

Weak and Strong Interactions: The Coevolution of Autogenic Processes and External Forcing in Experimental Deltas*

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Abstract

Physical experiments of depositional geomorphology and stratigraphy have proven very useful in the analysis of diverse autogenic processes in landscape evolution. This is largely because similar braided and distributive channel patterns emerge in sediment transport at experimental scales, and over time permit study of self-formed surface kinematics and patterns of erosion and deposition. The growth of new insights from and interest in experimental landscapes is timely for predictive stratigraphy in industry today, where the distillation of autogenic and allogenic records in subsurface architecture has important implications for the exploration and development of hydrocarbon reservoirs. Towards that end an important hurdle will be to quantify the types and magnitudes of dependence (or general independence) of internal processes on the external conditions.

A qualitative approach to the problem may be to consider that the extent to which one can resolve external stratigraphic records is related to the extent to which the external signal is capable of overprinting autogenic filtering. We quantify the autogenic filter as the magnitude of topographic effects from sediment storage and release, and the magnitude of external forcing by the rate of change of the boundary conditions. We use this method to explore the rich variety of interactions between the internal and external components of experimental basin filling, and have good reason to hypothesize relatively weak and strong autogenic responses to changing allogenic conditions, due largely to the degree to which changes in external forcing suppress or enhance deposition, respectively.

References

Hoyal, D.C.J.D. and B.A. Sheets, 2009, Morphodynamic evolution of experimental cohesive deltas: Journal of Geophysical Research, v. 114/F2, p. Citation FO2009.
doi:10.1029/2007JF000882.

Martin, J., B. Sheets, C. Paola, and D. Hoyal, 2009, Influence of steady base-level rise on channel mobility, shoreline migration, and scaling properties of a cohesive experimental delta: Journal of Geophysical Research, v. 114/F3, p. Citation FO3017.
doi:10.1029/2008JF001142.

Weak and strong interactions: the co-evolution of autogenic processes and external forcing in experimental deltas

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We acknowledge the following contributors:

Dora Novak, Mikhail Danilkin, Craig Hill, and Chris Paola



ExxonMobil
Upstream Research

Motivation:

Given that autogenic-process and external-forcing time scales overlap...

How might we approach the issue of recognizing “autogenic” and “allogenic” depositional records? *How to incorporate into high-resolution sequence stratigraphy?*

Goal:

Utilize physical experiments (cohesive (EM) and noncohesive (SAFL)) to explore depositional records produced from combinations of autogenic surface processes and external forcing

General Hypothesis:

Consider intrinsic variability in deposition as a filter that overprints changes in the boundary conditions, effectively masking allogenic depositional effects. *Changes in boundary conditions must be larger/longer than spatio-temporal aspects of autogenic depositional effects*

Conclusion

Experimental allogenic records produce lateral facies migration >> autogenic processes

$R_{\text{allo}} < R_{\text{auto}}$: autogenic depositional records locally mask mean system response

$R_{\text{allo}} > R_{\text{auto}}$: allogenic record is approximately system wide, but can be extremely subtle

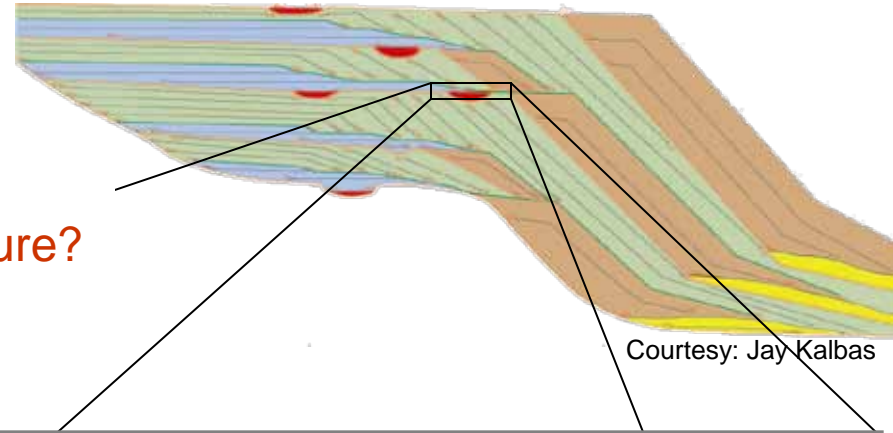
Sequence Stratigraphic Context

- Sequence stratigraphy is the dominant model in use in industry and is widely applied across many scales
- Acts as the null hypothesis for many data sets

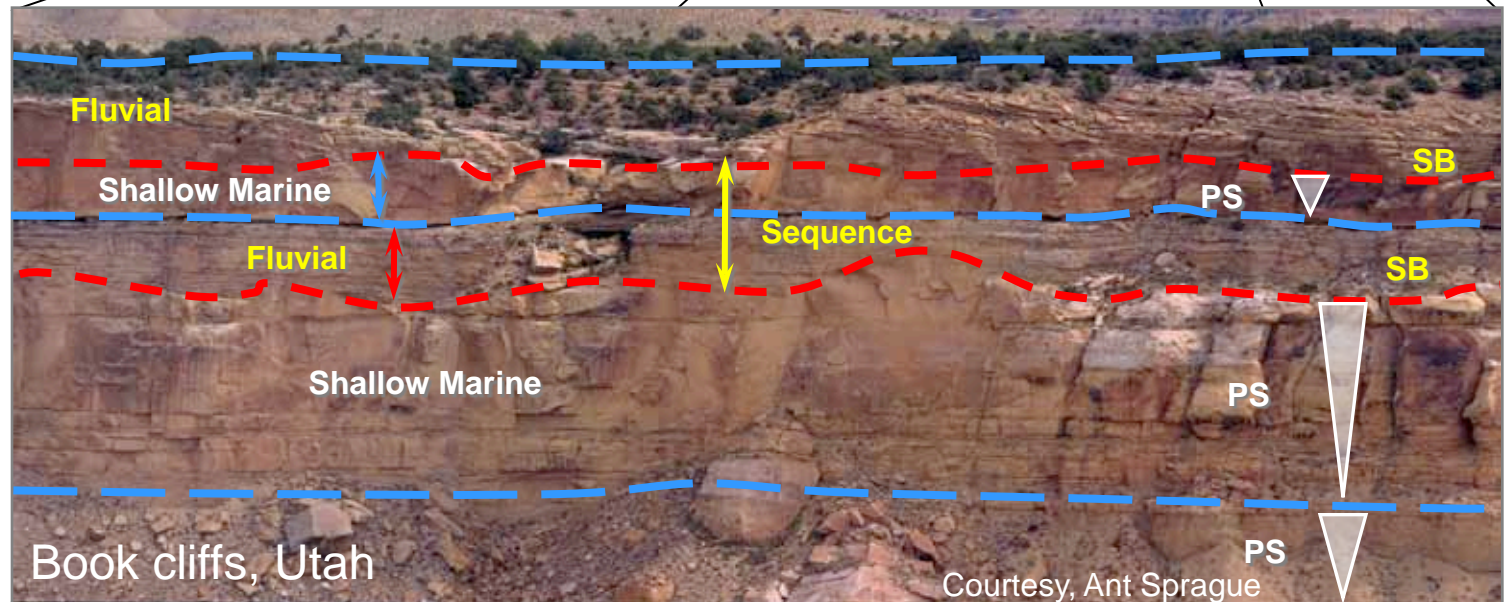
At reservoir (outcrop) scales, what roles do autogenic processes play in stratal architecture?

What does this imply for prediction?

