Deep Rivers in Deep Time:
Variation of rivers and their paleo-drainages in Mesozoic foreland basins of North America

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Invited review

Estimation of source area, river paleo-discharge, paleoslope, and sediment budgets of linked deep-time depositional systems and implications for hydrocarbon potential

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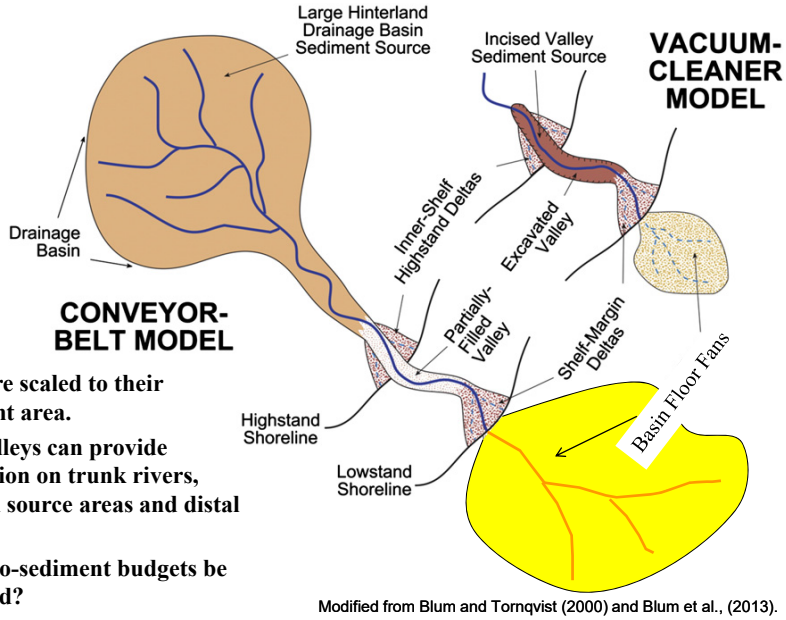
FUNDING COURTESY OF
bp
NSERC CRSNG

Outline

- S2S Concepts
- Estimating Scales of Rivers and Catchments
- Examples
- Evolution of North American Paleodrainage (Mesozoic)

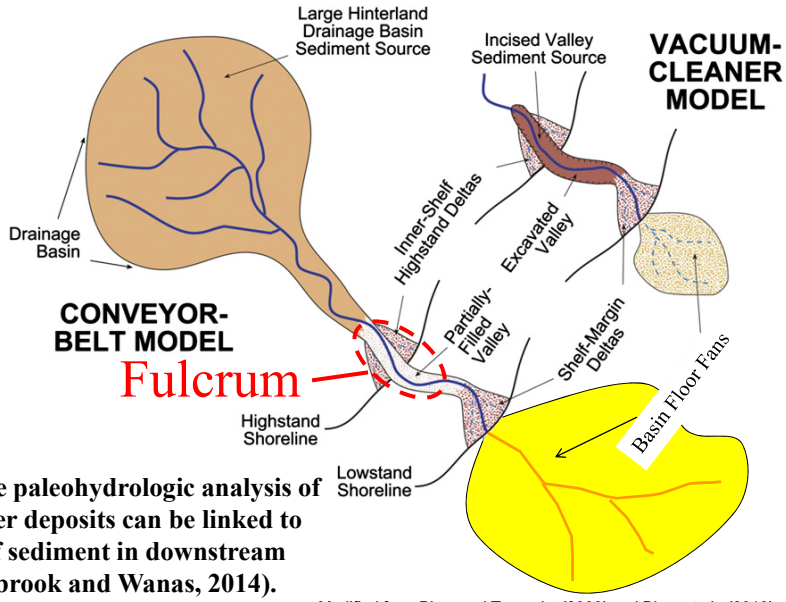
S2S in Plan View



- **Rivers are scaled to their catchment area.**
- **Paleo-valleys can provide information on trunk rivers, proximal source areas and distal sinks.**
- **Can paleo-sediment budgets be calculated?**

Modified from Blum and Tornqvist (2000) and Blum et al., (2013).

S2S in Plan View



Deep-time paleohydrologic analysis of trunk river deposits can be linked to volume of sediment in downstream sink (Holbrook and Wanas, 2014).

Modified from Blum and Tornqvist (2000) and Blum et al., (2013).

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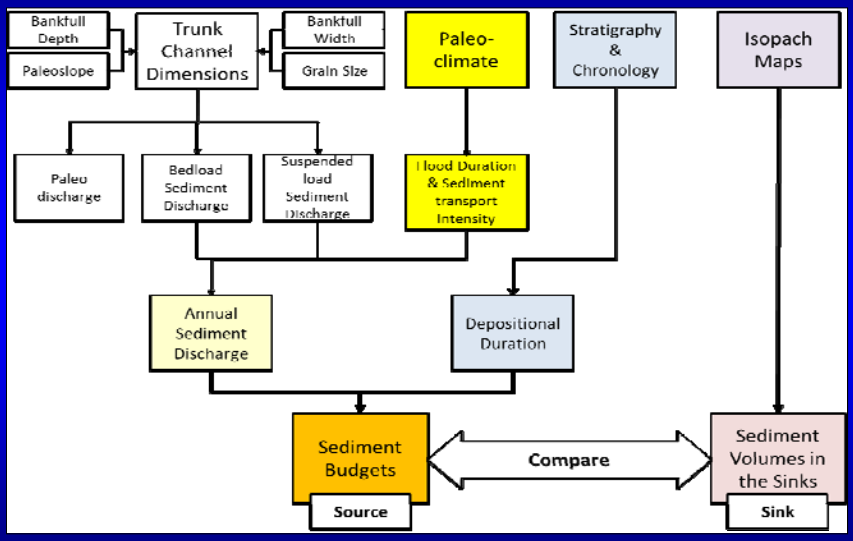
Paleo-sediment budget methods

1. Estimate short and long term sediment discharge (Q_s) of trunk rivers.
   - Compare estimates to deposits in downstream sinks
   - Use empirical relationships to estimate upstream catchment area, relief, and climate regime.
2. Use paleotectonic and paleogeographic reconstruction to estimate likely drainage areas and consequent downstream discharge, or river depth.
   - Compare to scale and size of downstream rivers.

