Fluvial Channel Belt Reservoirs*

Brian J. Willis[1], Richard Sech[1], Tao Sun[1], Michael Pyrcz[1], and Sean Connell[1]

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[1]Earth Science, Chevron Energy Technology, Houston, TX, USA (BWillis@chevron.com)

Abstract

Modern rivers are commonly classified as meandering or braided, but this distinction poorly differentiates the range of interval heterogeneities observed in fluvial channel-belt reservoirs. The problem with this division applied to reservoir type is that class definition is based on unrelated variables (sinuosity in one case, and number of active channel threads in the other), and inferences about a range of other variables that are only weakly related (e.g., mean grain size). Large-scale heterogeneity patterns within channel belts are generally not channel-shaped features, but rather reflect bodies formed as channel segments migrate and then are cut off. These bodies ("storeys") generally scale to formative river discharge (controlling channel width & depth and the downstream length of adjacent bars). The sinuosity of individual channel segments (before cutoff) defines the width/length ratio of these bodies and internal grain size patterns. Deposits within storeys can be divided into different depositional zones with distinct lateral grain-size trends across the channel bed (which can become vertical trends within the deposits by Walters' law shifts in bed position): inner-bank (bar), concave bank, and abandonment fill. Inward fining across the inner-bank zone bed becomes more pronounced with distance downstream along a channel bend and channel sinuosity. Upward-fining deposits are preferentially preserved when a channel bend migrates more downstream relative to rates of expansion. Concave bank zone deposits are highly variable depending on whether deposits form due to eddy aggradation or downstream accretion. Channel-fill-zone grain-size trends depend on rates of channel segment abandonment and vertical aggradation vs. lateral-fill deposition. The width of a channel belt formed by a river of given discharge increases with the sinuosity of individual channel segments and the number of storeys laterally stacked during the sum of channel-bend expansion and cutoff events before river avulsion. Connectivity patterns of subsurface fluid flow along a channel belt depends on storey internal character, lateral stacking pattern, net aggradation, and the width spanned by the final fill formed during belt avulsion.

Selected Reference

Willis, B.J., and H. Tang, 2011, Three-Dimensional Connectivity of Point-Bar Deposits: Journal of Sedimentary Research, v. 80/5, p. 440-454.

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Brian J. Willis, Richard Sech, Tao Sun, Michael Pyrcz, and Sean Connell
Earth Science, Chevron Energy Technology, Houston, TX, United States.

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Fluvial Channels

Bed is flat along cross over and dips most steeply outward at bend apex

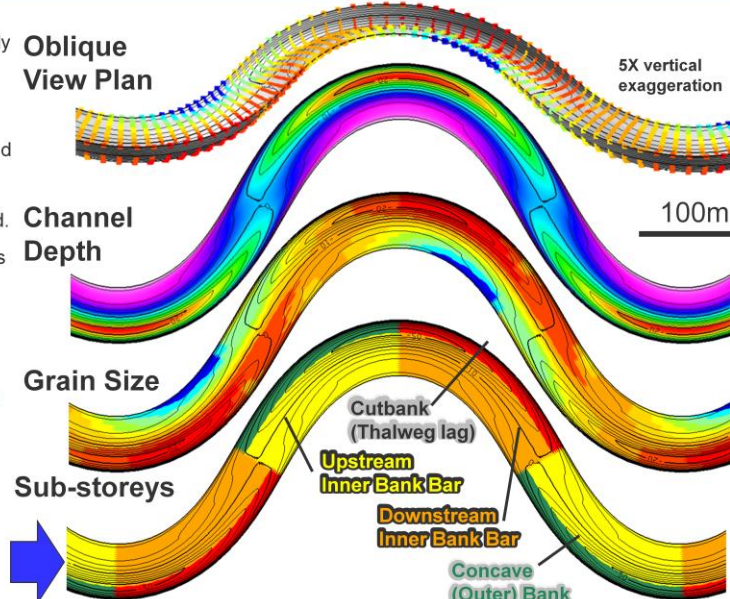
Grains are weakly sorted across the bed in the upstream parts of the bend and progressively more inward fining toward downstream parts of bend.

