Alluvial stratigraphic architecture viewed through a mass-balance lens

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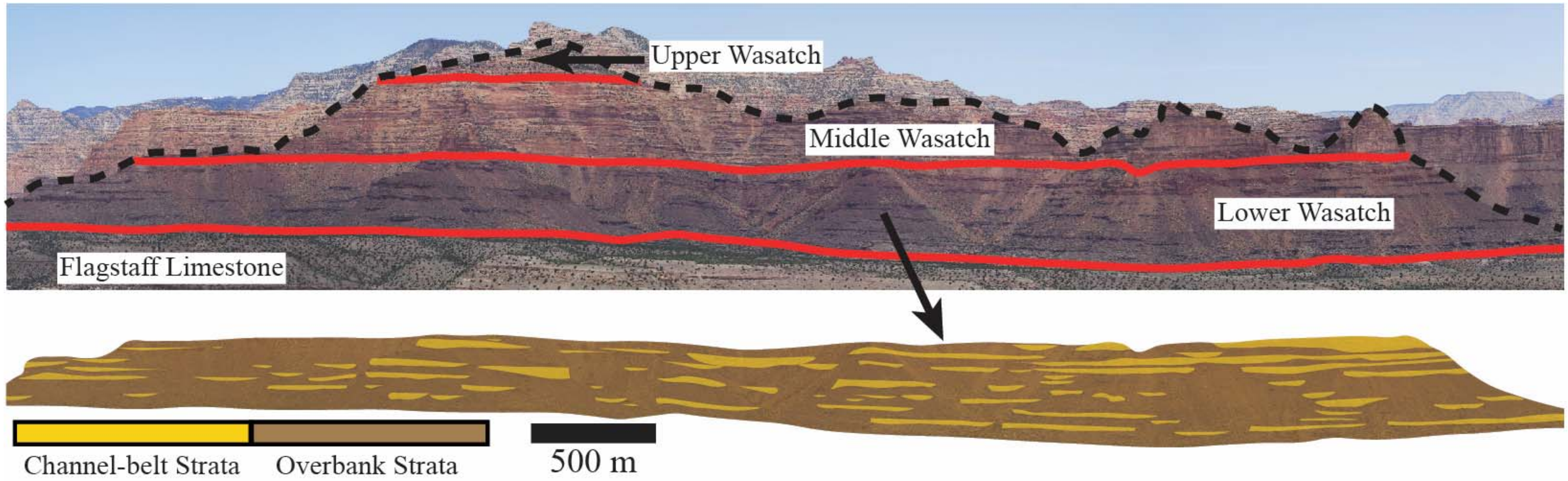

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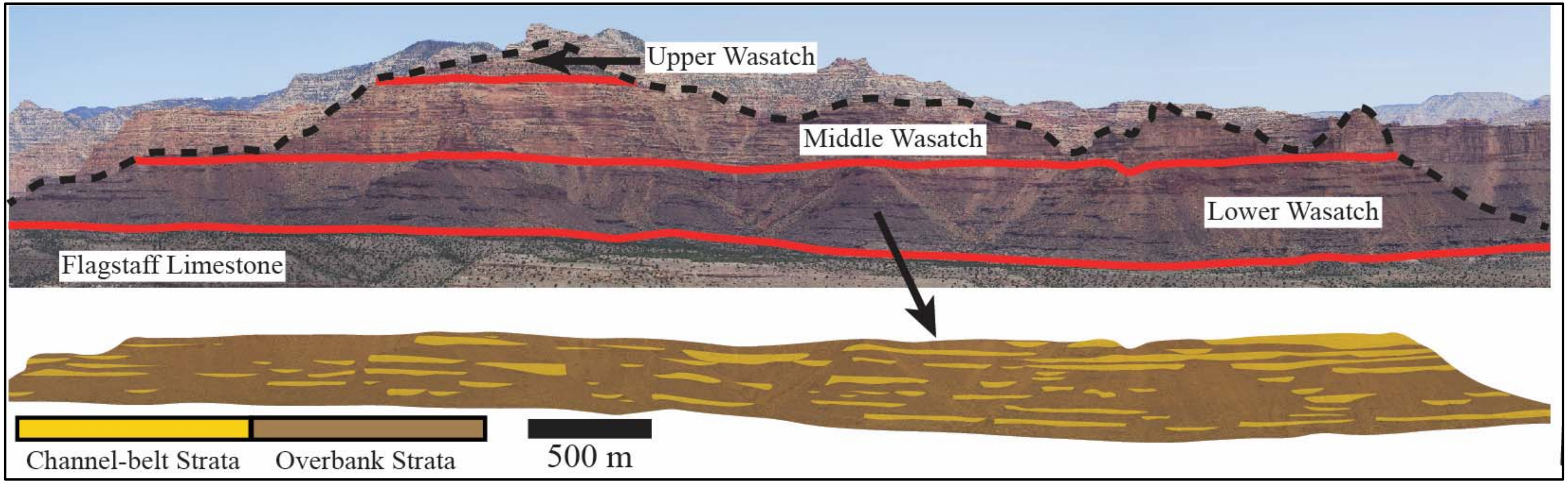
Alluvial stratigraphic architecture (ASA)

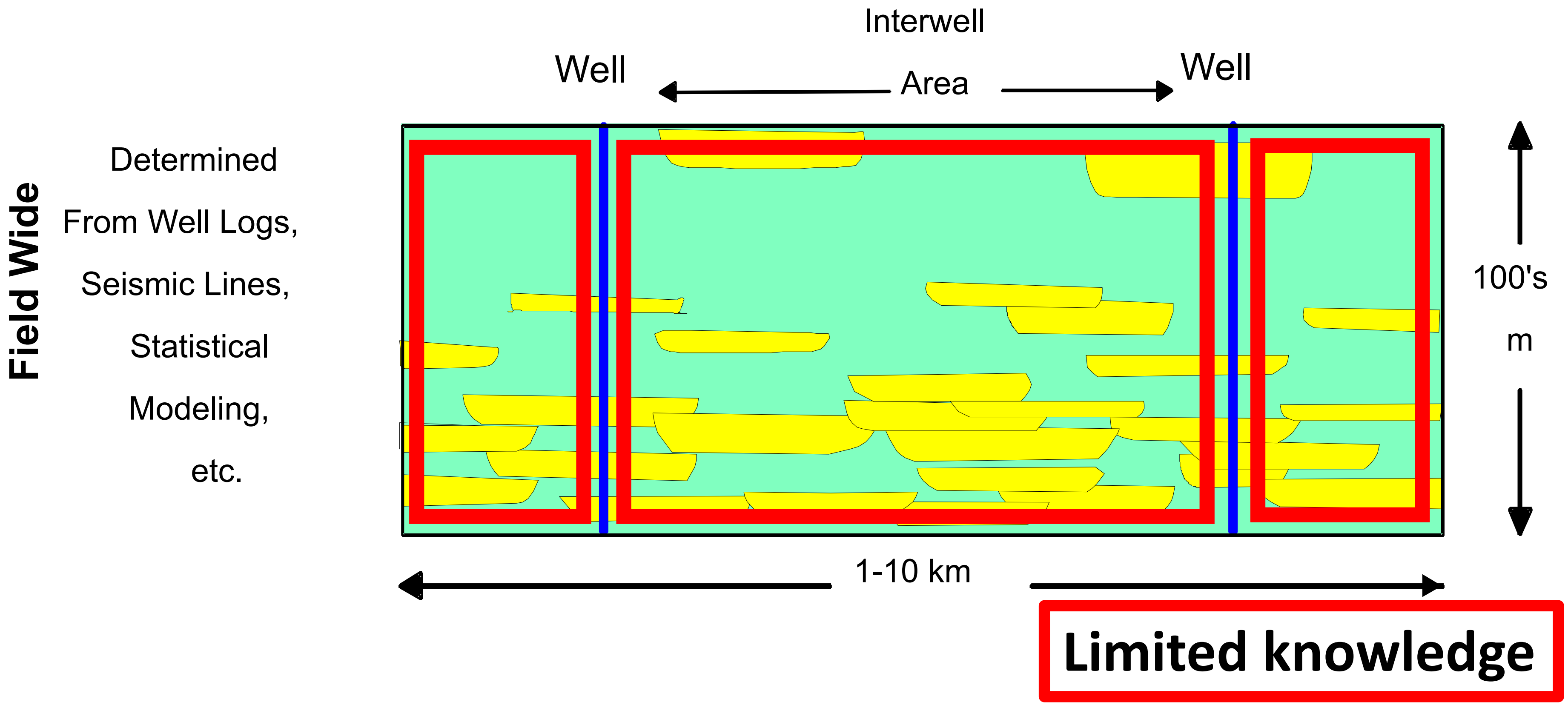
Field-wide heterogeneity



ASA: The spatial arrangement of channel bodies, encased within floodplain strata (Allen, 1978; Leeder, 1978)
Field-wide scale (10’s km wide and 100’s metres thick)

ASA: Predicting Trends and Filling Data Gaps

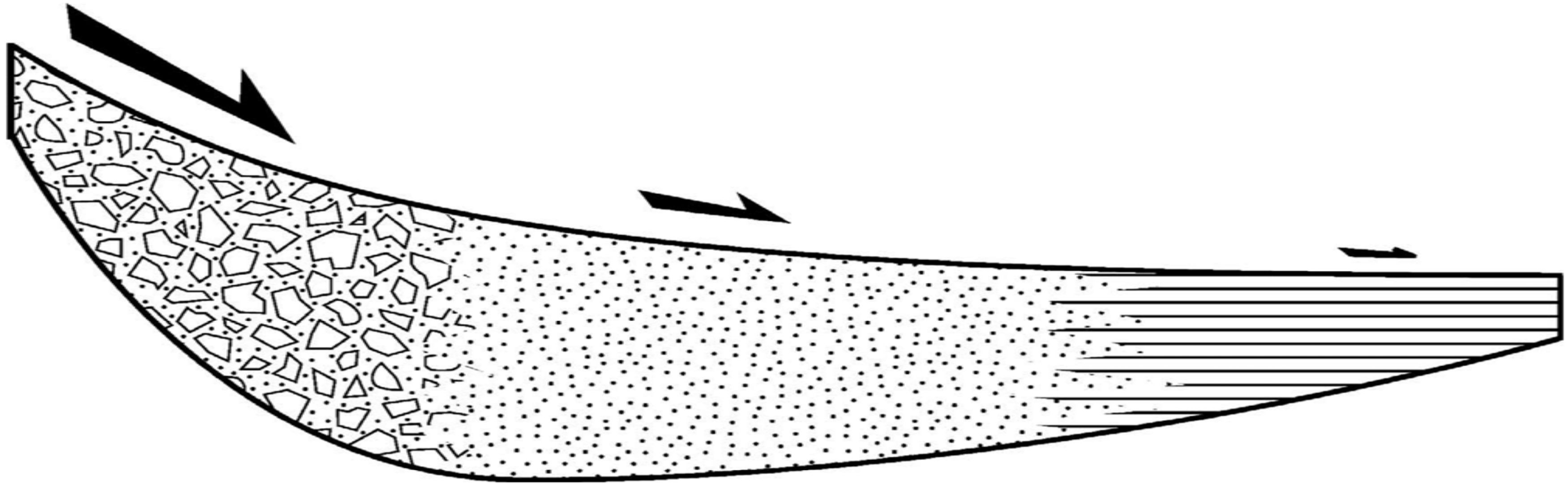
Field-wide heterogeneity



Key questions that have driven this research for decades: What determines this spatial arrangement and the size of sandstone bodies? And can we predict it?

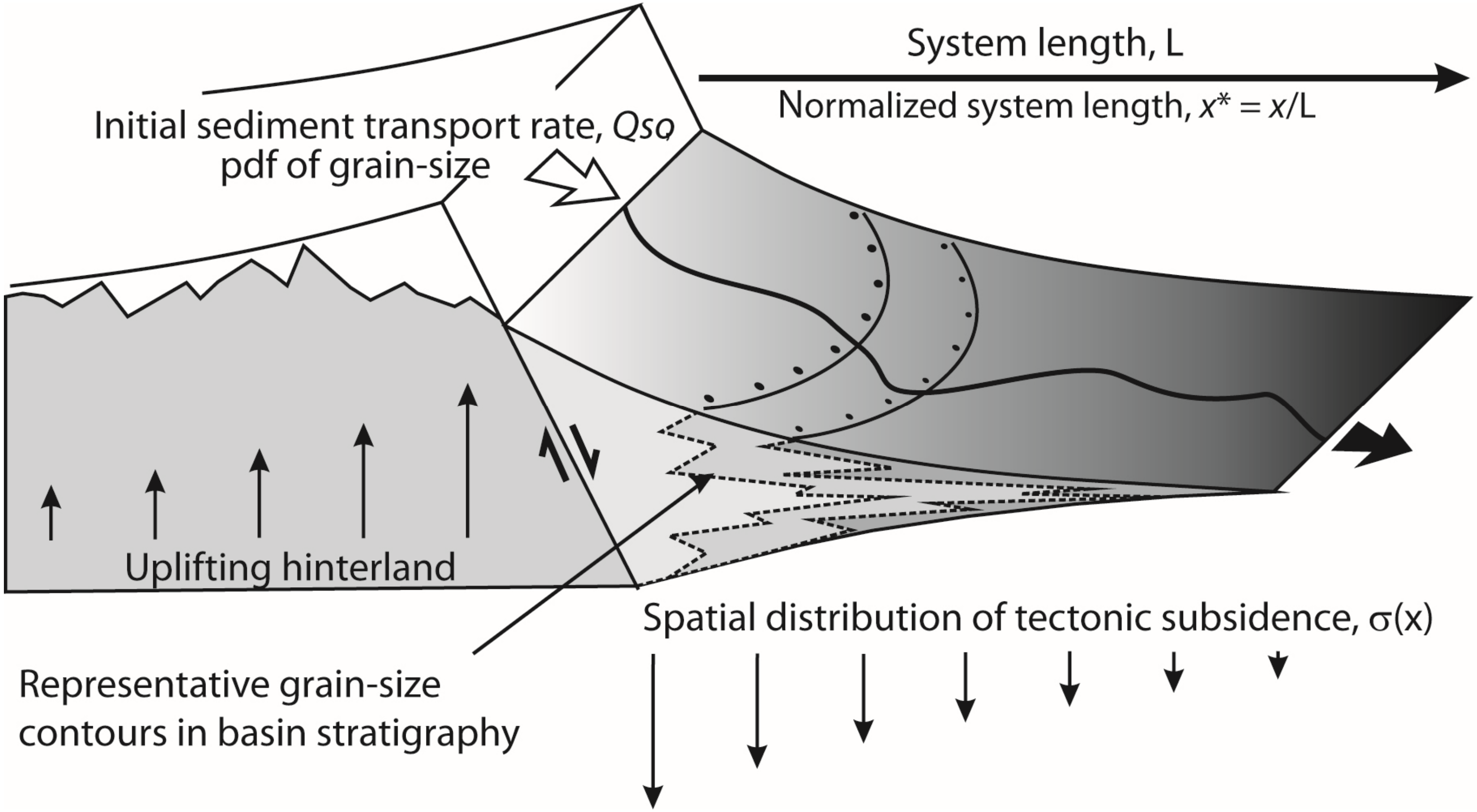
Mass balance in sedimentary systems

Sediment mass-balance: spatial distribution of deposition or subsidence over the long term.