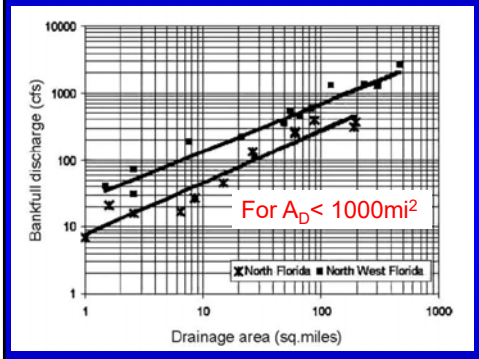
Paleobudget Workflow

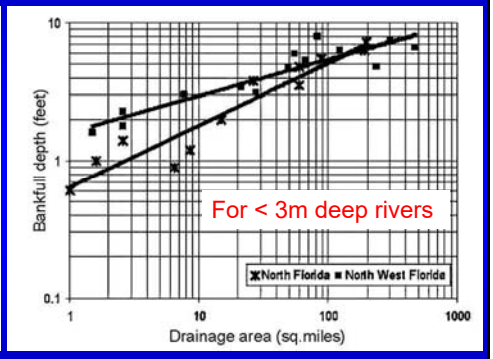


Lin and Bhattacharya (2017, JSR)

Paleoclimate: Regional climate curves predict discharge, channel depth, and drainage area

1. $Q_w = a(A_D)^b$ 2. $D = a(A_D)^b$





Q_W = Bankfull Discharge; D = Channel Depth; A_D = Drainage Area
a and b are empirically derived constants

- Paleosols can be used as climate proxy.

Davidson and North, 2009

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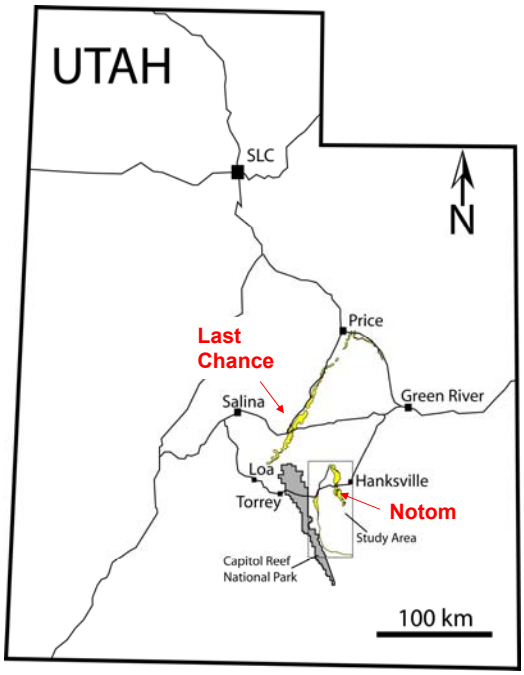
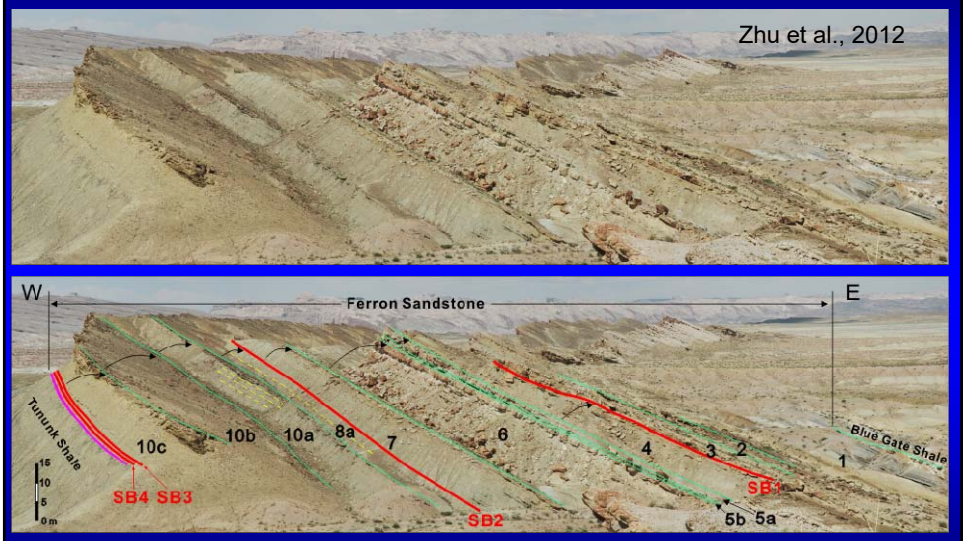
Turonian Ferron Sandstone

