Scaling Relationships in Fluvial Systems: Implications for the Mannville Group, Alberta Foreland Basin*

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Abstract

Scaling relationships developed from modern fluvial deposits provide useful guidance for interpretation of the stratigraphic record. At the system level, fluvial channel depth and the related thicknesses of channel-belt sand bodies scale to contributing drainage area, whereas, at the local to subregional level, characteristic width-thickness ratios exist for muddy abandoned channel fills (10–30:1) and laterally amalgamated channel-belt sand bodies (70–300:1). Moreover, net deposition as the river goes through its backwater reach, and feels the effects of sea level, results in significantly less lateral migration before avulsion: although muddy channel-fill dimensions may not change, channel-belt width-tothickness ratios are significantly less (20-50:1), and sand bodies are encased in muddy flood-basin or delta-plain strata. These and other relationships provide insight into the paleogeographic significance and scale of fluvial deposits in the Early Cretaceous Mannville Group, Alberta foreland. At the system level, thicknesses of Mannville point-bar sand bodies commonly exceed 30 m, which suggests a potential drainage area exceeding that of the modern Mississippi. This view is consistent with detrital-zircon signatures of a source terrain that stretched from the Appalachians in the SE US to the Western Cordillera. These two observations converge to indicate that Mannville fluvial-deltaic deposits record the continental-scale river of that time. At the local to subregional level, the well-imaged Lower Mannville McMurray Formation in Athabasca displays channel-fill dimensions consistent with those from modern rivers and sand body width-to-thickness ratios typical of amalgamated channel belts within the upper limits of, or above, the backwater reach. Backwater lengths in large river systems with deep, low-gradient channels can exceed 500 km, which would suggest contemporaneous McMurray shorelines would have been very far to the north of the type area. It would be rare to see tidal effects all the way through the backwater reach of any river, and very unlikely to see brackish conditions recorded this far upstream. Yet, sedimentological and ichnofacies characteristics in these deposits have historically been. and still are in many cases, interpreted to record brackish and/or tidal influences. Observations of scaling relationships for channel deposits therefore provide alternative interpretations of McMurray strata that are guiding ongoing investigations.

Selected References

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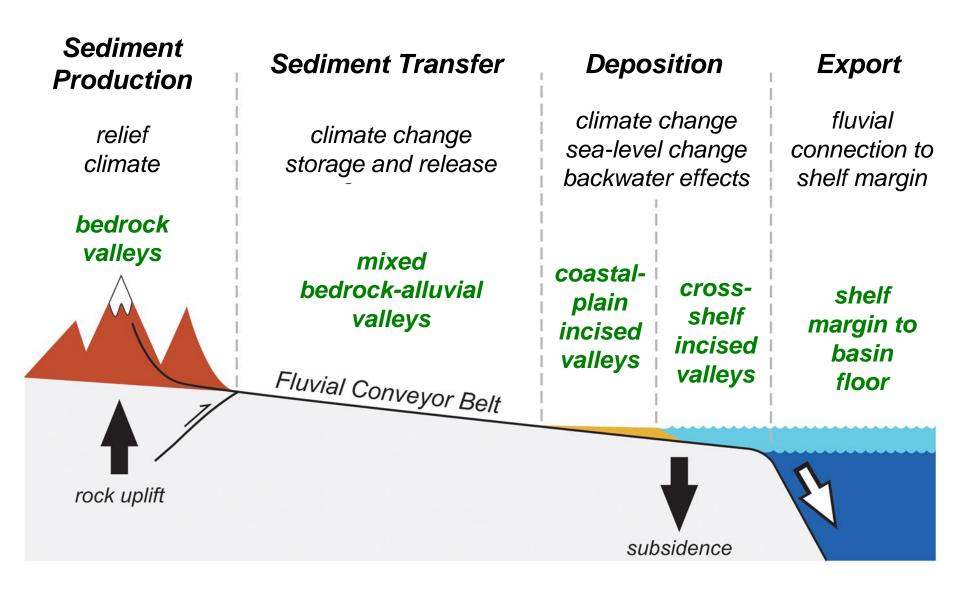
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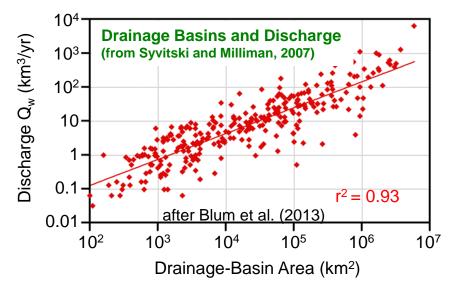
General Outline