"The mass-balance approach is designed for analysis, not simulation. Will not predict most of the variability and complexity in specific basins or outcrop-scale details, but it may explain major trends through a quantitative understanding of mass extraction." – **Paola and Martin (2012)**

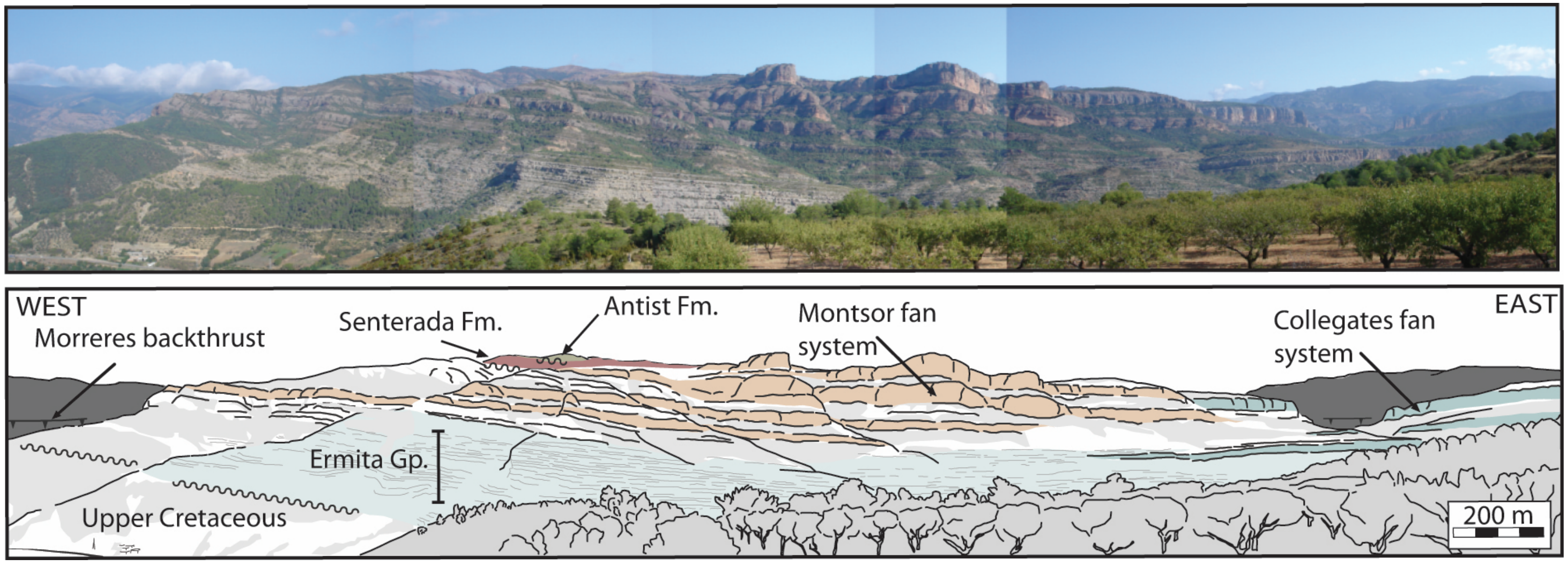
Mass balance in sedimentary systems

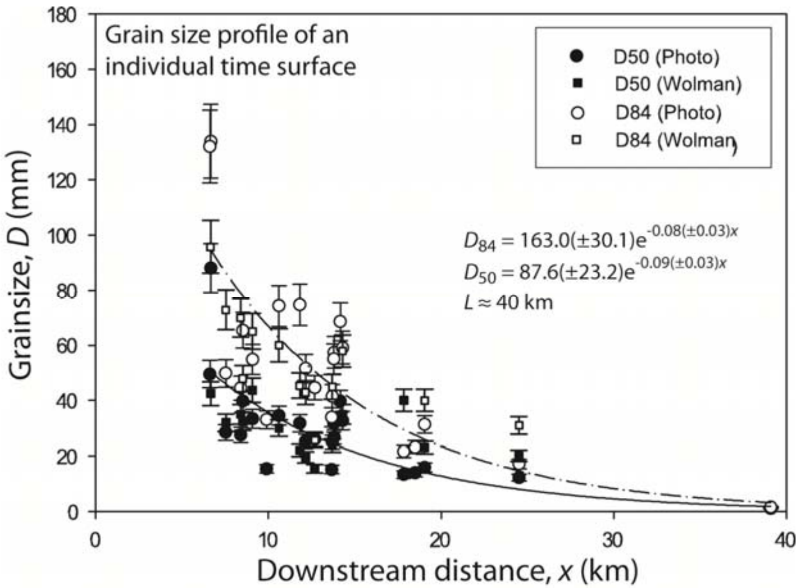


Duller *et al*. (2009)

Mass balance in sedimentary systems

Field application: Down-system grain size trends





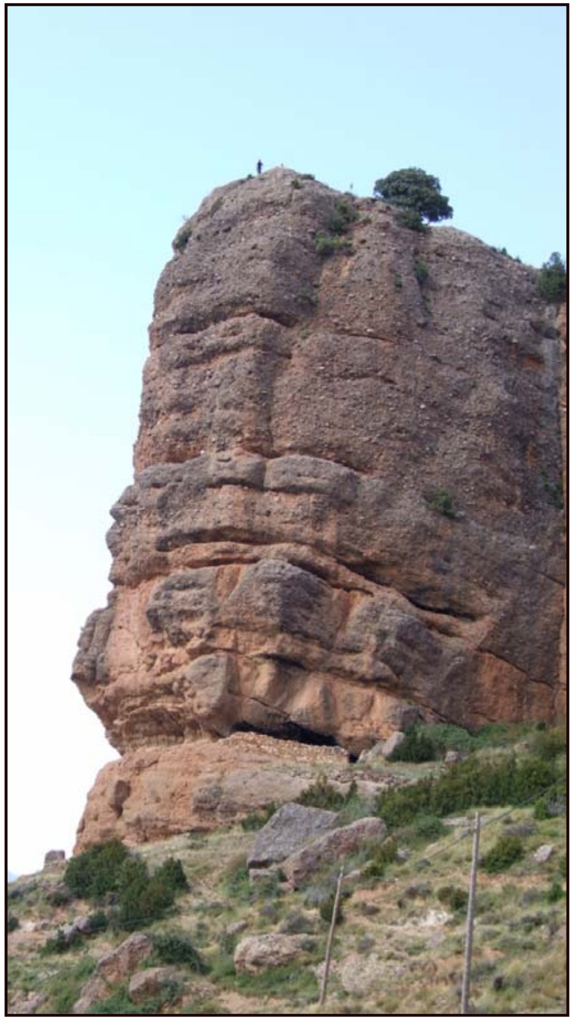
Eocene Montsor succession of La Pobla Basin, Spanish Pyrenees –

Duller *et al*. (2009)

Mass balance in sedimentary systems

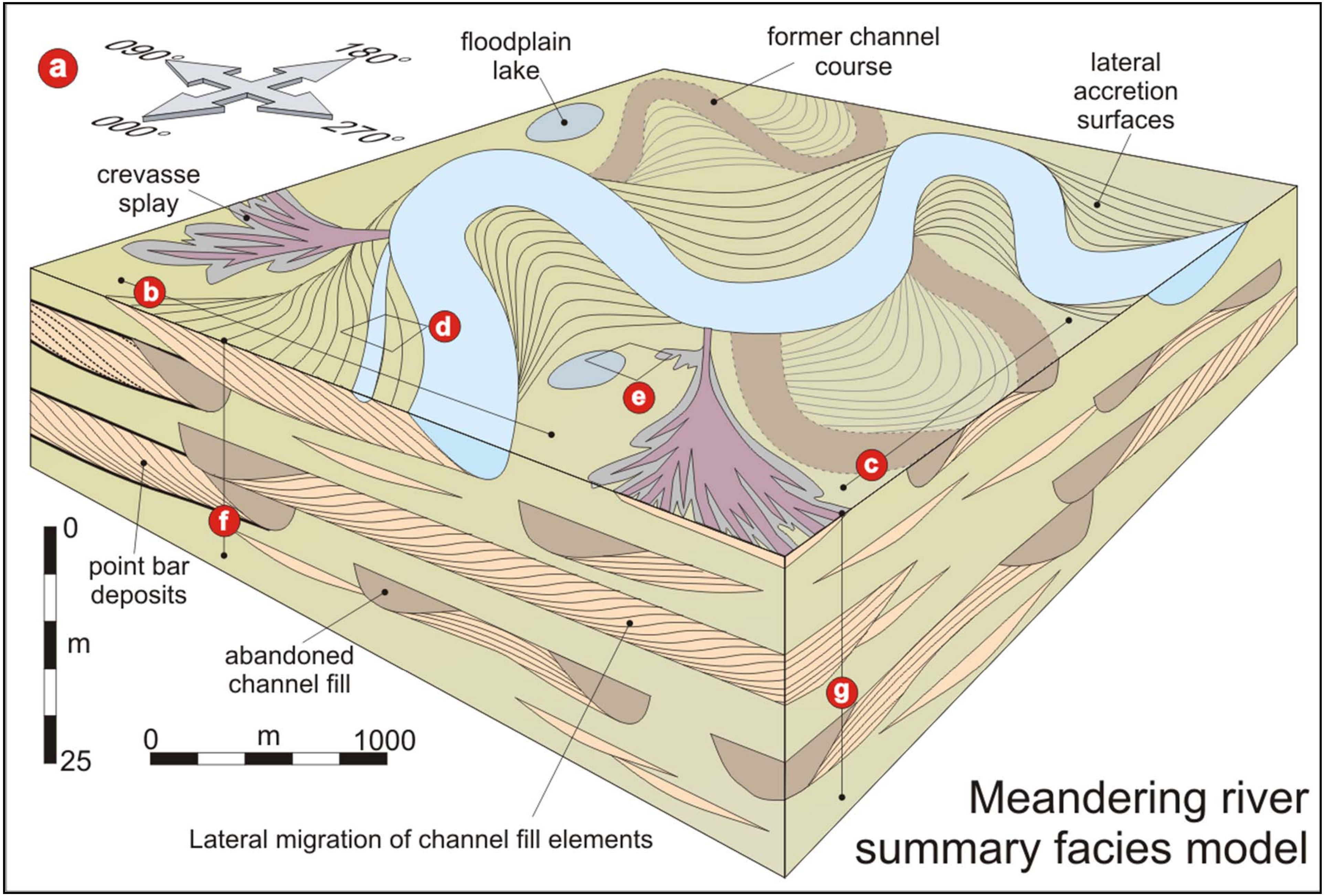
Field application: Down-system grain size trends

- Typically achieved with physics-heavy or statistical models that lack mechanistic underpinning.
- Adds texture to fluvial basin fills, enabling **more testable** stratigraphic models.



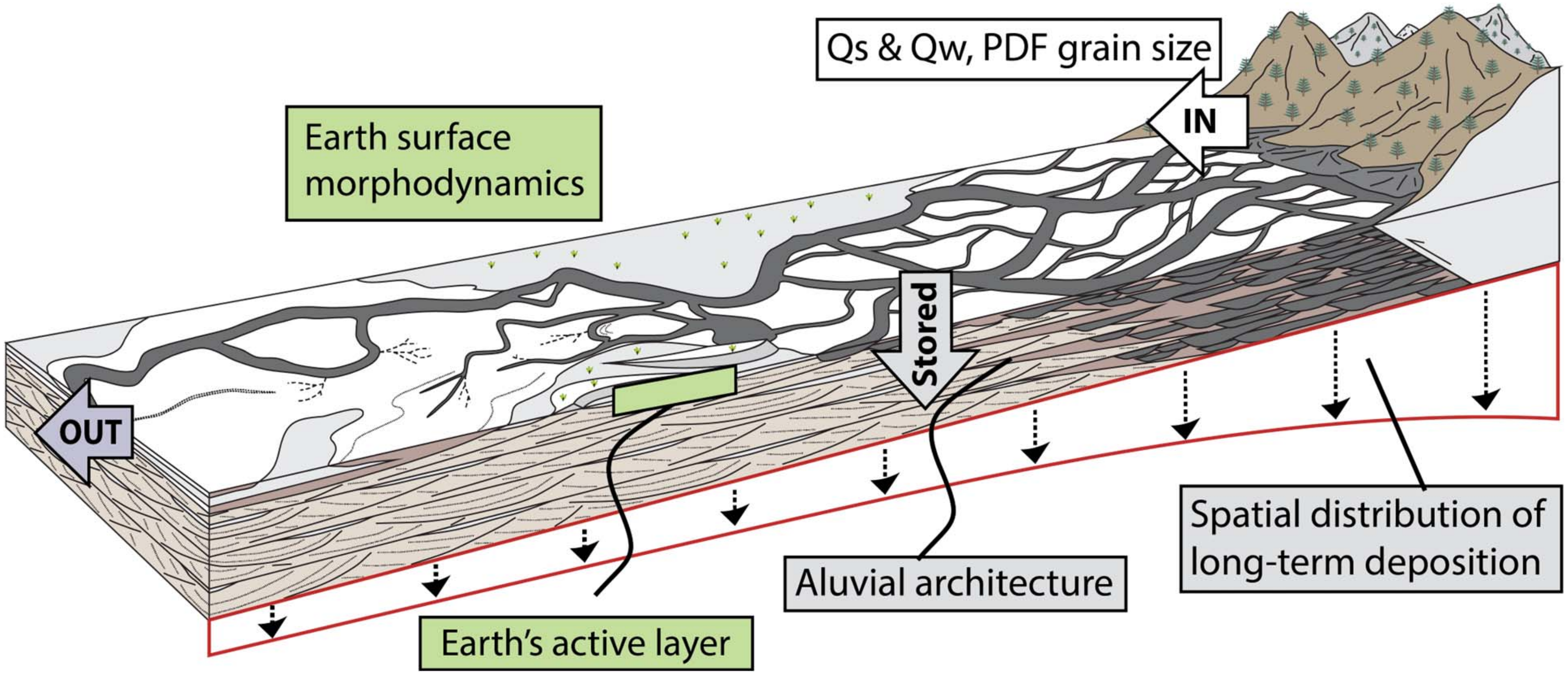
Duller *et al*. (2009) From grain size to tectonics, *Journal Geophysical Research – Earth Surface*.