- Superb exposures near Capitol Reef, Utah
- 25 students over 11 years

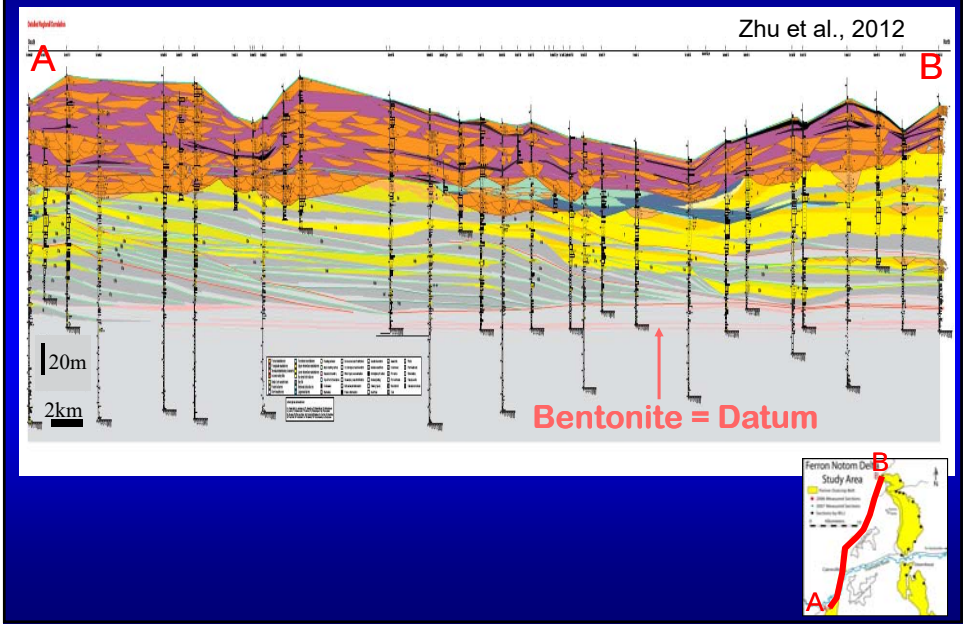


Caineville Reef, Utah

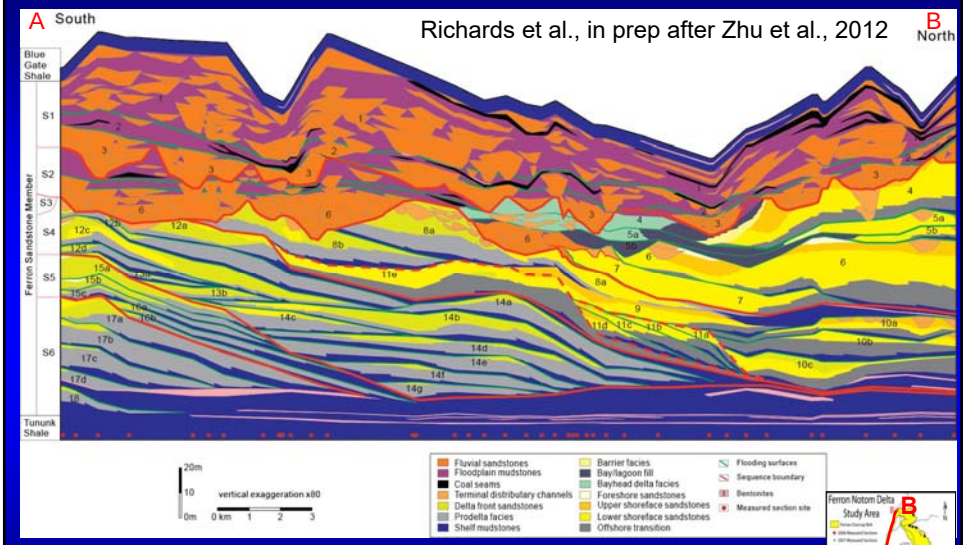


- 20°-30° structural tilt of the outcrops enable walking on hogsback ridges to trace key surfaces and sandstone bodies.

