Another Look at Fluvial Sequence Stratigraphy*

Brian Willis¹, Bryan Bracken² and Tobias Payenberg³

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¹Clastic Stratigraphy R&D, Chevron ETC, Houston, TX. (bwillis@Chevron.com)
²Clastic Stratigraphy R&D, Chevron ETC, San Ramon, CA.
³Clastic Stratigraphy R&D, Chevron ETC, Perth, WA, Australia.

Abstract

Vertical changes in fluvial deposit net/gross over 10’s to 100’s of meters and associated changes in depositional style and channel belt connectivity are widely observed within thick alluvial successions. It is popular to interpret these variations in terms of allogenic accommodation variations defined under a fluvial equilibrium profile of fixed geometry that is coupled to shoreline position. These interpretations generally infer that fluvial gradients steepen during sea-level fall, leading to declining accumulation rates (and eventual channel incision), floodplain narrowing, preferential preservation of channel relative to overbank deposits, and internally sandy channel belts. Sea-level rise is inferred to decrease fluvial gradients and widen floodplains as sediment aggradation accelerates and river incisions fill, leading to greater preservation of floodplain deposits and more internally heterolithic channel belts. Despite their popularity, we suggest current sequence stratigraphic models for fluvial systems based on these ideas are too simplistic and in many cases the underlying assumptions may be wrong. Fluvial stratigraphic interpretations commonly reverse cause and effect on alluvial architecture variables, wrongly predict that most large-scale fluvial successions fine upward, and over-emphasize accommodation controls and the ability of coastlines to buttress fluvial aggradation during relative sea-level rise. As an alternative, we interpret fluvial successions as regionally and locally prograding sediment wedges that initially expand as rates of downstream slope decline gradually decay over time and then back-step as sediment aggradation rates locally fall below subsidence rates (c.f., Autoretreat of Muto & Steel, 1997). Progradation can be initiated by allogenic changes or by autecyclic avulsions of sediment supply to areas that have previously undergone gradual subsidence. Sea level is inferred to have little influence on alluvial slopes and rates of sediment progradation, except perhaps in some areas directly adjacent to the coast. The idea that fluvial deposits are composed of prograding and retrograding units (at multiple scales) is used to interpret variations within several thick alluvial successions that gradually coarsen upward as channel belts progressively become larger and more obviously clustered. These successions tend to be capped by a relatively thin, erosionally-based sand-dominated interval, before fairly abruptly fining upsection.
Selected References


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Brian Willis¹, Bryan Bracken², Tobias Payenberg³
Clastic R&D, Chevron Energy Technology Company, ¹Houston, ²San Ramon, ³Perth
Popular Concept 1

Proportion of channel belt deposits within a succession is inversely related to aggradation rate. If all other variables are assumed constant!

The LAB alluvial architecture models define the variables that account for variations in deposit net/gross, but they do not explicitly define relationships between these variables, nor allocyclic process that control changes in these variables.
Fluvial accommodation can be defined by reference to a graded profile, fixed in shape, that is coupled the coast.

Fluvial Sequence Stratigraphy Concepts

Popular Concept 2

Fluvial accommodation can be defined by reference to a graded profile, fixed in shape, that is coupled the coast.

Point to which the profile is adjusted
Equilibrium profile (based on load grain size, sediment volume, & discharge.)

Distance along longitudinal profile
Sea Level (Ultimate base level)

Original position

Accommodation

Shifted position

Rising sea level
Shoreline Buttress

Rising sea level

Shoreline

(Wright and Marriott, 1993)
Mature soil Hydromorphic soil Channel deposits Floodplain deposits

Holbrook 2008

Unlike dams, shorelines are not locked in position along a fluvial profile

Little Influence downstream

Greater influence upstream

Bureau of Reclamation

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Popular Concept 3
Upward fining major fluvial depositional cycles

In Posamentier & Vail (1988) most fluvial deposition was predicted to occur in the early highstand when shorelines moved basinward.