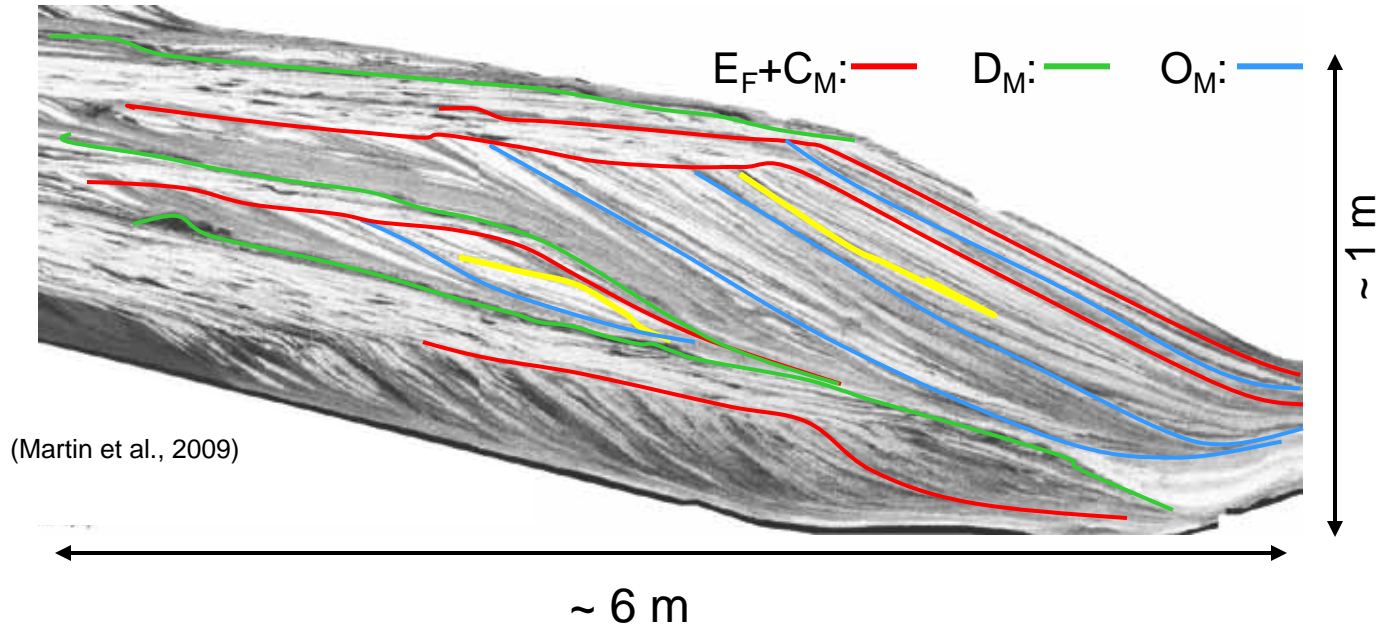
General sequence stratigraphic model



Courtesy: Jay Kalbas



Autogenic Records in Experimental Sequence Stratigraphy



Key stratal discordances:

Some are “allogenic” records – basin-wide shifts in sediment mass

Some are “autogenic” records – local shifts in sediment mass (internal onlap/downlap)

How do we constrain what “local” vs. “regional” is from ancient systems?

What insights might physical modeling provide us with?

Experimental Data Sets Description

Delta Basin Facility [5m x 5m x 0.61m]
St. Anthony Falls Laboratory, University of Minnesota

Designed using a weakly cohesive
sediment mixture (Hoyal and Sheets, 2009)

Base-level = variable

$Q_s, Q_w = \text{constant}$

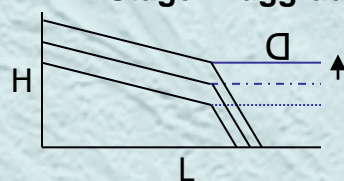
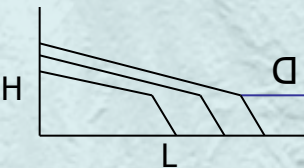
Data collection:

Overhead images
Topography

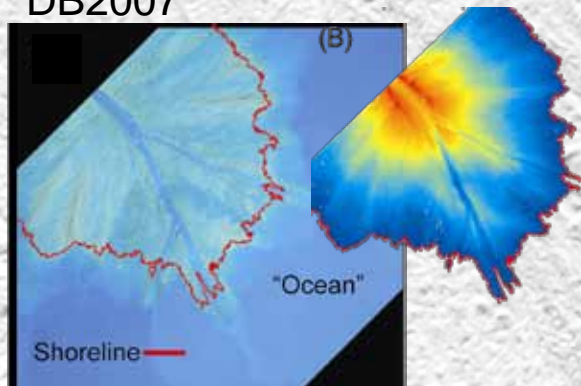
DB2007
200-hour experiment:

Stage 1: progradation

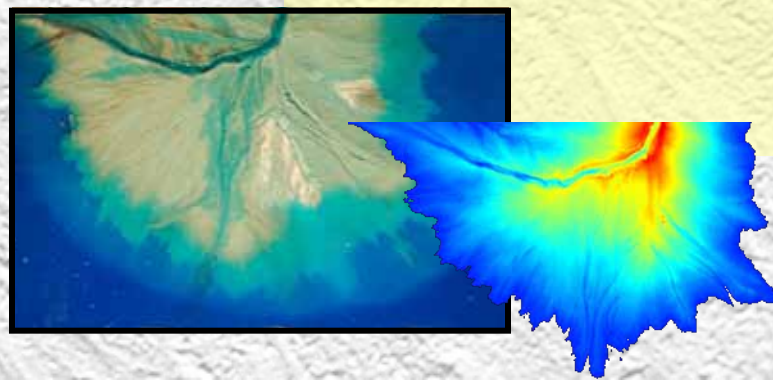
Stage 2: aggradation



DB2007



DB2009

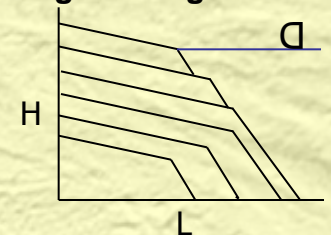
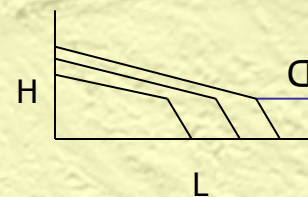


DB2009

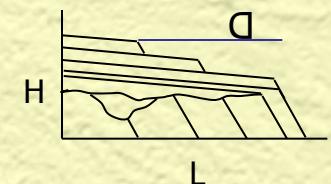
550-hour experiment:

Stage 1: progradation

Stage 2: long-term P - R



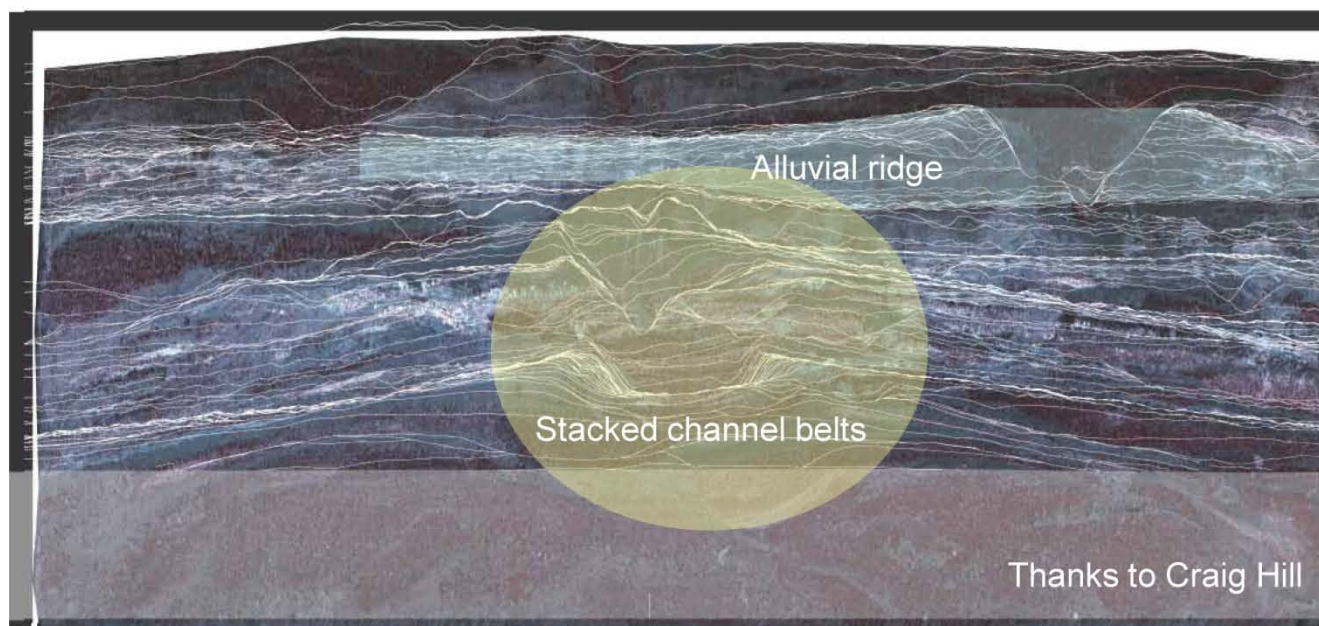
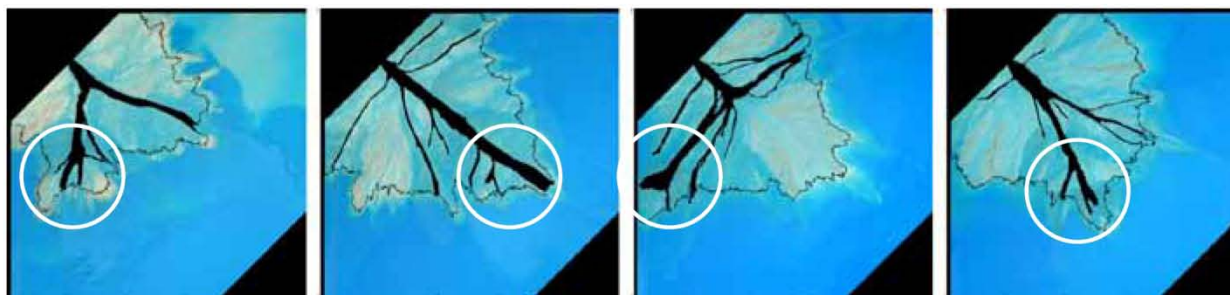
Stage 3: base-level cycle



Autogenic Processes and Deposits

Sediment transport in experimental distributary channel systems is unsteady

Channel elongation/splitting forms delta lobes. Avulsion sets growth location



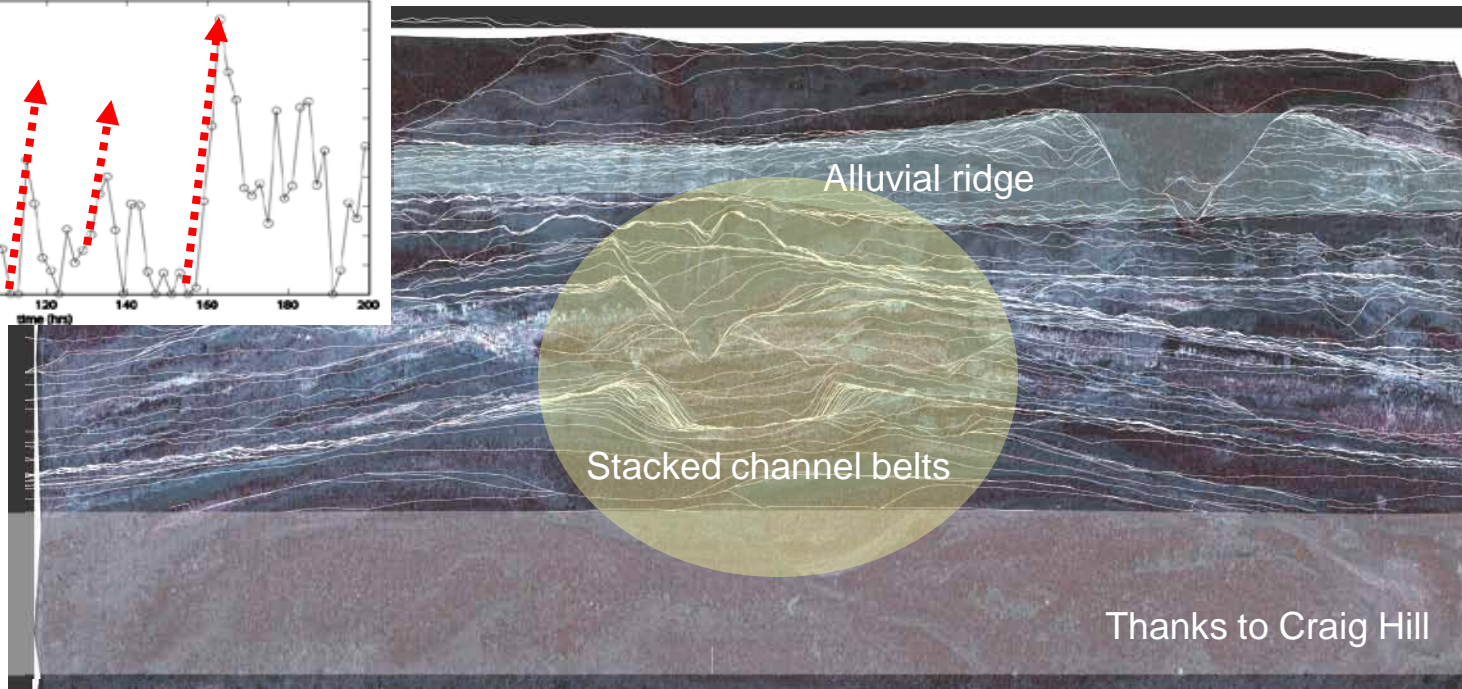
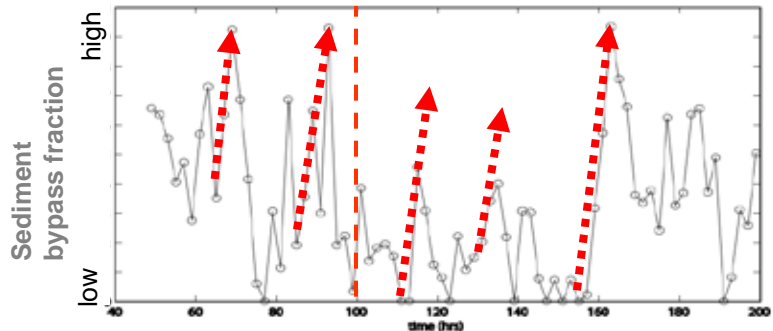
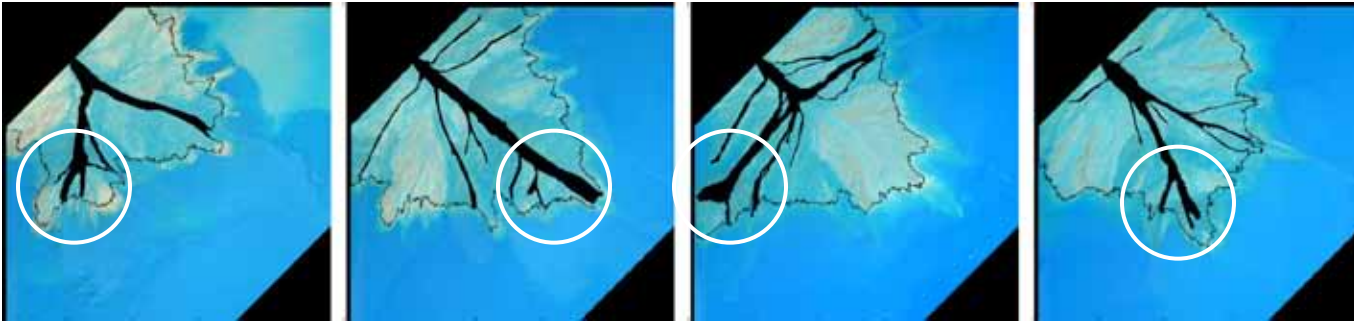
Presenter's Notes: Focus is on:

Deposition/release of sediment produces much of the organization we interpret from modern landscapes and stratigraphic successions.