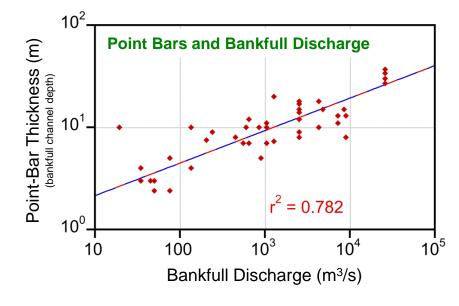
- General Concepts in Fluvial Scaling Relationships
- The McMurray as a Continental-Scale River from Detrital Zircons and Point-Bar Scales
- The McMurray as a Mixed Bedrock-Alluvial Valley System
- McMurray Channels within a Source-to-Sink Perspective.....the McMurray Conundrum.

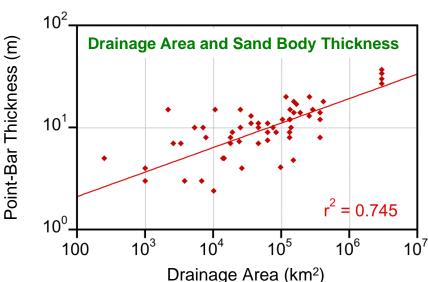
Types of Valleys – A Source-to-Sink View

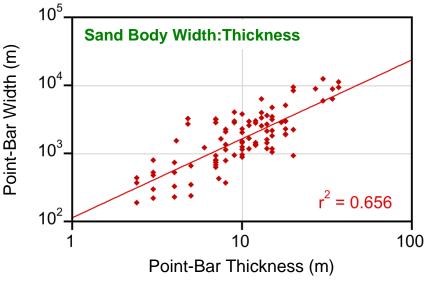


Scaling in Modern Fluvial Systems





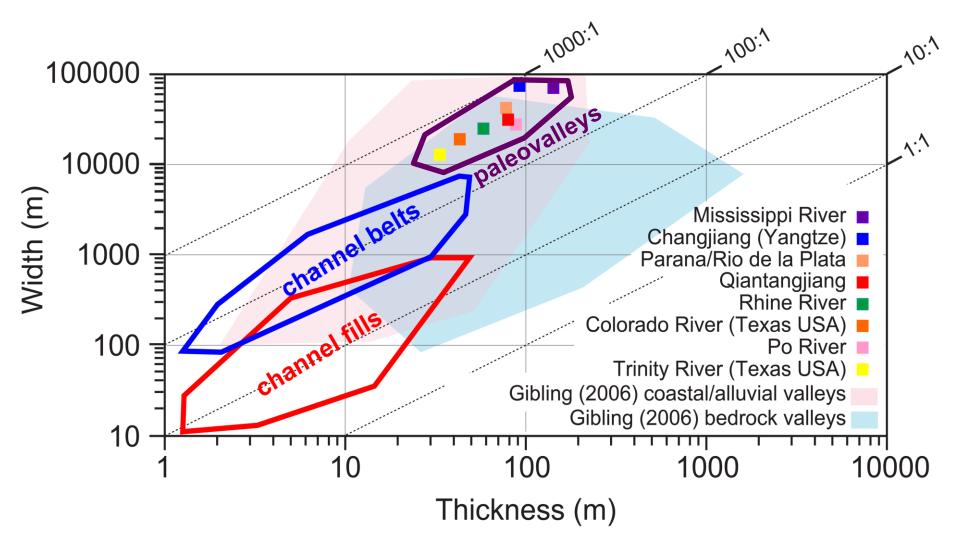




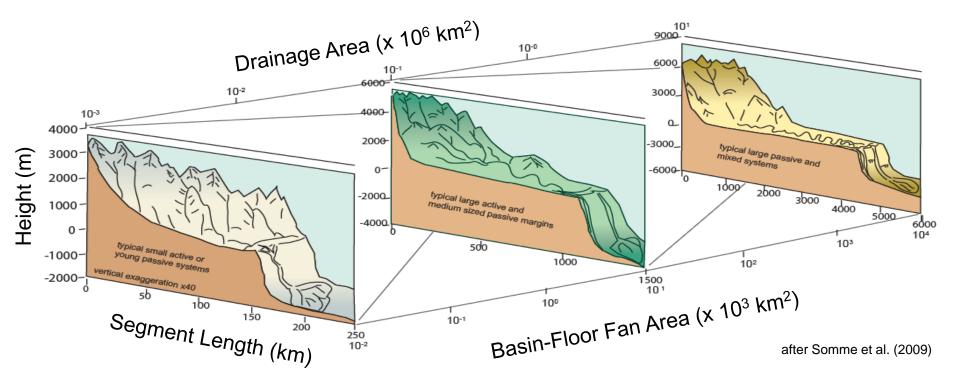
after Blum et al. (2013)