Grain size patterns across the channel bed can be simplified to occur within five depositional zones:

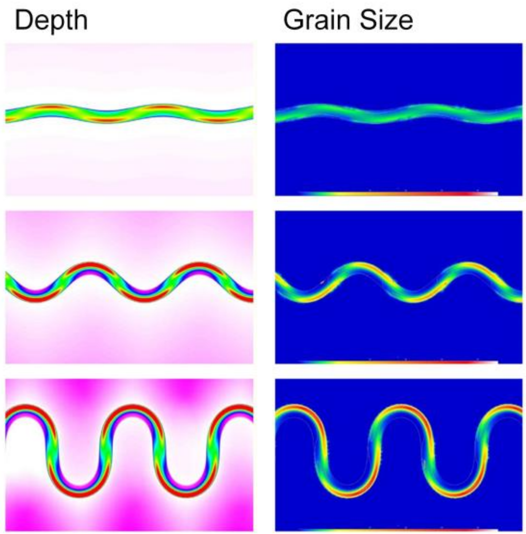
Zones within Channels

1) Upstream Inner bank
2) Downstream inner bank
3) Concave Bank
4) Cutbank (Thalweg)
5) Abandonment fill

Flow direction

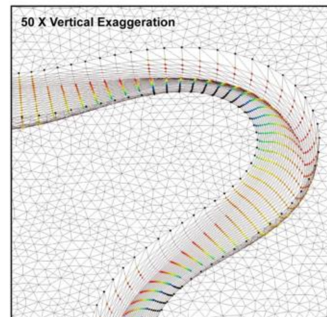


Fluvial Channels



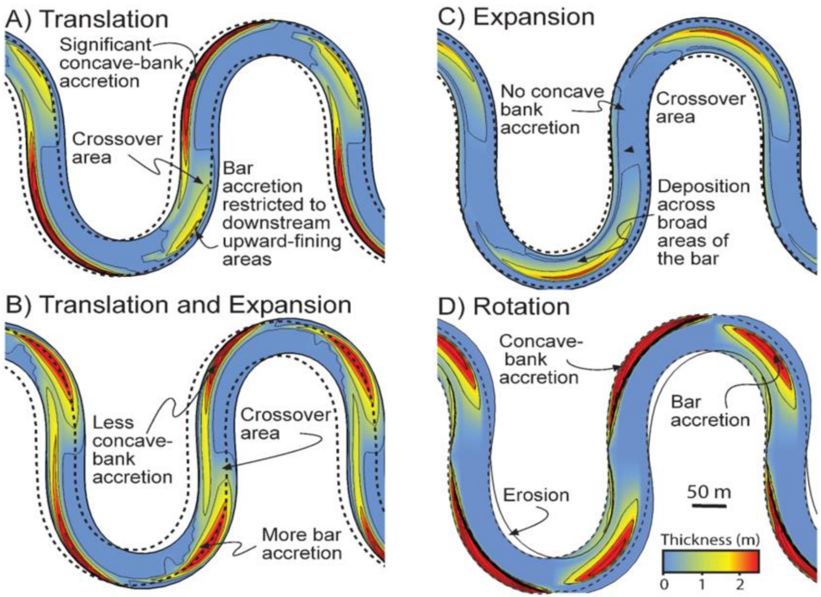
Storeys record changes in the bed position, shape and grain size during channel bend migration.

- **Bed topography increases with sinuosity**
- **Maximum depth increases with sinuosity**
- **Grain sorting across the bed increases with sinuosity**

