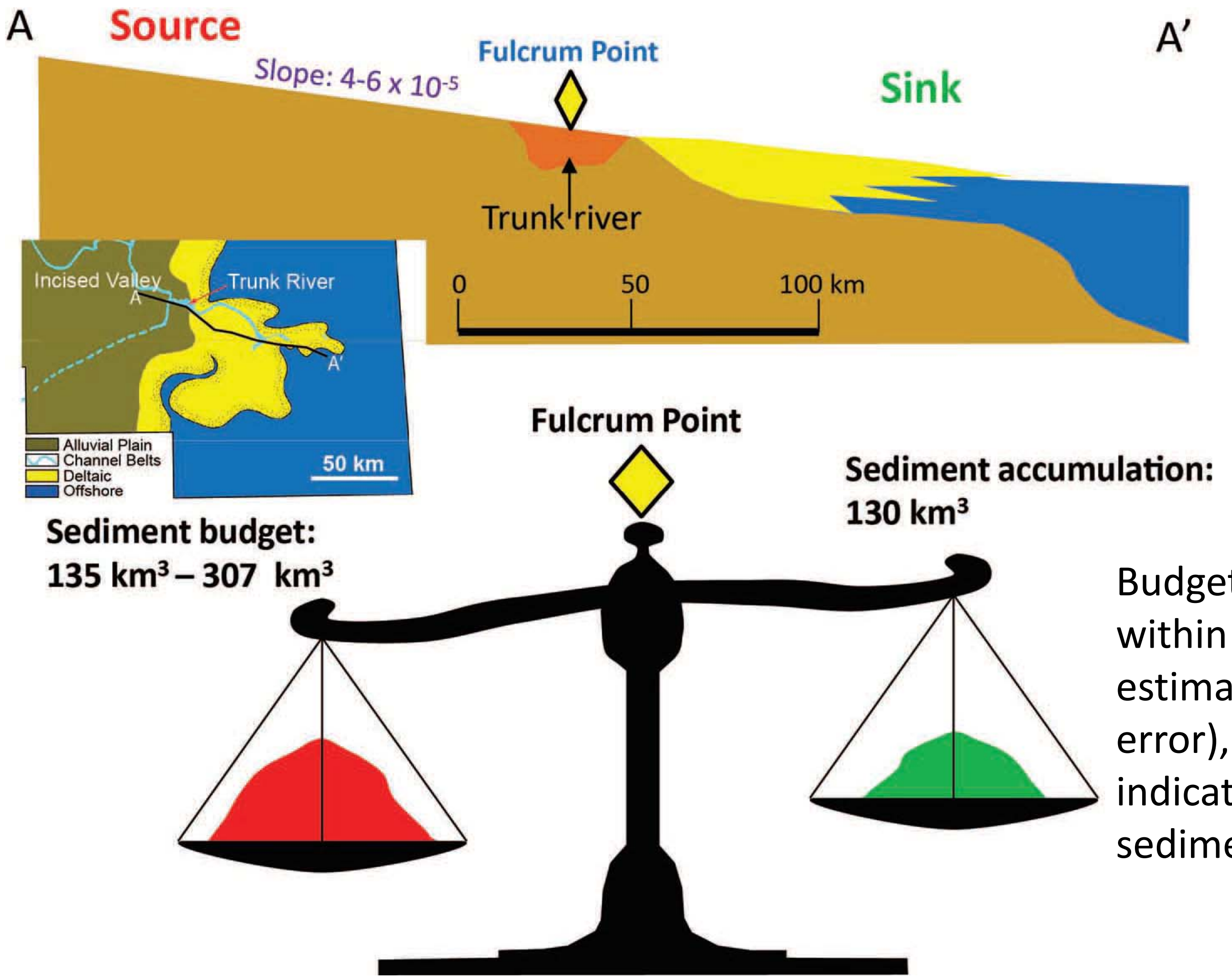


32 km^3 of sandstone beyond fulcrum

340 km^3 of sediment in Allomember E,
130km^3 in Allomember E1 lowstand

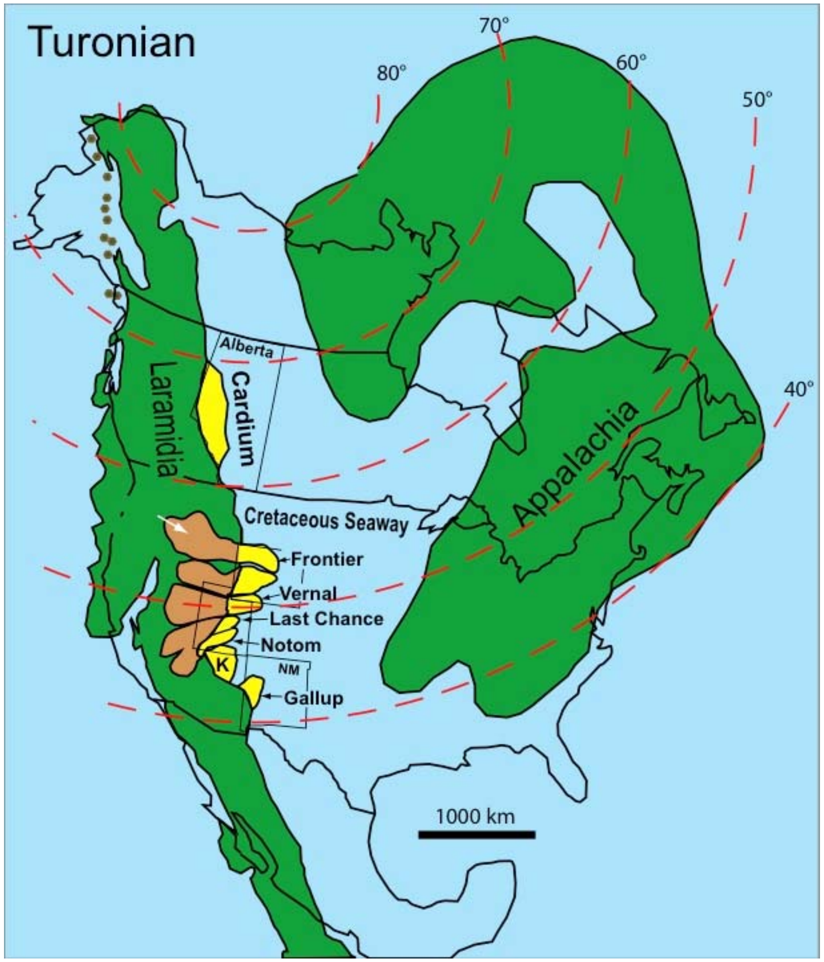
Lin and Bhattacharya, 2017

Dunvegan Fulcrum Analysis



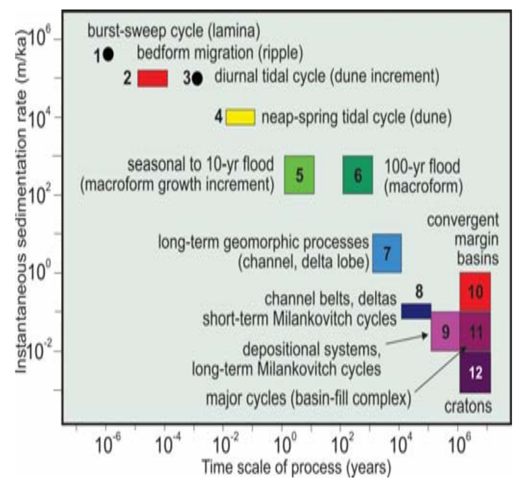
Budget analysis balances within the range of the estimates (and within error), although there is indication of some sediment escape.

