# Grain Size Controls on the Facies Sequences and Clinoforms of River-Dominated Deltas*

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Search and Discovery Article #50685 (2012)**
Posted August 13, 2012

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012


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## Abstract

Four external variables are thought to control delta geometry and stratal architecture--grain size, waves, tides, and river discharge--but teasing apart the relative contributions of each has been difficult. The number of distributary channels covering a delta is significantly correlated with maximum monthly discharge, but part of this correlation could be due to the fact that rivers with higher discharges (e.g., Amazon, Mekong, and Orinoco) deliver finer-grained sediment to their deltas. Coarse-grained sediment is thought to produce fan deltas with more continuous sandbodies and steeper clinoforms, but these deltas often occur in regions of higher wave power. Here we investigate the affect of sediment size on the shapes, number of active distributaries, internal facies, and clinoform architecture of river-dominated deltas using Delft3D v. 3.28, an engineering-quality, morphodynamic model. Thirty experiments simulate self-formed delta growth from a sediment-laden river entering a standing body of water devoid of waves, tides, and buoyancy forces. At the inlet boundary a steady, uniform discharge of 1000 $m^3 s^{-1}$ carries varying size distributions of both cohesive silt and noncohesive sand grains, each in equilibrium concentrations. Results show a variety of self-formed deltas are generated by the same three processes observed in field-scale deltas: 1) channel bifurcation around stagnant river mouth bars; 2) subaqueous dissection of the mouth bar and the levees; and 3) subaerial channel avulsion. Furthermore, the partitioning of discharges down distributary arms by subtle bed adjustments at bifurcations produces discharge ratios between bifurcate pairs that are similar to field deltas. A finer sediment feed produces bird's foot-like deltas with rugose shorelines and rough floodplains because levees aggrade rapidly and confine the flow, thereby promoting rapid channel progradation. Delta clinoforms show a lower range of dip direction and lower dip angles. Sand bodies are disconnected shoe strings encased in mud. A coarser-grained, less cohesive sediment produces fan-like deltas with smooth shorelines and floodplains because levees are easily incised and the flow is more uniformly distributed over the delta topset. Clinoforms show a higher range of dip direction and higher dip angles. Sand bodies are coarsening-upwards continuous sheets. Clinoform data from the Cretaceous Ferron Last Chance delta are consistent with these trends.

## References

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McKeown, H.A., P.J. Bart, and J.B. Anderson, 2004, High-resolution stratigraphy of a sandy-ramp-type margin-Apalachicola, Florida, USA, *in* J.B. Anderson and R.H. Fillon, (eds.), Late Quaternary Stratigraphic Evolution of the Northern Gulf of Mexico margin: SEPM Special Publication 79, p. 25-41.