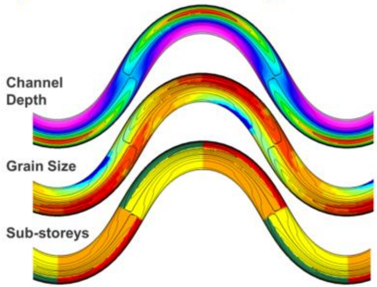


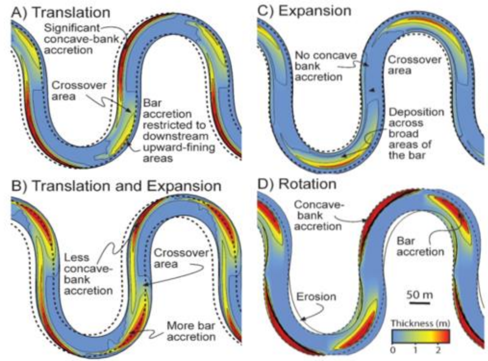
Channel Segment Migration

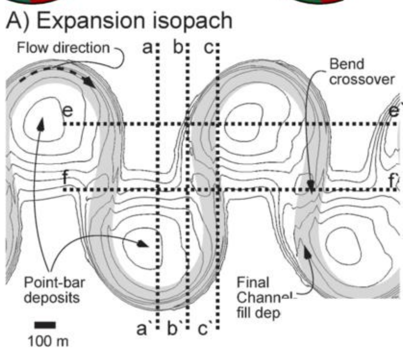
Location of Deposition

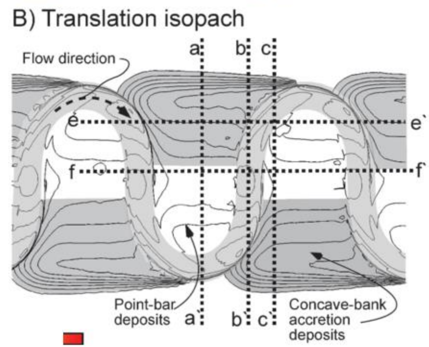


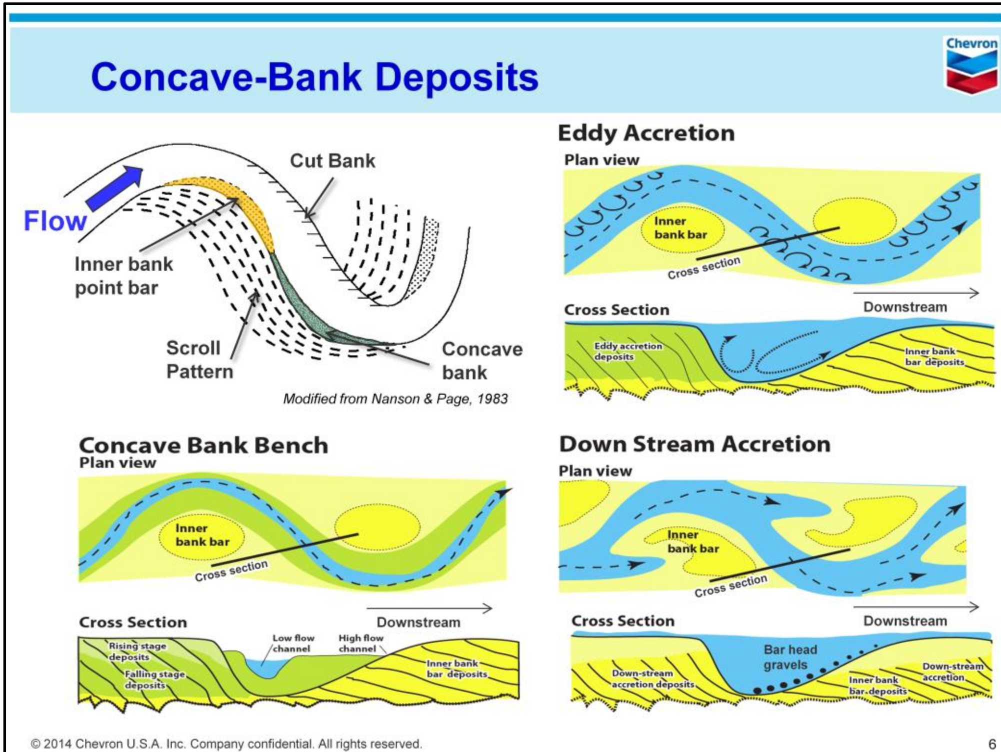
Forming a Storey Deposit by Channel bend migration