Outcrop Correlation Panel

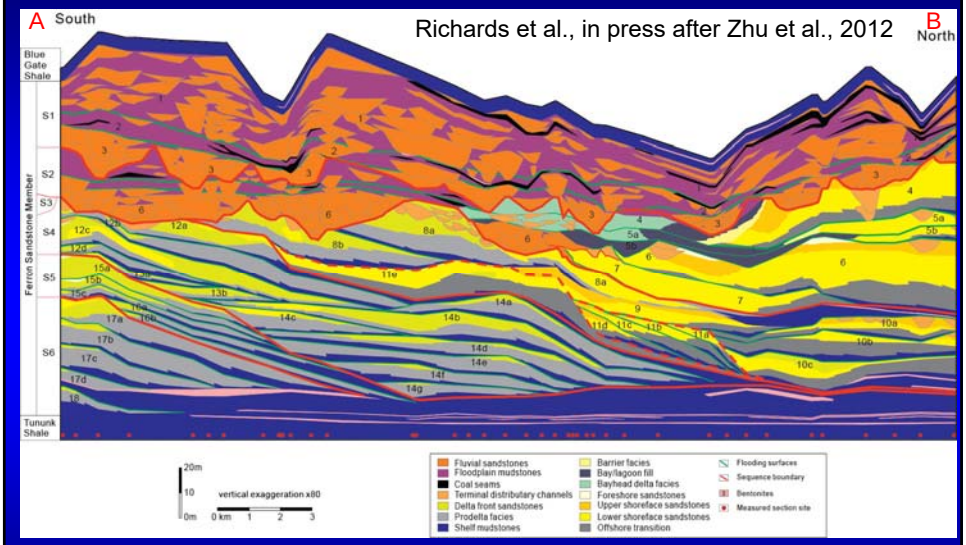


Ferron Sandstone Dip Sequence Stratigraphy

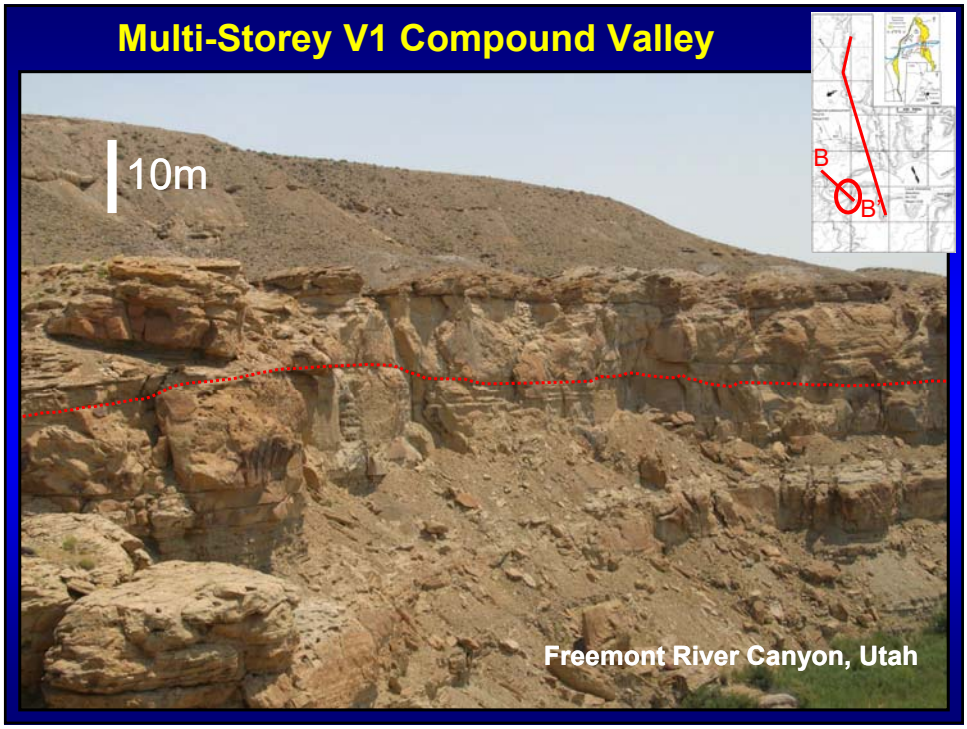


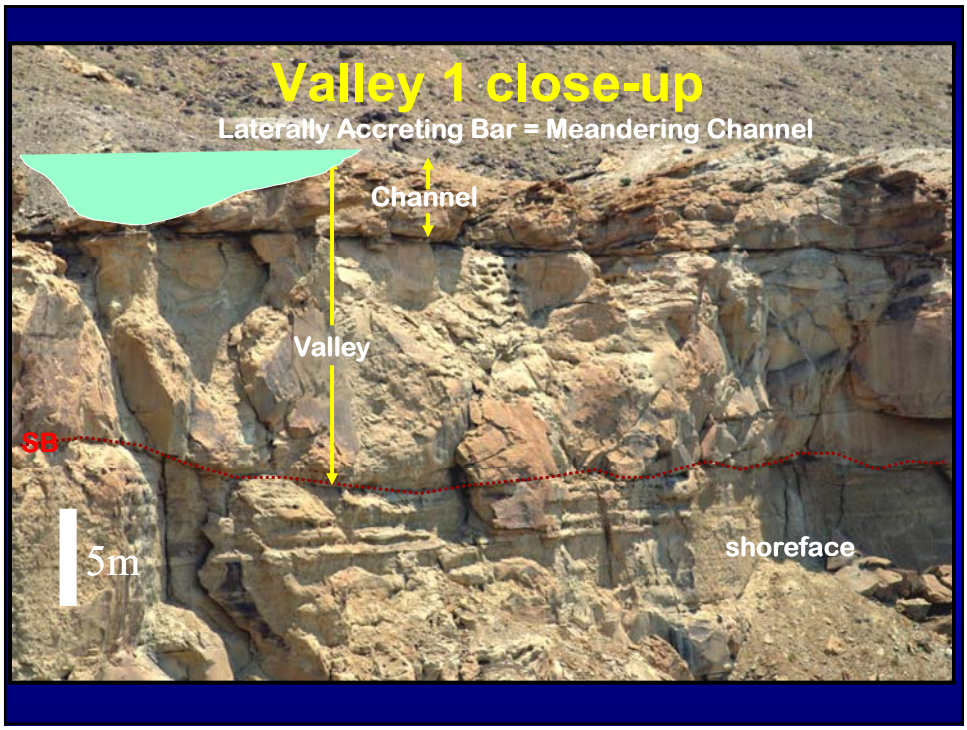
- **43 Parasequences, 18 Parasequence Sets, 6 Sequences**
- **Well-developed parasequence stacking patterns define systems tracts.**

Ferron Sandstone Dip Sequence Stratigraphy



- **Dating of Bentonites shows entire Ferron occupied about 620,000 yrs.**
- **Valleys occupy about ½ a sequence so may have existed for <50,000 years.**
- **Parasequences about 14,000 years**