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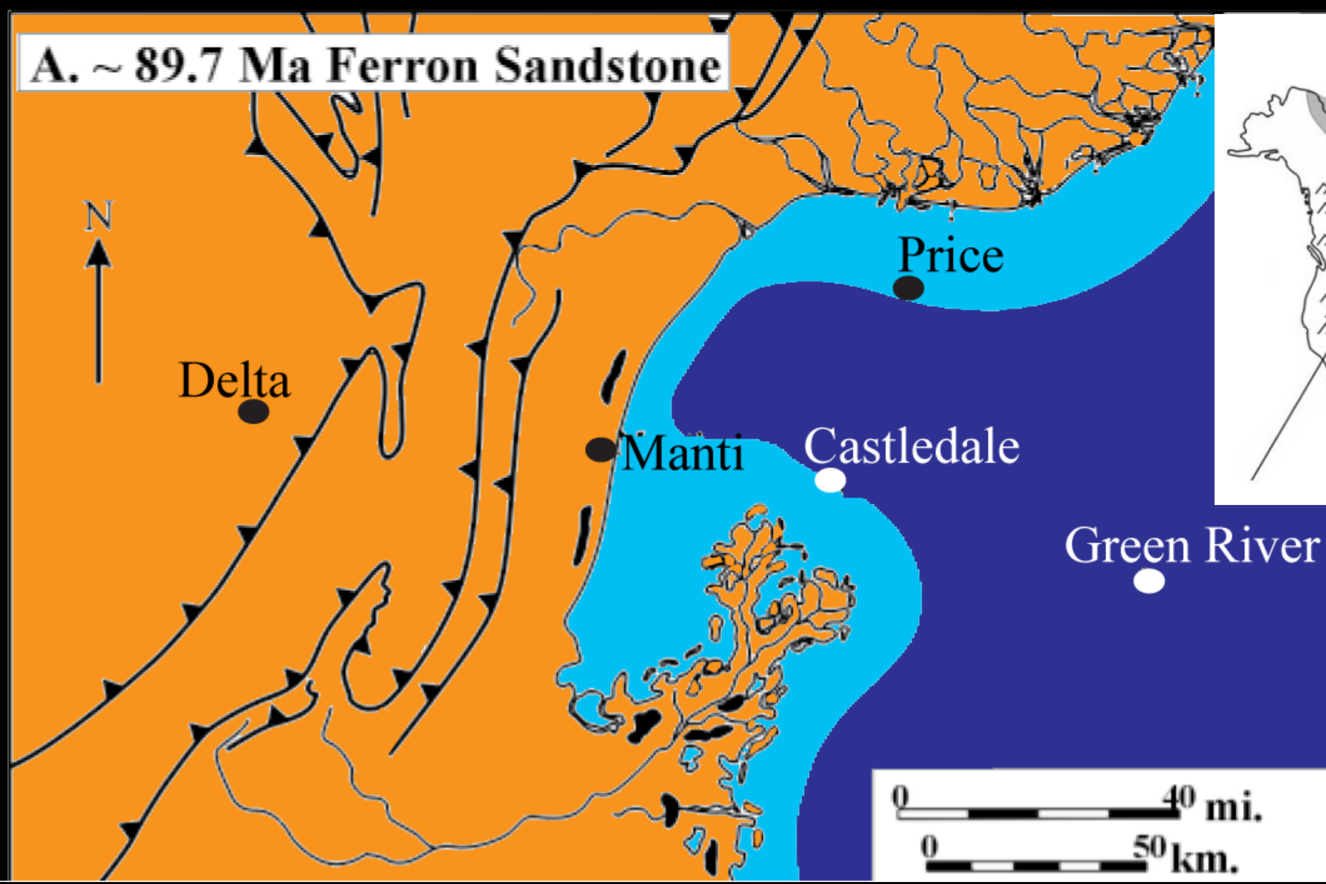
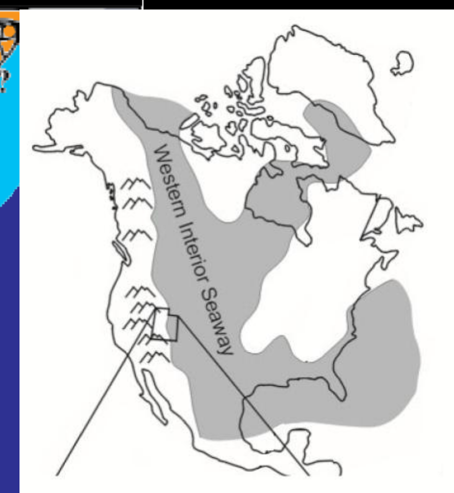
AAPG 2012

# Question

- How do a delta’s facies sequences and clinoform architecture depend upon the caliber of sediment delivered to it by its catchment?