Small Rivers in North America

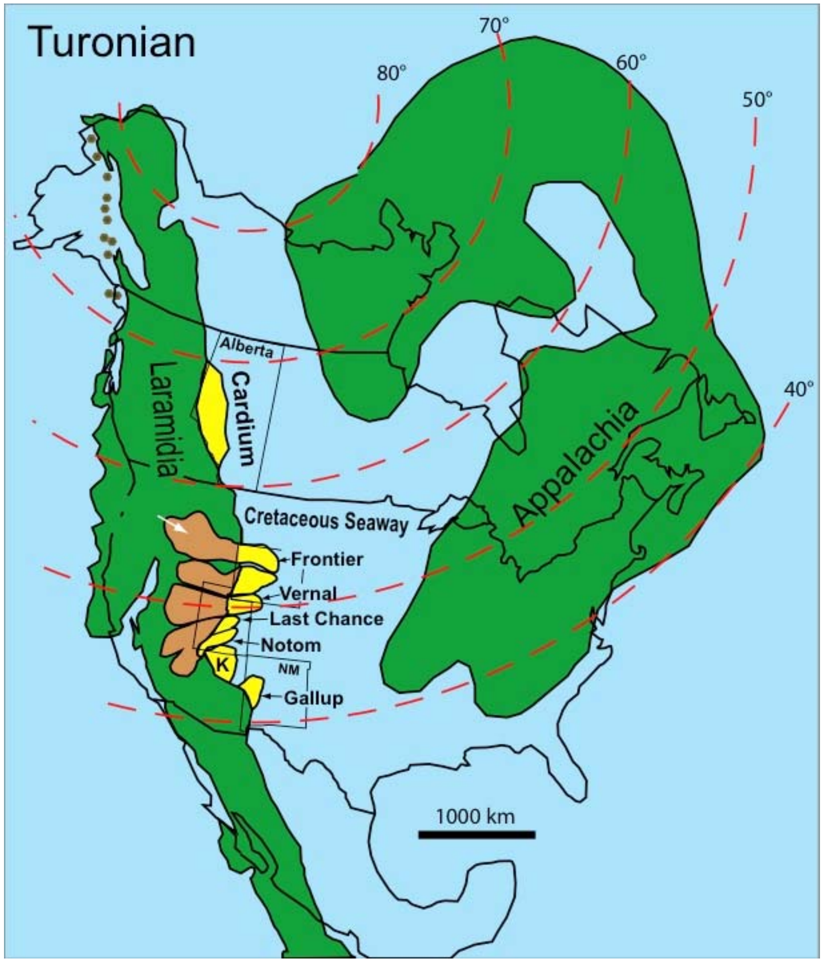


- Central portion of Seaway contains about 9 x 10^6 km^3 of seawater.
  - 1000km x 3000km x 0.3km
- Typical 5-10 m deep Late-Cretaceous river delivers about 1 x 10^{-2} km^3/year, or about 12 km^3/Ka.
- Given parasequences are typically about 20 m thick, this gives a vertical accumulation rate of about 1m/1000 years.

Between 7 and 8



Small Rivers in North America



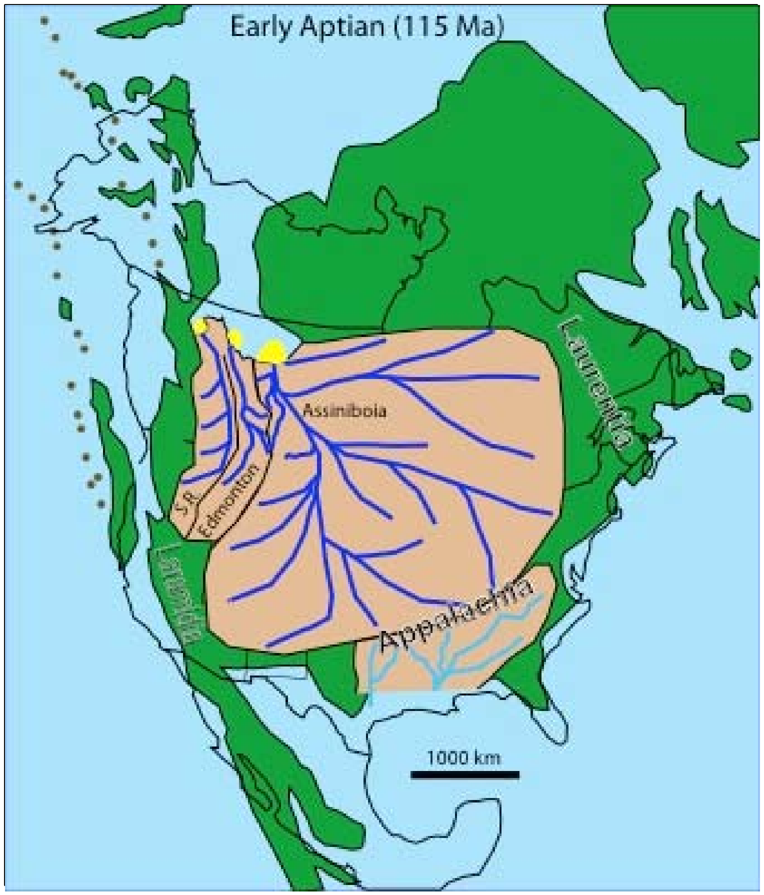
- To fill 9 x 10^6 km^3 of seawater the 8 systems shown would take about 100 million years to fill the seaway!
- Wedges typically are 1-2 million in duration.
- Thus basin at times is chronically underfilled. Either more time or less accommodation is needed (e.g., tectonics).
- No one vertical section can sample all of the time.
  - Note, we have not considered pelagic sediment and carbonates.