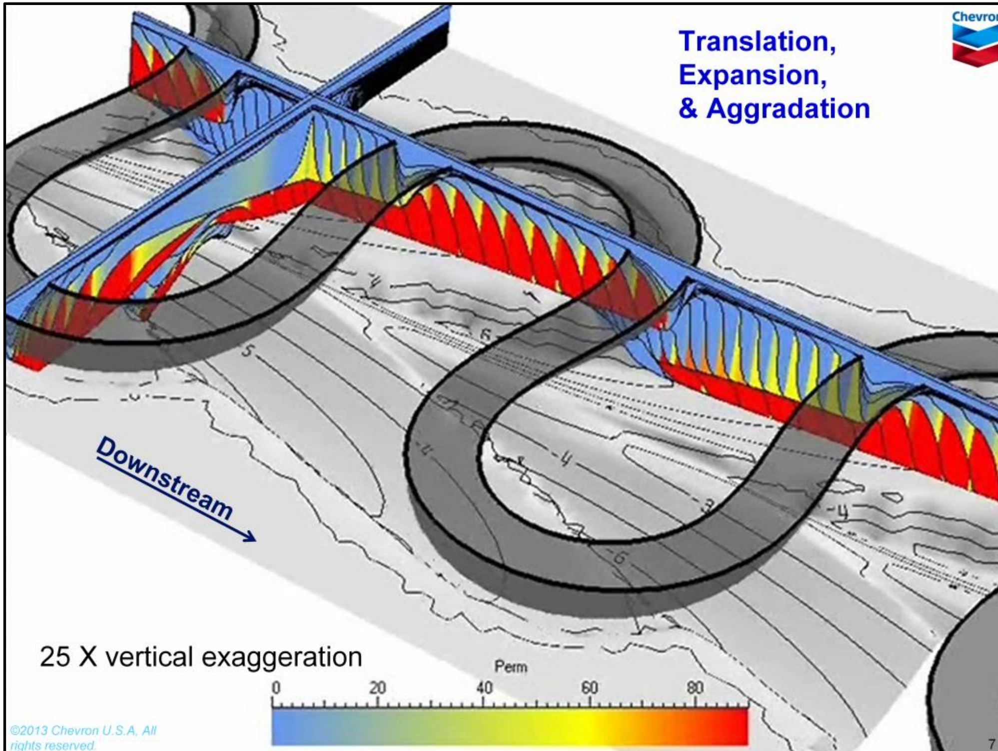






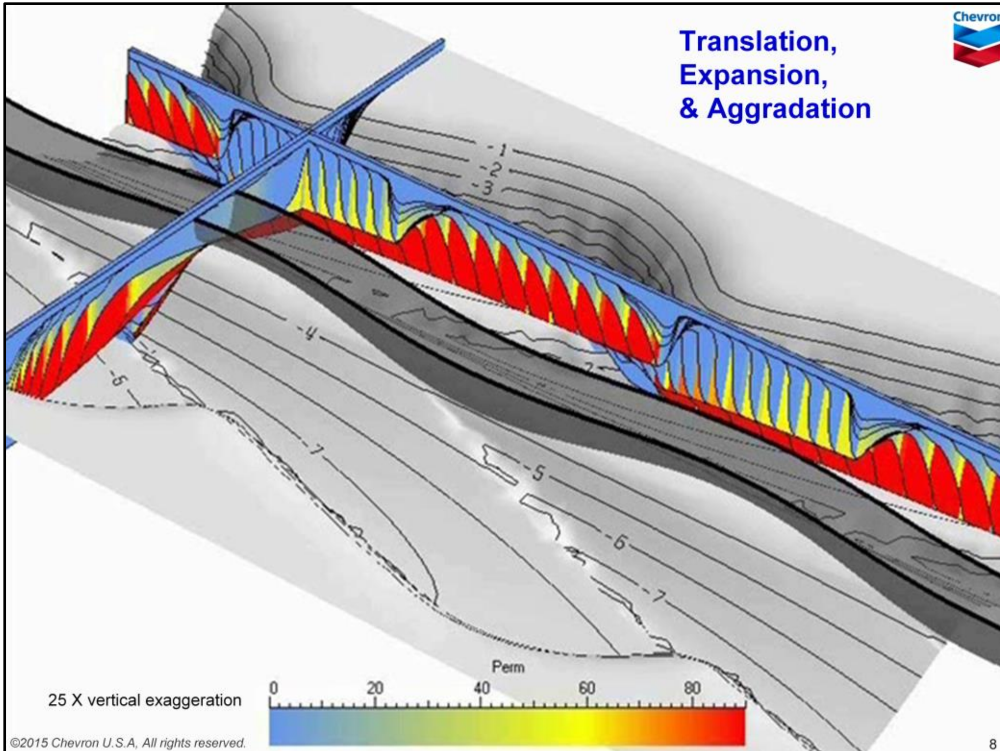
Presenter's notes: A number of different models have been proposed for the formation of deposits in the concave bank zone, and folks use different names for these deposits: for example counterpoint bar, eddy accretion, concave bank bench. I do not have time to go into all the details, but I see two end member types. The concave bank deposits might be finer-grained relative to the inner bank bar deposits. The mechanisms to form these finer-grained deposits include: 1) simply continuing the inward fining along the point bar down stream into the concave bank zone, 2) The idea that there is a eddy flow separation zone that preferentially attacks finer deposits in the concave bank zone, or 3) that low flow deposits or overbank deposit slumps are preserved in this zone between episodes of river flood induced bend migration. Alternatively, the concave-bank deposits might be fairly coarse-grained, with average grain size similar to that of the inner bank bar deposits. The most obvious mechanism for this is that deposits accumulate in this zone by sediment bypass over the top of the bar, and fill this zone by downstream accretion. So just to make it simple, I generally refer to the concave bank deposition as eddy accretion or downstream accretion…even though it may be more complex than this.