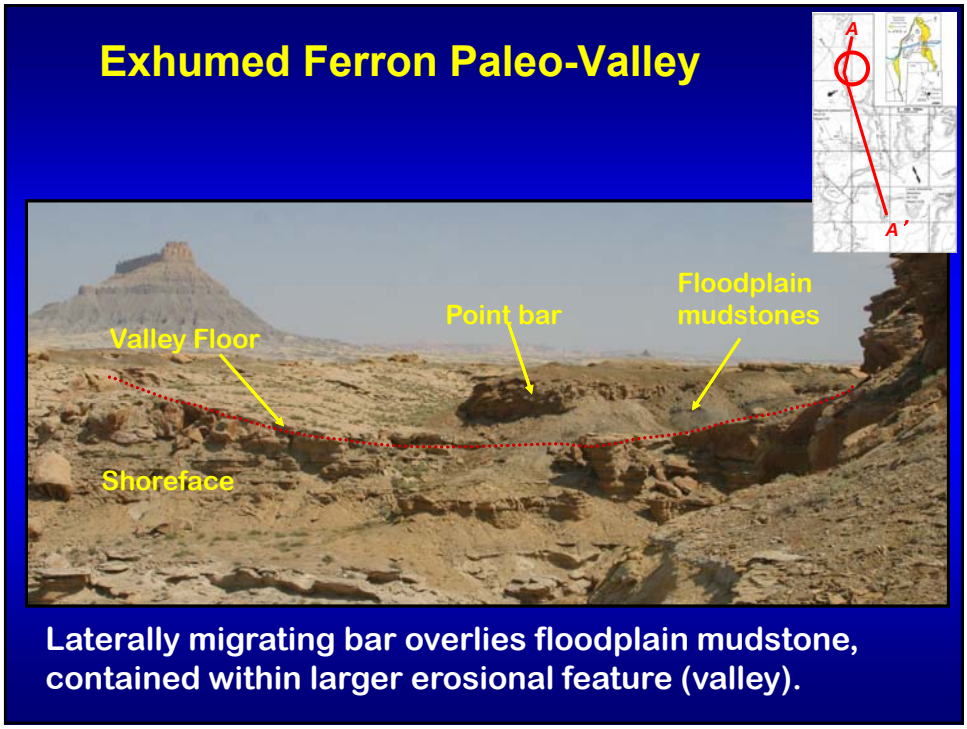

Multi-Storey V1 Compound Valley
10m
B
B'
Freemont River Canyon, Utah


Valley 1 close-up
Laterally Accreting Bar = Meandering Channel
Channel
Valley
SB
5m
shoreface

Channel fills locally conglomeratic

Note: No granules, pebbles, or cobbles are found anywhere in any of the shoreline or delta front parasequences, only in the fluvial facies.

Cross beds


Exhumed Ferron Paleo-Valley
A
A'
Valley Floor
Point bar
Floodplain mudstones
Shoreface
Laterally migrating bar overlies floodplain mudstone, contained within larger erosional feature (valley).


Exh
Rooted paleosol marks interfluve
Valley
Shorefa
cm

Dinosaurs!

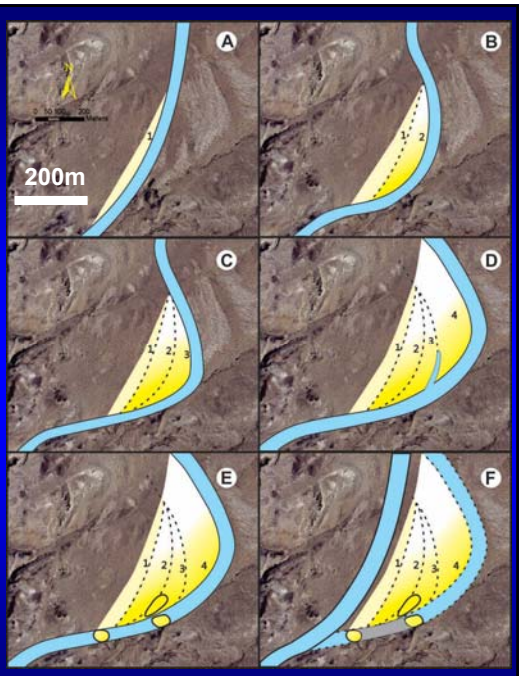
Highstand Fluvial Deposits

- Mudstone Dominated.

In-situ fossilized tree trunk preserved in floodplain lake facies

Evidence for single-thread, meandering streams

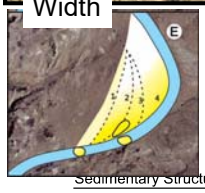
Paleochannels in plan view



Wu et al. 2015

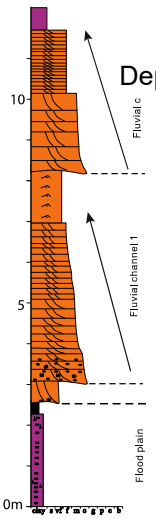
Flow velocity and Discharge estimation

Width

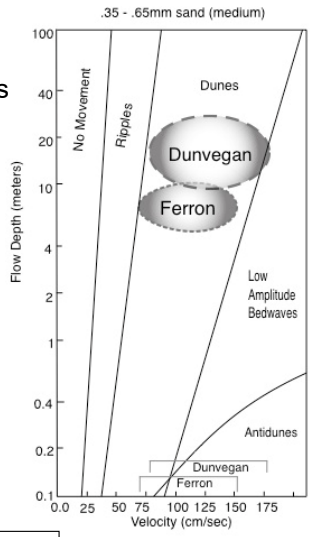


Sedimentary Structures
- Current ripple cross lamination
- Dune-scale cross stratification

Lithologic Accessories
- Mud chips
- Wood chunk
- Coal chips
- Roots
- Plant materials