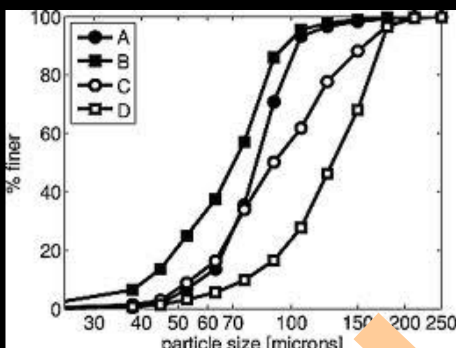

After EDWARDS, HOWELL, & FLINT, 2005

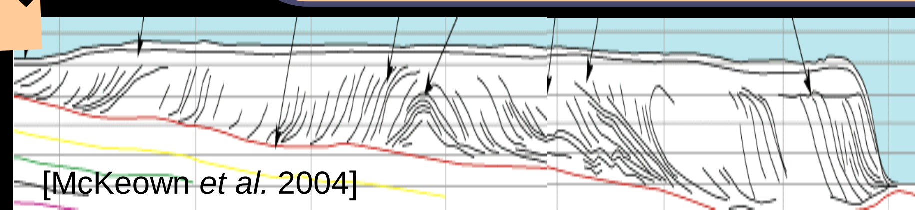
# Main Thesis of this Talk

Sediment caliber controls:
- a) number of distributaries;
- b) proportion of sediment passed across levees;
- c) frequency of mouth bars;
- d) particle path lines in turbulent jet

These variables determine the delta planform morphology:
- a) complexity of shoreline;
- b) frequency and shape of delta lobes;
- c) lengths and sinuosities of channels; and
- d) topographic roughness of floodplains

These variables control:
- a) clinoform concavities;
- b) dip magnitudes and directions;
- c) size, shape, and sandbody connectivity



[McKeown *et al.* 2004]

# Our Approach

- Conduct numerical experiments using a morphodynamic model (Delft3D) simulating delta evolution
- Compare predictions to outcrop and seismic data

- Experimental Design
  - Solve the shallow water equations over a dynamic loose bed in two dimensions
  - Erode, transport, and deposit six grain sizes from 350 to 7 microns
    - Two important sediment parameters
      - Mud to sand ratio of sediment feed
      - Shear stress needed to erode mud once deposited

# Our Approach

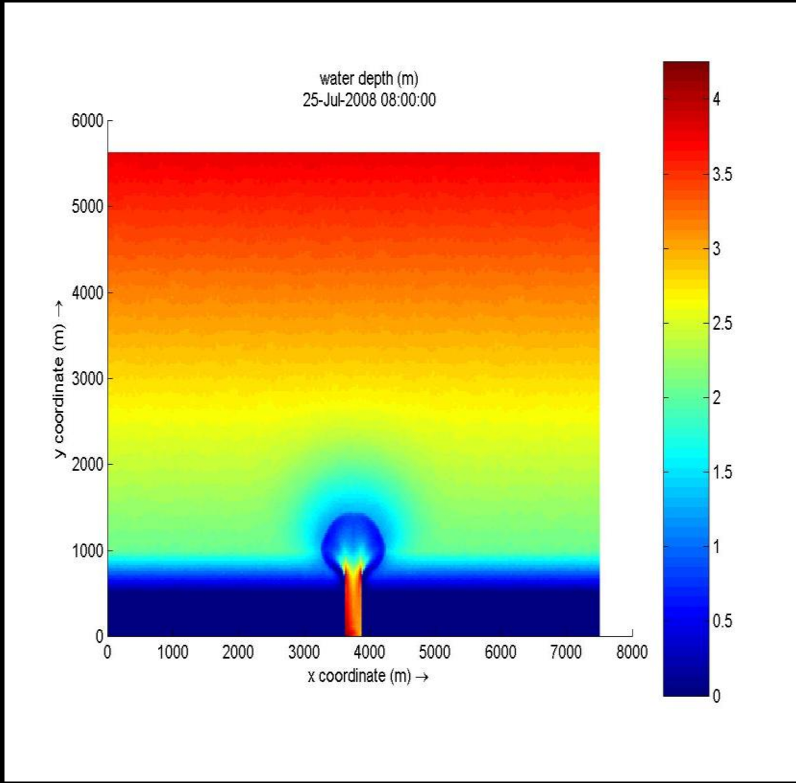
- Experimental Design
  - Basin of 300 by 225 computational cells, each 625 $m^2$ positioned at the equator
  - Initial bed slope to the north with initial depths from 1 to 3.5 m (similar to the bathymetry of Atchafalaya Bay, LA)
  - Rectangular river channel 250 m wide and 2.5 m deep;
    $Q = 1000\ m^3\ s^{-1}$
    $Q_s$ = equilibrium fluxes