Translation, Expansion, & Aggradation



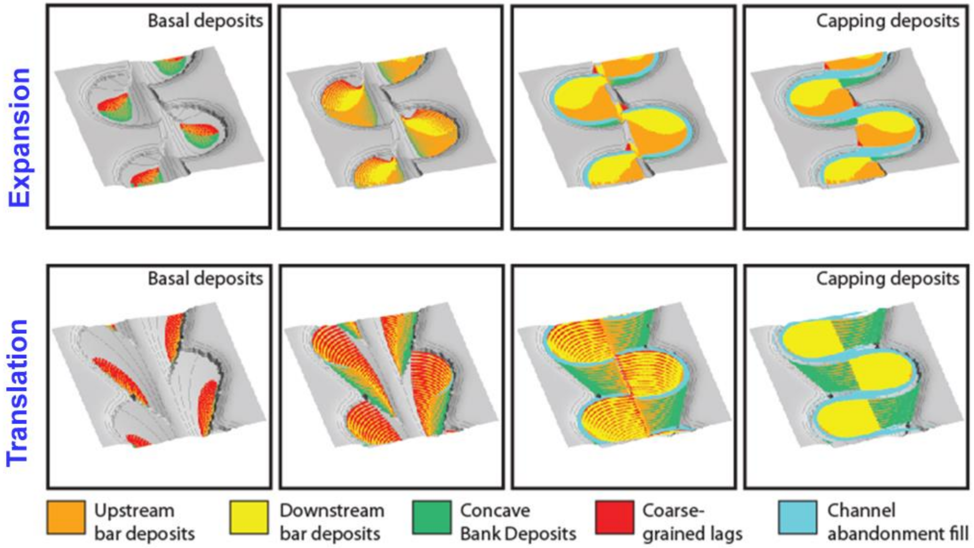
25 X vertical exaggeration

Translation, Expansion, & Aggradation

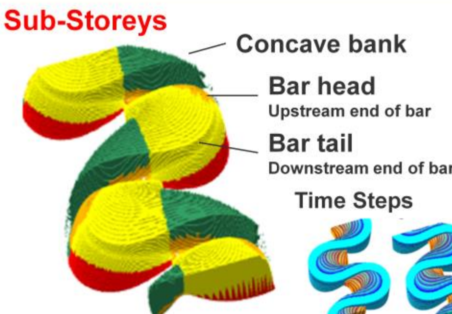


25 X vertical exaggeration

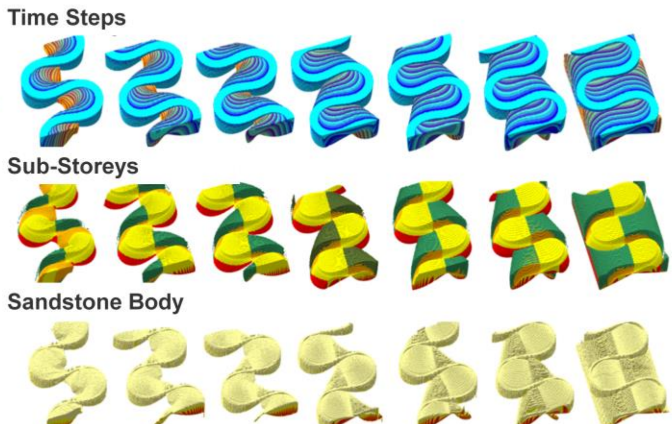
Sub-Storey Patterns within Channel Belts



Channel Migration and Preserved Sub-Storeys



Final sand body geometry within belt depends on what sub-storeys preserved during channel migration.