Scaling of Paleovalleys, Channel Belts, and Channel Fills

Quaternary Systems



Summary of 1st-Order Source-to-Sink Scaling Relations

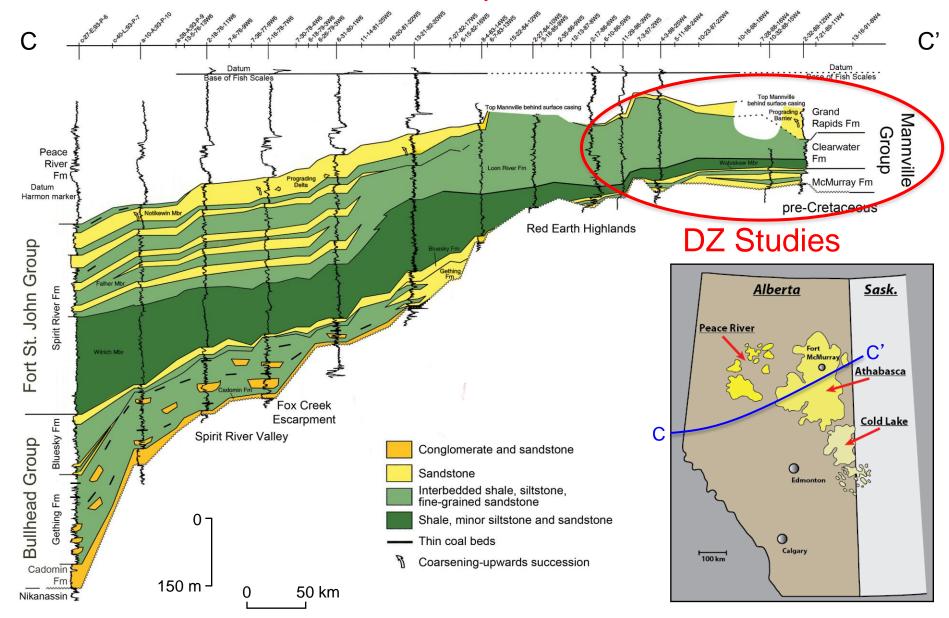


Scaling relationships between drainage-basin area, length of fluvial system, thickness of fluvial sand bodies, length of basin-floor fans, and basin-floor fan area

	Drainage basin area (km²)	Fluvial system length (km)	Fluvial sand body thickness (m)	Backwater Length (km)	Fan Length (km)	Fan Width (km)	Fan Area (km²)
Small	10,000	75-100	5-7	10-30	<25	25-50	<1000
Moderate	100,000	750-1000	10-15	50-100	100-200	100-200+	100,000
Large	1,000,000+	2000-4000	25+	300-500+	500-1000	500-1000+	10,000,000

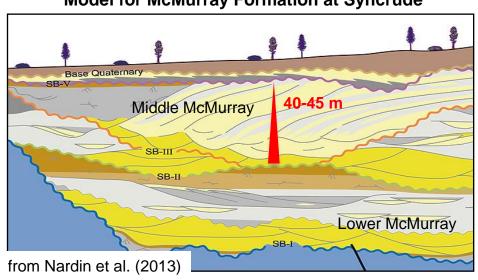
after Somme et al. (2009) and Blum et al. (2013)

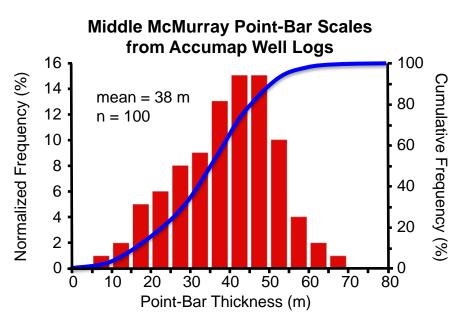
Lower Cretaceous Mannville Group - Alberta Foreland Basin



The McMurray Deposited by a Continental-Scale River?