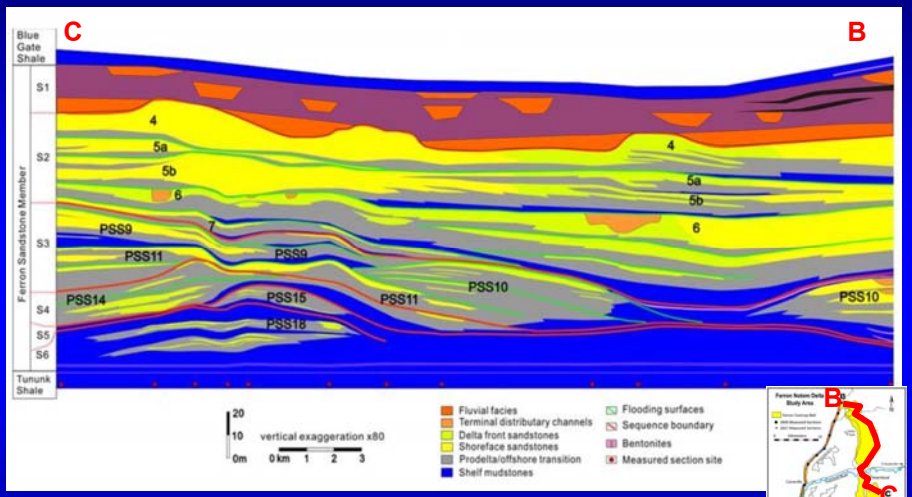
Depth ≅Thickness



$$U = 1/nR^{2/3}S^{1/2}$$

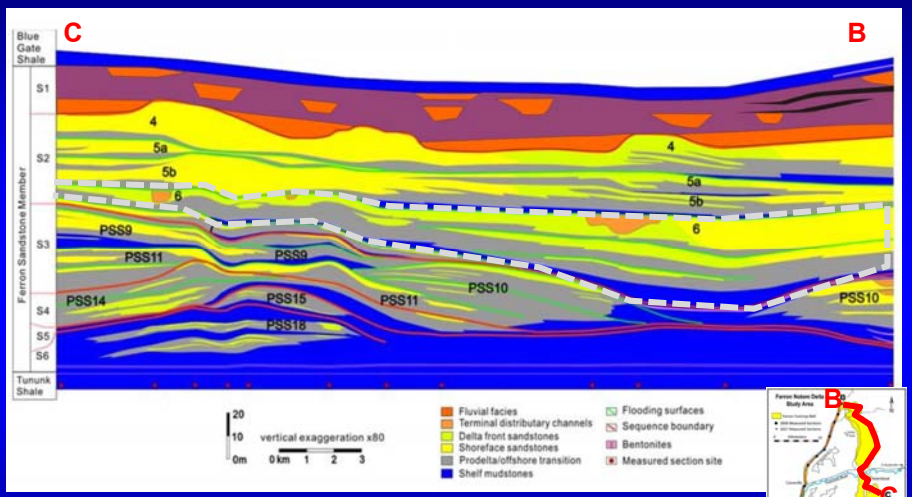
$$Q_w = UA$$

Strike X-Section



Modified from Li et al., 2010 and Zhu et al., 2012

Strike X-Section



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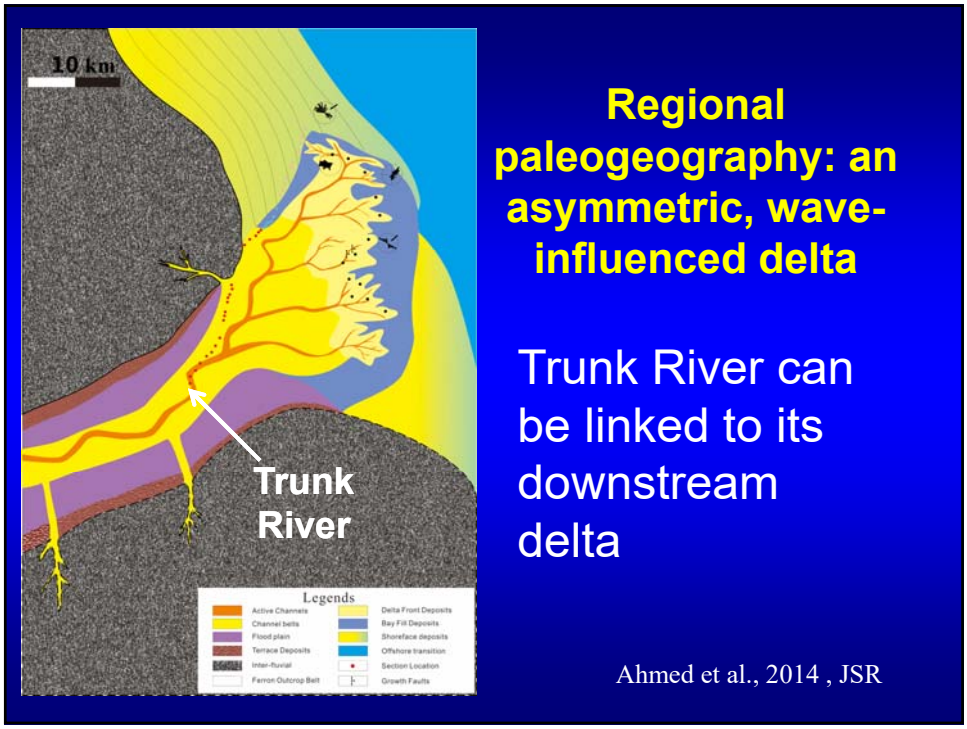
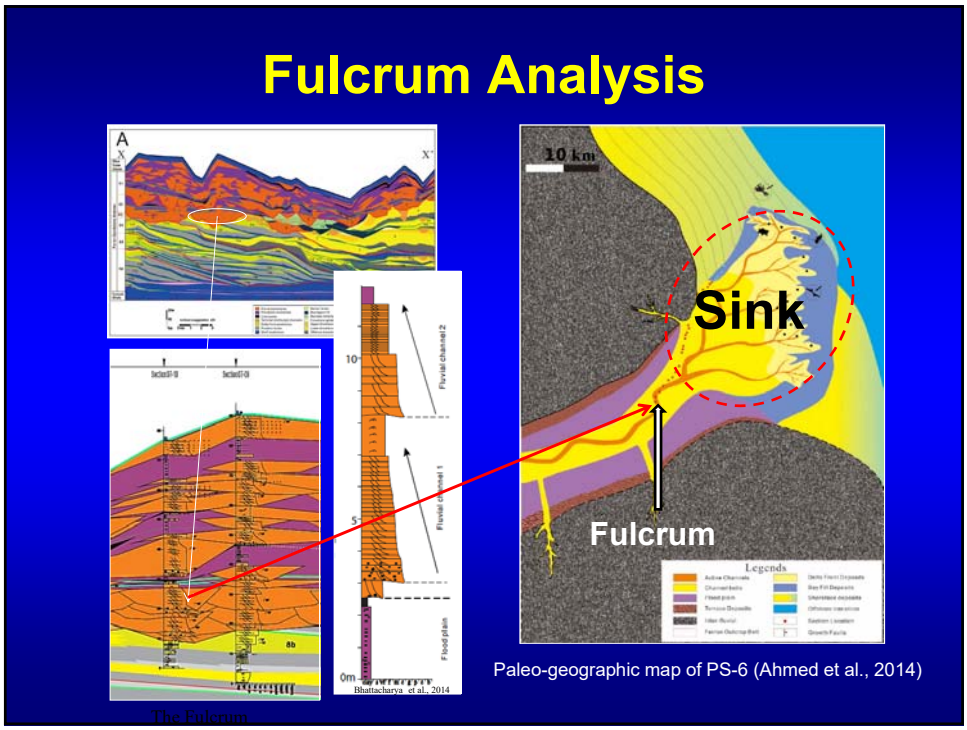