Mass balance in sedimentary systems



Mass balance in sedimentary systems

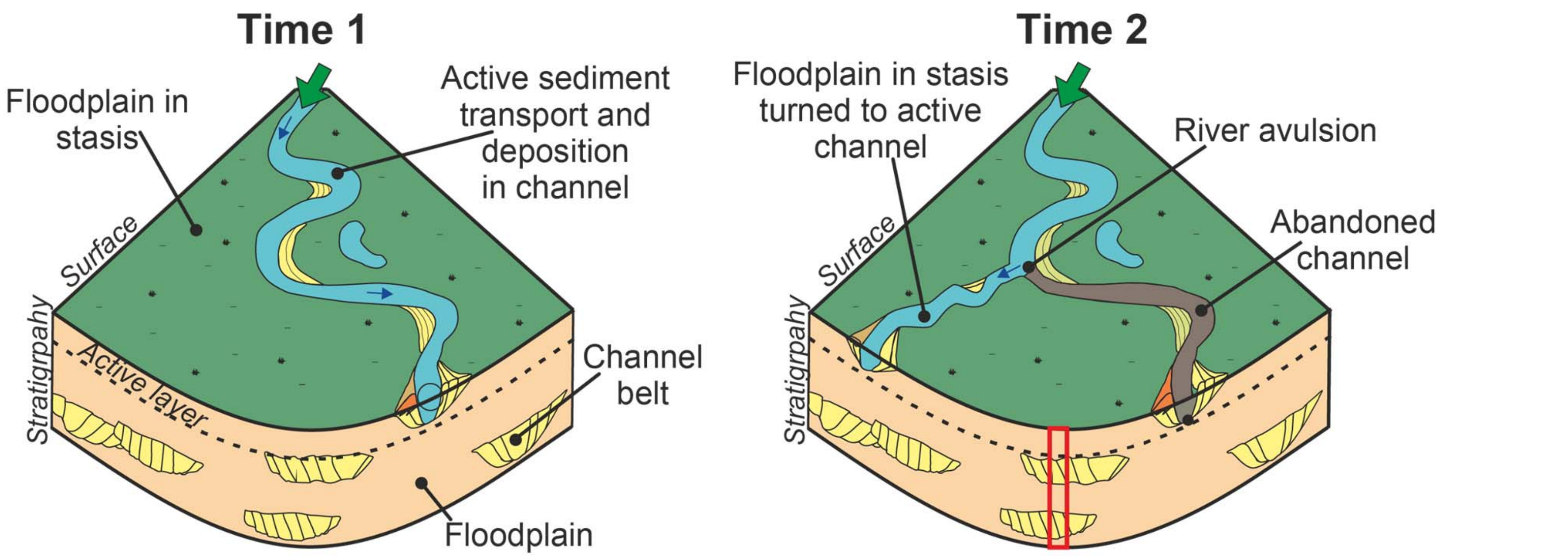
Link mass balance to surface processes and alluvial architectue

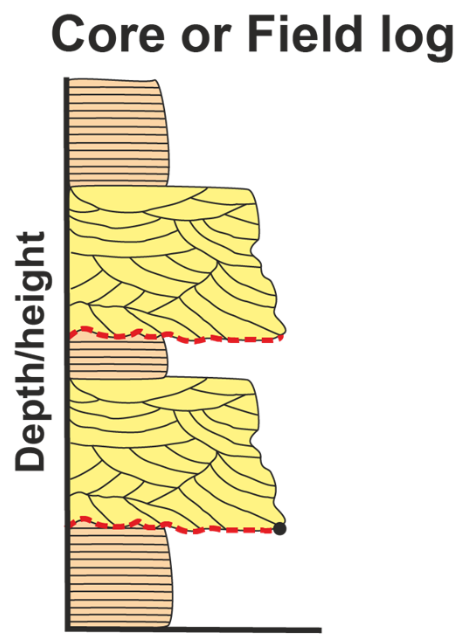


Modified from Cain and Mountney (2009)

Exploring key timescales that quantify the lateral mobility of fluvial networks and the vertical accumulation of alluvial strata.

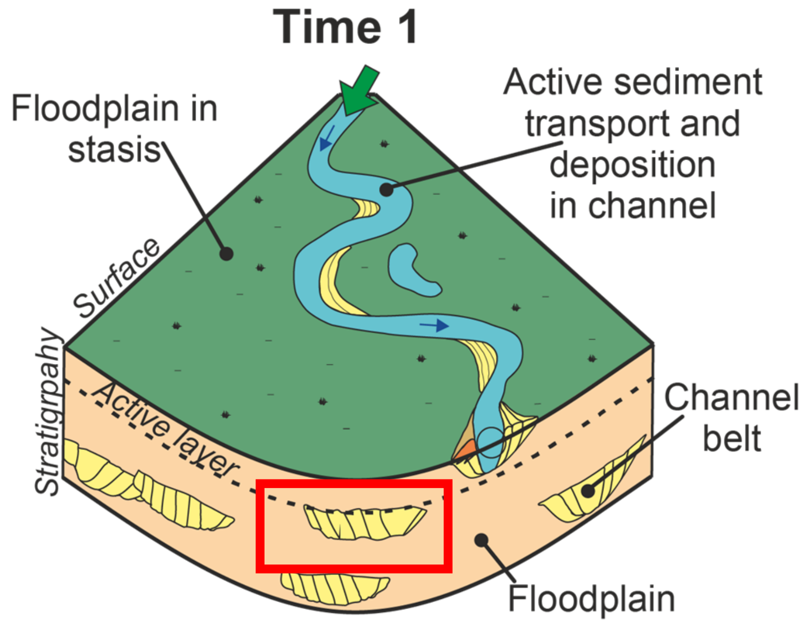
Alluvial stratigraphic architecture (ASA)



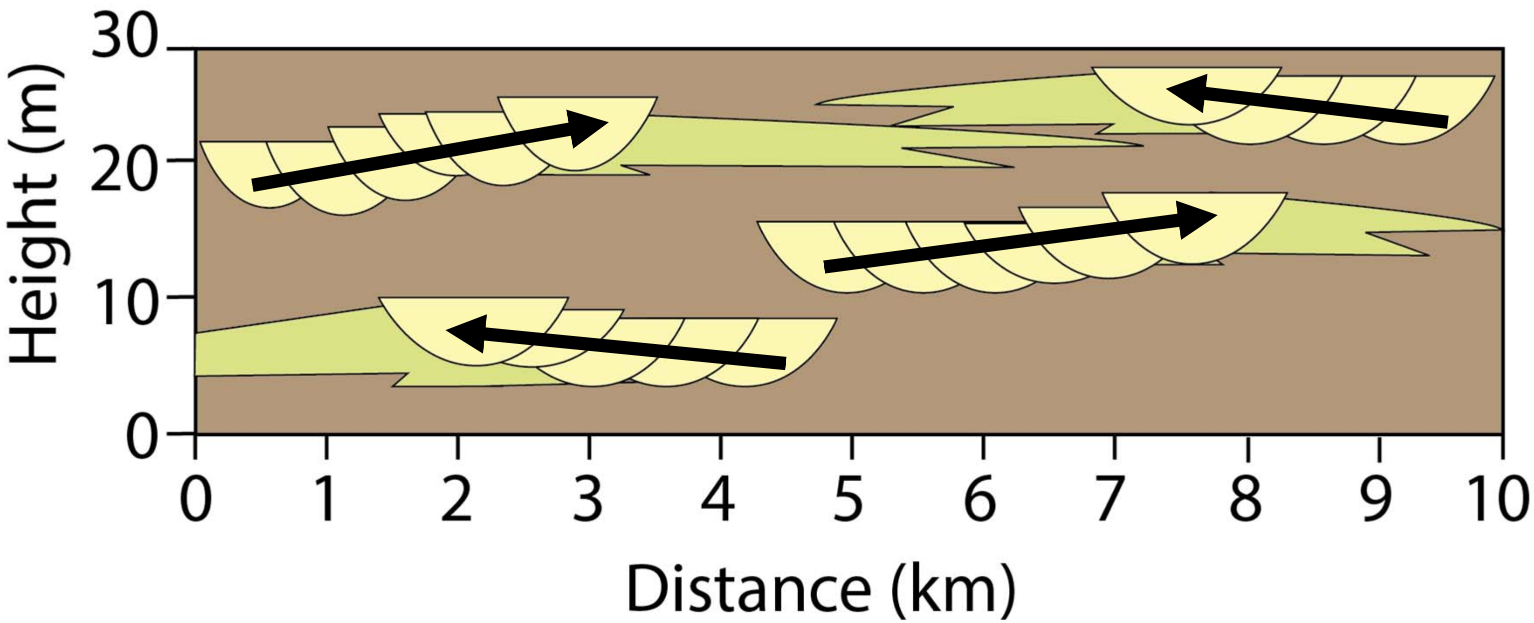


River avulsion: The rapid shift of a river channel to a new course, caused by sediment buildup raising the channel bed above the floodplain.

Alluvial stratigraphic architecture (ASA)

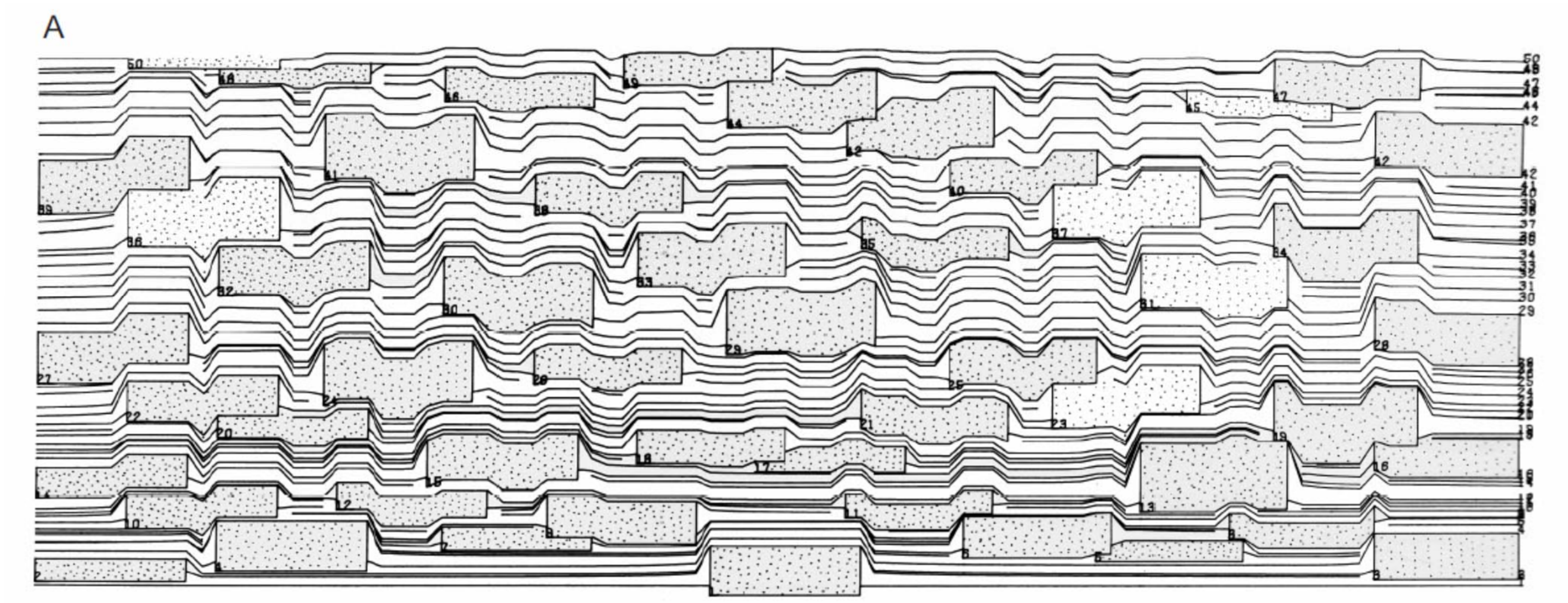


Lateral river migration: cannibalisation of the floodplain and the generation of channel belts elements



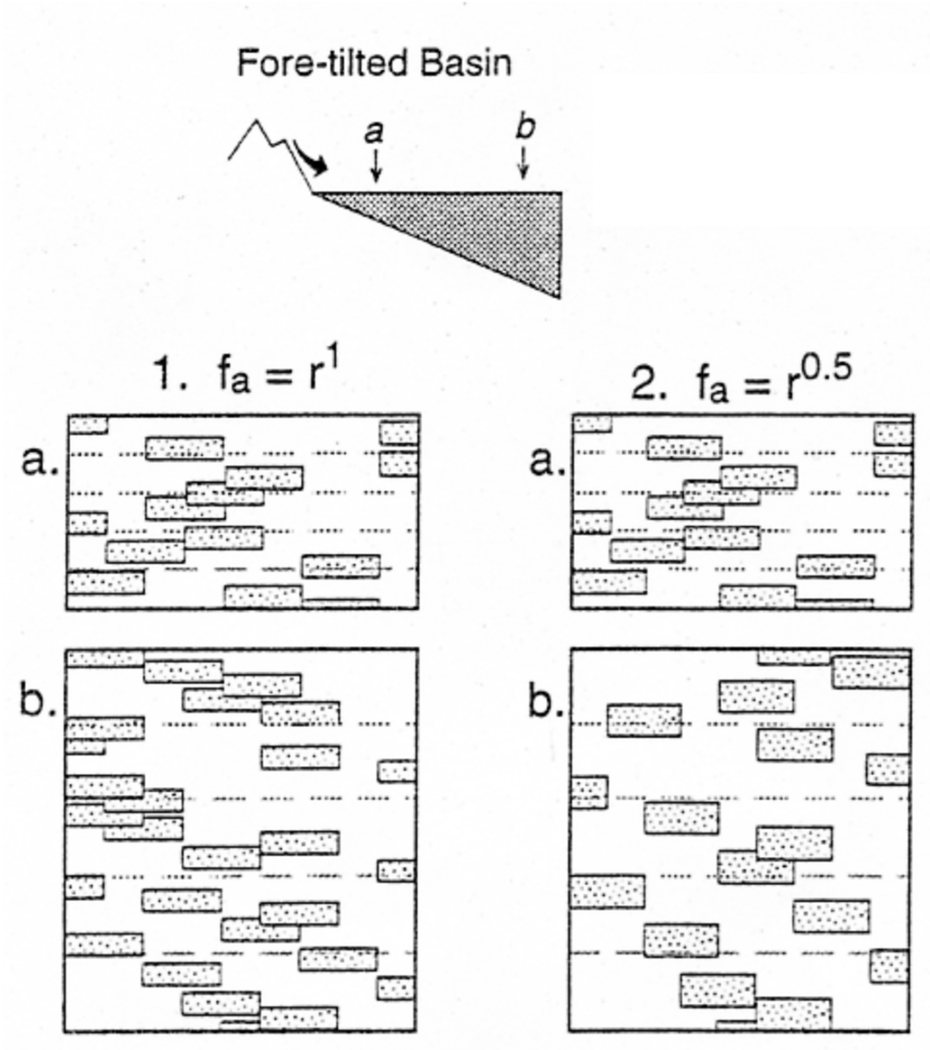
Leeder-Allen-Bridge (LAB) models of ASA

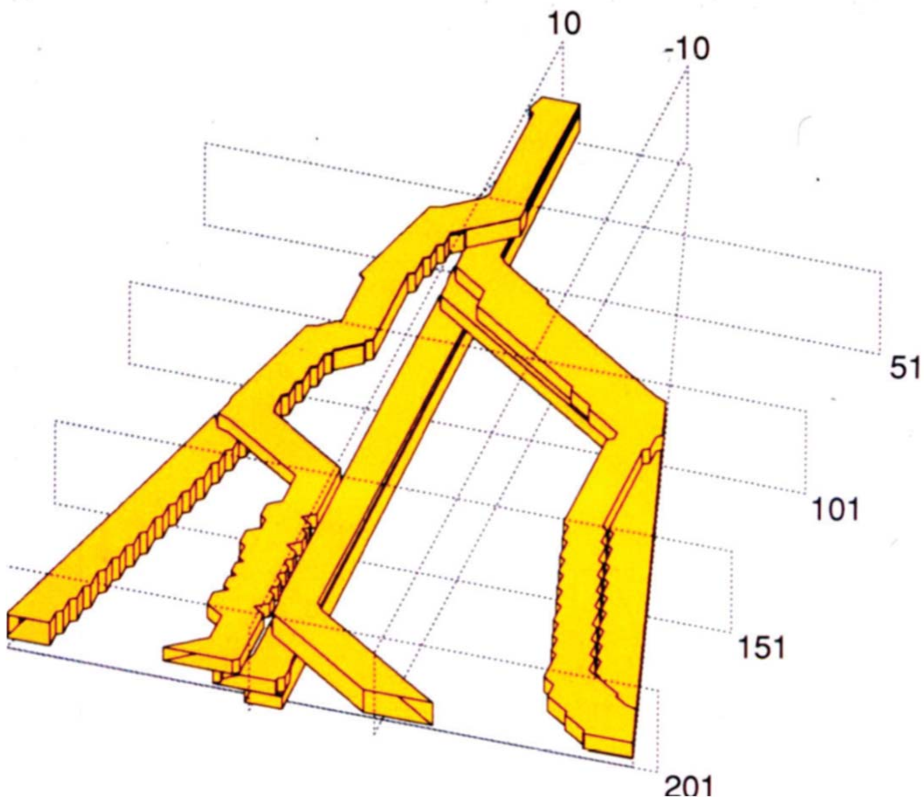
Cross section of alluvial architecture constructed by 2D model