Autogenic Processes and Deposits

Sediment transport in experimental distributary channel systems is unsteady

Channel elongation/splitting forms delta lobes. Avulsion sets growth location



Thanks to Craig Hill

Autogenic processes as a Buffer to Allogenic Sedimentary Records

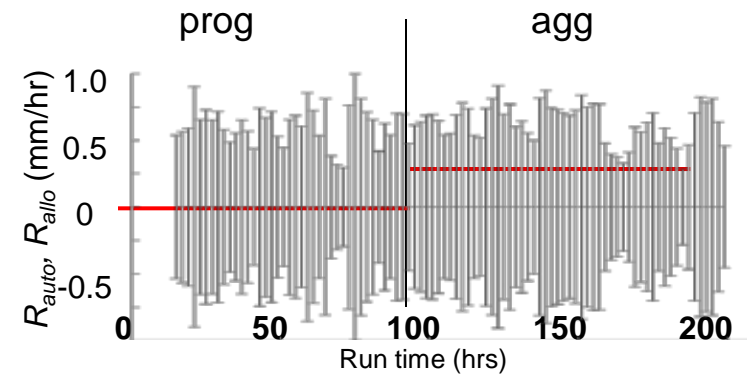
Explore a related thread to time scale analysis: depositional variability (R_{auto}) against external change (R_{allo})

$$R_{allo} = \frac{dh_{land,t}}{Dt}$$

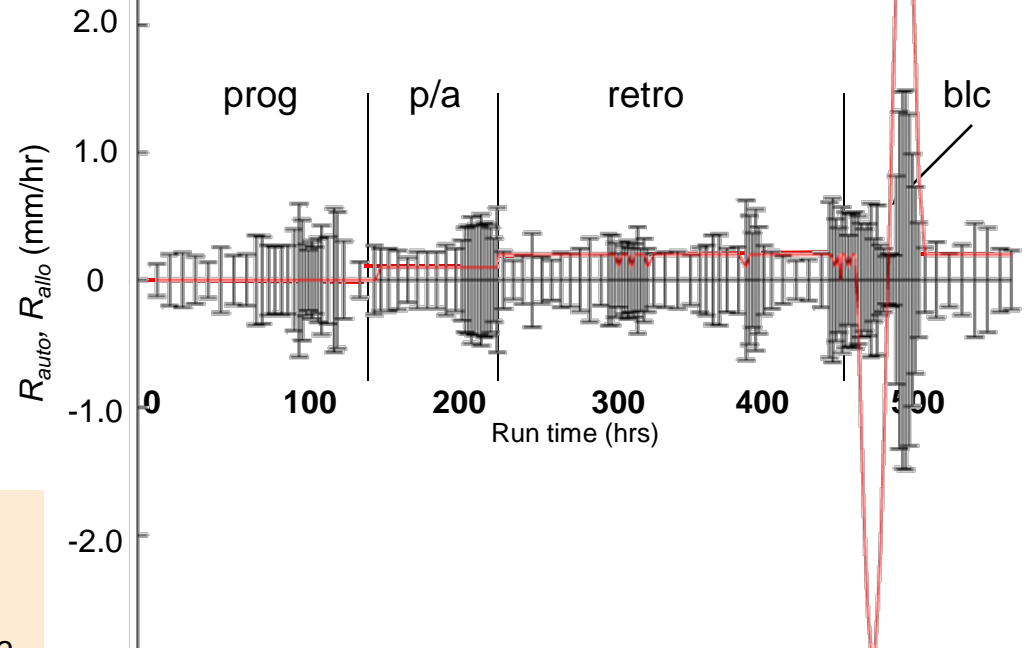
$$R_{auto} = \frac{rms_{deposition}}{Dt} = \frac{rms(h_{land,t+1} - h_{land,t})}{Dt}$$

Allogenic records persist when $R_{allo} > R_{auto}$

DB2007



DB2009



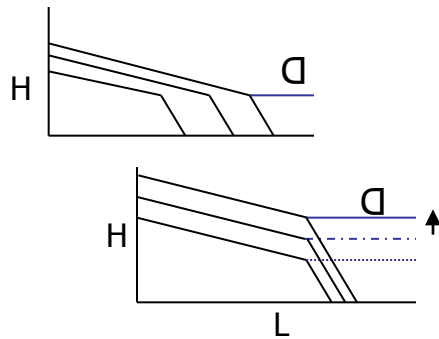
$R_{auto} \text{ DB2007} > R_{allo} \text{ DB2009}$

R_{auto} shows some dependence on R_{allo}

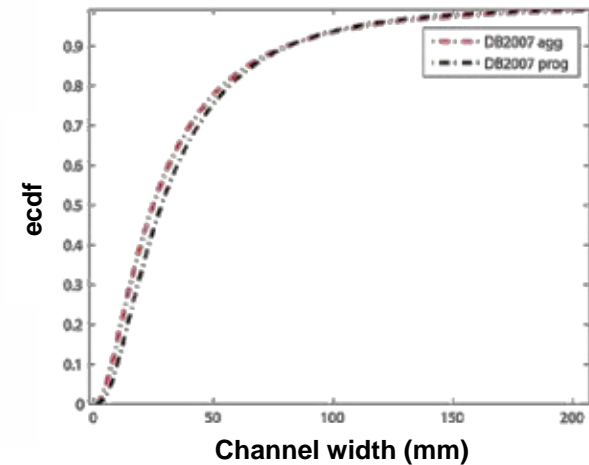
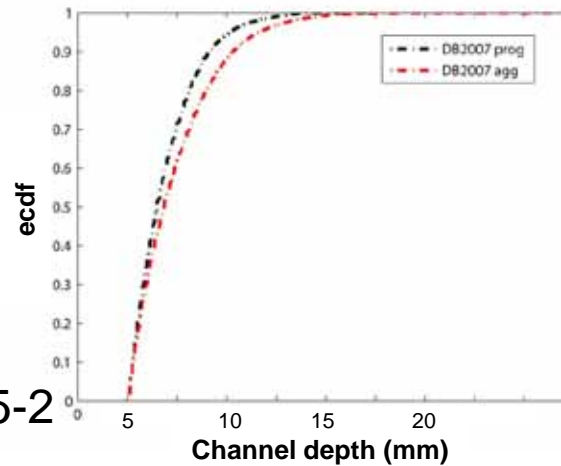
$R_{allo} > R_{auto}$ for base-level cycle (blc), DB2009 only

DB2007 Experimental Delta Stratigraphy Results

The onset of base-level rise results in changes in mean deposition rate but very little in R_{auto} , *synoptic* channel geometry, or distributary network properties