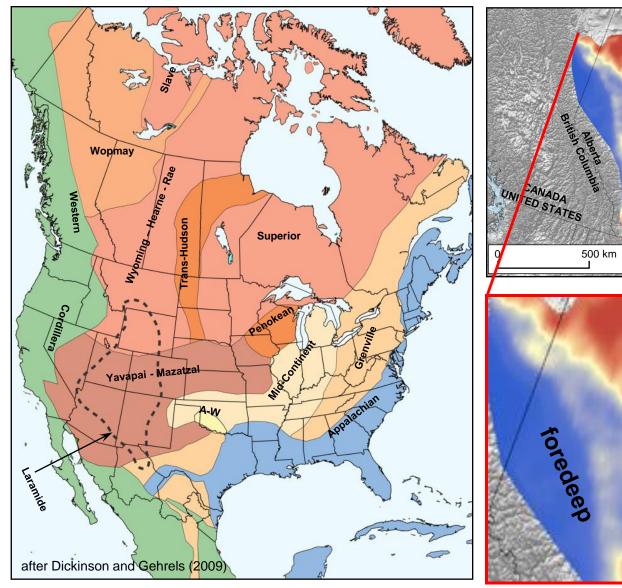


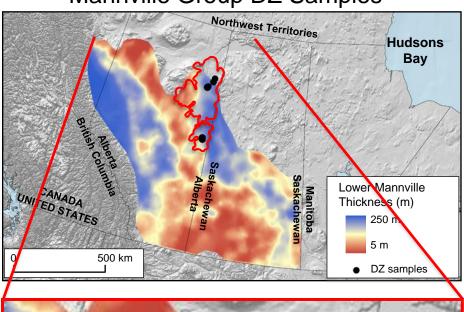


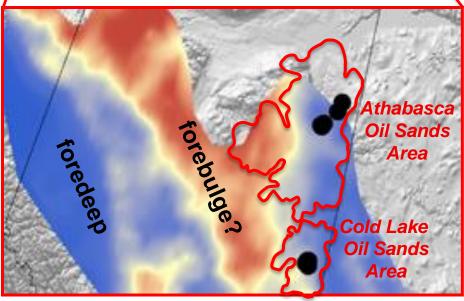
DZ Results - Lower Cretaceous of the Alberta Foreland Basin