- Decoupled sedimentation rate from avulsion frequency, *i.e.* low sedimentation rate = densely stacked channel bodies.
- 2D cross sectional models and so do not account for the spatial change in deposition and effect on architecture

Alluvial stratigraphic architecture (ASA)

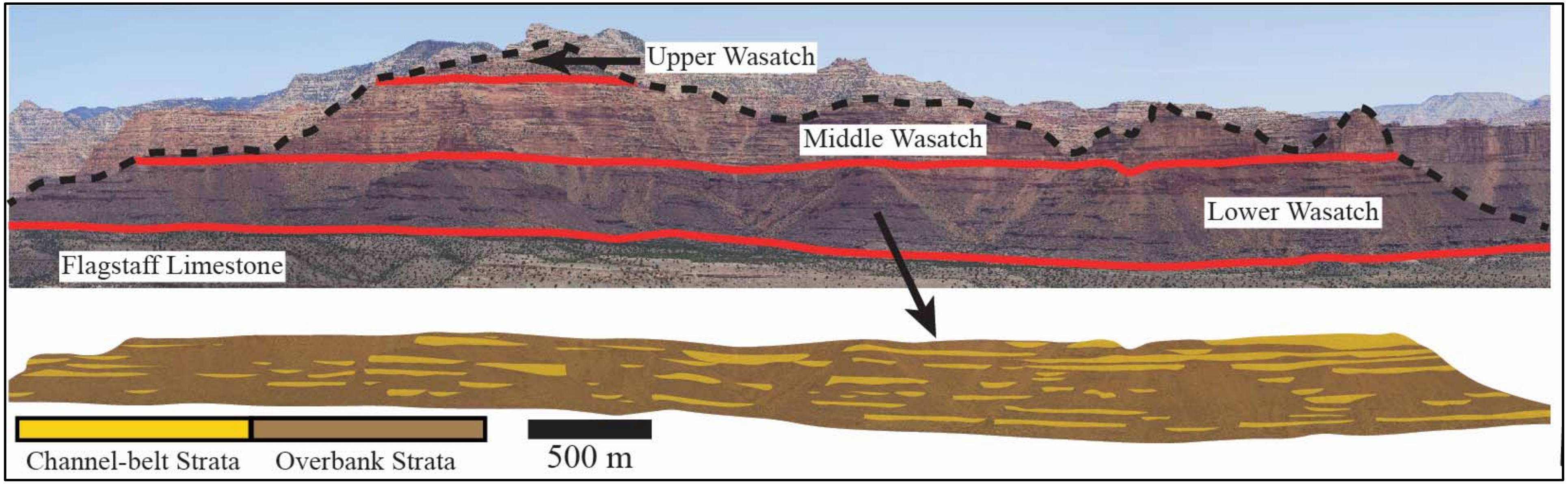




Heller and Paola (1996)

Mackey and Bridge (1995)

Alluvial stratigraphic architecture (ASA)



Width, depth, number of active channels
River mobility (avulsion, lateral migration) → **Earth surface processes**

Subsidence, RSL → **Accommodation generation**

Key lateral timescales

Surface (lateral) timescales:

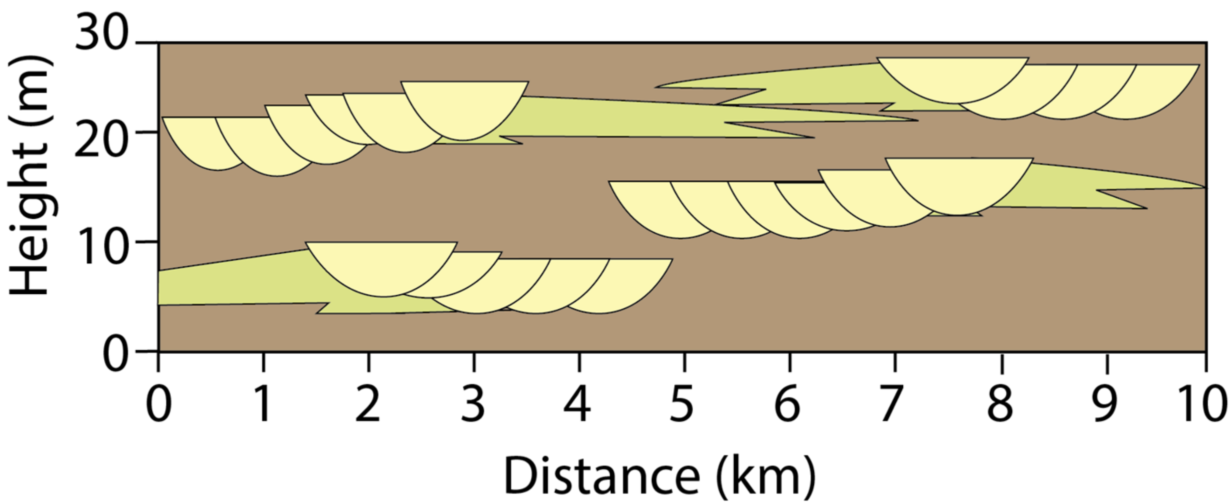
Channel avulsion timescales (T_A):

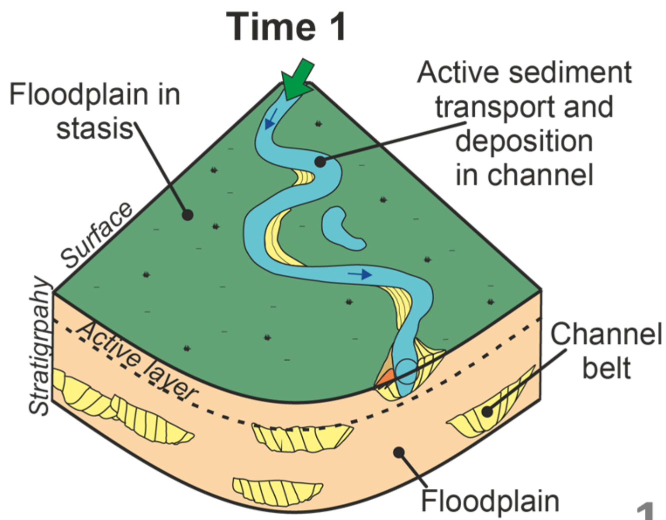
$$T_A = \frac{H}{D_c - D_{FP}}$$

Channel mobility timescale (T_V):

$$fUM = ae^{-bt}$$

H = channel depth
H_{max}= max. channel depth
D_c = channel dep. rate
D_{FP}= (floodplain dep. rate
fUM = frac. of un-modified area
D_{LT} = basin wide, long-term dep. rate





Key stratal (vertical) timescale

Longer term deposition

Accretion timescale (T_c)

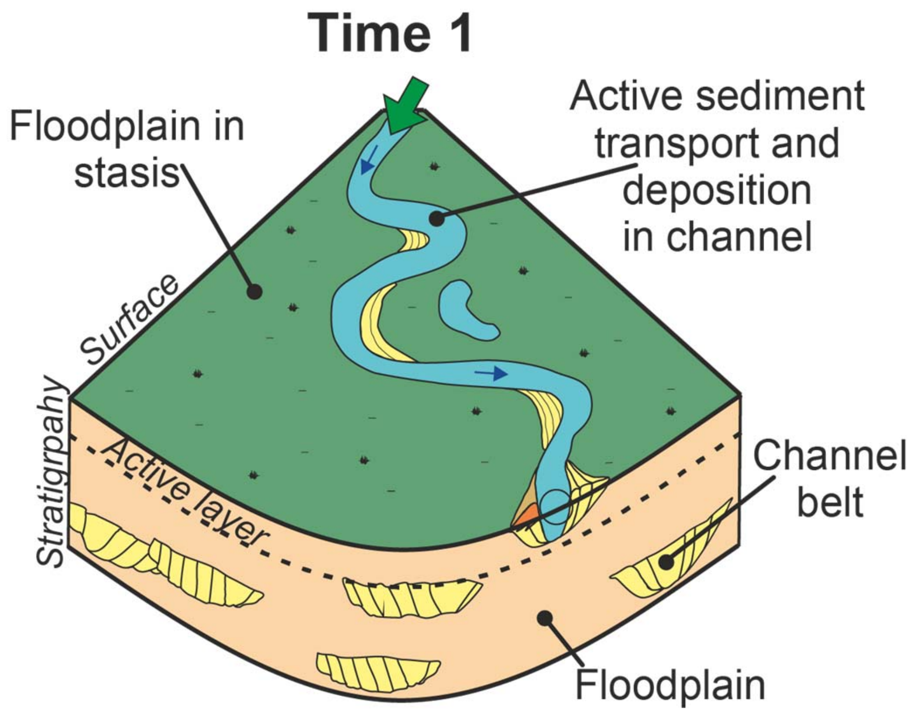
$$T_c = \frac{H_{max}}{D_{LT}}$$

H = channel depth
H_{max}= max. channel depth
D_c = channel dep. rate
D_{FP}= (floodplain dep. rate
fUM = frac. of un-modified area
D_{LT} = basin wide, long-term dep. rate

The compensation timescale (T_C) quantifies the time necessary for the products of autogenic channel movements, including avulsions, to average out in the structure of the basin fill (Wang et al., 2011).

Key timescales used to capture system behaviour in mass balance space

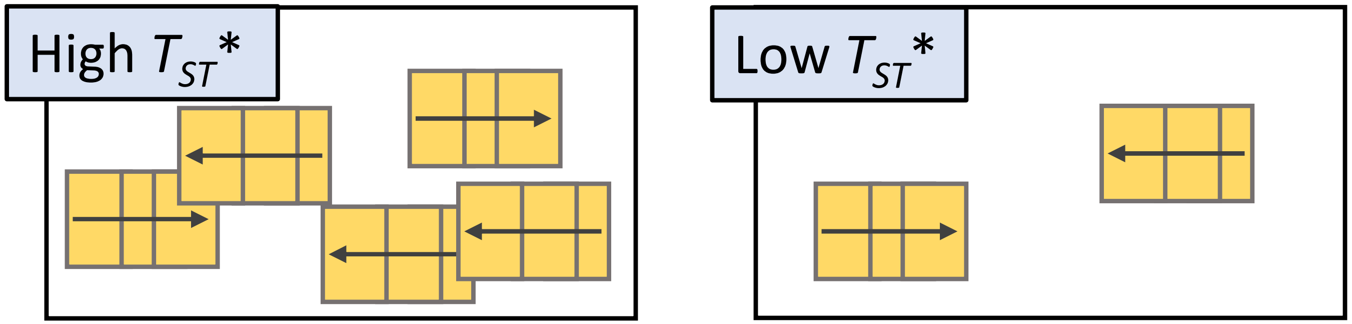
Are some autogenic rates are more sensitive to accommodation production than others?



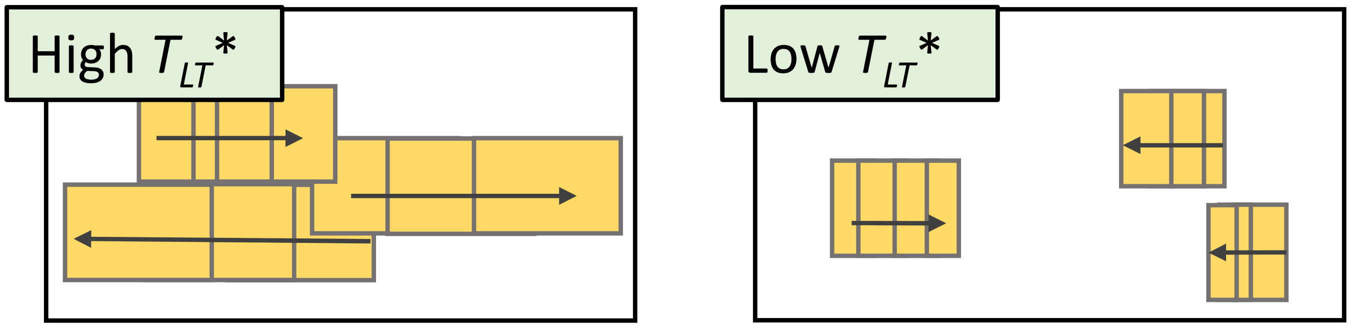
Key timescales used to capture system behaviour in mass balance space