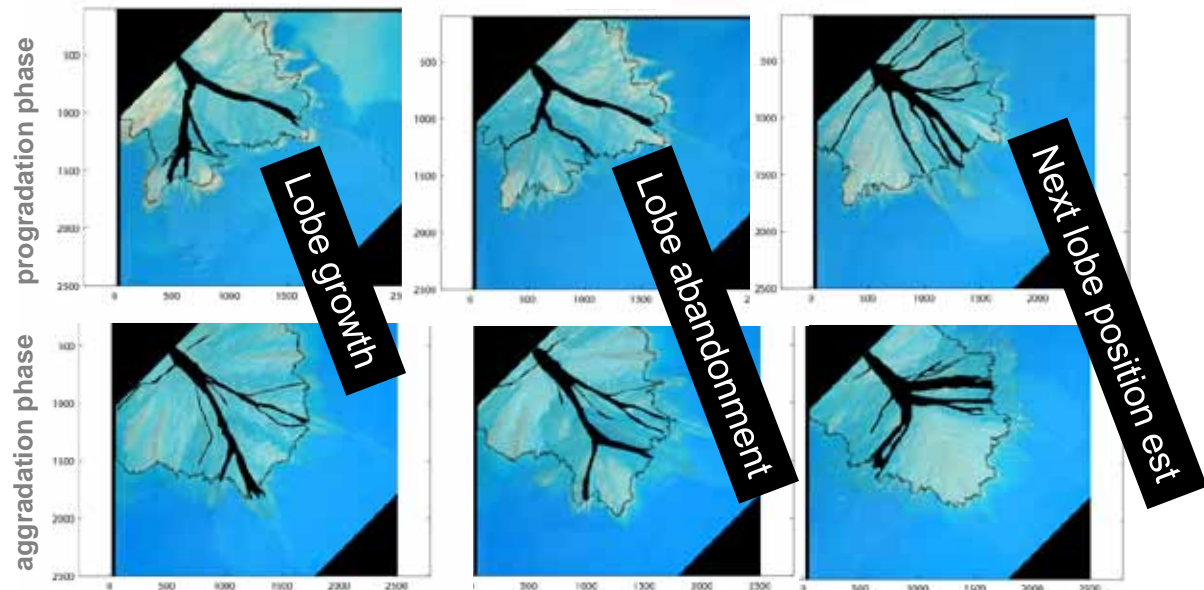


$$\frac{\text{Deposition rate agg}}{\text{Deposition rate prog}} = \sim 1.5-2$$



Shorelines are statistically similar:

Delta lobes are similar in length and expansion angle



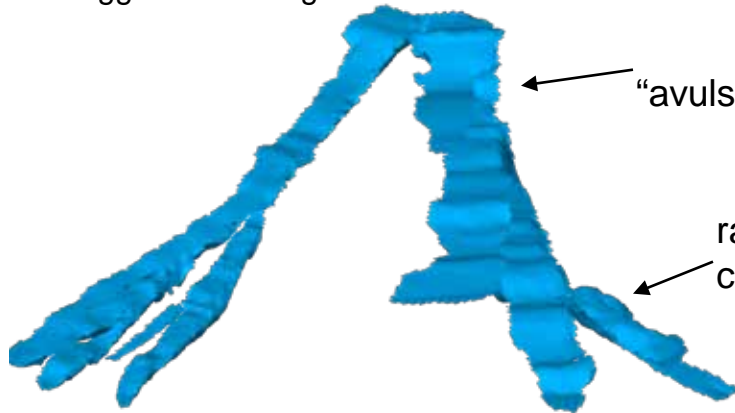
DB2007 Experimental Delta Stratigraphy Results

What does this imply for the stratigraphy?

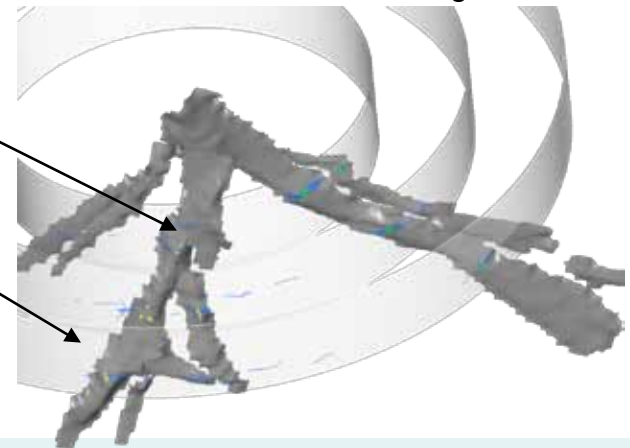
Constructing stratigraphy faster on average, but no strong geometric differences

Characteristic channel-belt network

Aggradation stage

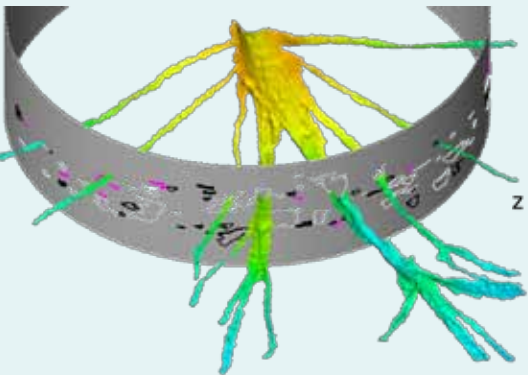


Progradation stage

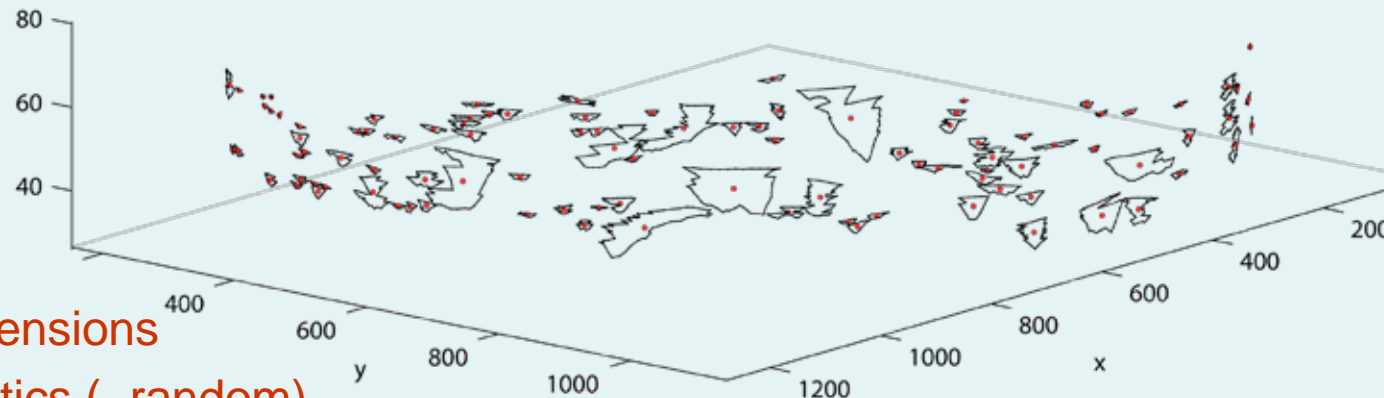


“avulsion” channel belts

radiating delta lobe channel belts



Avulsion (large) channel belts and secondary (small) bodies are present in 2D



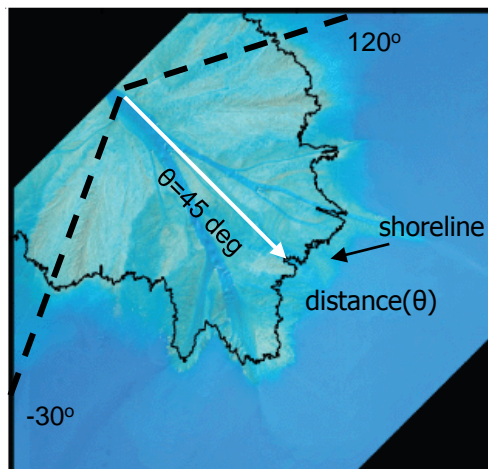
Similar channel-belt dimensions

Similar distribution statistics (~random)

DB2007 Experimental Delta Stratigraphy Results

What does this imply for the stratigraphy?