    Muddy: $Q_{coh}/Q_{nc} > 15$

    $\tau_{crit} > 1.5\ N\ m^{-2}$

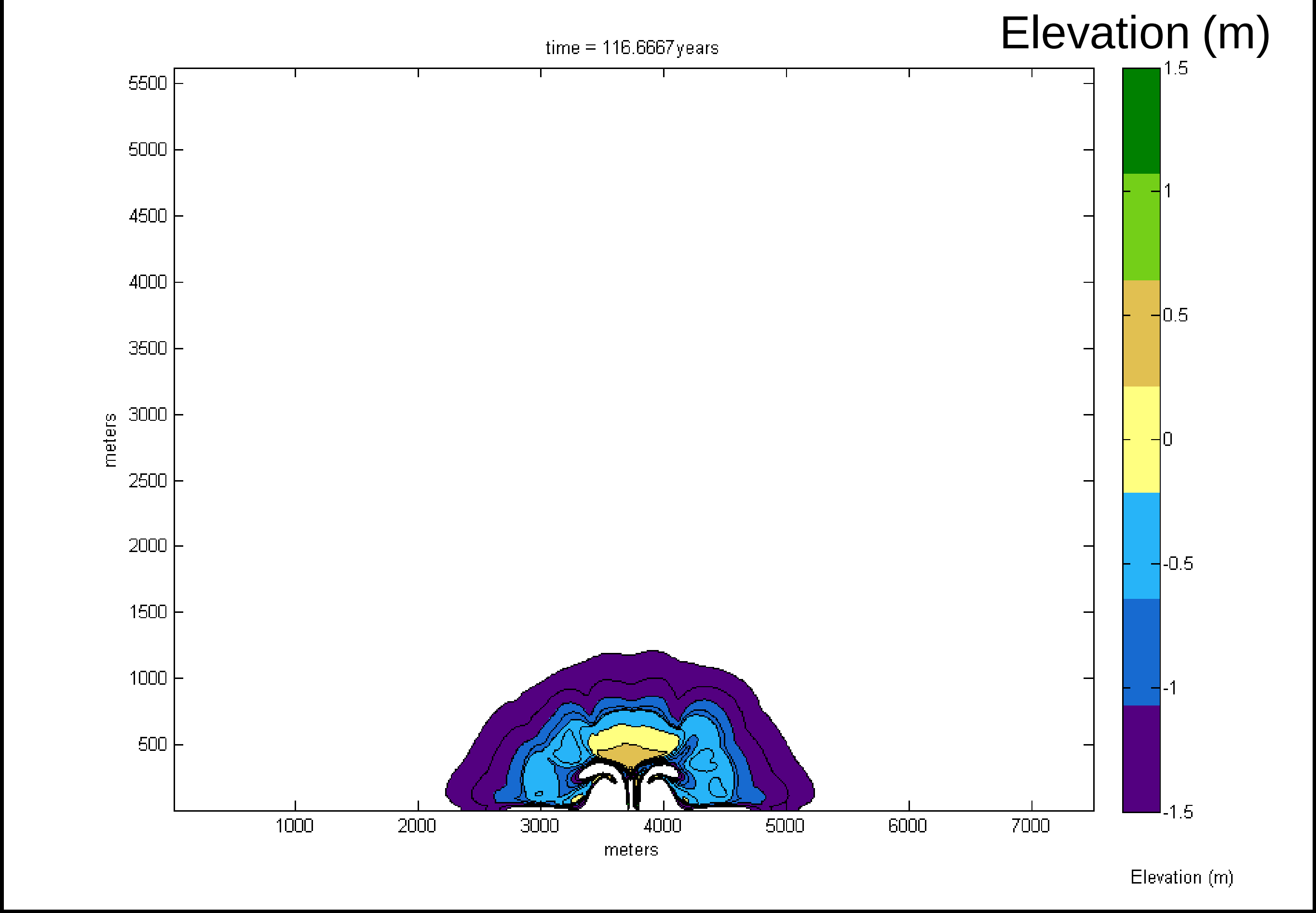
    Sandy: $Q_{coh}/Q_{nc} < 10$

    $\tau_{crit} < 0.5\ N\ m^{-2}$
  - Western, northern, and eastern boundaries are open