Dimensionless mobility metrics:

$$T_{ST}* = \frac{T_c}{T_A}$$



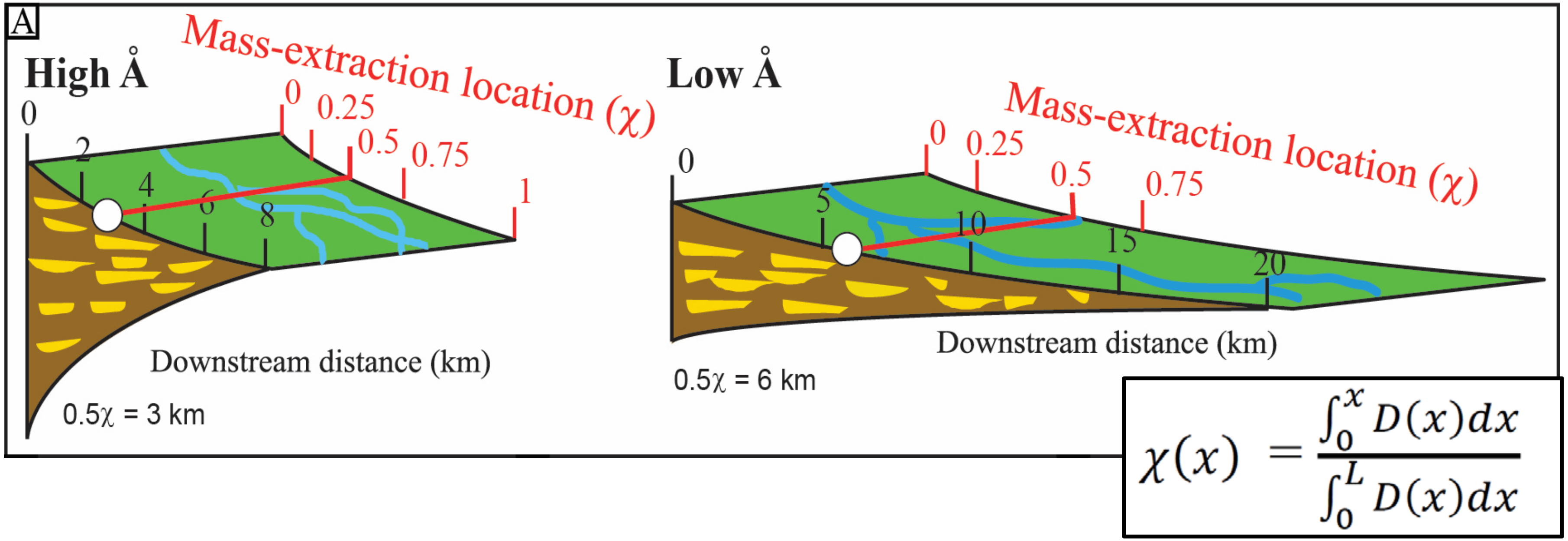
$$T_{LT}* = \frac{T_c}{T_v}$$



$T_{ST}*$ + $T_{LT}*$ = alluvial stratigraphic architecture

T_{LT}* constant in T_{ST}* scenario above, and vice versa

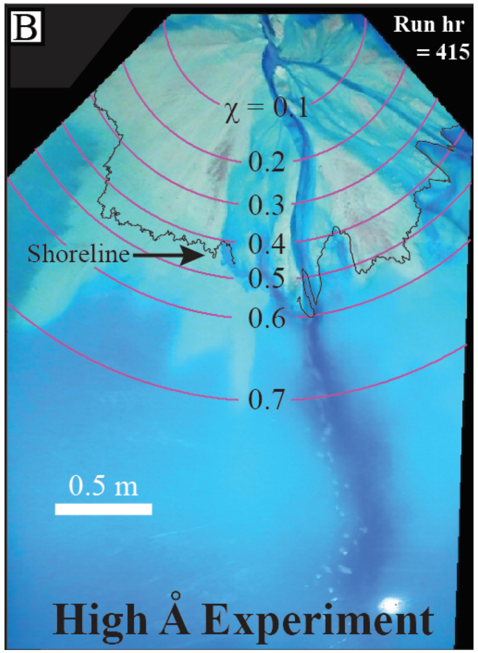
Sediment mass balance and the spatial distribution of deposition



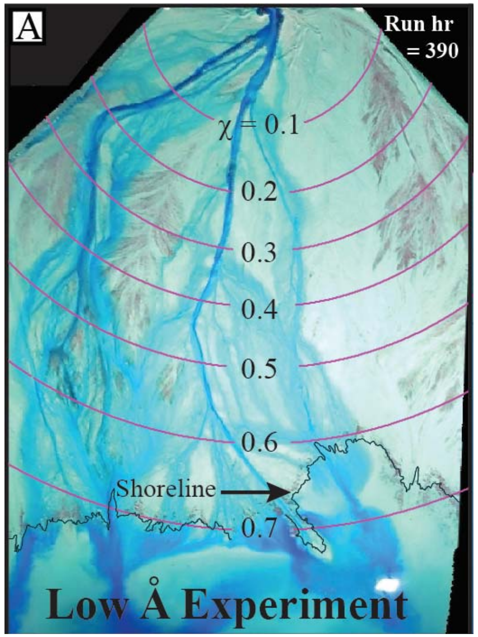
- Basin-wide accommodation and sediment mass deposition can exert a fundamental control on ASA.
- How does accommodation production influence channel process and floodplain process.

Fan delta experiments: set-up

HIGH Å EXP



LOW Å EXP

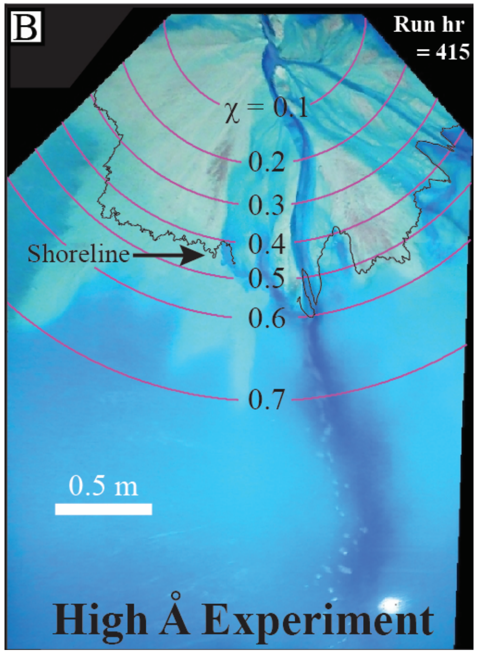


- Two experiments where only accommodation (*Å*) production varied
- Low *Å* experiment had a sea-level rise rate (*r*) of 0.1 mm/hr, The high *Å* experiment had a sea-level rise rate of 0.25 mm/hr.
- Q_S and Q_W were the same and kept constant for each
- Sediment mixture 1-1000 *μm* (*av.* 67 *μm*)
- Runs were 560 hours in duration

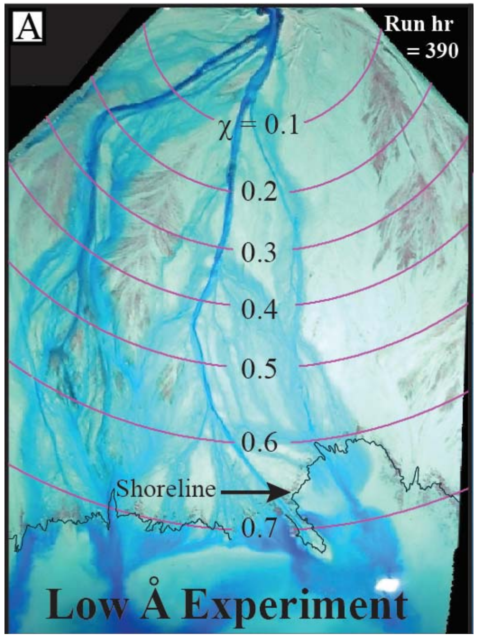
Two deltaic successions with different mass-extraction profiles.

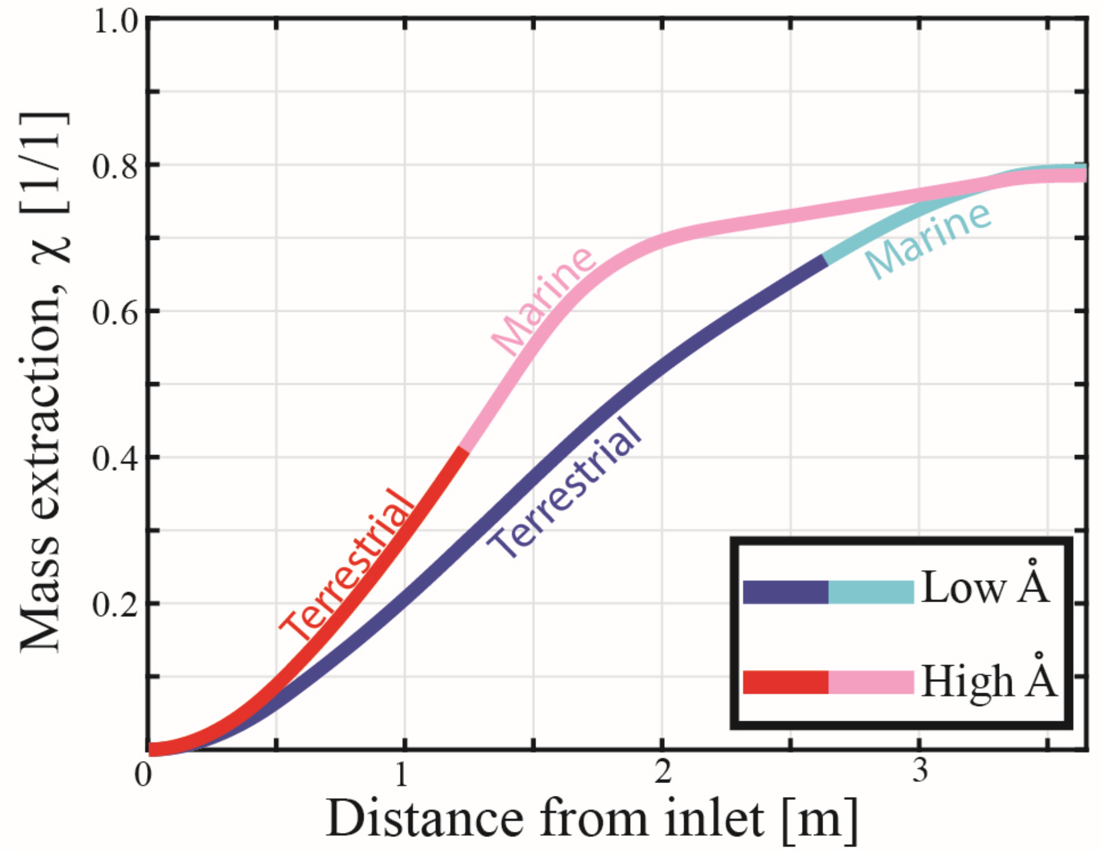
Fan delta experiments: set-up

HIGH Å EXP



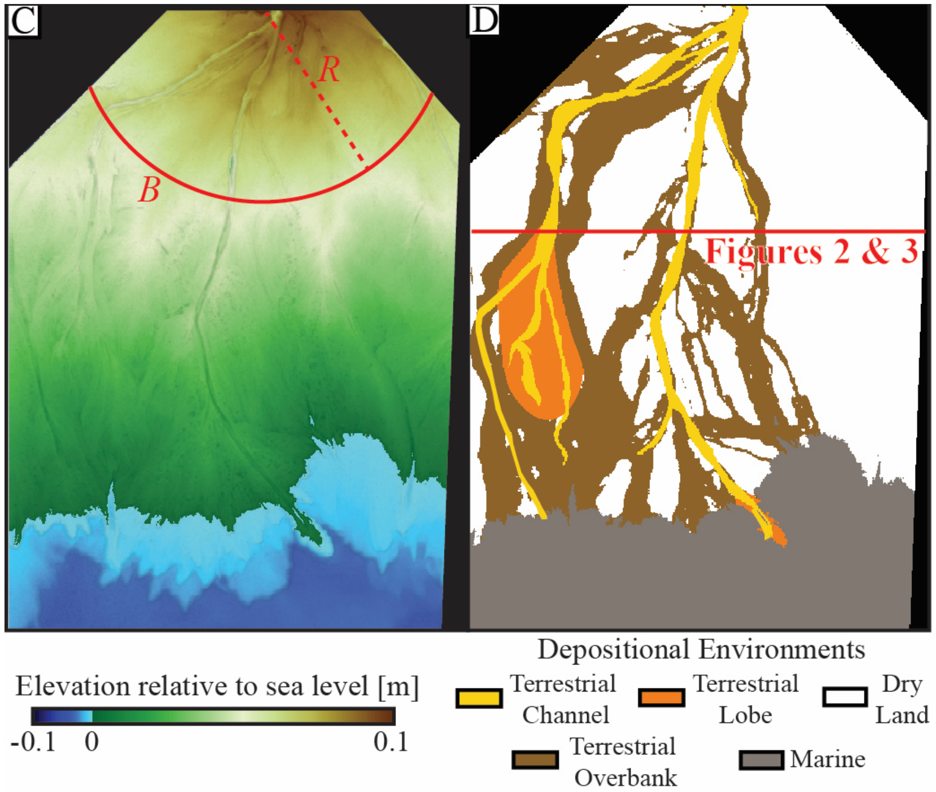
LOW Å EXP



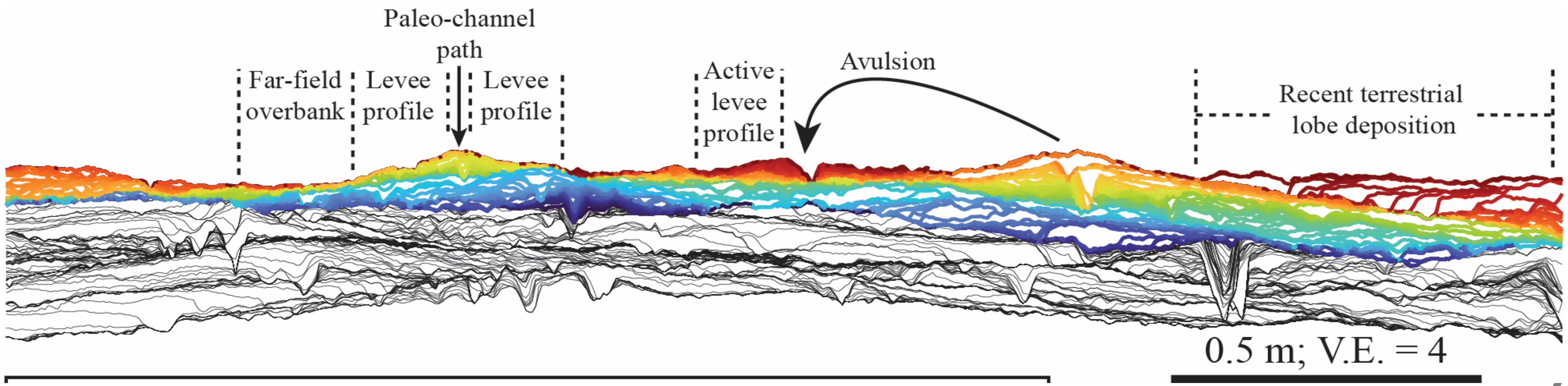


Two deltaic successions with different mass-extraction profiles.