Migration Dominated by Expansion

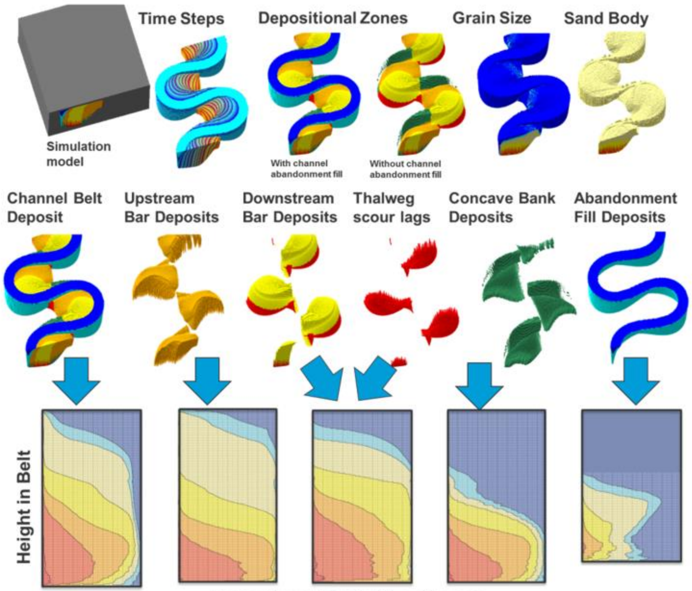
Sub-Storeys

Bar Head
Blocky

Bar Tail
Bell

Concave Bank
Minor volume

Channel Fill
Fine-grained



Migration Dominated by Translation

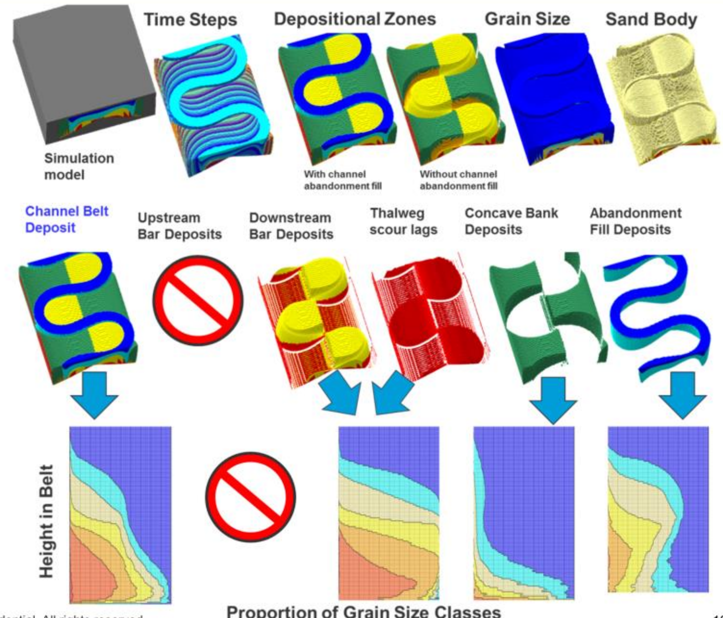
Sub-Storeys

Bar Head
Not Preserved

Bar Tail
Bell

Concave Bank
Fine-grained

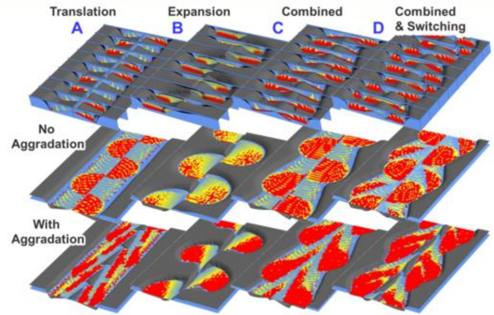
Channel Fill
Fine-grained

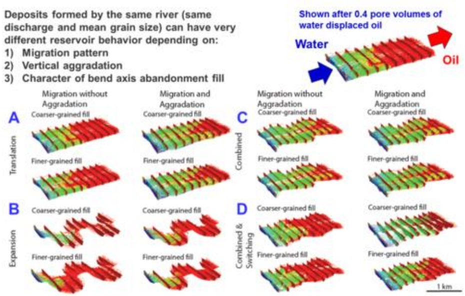


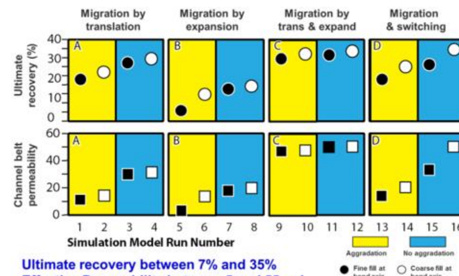
Same River – Different Channel Belt Reservoirs

Different channel belts formed by a river of the same size, mean grain size and final sinuosity.

Differ only in migration pattern and amount of vertical aggradation





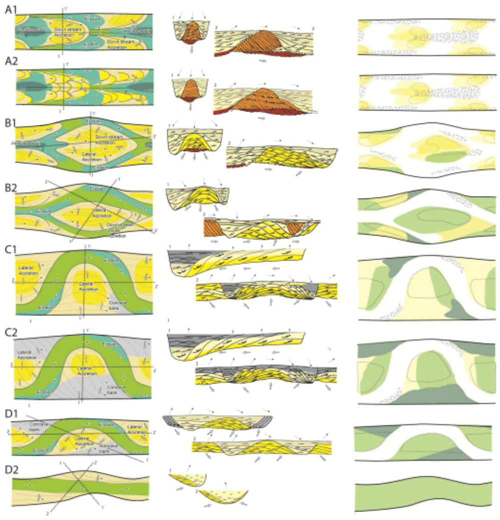


Ultimate recovery between 7% and 35%
Effective Permeability between 5 and 55 md

After Willis and Tang, 2011

Channel Belt Classification

Planview Accretion pattern | **Cross section** Facies pattern | **Key Facies** Heterogeneity