Conclusions

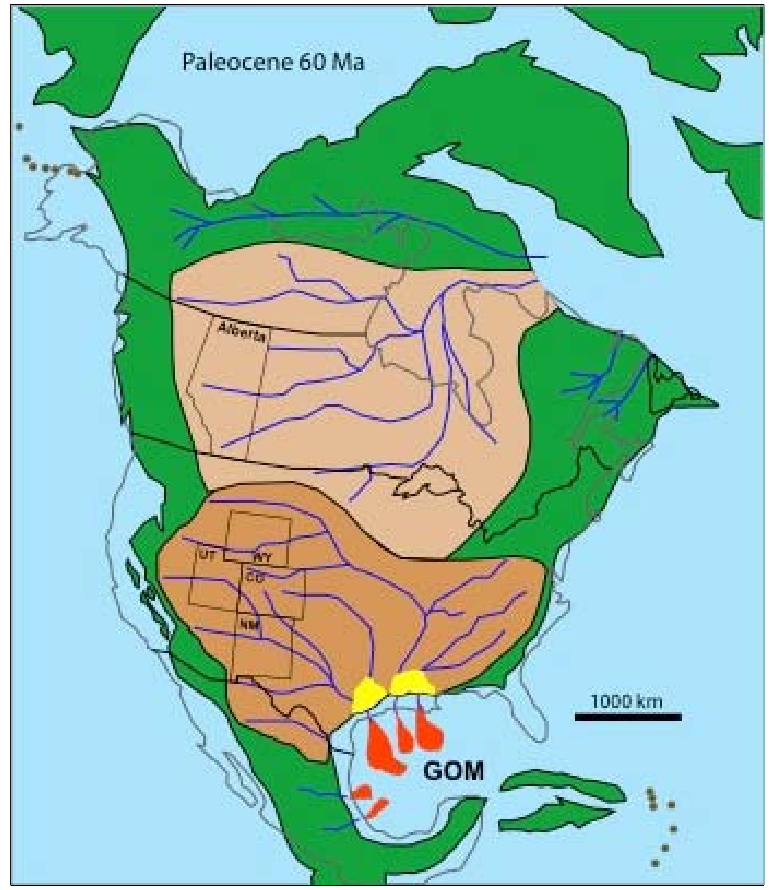
- River's flood infrequently and do not supply much sediment volume compared to the volume of marine basins.
- Sediment is thus highly localized.
  - Some areas may be devoid of sediment for long periods of times at various scales.
- Clinoforms, whether delta fronts or river bars represent local high sediment zones.
- This explains the sparsity of the sediment record, which is particularly acute in 1D.

Big Rivers in North America

Early Cretaceous (Mannville)



Paleocene (Mississippi)



Continental scale drainages produce larger river systems, but even here, sediment is localized to large deltas and submarine fans.