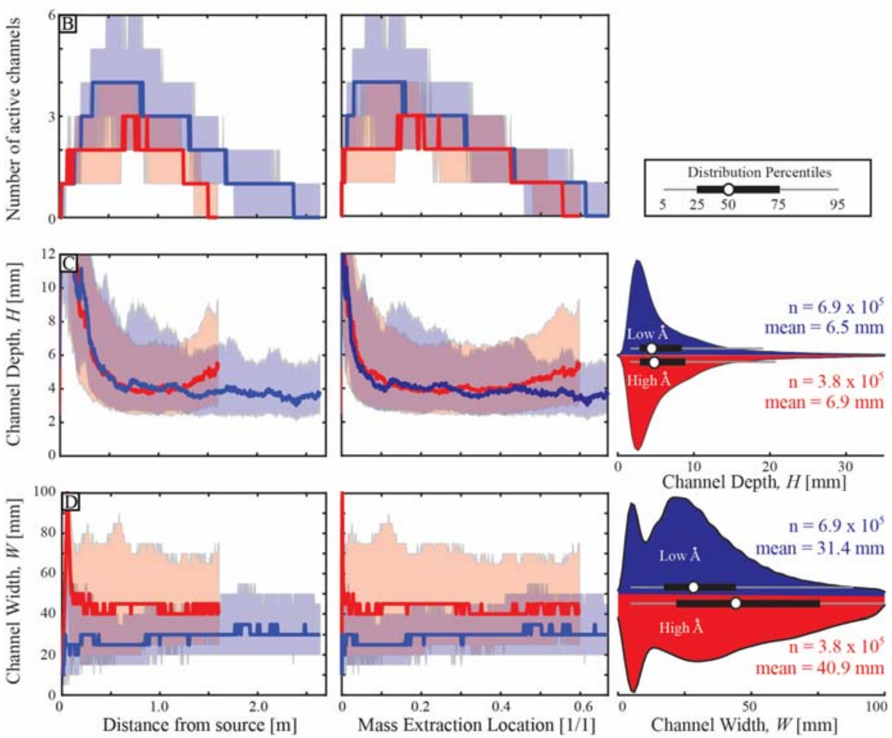
Fan delta experiments: data collection

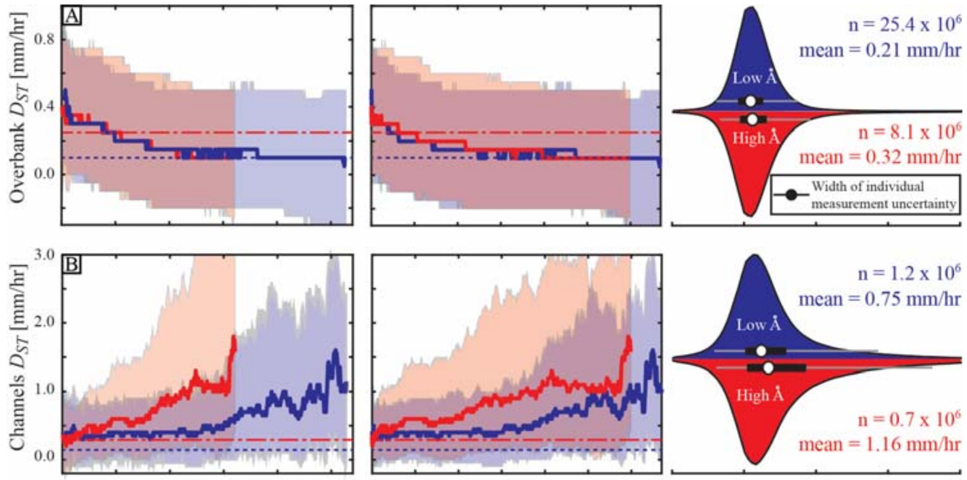


- Topographic scans and co-registered images of the experimental surface
- Five environments: terrestrial channels, terrestrial lobes, wet terrestrial overbank (floodplains), and marine.

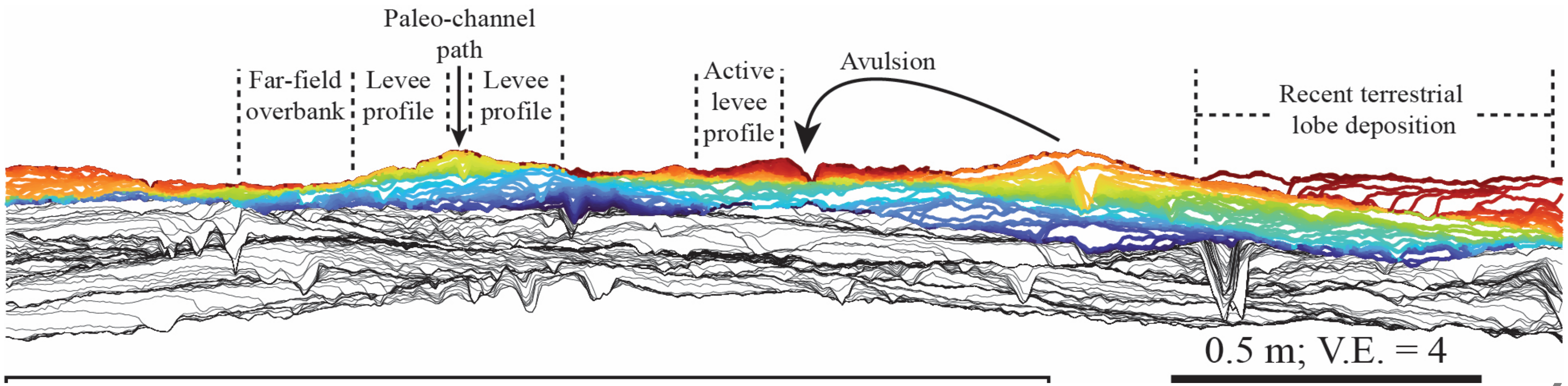


Fan delta experiments: data collection

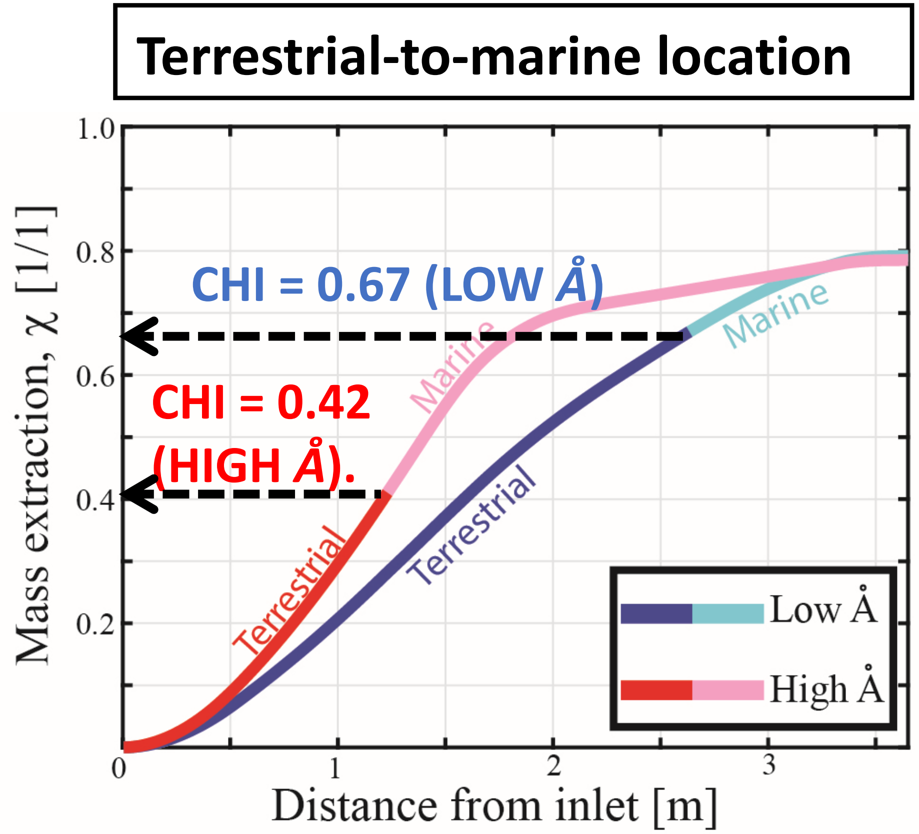




Morphometrics: Depth, width, no. of channels, channel and floodplain aggradation rates

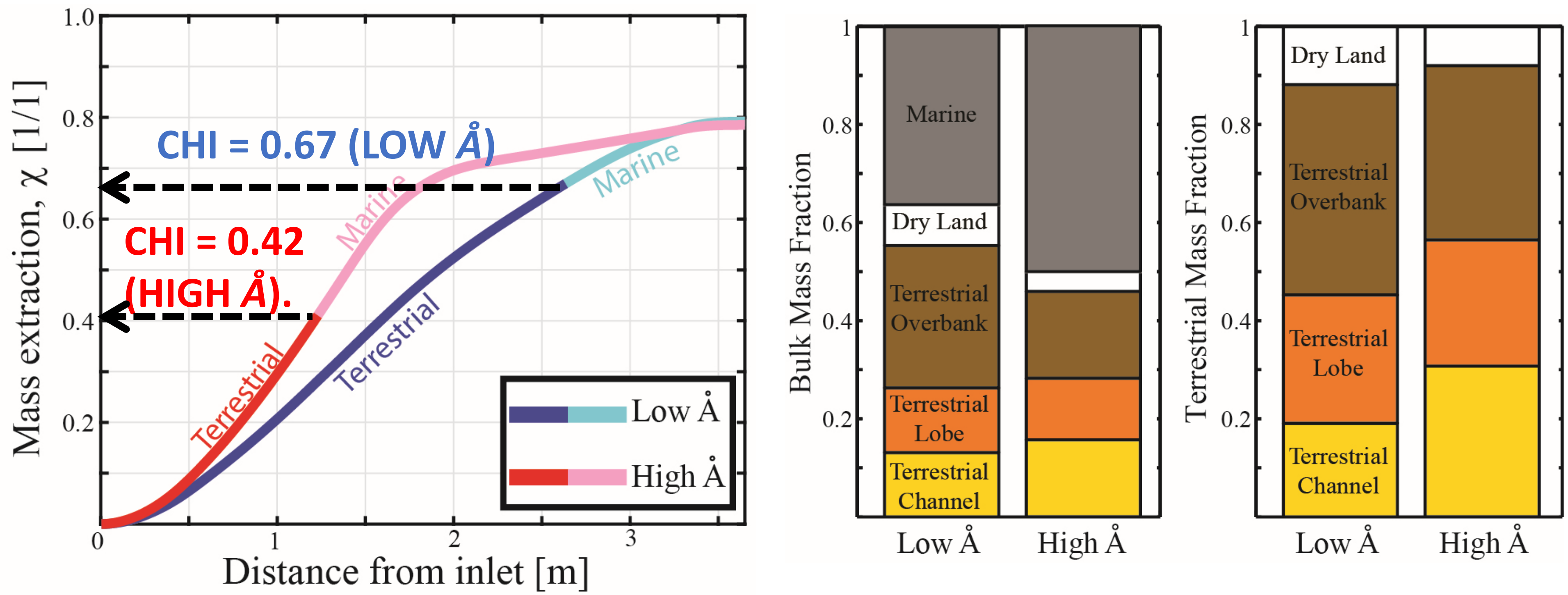


Results: bulk partitioning of sediment mass



Results: bulk partitioning of sediment mass

Terrestrial-to-marine location | **All environments** | **Terrestrial only**



- Significant overbank strata in both experiments

[29% in **Low Å experiment**, 18% **High Å experiment**]

- Terrestrial segment only, the fraction of overbank strata increases

  [43% in **Low Å experiment**, 36% **High Å experiment**]

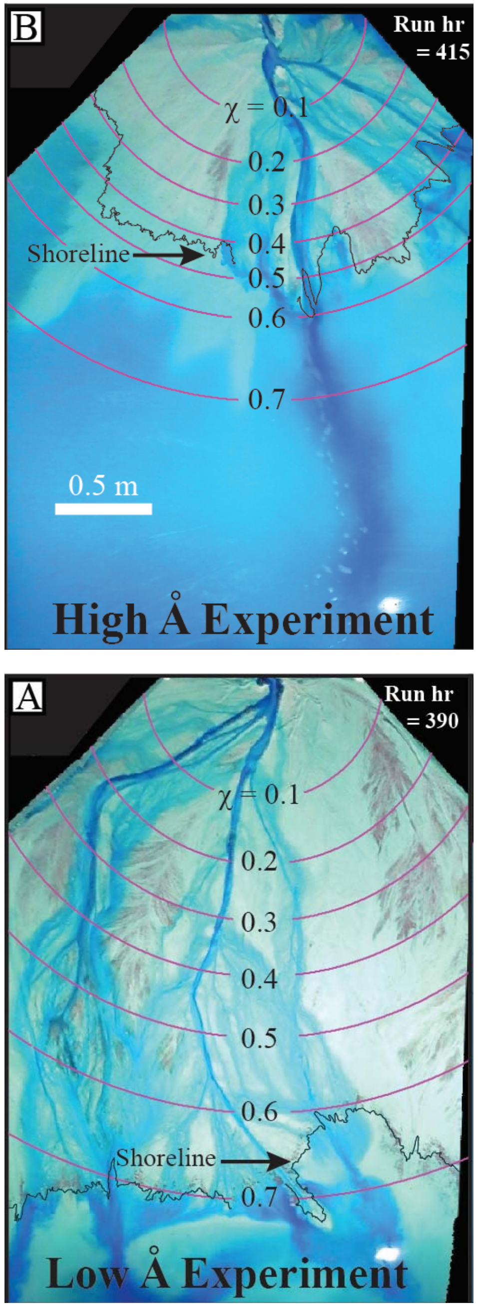
- A large fraction of sediment deposited in the marine

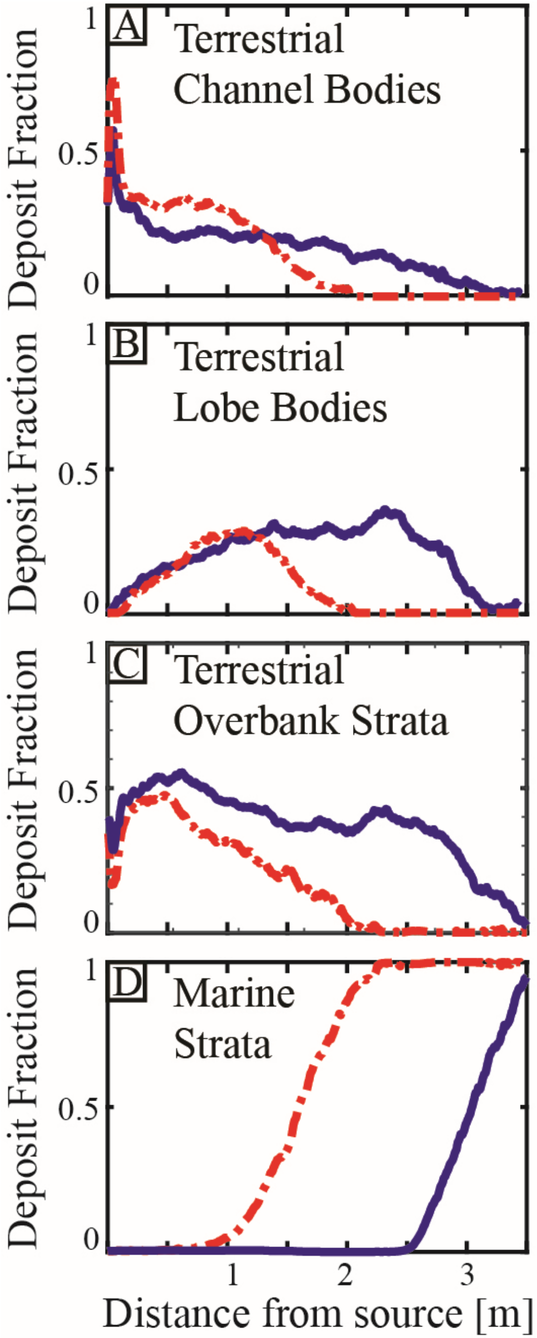
[38% in **Low Å experiment,** 50% **High Å experiment**