North American DZ Source Terranes

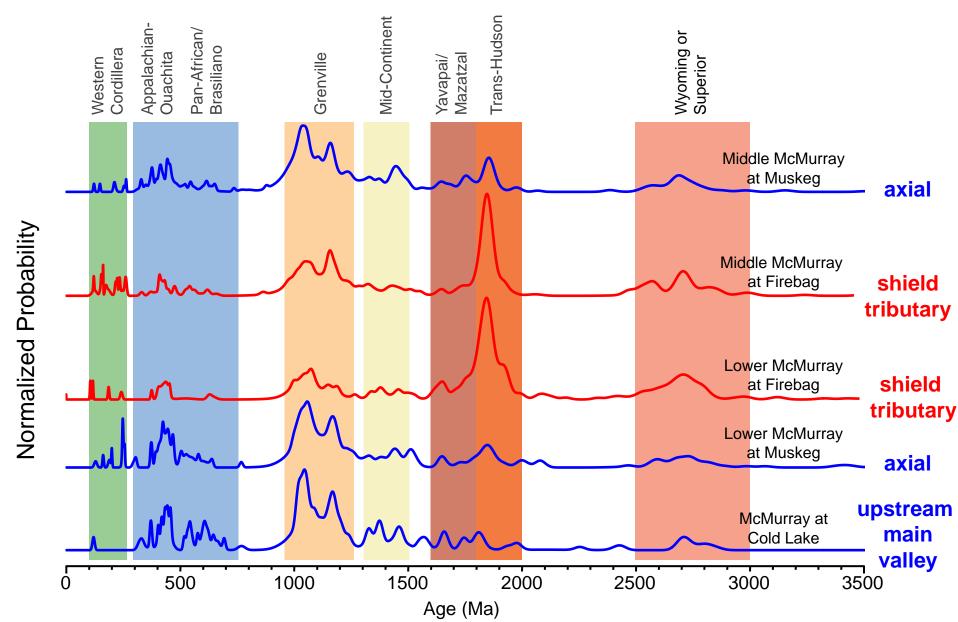
Mannville Group DZ Samples





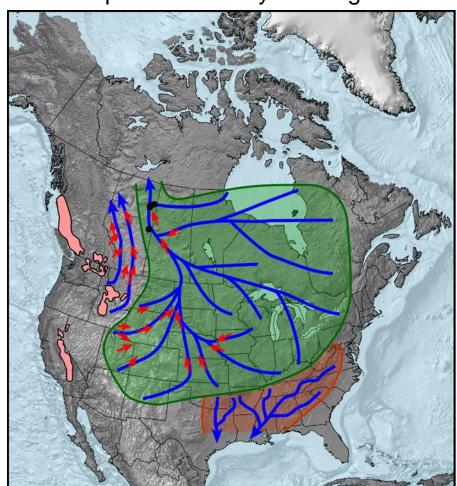


DZ Signature for the McMurray Formation



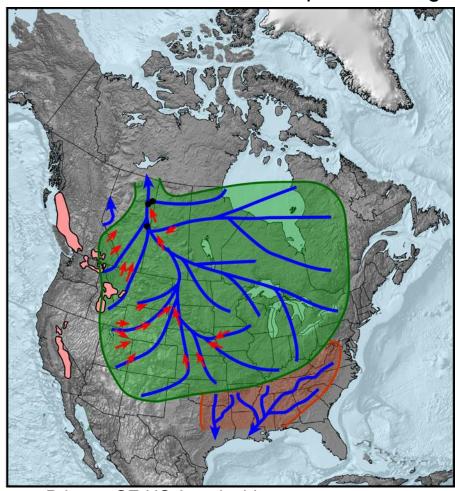
Early Cretacous Paleodrainage Reconstruction from DZs

Aptian McMurray Drainage



- Primary SE US Appalachian source
- Tributaries from the Canadian Shield
- Tributaries from the SW US

Albian Clearwater-Grand Rapids Drainage

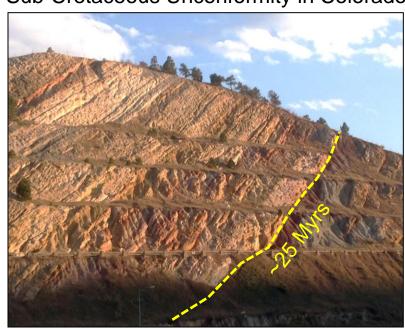


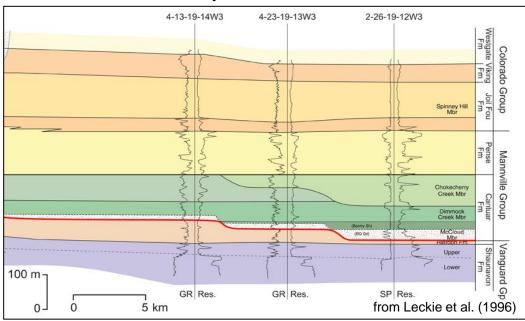
- Primary SE US Appalachian source
- Tributaries from the Canadian Shield
- Tributaries from the SW US
- Tributaries from the NW US and SW Canada

The McMurray as a Mixed Bedrock-Alluvial Valley System?