# Results: Processes of Delta Growth

## Muddy Cohesive Delta



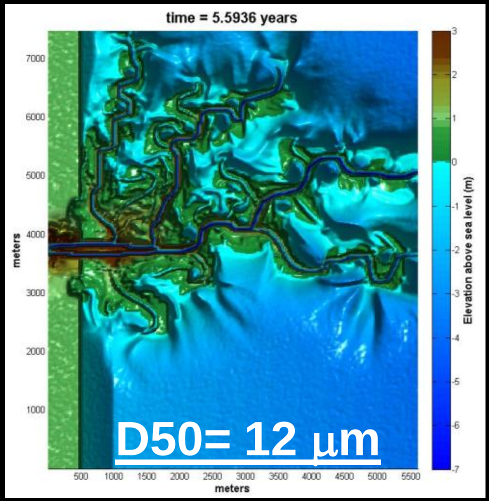

1) channel bifurcation around stagnant river mouth bars;
2) subaqueous dissection of the mouth bar and the levees;
3) subaerial channel avulsion

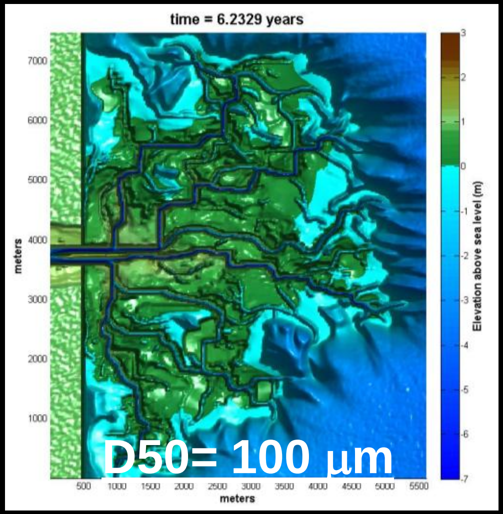
# Results: Planform Shape

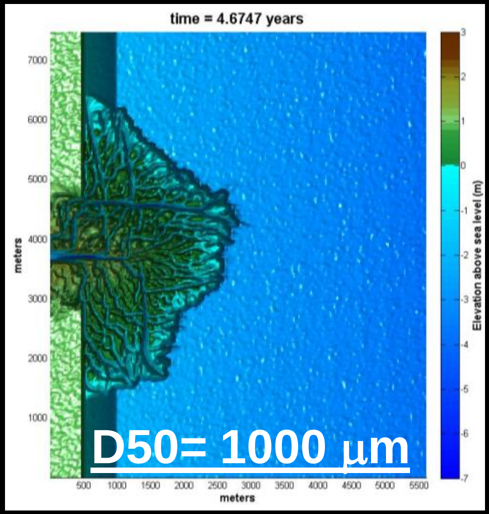
Muddy Delta → Sandy Delta

high mud/sand ratio — low mud/sand ratio