Constructing stratigraphy faster on average, but no strong geometric differences

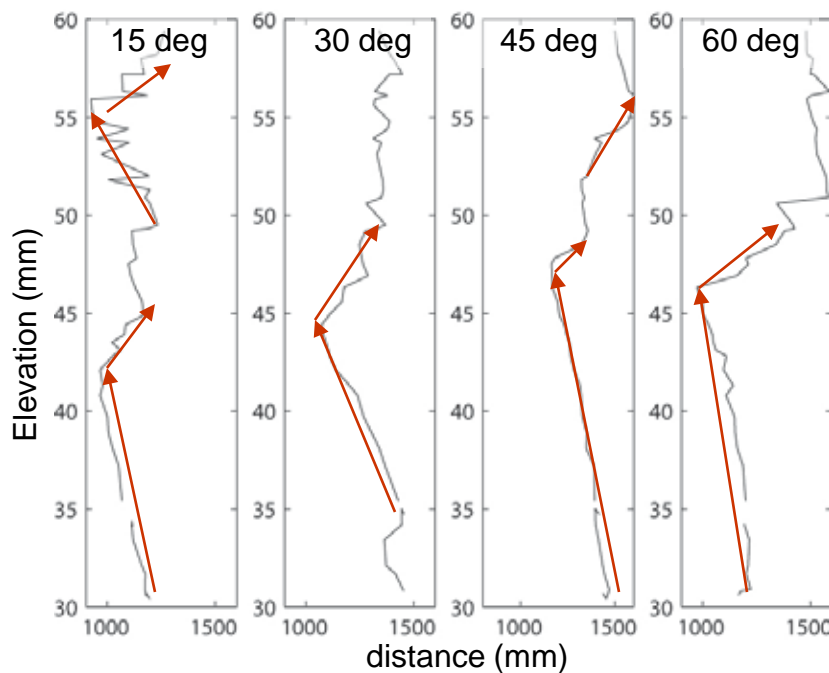


Characteristic delta-lobe length

$$L_{prog} \sim \frac{1}{\delta_{shore}} T_{avul} = 100 - 200mm$$

$$L_{prog} \sim L_{lobe}$$

$$L_{lobe} = 200mm \quad (+/- \text{ factor of } 2)$$



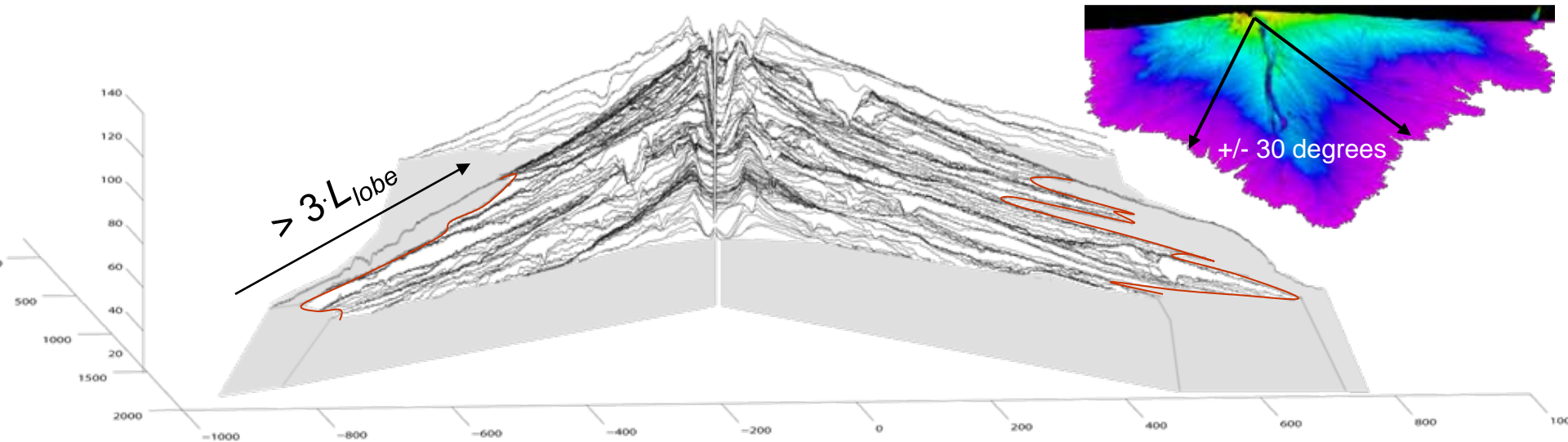
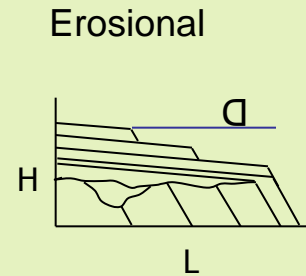
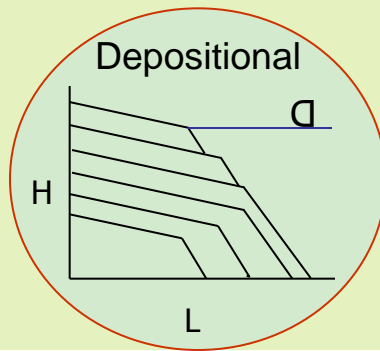
Stratigraphic effects of steady, equilibrium base-level rise

Longitudinal shifts in fluvial-marine facies boundary $\sim L_{lobe}$

What does this imply for correlation lengths?

DB2009 Experimental Delta Stratigraphy Results

Mean shifts in marine-nonmarine facies

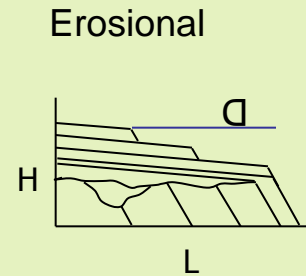
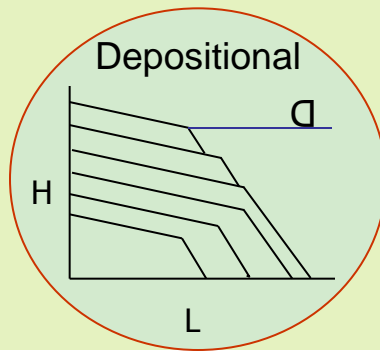