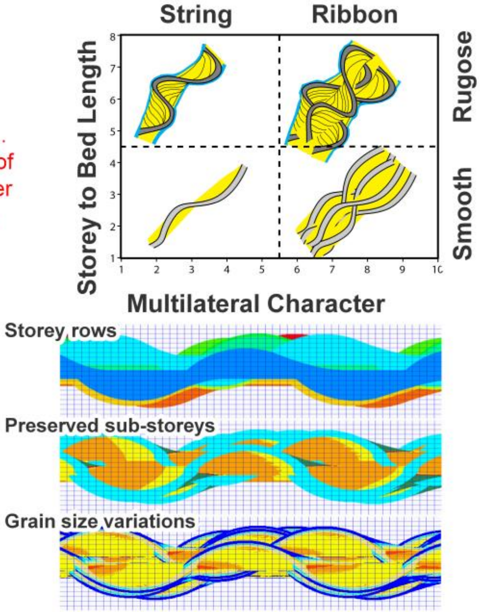
Style	Accretion dominance	Storey geometry	Abandonment fill	Key storey heterogeneity
A1	Downstream	Elongate	As coarse	Coarse lags
A2	Downstream w/ unit bars	Elongate	As coarse	Coarse lags in junction scours
B1	Mixed Downstream & Lateral	Elongate	As coarse	Lateral-downstream accretion contrasts
B2	Lateral	Somewhat elongate	slightly finer	Downstream bar fining and fills
C1	Lateral	Equant	finer	Bar fining, mud drapes & mud plugs
C2	Lateral & concave bank	Equant	finer	Lateral and concave bank contrasts
D1	Lateral & concave bank	Elongate, Anastomosing	slightly finer	Downstream fining & bar-channel fill contrasts
D2	Weak Lateral	Mostly abandonment fill	simularly fine	Margin-axis contrasts

Storey Stracking & Multi-Lateral Character

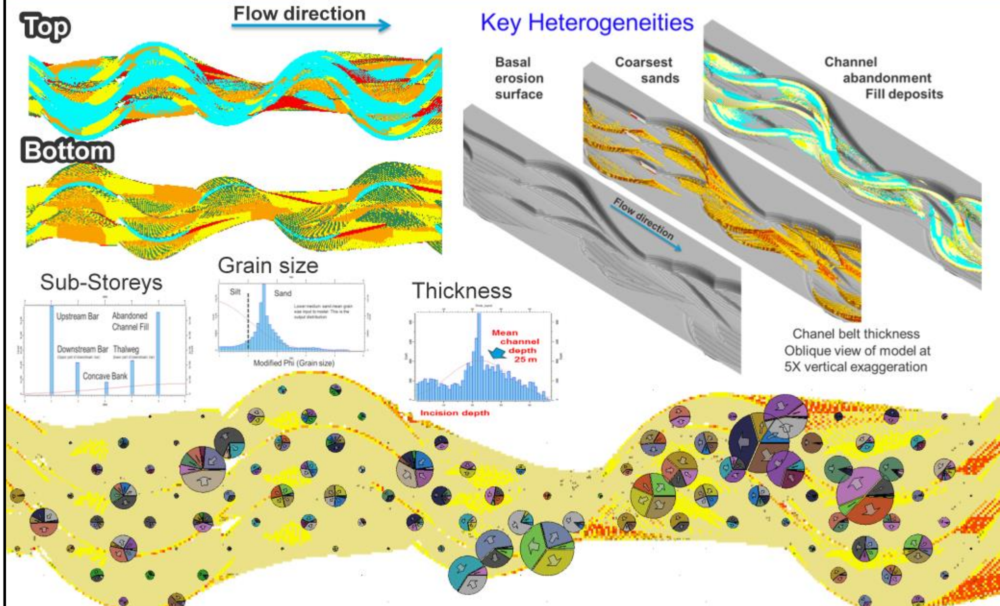
Superimposed Rows of Storeys within Belts

Channel belts can contain a single or multiple rows of storeys.

Do not confuse the number of preserved rows with the number of active channels (braiding) … a single thread river can deposit multiple rows of storeys by switching within the channel belt over time before whole the river avulses elsewhere.

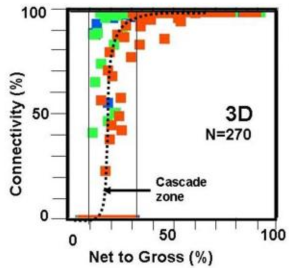


Channel Belt Model (Mungaroo?)