10 km
Trunk River
Legends
Regional paleogeography: an asymmetric, wave-influenced delta
Trunk River can be linked to its downstream delta
Ahmed et al., 2014 , JSR


Fulcrum Analysis
A
X
X'
10
5
0m
Fluvial channel 2
Fluvial channel 1
Flood plain
Bhattacharya et al., 2014
8b
10 km
Sink
Fulcrum
Legends
Paleo-geographic map of PS-6 (Ahmed et al., 2014)
The Fulcrum

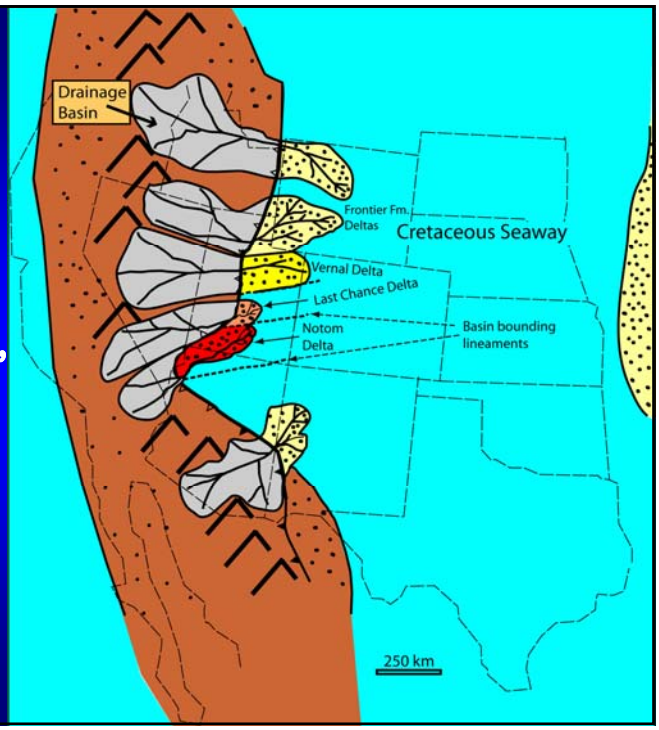
Fulcrum analysis - Ferron Sandstone

Seq	W_{bf} m	D_{bf} m	Grain Size mm	S	U	Q_w	Q_b	Bedload M^3		Qs	Suspended load m^3		Total Load $10^{10}m^3$
			D90 D84 D50 D16	10^{-4}	m/s	m^3/s	m^3/s	Annual 14.6 days 10^5	$14x10^3$ years 10^9	m^3/s	Annual 14.6 days 10^6 m^3	14Ka $10^{10}m^3$	14Ka
2	128	4.4	3.0 2.0 0.6 0.25	4.2	1.7	1030	0.34	4.2	6.1	2.8	3.5	5.0	5.7
	76	3.3		5.6	1.6	420	0.17	2.1	3.1	1.2	1.5	2.2	2.5
	192	5.5		3.3	1.9	2065	0.58	7.3	10.0	5.3	6.7	9.7	11

- Total bedload volume for PS-6 (14,000years):
  - **3 x 10^9 m^3 to 10 x 10^9 m^3 (3km^3-10 km^3)**
- Total mapped bedload in deltaic "sink" (excludes downdrift shoreface):
  - **2.4 x 10^9 m^3 (2.4 km^3) - *this on the low side***
  - Although within the uncertainty range of estimates but could suggests significant sand was transported offshore by hyperpycnal flows and deflected to downdrift shorefaces.

Ferron

- **Drainage basins reconstructed from a variety of sources (e.g., Gardner, 1995).**
- **A ≈ 50,000Km²**



Outline

- S2S Concepts
- Example
- **Evolution of North American Paleodrainage (Mesozoic)**

Triassic

Pangea about to break.
Includes Prudhoe Bay oil field (Alaska).
Dockum Group, TX.

Palo Duro Canyon, Texas
Triassic Dockum Group Redbeds

Superb outcrops suggest 10-15m deep coarse- grained trunk rivers. DZ work extensive but very little facies architecture or up-to-date sedimentology. Paleohydrology awaits! Thesis anyone?