“weak” autogenic
role

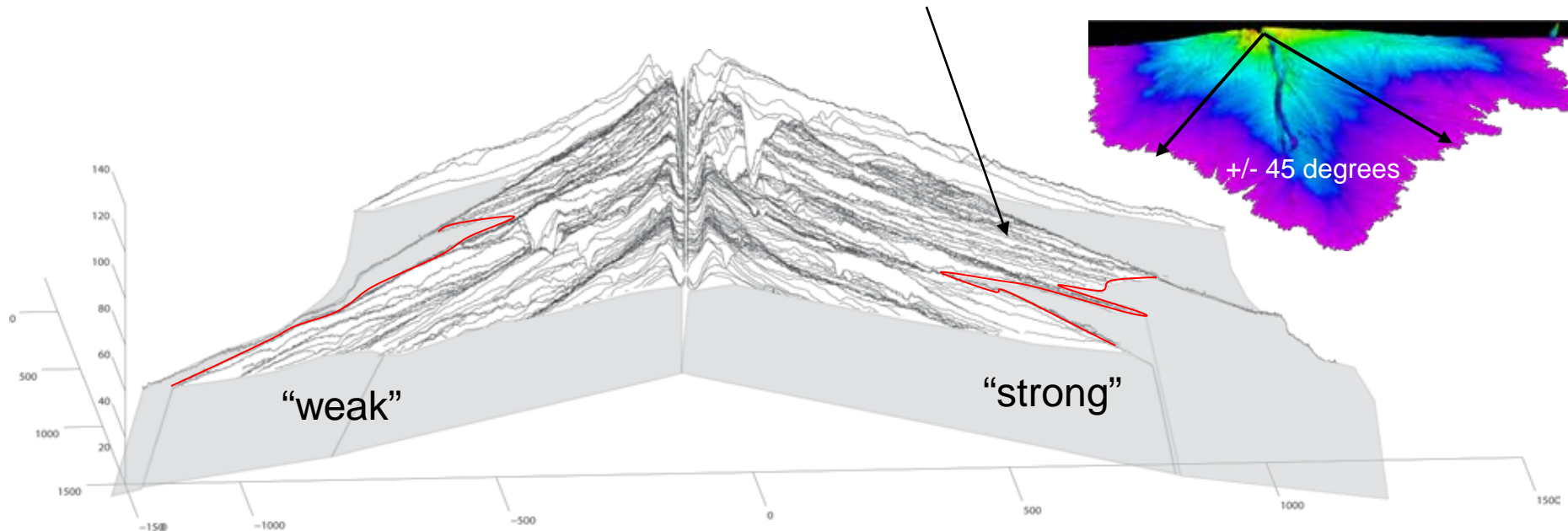
“strong(er)” autogenic
role

DB2009 Experimental Delta Stratigraphy Results

Mean shifts in marine-nonmarine facies

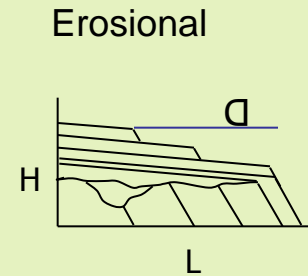
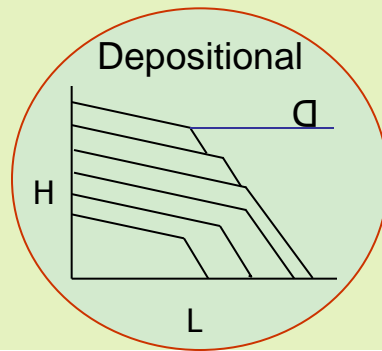


Autogenic sedimentation patterns result in net aggradational stacking

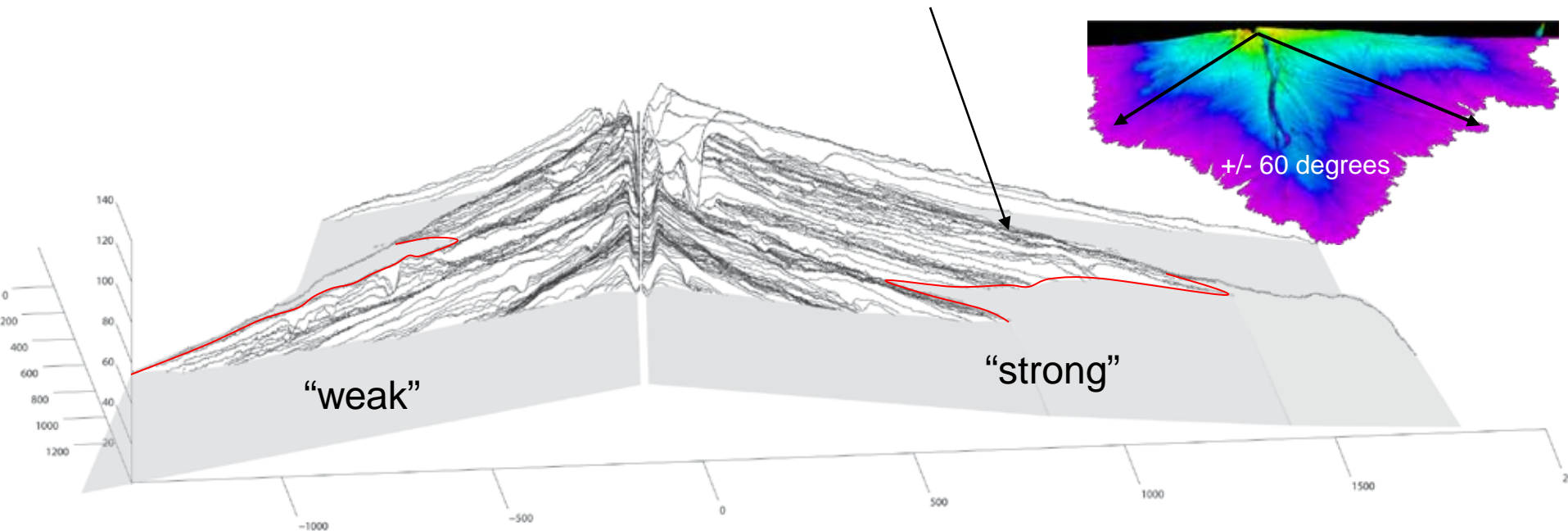


DB2009 Experimental Delta Stratigraphy Results

Mean shifts in marine-nonmarine facies



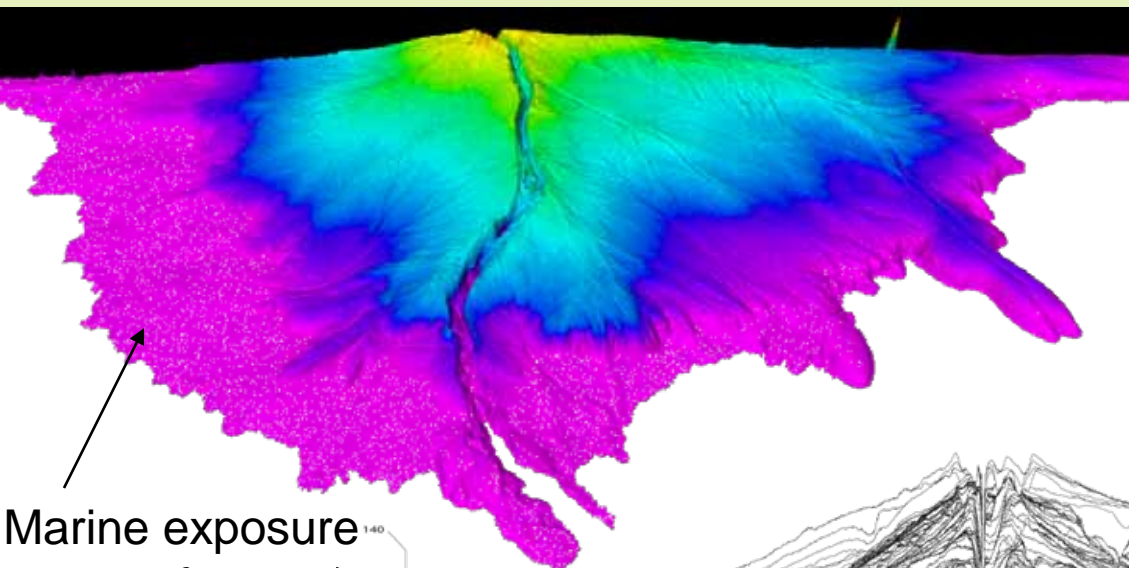
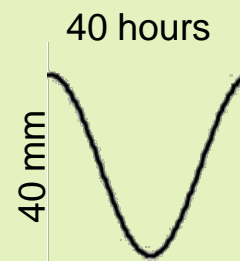
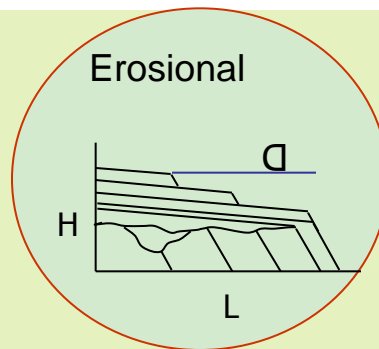
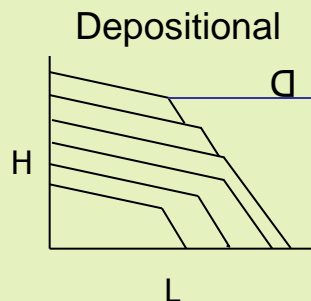
Autogenic sedimentation patterns result in net progradational stacking