“It is now widely understood that fluvial aggradation and coastal onlap occur on the rising limb of a relative sea-level curve”

Downstream Slope

Rate of downstream slope change depends on:
- Sediment to water discharge ($Q_s/Q_w$)
- Sum of channel wetted parameters ($P/Q_w$)
- Bed roughness (grains and sediment structures)

\[
\frac{dh}{dx} = f(ae^{-x+b})
\]
All else constant (no subsidence):
- Accumulation proportional to rate of slope decrease
- Zone B (area of sediment accumulation) expands as rate of slope change decays over time.

\[ \frac{\partial h}{\partial t} = f\left(\frac{\partial^2 h}{\partial^2 x}\right) \]
Sediment Partitioning

All else constant (no subsidence):

• Grain size and net/gross of deposits decrease downstream due to preferential deposition of coarser grains.

• Down-basin lithic partitioning is more pronounced across regions with greater rates of slope decline.
Channel Belt Patterns & Avulsion Behavior

- **Steep Rate of Change of Slope**
  - Frequent avulsions.
  - Multiple coeval active channel belts (strongly distributive).
  - Rapid down-dip decline in net/gross.

- **Gradual Rate of Change of Slope**
  - Rare avulsions.
  - Single active channel belt (weakly distributive).
  - Slow down dip decline in net/gross.

Kosi River, India

Chenab River, India

Images from Google Earth

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Channel Pattern

Channel pattern depends on slope (relative to discharge) and only indirectly on grain size or net/gross of deposits.
Deposition expands until auto-retreat detachment of water sediment supply can not keep pace with subsidence.

Following Muto and Steel, 1992
Tectonic Fluvial Depositional Cycle

Landward shift due to asymmetrical subsidence

Basinward shift due to increasing sediment supply

Landward shift due to auto-retreat

Distance (x)

Elevation (h)

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Sea Level: Shoreline Regression

Shorelines affect fluvial transport?

If all else constant (not subsidence):
- Fluvial expands with slope decay
- Shorelines regress due to fluvial sediment supply to the shoreline

Distance (x)

Elevation (h)

Backwater distance

\[ B_d \sim d/S = d/(\sigma h/\sigma x) = d \ast \sigma x/\sigma h \]

Bayline

Shoreline

No change in slope or \( Q_w/Q_s \) due to sea level
Sea Level: Transgression Due To Auto-Retreat

If all else constant (including constant subsidence):
- Fluvial systems auto-retreat
- Shorelines regress only when in zone B.

Subsidence generated auto-retreat

Shoreline then occurs where fluvial system runs out of sediment

Regression when sediment supply greater than subsidence

Constant eustatic sea level

Relative sea level rise due to subsidence
Eustatic Sea Level Rise

Auto-retreat leaves a succession of “stranded” coastal deposits (e.g., barrier islands) because the termination of fluvial sediment supply defines the shoreline position.

The farther the coast is “forced” onto the fluvial wedge by eustatic sea level rise, the faster successive shorelines will prograde.

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Eustatic Sea level Change

Relative sea level rise
- Sediment supply
- Detached shorelines

Relative sea level fall
- Sediment supply
- Auto-retreat
- No fluvial incision until sediment supply from the fluvial system falls behind subsidence.

More relative sea level fall
- Sediment supply
- Knickpoint
- Re-deposited
- Not enough sediment to fill space

Fluvial system slope
- Incision only where shoreline trajectory slopes are steeper than those in fluvial system.
- Rate of incision decreases landward as incised slope and fluvial system slope become more similar.
Conclusions

• Applying shoreline sequence stratigraphic concepts to fluvial systems puts the wrong emphasis on controlling processes.

• Concept of accommodation defined by a fixed fluvial profile linked to the coast is poorly developed and probably wrong for most large fluvial systems.

• Large-scale fluvial successions are better visualized as driven by changes in sediment supply relative to subsidence (probably related to tectonics or climate change) rather than by sea level driven changes in accommodation.