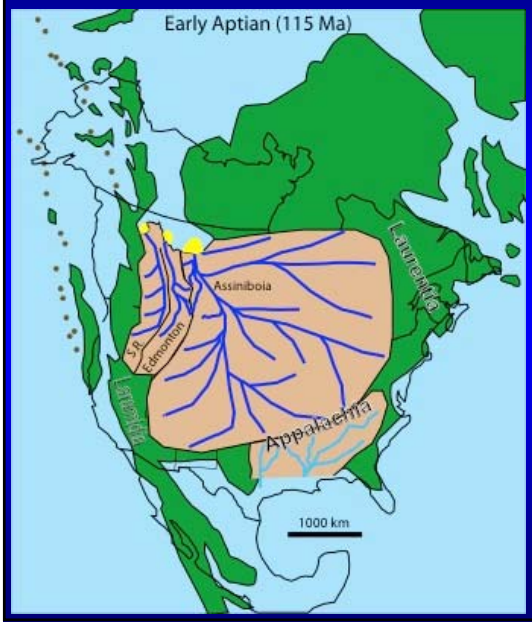
Redbeds and Palosols

Calcareous vertisol (left) with slickensides (top) from Triassic Dockum Group indicate semi-arid floodplain and river channel environment.

Jurassic Morrison

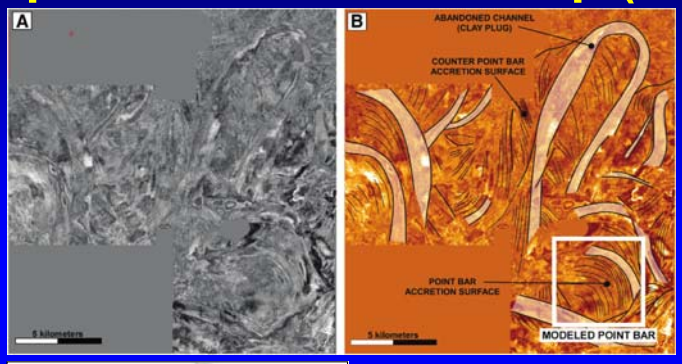
Salt Wash channels gravelly and up to 18m deep.

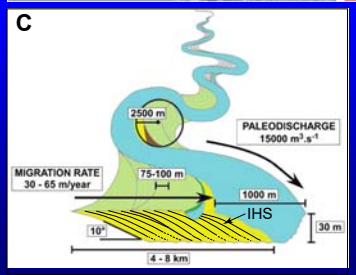
Aptian- Manville Group (Alberta)



Appalachian sources still significant, but increasing sediment contribution from emerging Western Cordillera. Drainage divide in the southern USA.

Aptian- Mannville Group (Alberta)





- Continental-scale medium sandriver
- QW = 15,000m^3/s, D=40m
- S=0.0003 (or lower?)
- Questions about slope and backwater length, >100km.

Aptian- Manville Group (Alberta)

Major change coming next as Cretaceous Seaway expands

Cenomanian

- Less is known about sediment draining into the eastern margin.
- Southern transcontinental arch still significant
- Dunvegan S2S shows 15m deep sandy river, Q_w<6,000 m^3/s.

Turonian

- Increasing amalgamation of western deltaic systems.
- All are relatively small, steep gradient coarse-grained rivers.
- D<10m
- Q_w<2000 m^3/s

Campanian

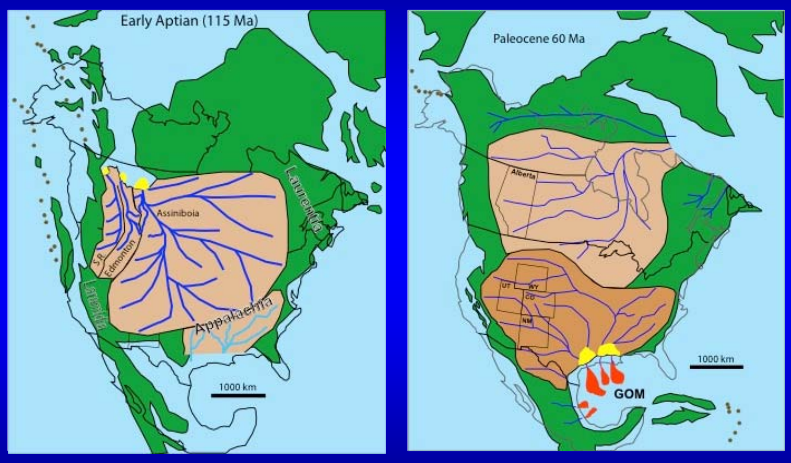
- Extensive transverse-drained Bajada
- Flat-slab subduction results in uplift.
- Belly River (Canada)
- Book Cliffs (USA)
- Difunta Gp. (Mexico)

Paleocene

- Emergence and return to continental-scale drainage.
- Drainage divide closer to USA-Canada border.
- Mississippi-GOM systems.

Big Rivers in North America

Early Cretaceous (Mannville) Paleocene (Mississippi)



Continental scale drainages match large river systems. Overall shift in position of drainage divide reflects plate tectonic controls. Stratigraphy indeed reoords tectonic.s

Small Rivers in North America

- Cretaceous inter-regnum characterized by separate catchments with smaller rivers and deltas largely derived from the increasingly important Cordillera, again reflecting tectonic control.
- High global sea-levels also record tectonic

Small Rivers in North America

- Seaway contains about 3 x 10^9 km^3 of seawater.
- Typical 5-10 m deep Turonian river yields about 300 -1000 km^3 of sediment per 14,000 years. The 8 systems shown would take about 4 billion years to fill the seaway!
- Wedges typically are 1-2 million duration.
- Thus basin at times is chronically underfilled. Either more time or less accommodation is needed (e.g., tectonics).

Outline

- S2S Concepts
- North American paleodrainage
- Conclusions
- The End