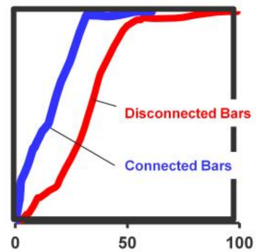


Impact of Channel Belt Heterogeneity

Static Connectivity



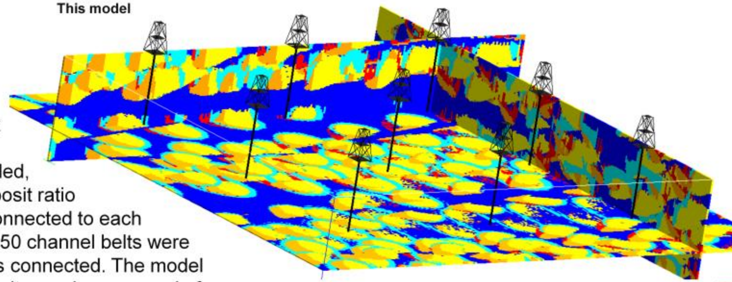
Larue and Hovadik, 2006



This model

Previous studies examined effects of channel belt geometry, but less work has examined performance variations with changes in internal channel belt heterogeneity. Here two cases are compared: 1) Storeys connected along the channel belt, and 2) Storeys disconnected along the channel belt.

Connectivity with wells was accessed by incrementally adding channel belts to a 6.5km by 6.5km by 25m thick reservoir volume. Each time another channel belt was added, channel belt to floodplain deposit ratio (Net to Gross) and volume connected to each well was calculated. After 30-50 channel belts were added, the whole volume was connected. The model shown contains 99 channel belts, each composed of a string of storeys.

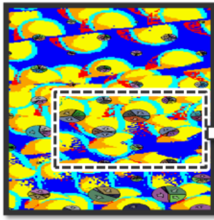


Successive channel belts were added at random locations along the west side of the volume and random elevation. The path of the channel belt was randomly varied from +/- 30 degrees from east.

Presenter's notes: We can quantify the differences between these different models using two parameters: 1) the ultimate recovery before water breakthrough at the producing well, and 2) the effective permeability of the channel belt, which is a measure of the speed that the water moved through the channel belt. I do not have time to describe these metrics in detail but here variations are huge: recovery estimates vary by a factor of five … for models produced by the same river channel…same size and mean grain size….just different migration and channel abandonment fill styles.

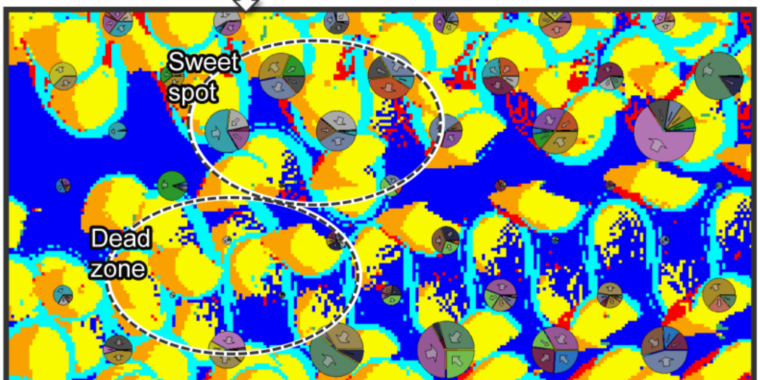
Impact of Channel Belt Heterogeneity

Dynamic Connectivity

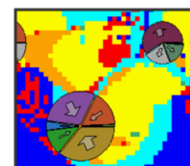


This Fluvial Deposit Model is 100% Connected!

Complete static reservoir connectivity does not imply uniform well performance. A simple FrontSim simulation of an injector-producer array in the 100 channel belt model produced at the end of the static connectivity study shows dramatic performance differences between adjacent wells.



Circle diameter show flow rate and colors indicate which well is communicating with this specific well.
Arrows point away from injectors
and toward producers.



Conclusions

- A **simple model** for flow and sediment transport within river channels is used to predict facies patterns within fluvial channel belts.
- The model suggests **"storeys"** formed by the growth and lateral translation of individual curved channel segments define the major facies heterogeneity patterns. In most cases the predicted patterns are not defined by channel shaped bodies, and are poorly demarcated by channel axis-margin trends observed within deep water channel deposits.
- **Sub-storey** deposits form in different areas of a migrating river channel, and their relative preservation within a channel belt depends on patterns of channel migration.
  - **Bar head deposits** (upstream inner bank) tends to be "blocky"
  - **Bar tail deposits** (downstream inner bank) tend to fine upward ("bell")
  - **Concave bank** and **Channel abandonment fill** deposits are predicted in this model to be more strongly upward fining than bar tail deposits, but this is probably not the case in all types of channel belt deposits.
- **Reservoir connectivity** of fluvial channel belts is not a simple function of net/gross, but rather depends on how the intra-channel belts heterogeneities link up across connected channel belts.