Results: partitioning of sediment mass

HIGH Å EXP

LOW Å EXP

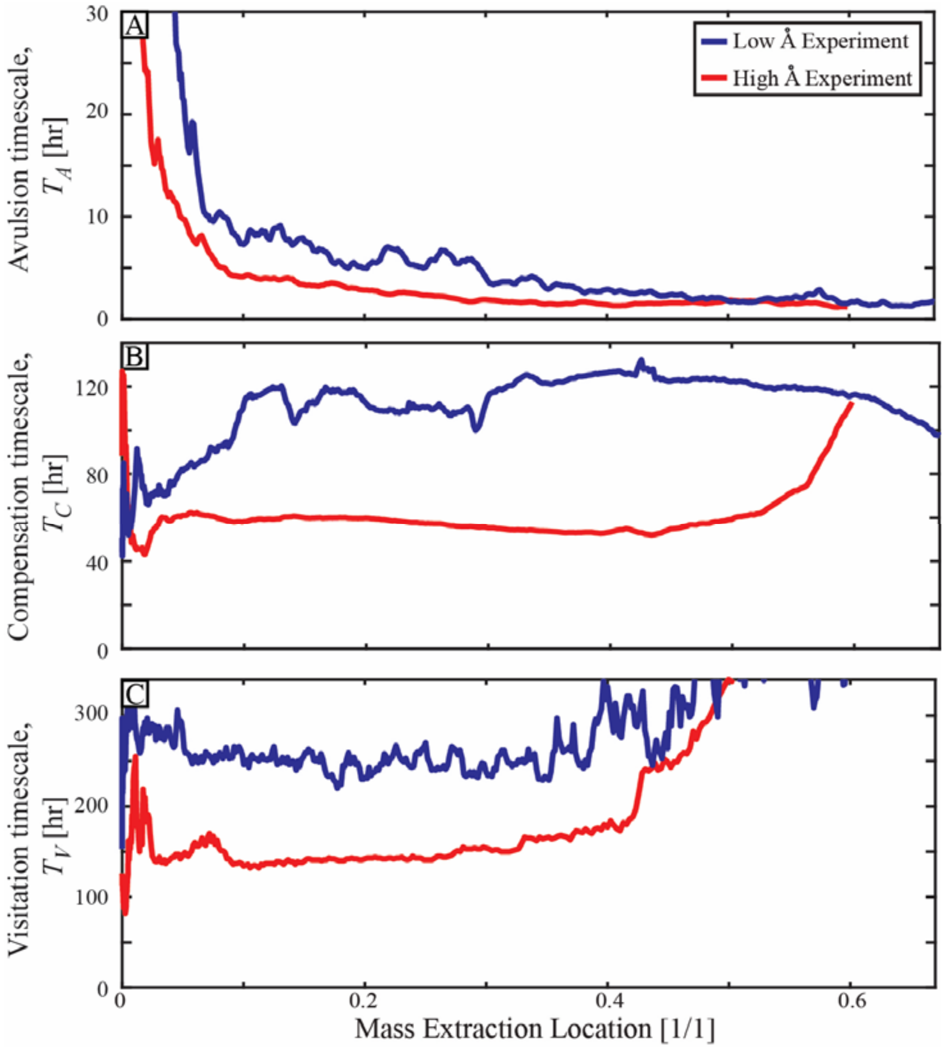




Bed-load

Suspended-load

Results: key autogenic timescales



- T_A trend driven by decreases in channel depth and increases in channel deposition rates

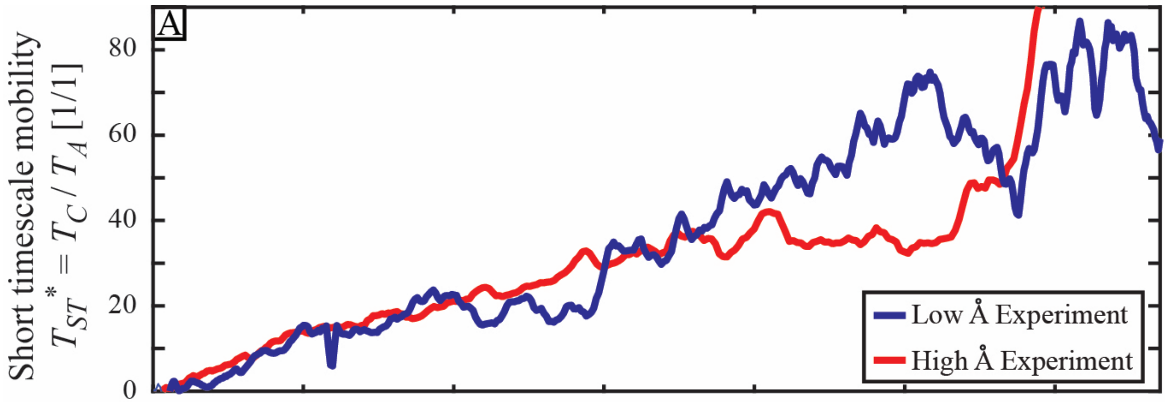
- T_C trend generally stable over the region. Divergences relate to D_{LT} and *H* values at geo-boundaries

- T_v trend constant at X-values of 0 to 0.4 over the region
- Difference by a factor of 2

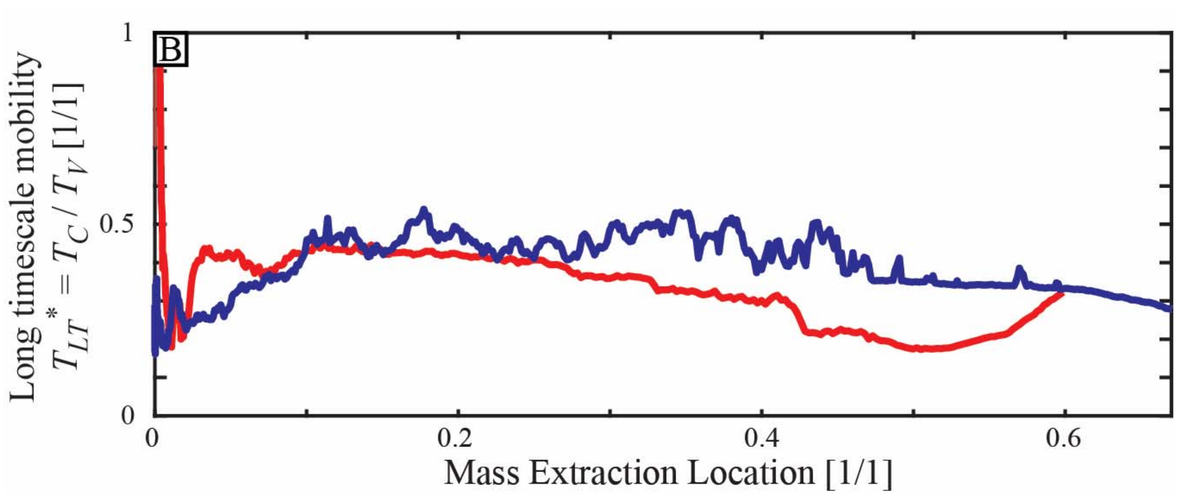
The measured autogenic timescales suggest that accommodation production rates scale with rates of autogenic processes (i.e., higher *Å* - shorter autogenic timescales).

Results: mobility metrics in mass balance

Are autogenic rates sensitive to accommodation production?



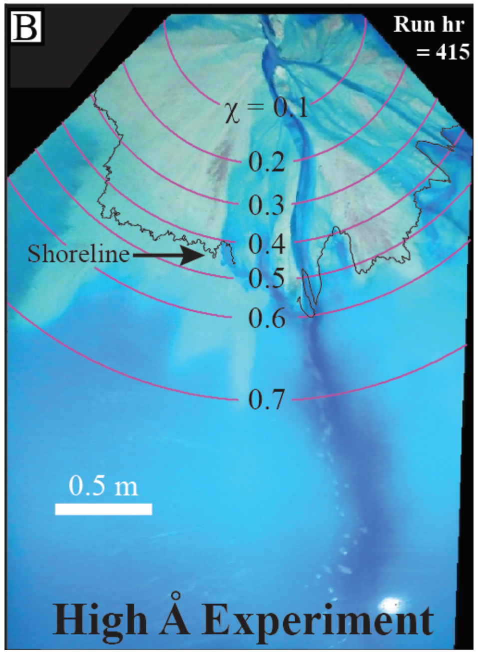
T_{ST}* increase suggests channels are more prone to avulse at distal basin locations



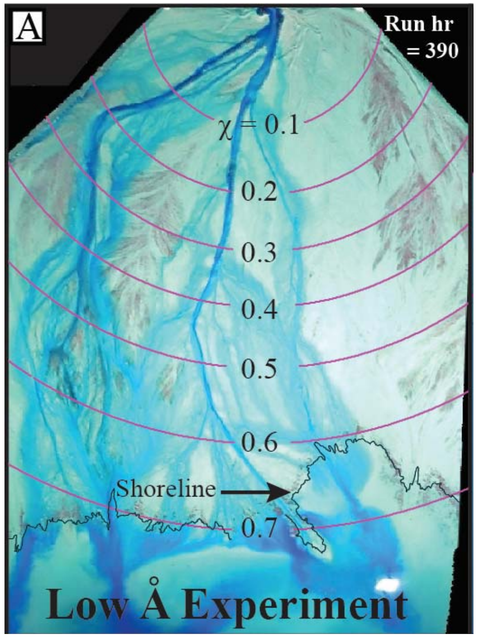
T_{ST}* and T_{LT}* are approximately equal in the two experiments at equivalent *X* locations

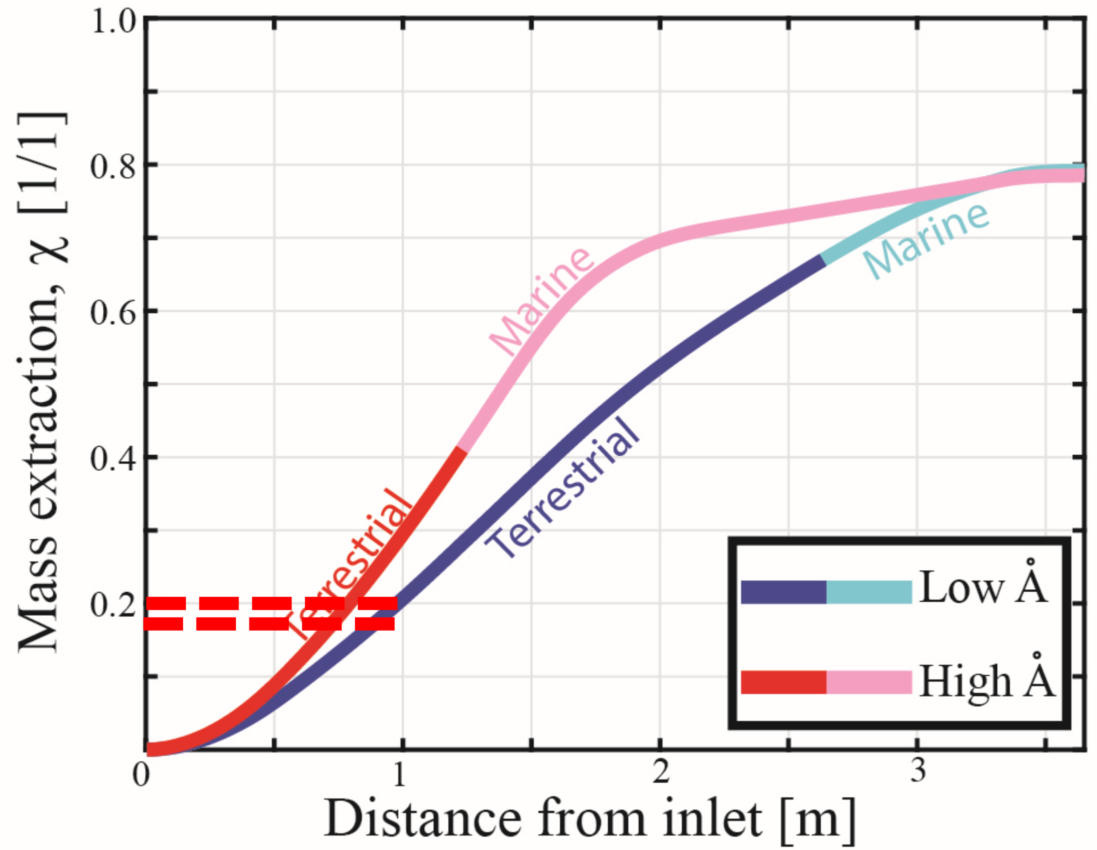
Fan delta experiments: set-up

HIGH Å EXP



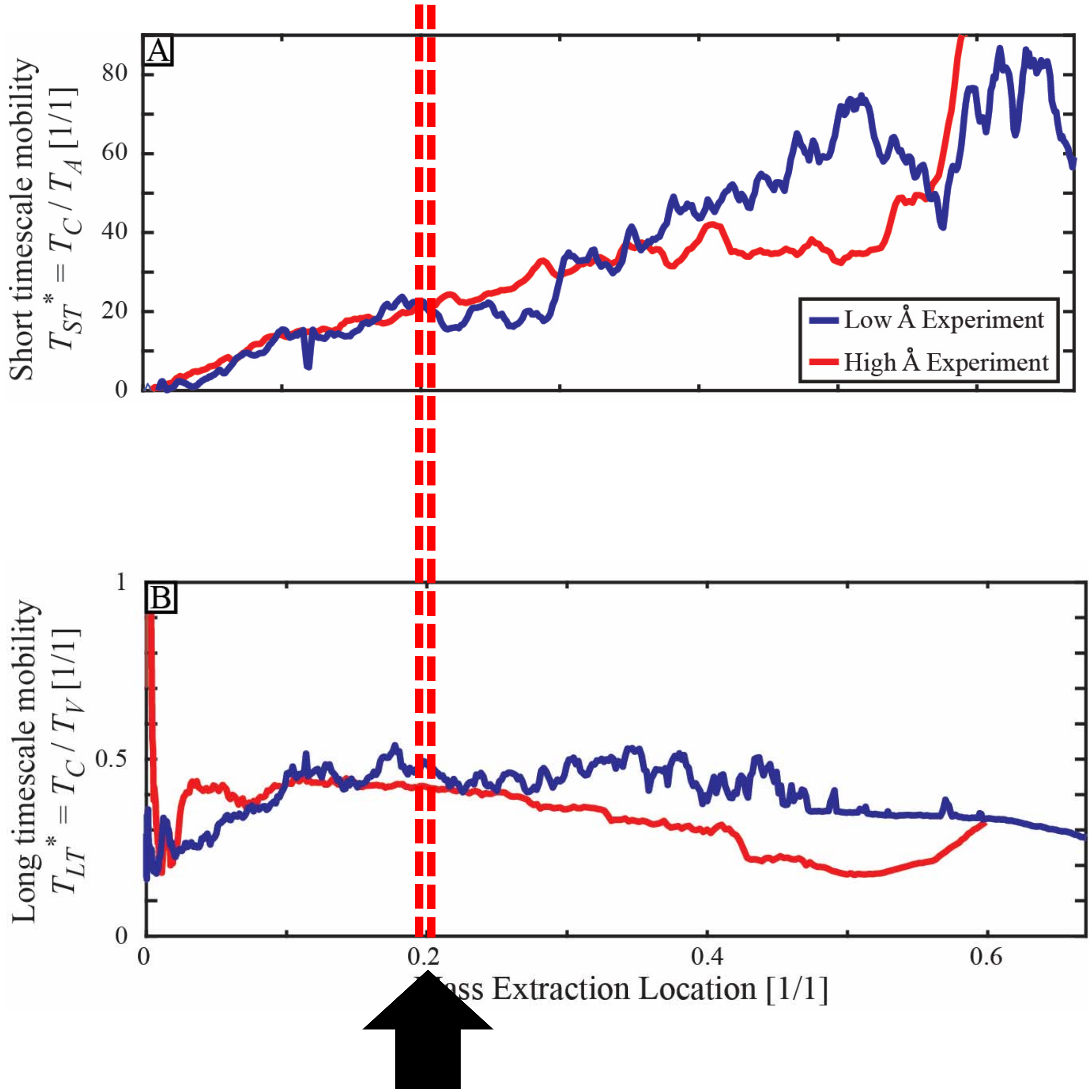
LOW Å EXP





Results: mobility metrics in mass balance

Are autogenic rates sensitive to accommodation production?