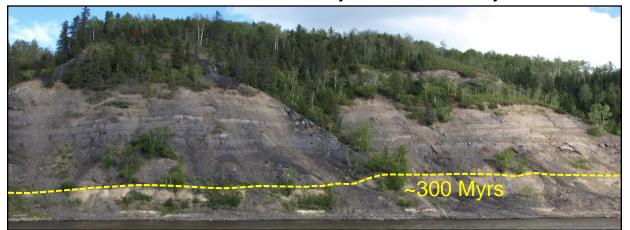
Sub-Cretaceous Unconformity in Colorado

Bedrock Valley in SW Saskatchewan



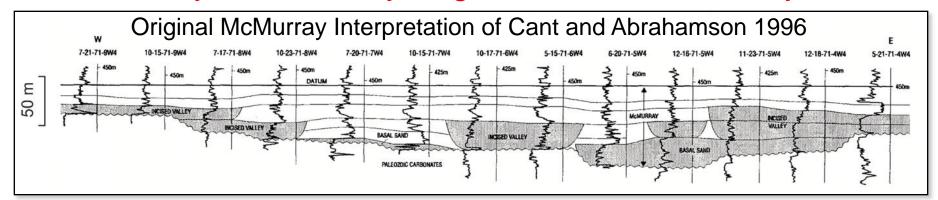


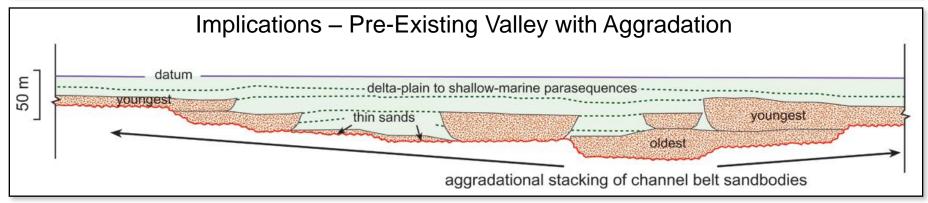
Sub-Cretaceous Unconformity in Ft. McMurray Area

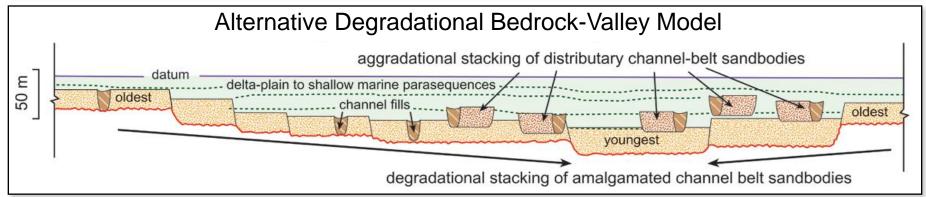




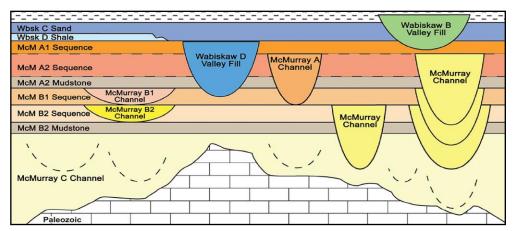
Bedrock Valleys – Inherently Degradational over >>10⁶ yrs

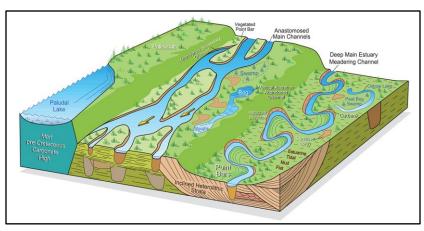


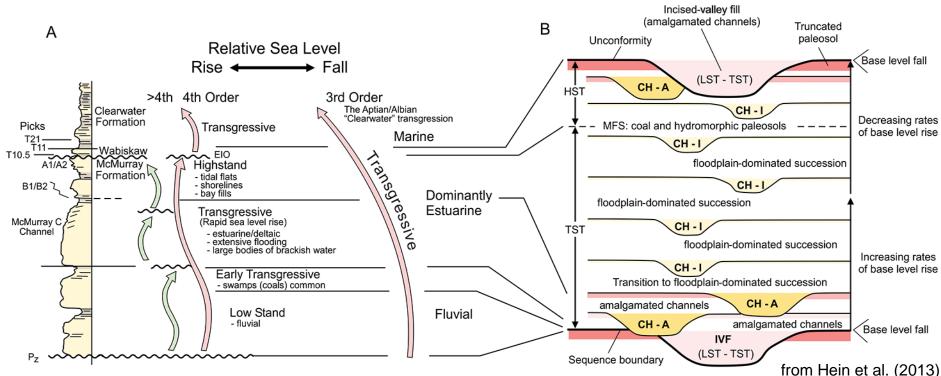




McMurray as an Estuarine and Tidally-Influenced Fluvial Deposit?

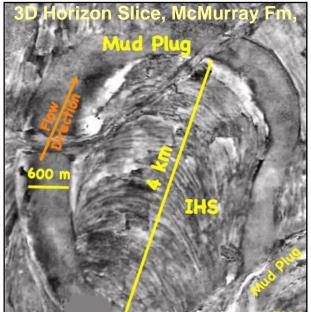


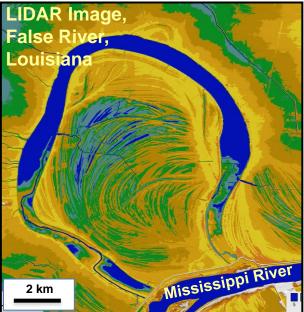


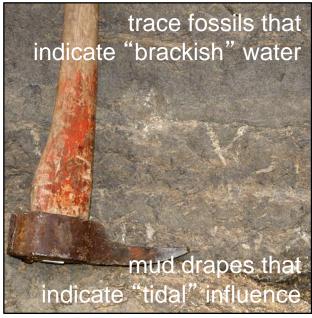


Conflicting Observations and the "McMurray Conundrum"