stiff mud — loose mud




Planform Shapes

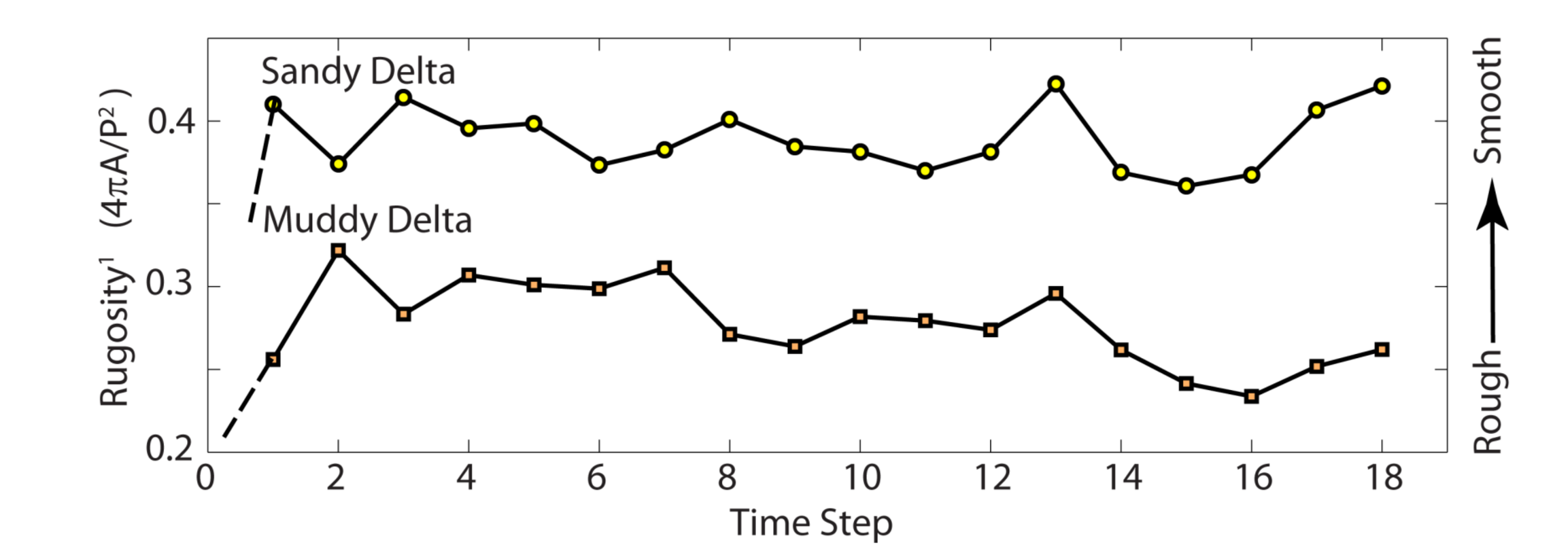
birdsfoot → fan delta

Number of Distributaries

fewer → many more

# Results: Planform Shape

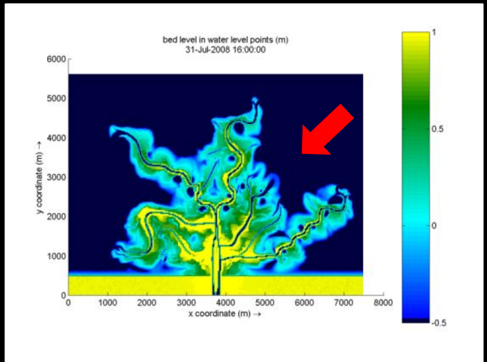
- Delta shorelines differ; grow self-similarly….



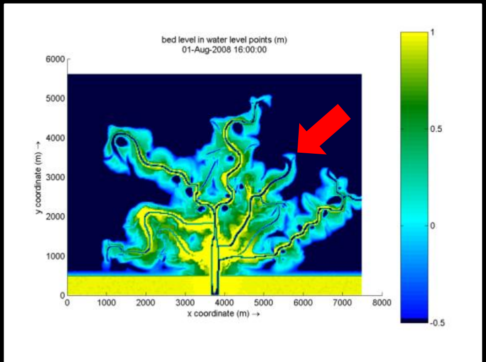

[1]Rugosity = ratio of the area of delta top to the area of a circle with the perimeter of the delta