Autogenic dynamics produce stacking that masks mean delta behavior

DB2009 Experimental Delta Stratigraphy Results

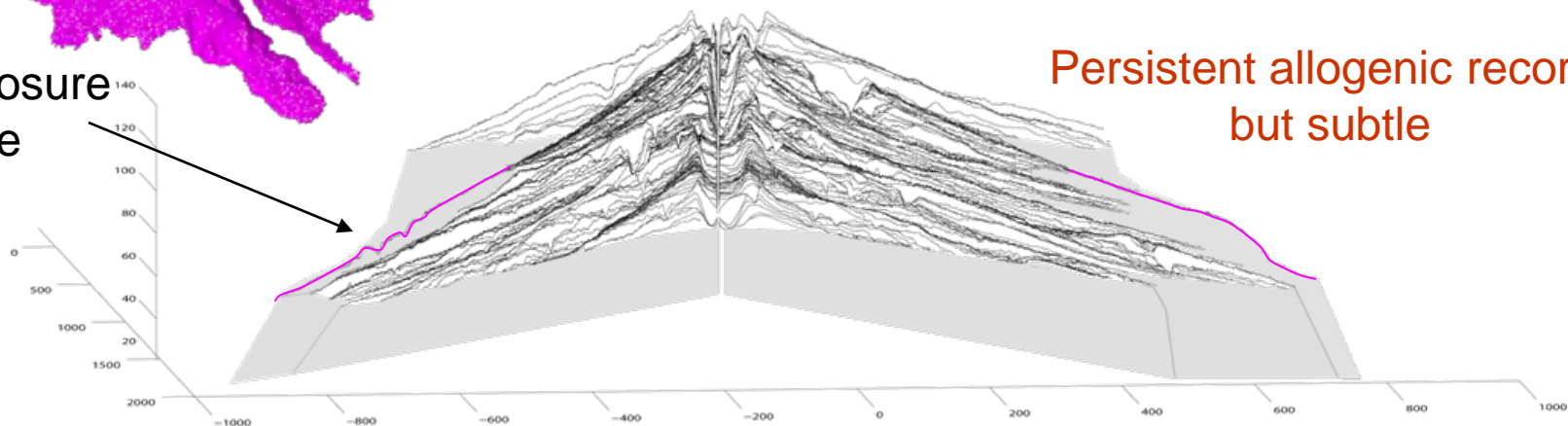
High-amplitude forcing



Flow focused in incised channel
 Q_s in same direction as
base-level-fall-induced shoreline
migration

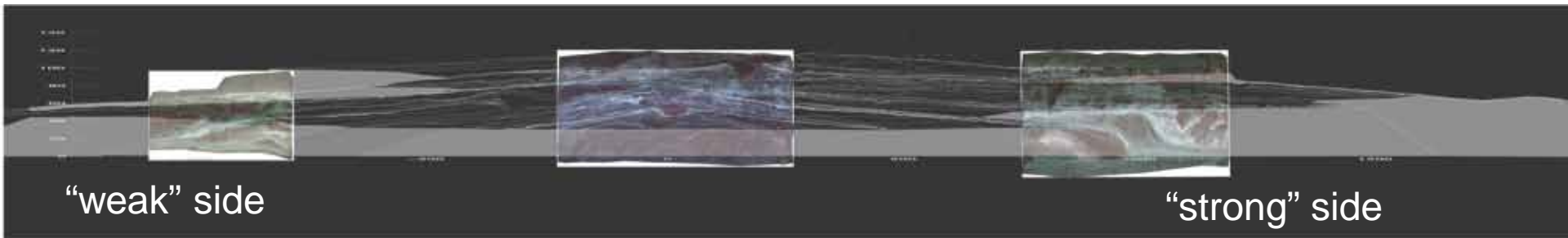
Flow trapped in incised channel
during base-level rise

Marine exposure
surface



Persistent allogenic record
but subtle

DB2009 Experimental Delta Stratigraphy Results



Heuristic scaling

Estimates

$$h_{ch} \sim 5 \text{ m}$$

$$S_A \sim 5 \cdot 10^{-4}$$

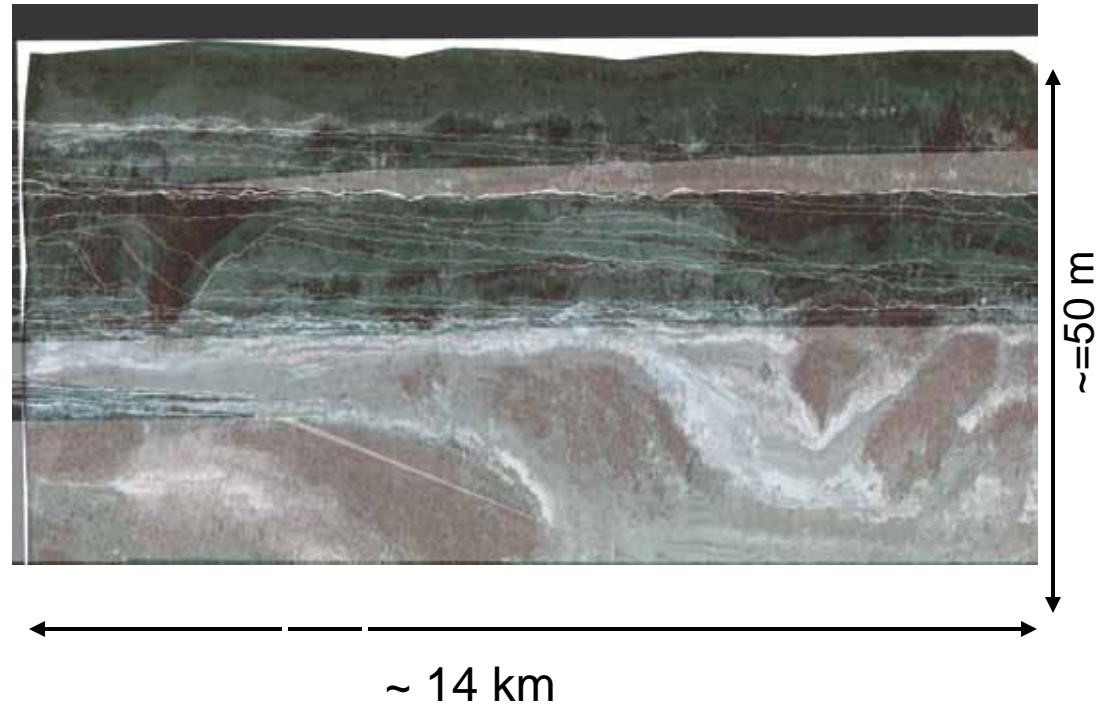
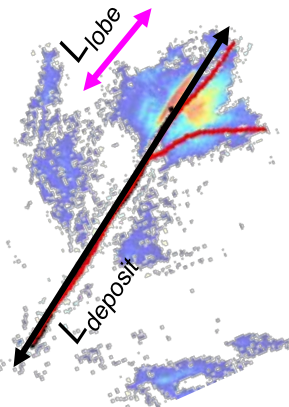
Results

$$\alpha_h = 500$$

$$h_{deposit} \sim 50 \text{ m}$$

$$L_{deposit} \sim 100 \text{ km}$$

$$L_{lobe} \sim 20 \text{ km}$$



Conclusions and Outstanding Questions/Issues

Autogenic processes are shown experimentally to mask changes in environmental conditions.

Autogenic process overprint changes in mean deposition caused by equilibrium base-level rise in DB2007

Autogenic processes overprint mean delta response (progradation-retrogradation) when the $R_{allo} < R_{auto}$

Allogenic depositional records can be correlated around the experimental delta when $R_{allo} > R_{auto}$, but they are extremely subtle

Is it possible to establish the upper limits of autogenic depositional records?

How do we attempt to constrain system size, rates, and overall “autogenic potential”?
What are the important measurements?

Rates inevitably incorporate fluxes (e.g., Q_s) and time (e.g., T_{avul}). Are canonical values and modern empirical relations a good place to start?

A process-framework for stratigraphic interpretation

Would a more process-oriented approach to sequence stratigraphy help elucidate autogenic effects?