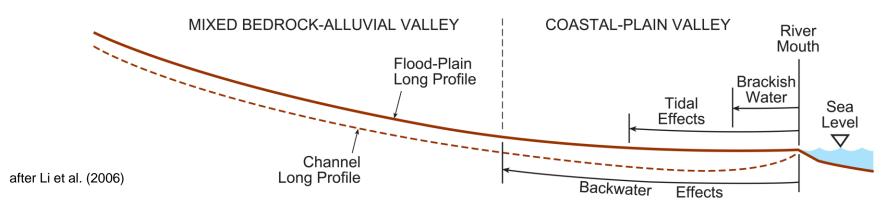




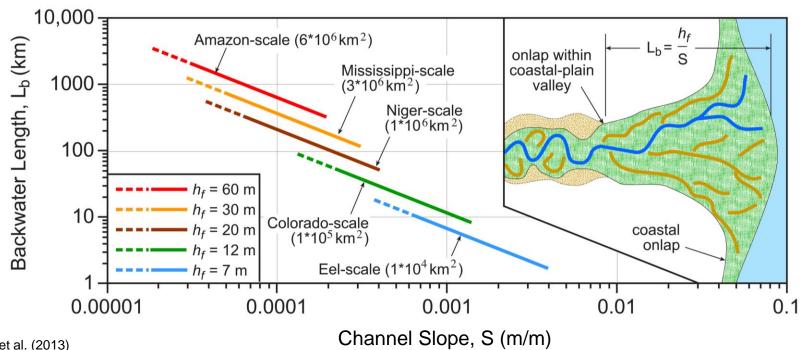




The Backwater Concept

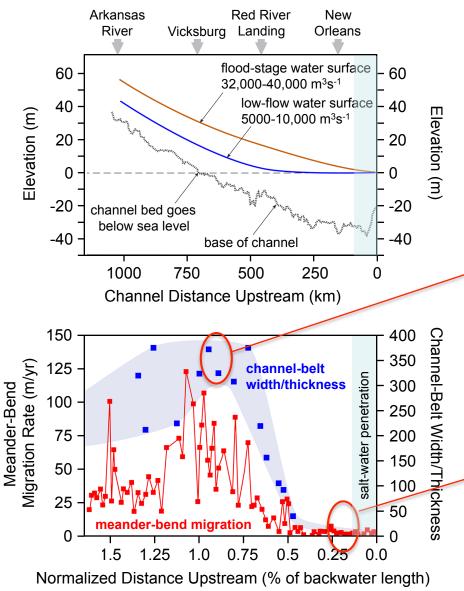


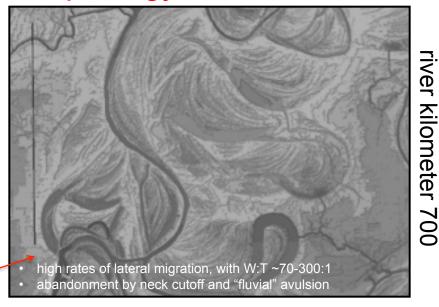
Backwater Length Scales

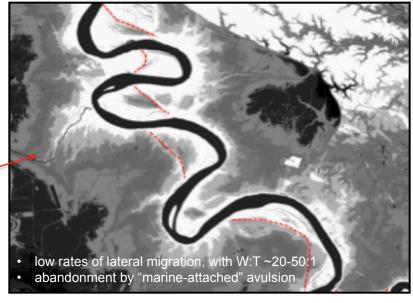


after Blum et al. (2013)