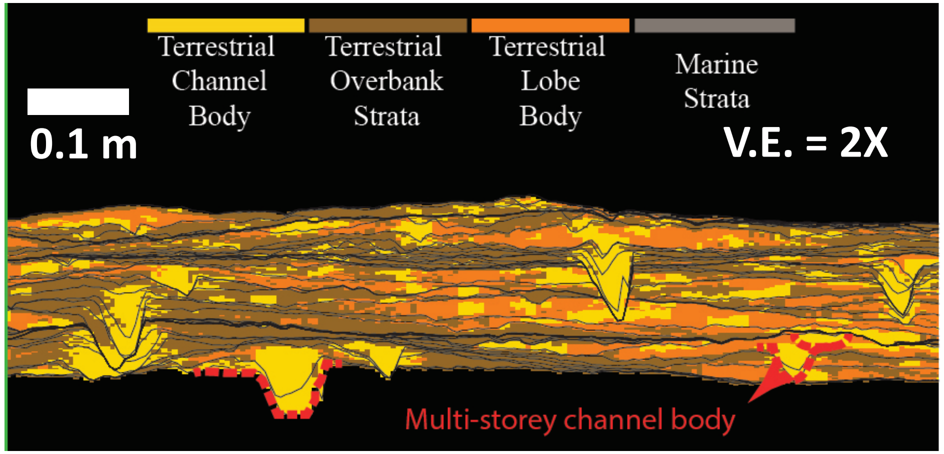


Changes in the vertical mobility of each system driven by changes in accommodation production will induce proportional changes in lateral mobility.

i.e. accommodation production rates influence autogenic process timescales in a manner that preserves mobility metrics important for stratigraphic architecture

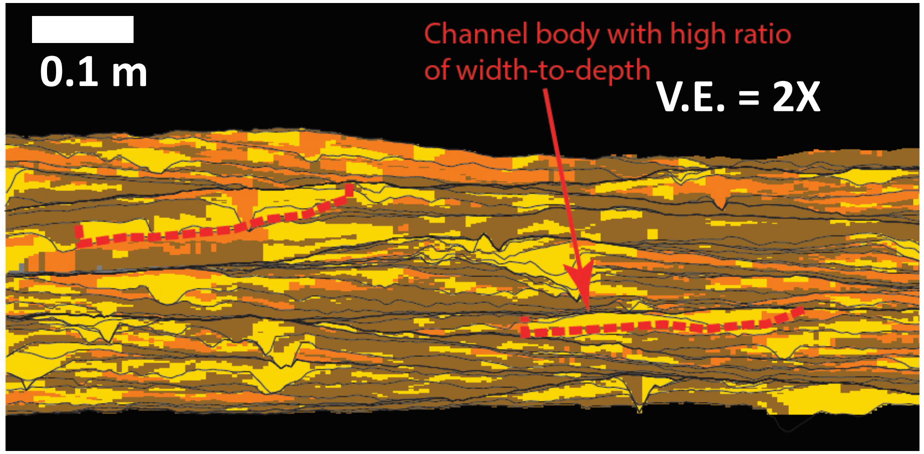
Results: alluvial stratigraphic architecture

Low Å experiment



Narrow and thick channel storey complexes caused by greater in-channel aggradation between avulsion events.

High Å experiment



Wide and thin multilateral storey complexes related to greater channel mobility.

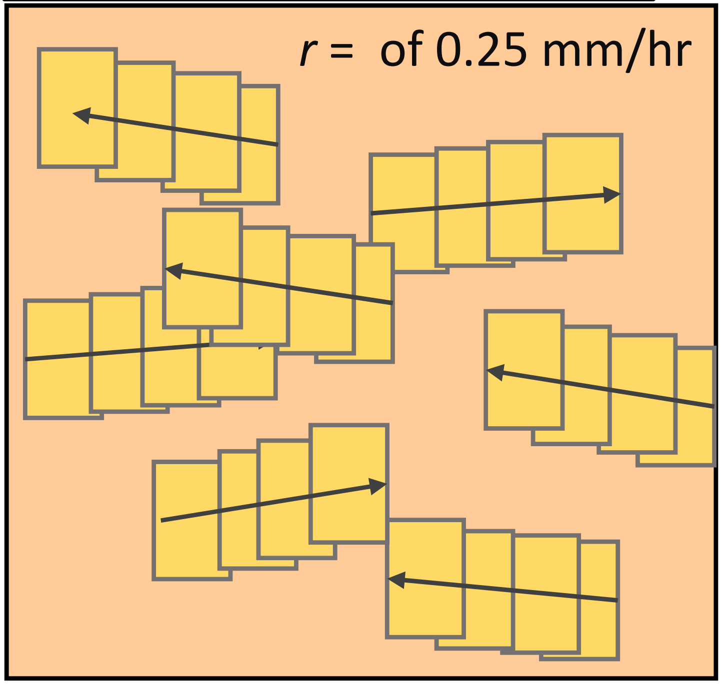
Channel deposit fractions and dimensionless mobility metrics (T_{ST}* and T_{LT}*) were similar in the two experiments, but display differences in architecture owing to absolute autogenic values

Results: mobility metrics in mass balance

$$T_{ST}* = \frac{T_c}{T_A}$$

$$T_{LT}* = \frac{T_c}{T_v}$$

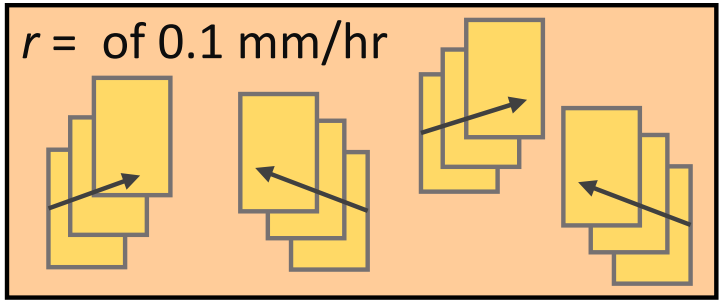
High Å experiment



T_c = 60 hrs
T_v = 140 hrs
T_a = 3 hrs

$T_{ST}*$ = 20
$T_{LT}*$ = 0.43

Low Å experiment

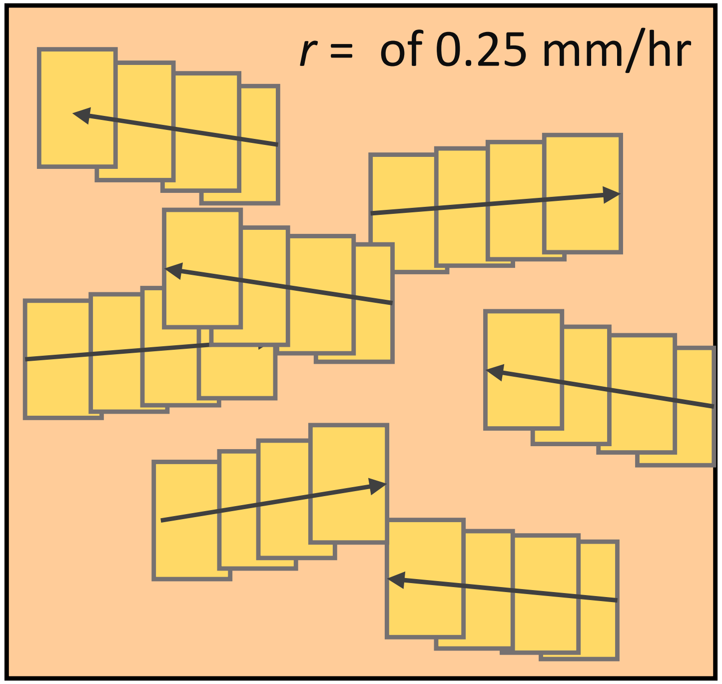


T_c = 120 hrs
T_v = 250 hrs
T_a = 6 hrs

$T_{ST}*$ = 20
$T_{LT}*$ = 0.48

Results: mobility metrics in mass balance

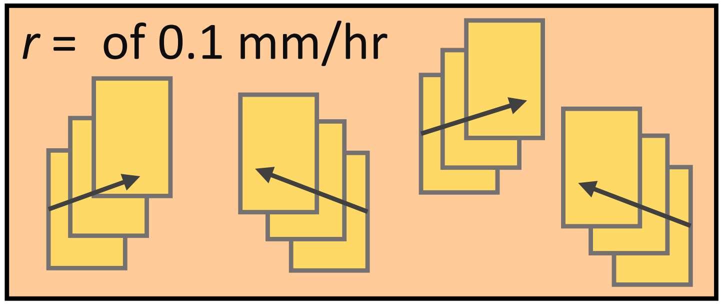
High Å experiment



Meaning that T_c, T_A and T_v co-vary proportionally in response to accommodation production – ***a self-organized system.***

$T_{ST}* = 20$
$T_{LT}* = 0.43$

Low Å experiment



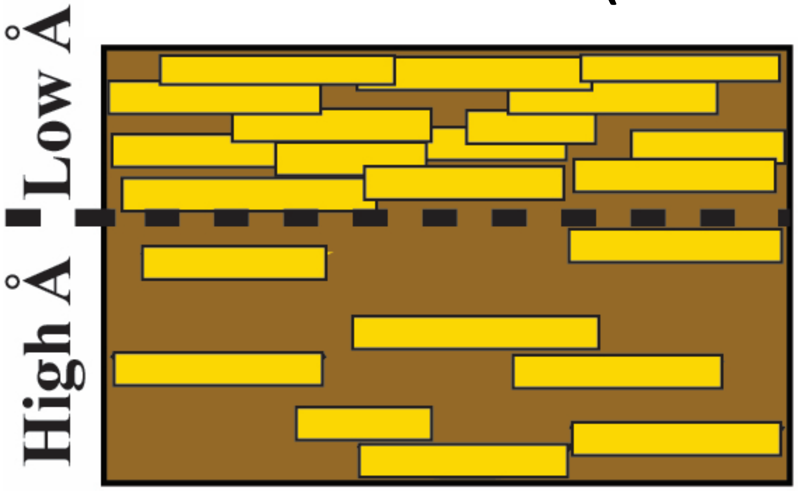
$T_{ST}* = 20$
$T_{LT}* = 0.48$

$$T_{ST}* = \frac{T_c}{T_A}$$

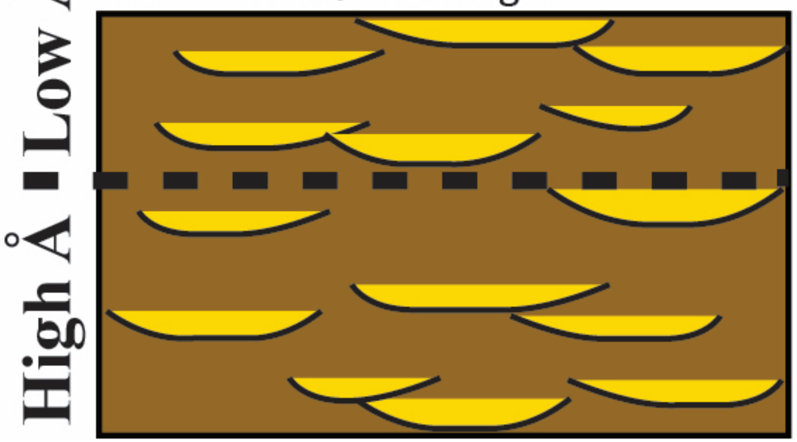
$$T_{LT}* = \frac{T_c}{T_v}$$

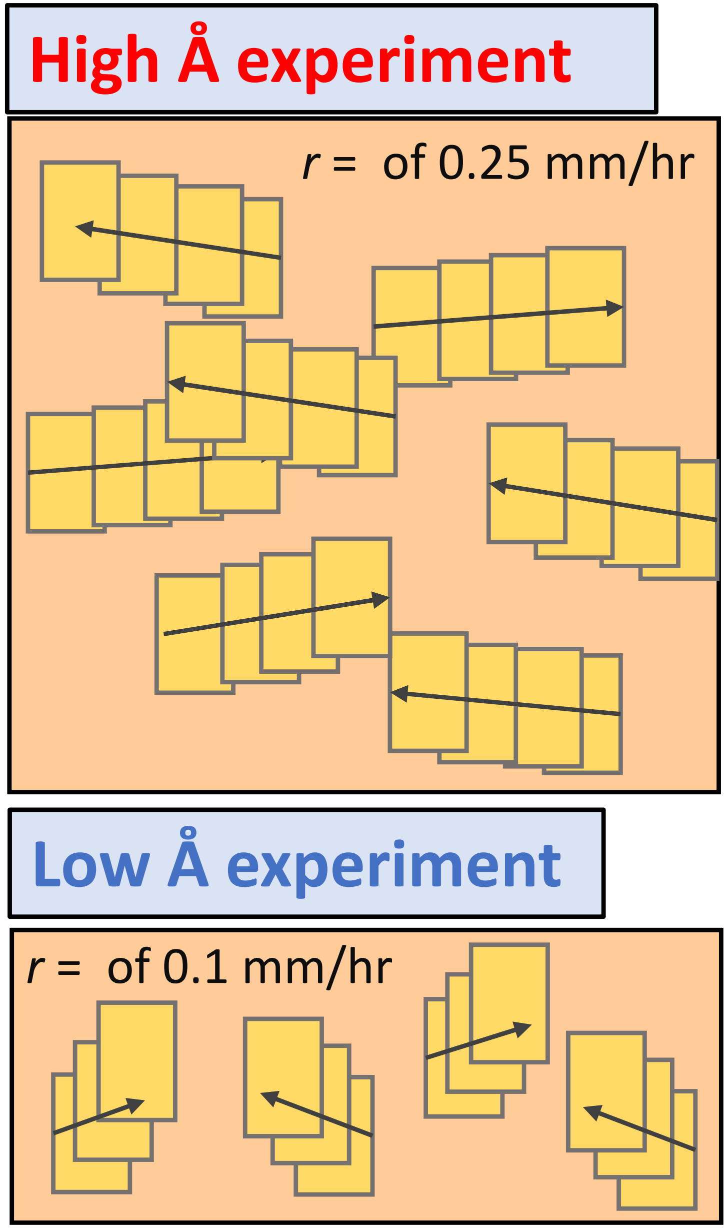
Some advancements on ASA prediction

Fixed distance (LAB models)



Fix in mass balance
(Strong et al. 2006)





Conclusions and wrap up

- Our results support the initial findings and assertions of Strong *et al*. (2005) regarding the control of sediment mass extraction on alluvial stratigraphic architecture.
- Accommodation production rates influence autogenic processes in a way that preserves mobility metrics (self-organization).
- Provides insights into the underlying control on ASA that can be directly validated or applied field-scale datasets.
- Provides a basis for improving geostatistical models at exploration and appraisal stage.

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