Backwater Effects on Channel-Belt Morphology and Scales



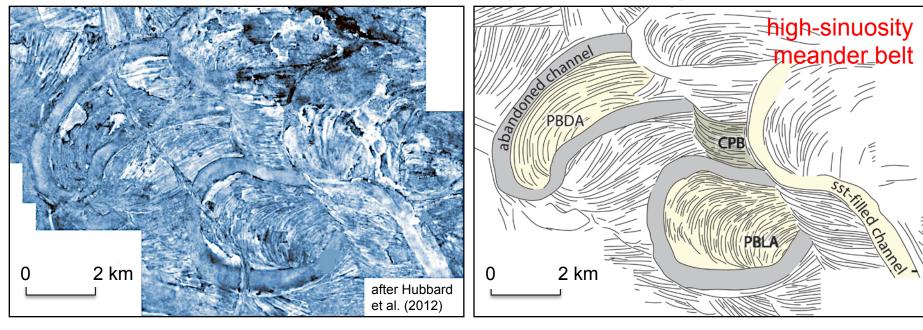




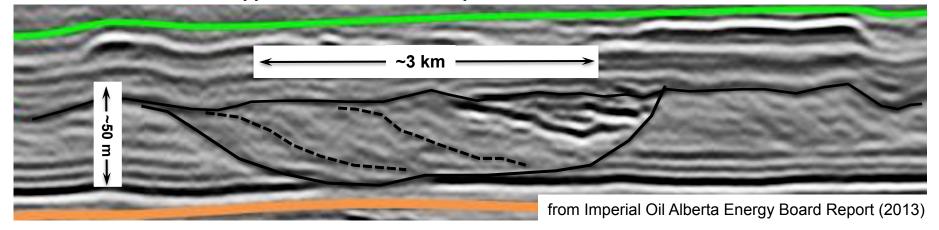
river kilometer 200

Mannville Group Channel-Belt Sand Bodies and Channel Fills

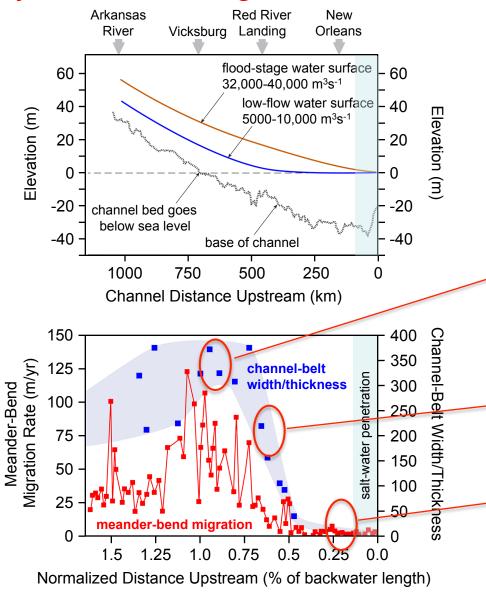
Lower Mannville Middle McMurray Formation at Long Lake

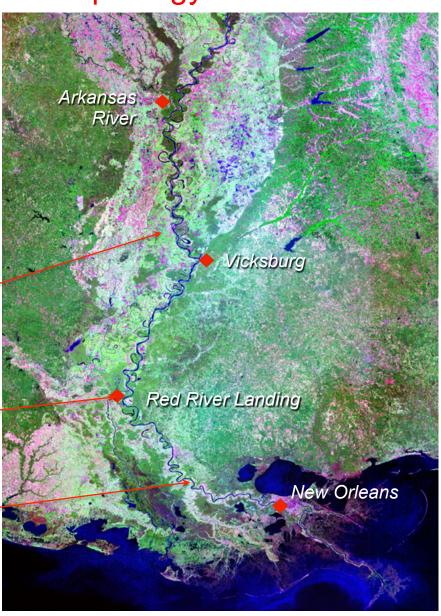


Upper Mannville Grand Rapids Formation at Cold Lake



Systematic Changes in Channel-Belt Morphology and Scales





after Hudson and Kesel (2000), Nittrouer et al. (2011), Blum et al. (2013)

SUMMARY

From detrital zircons and point-bar scaling relationships, the Aptian McMurray Formation records a continental-scale drainage, the Mississippi of its time:

- The McMurray is part of a long-lived mixed bedrock-alluvial valley system that extends from the Appalachians and shield to the Sevier fold and thrust belt, with major tributaries joining from the shield all the way to the Ft. McMurray "Athabasca Oil Sands Area".
- Mixed bedrock-alluvial valleys are inherently degradational due to rock uplift, and usually consist of broad terraced valleys, a model that requires a different correlation framework.

Interpretation of the primary Middle McMurray reservoir depositional environment is a conundrum, with observations that are not easily reconciled and need to be further investigated for practical and scientific reasons.

- Trace fossils and sedimentary structures have long been interpreted to represent tidally-influenced fluvial deposition, or even deposition by tidal bars within an estuary
- This interpretation is inconsistent with scaling relationships from seismic data, which place the McMurray too far upstream to be significantly impacted by tidal processes, and way too far upstream for brackish influence.