- …but noisy due to periods of lobe growth

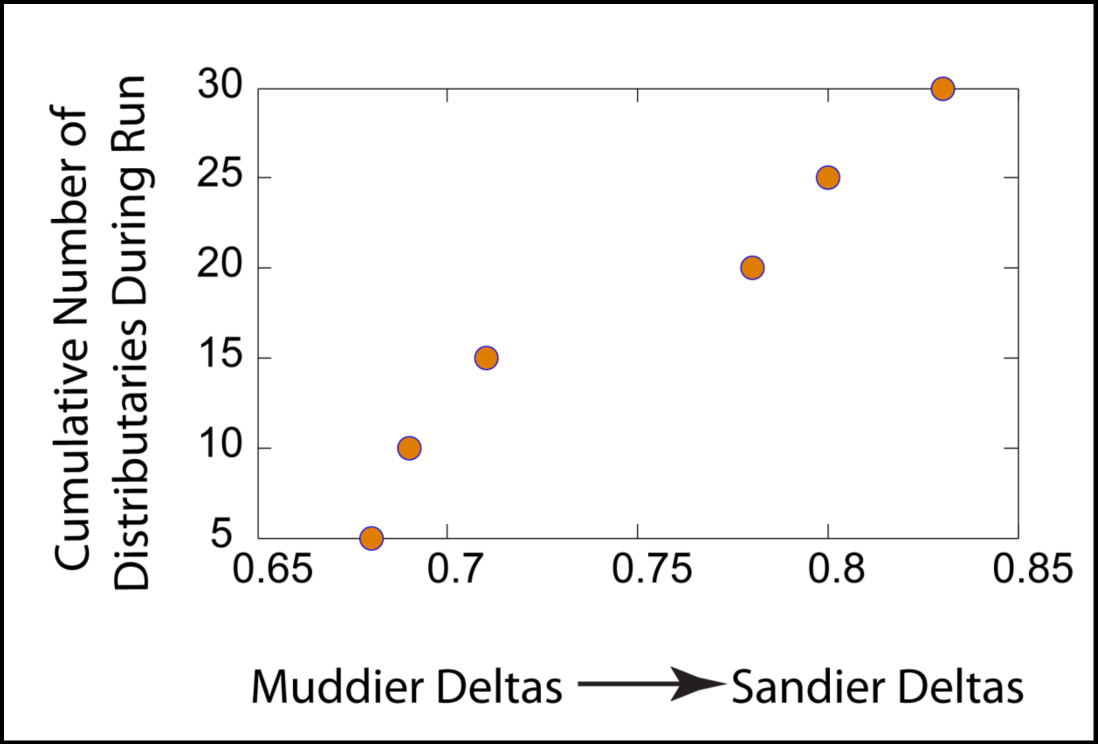
Infilling



Lobe Growth



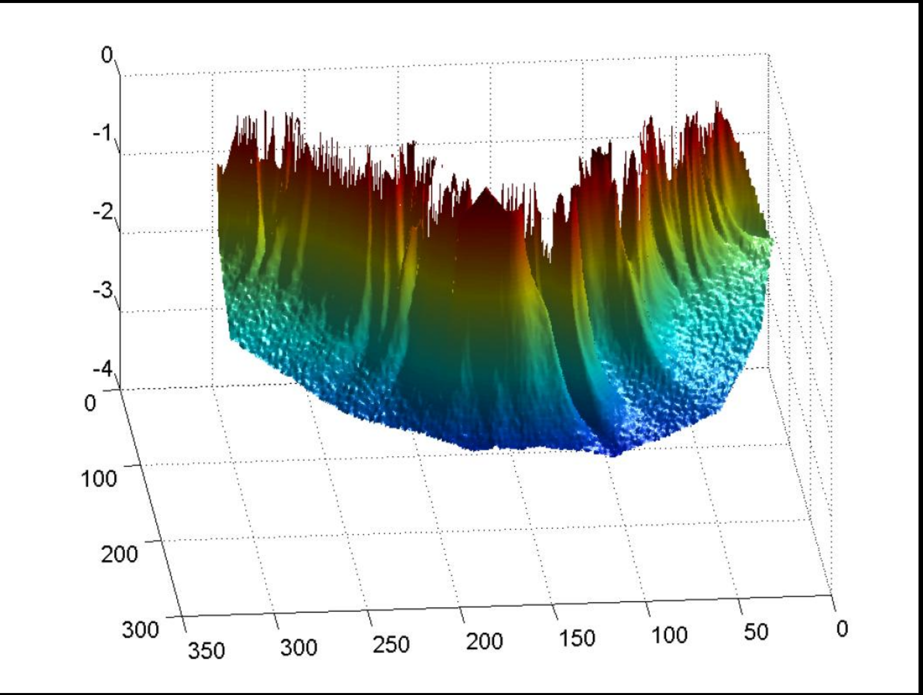
# Results: Number of Distributaries




- Number of distributaries increases as critical shear stress for eroding mud decreases and sand content increases

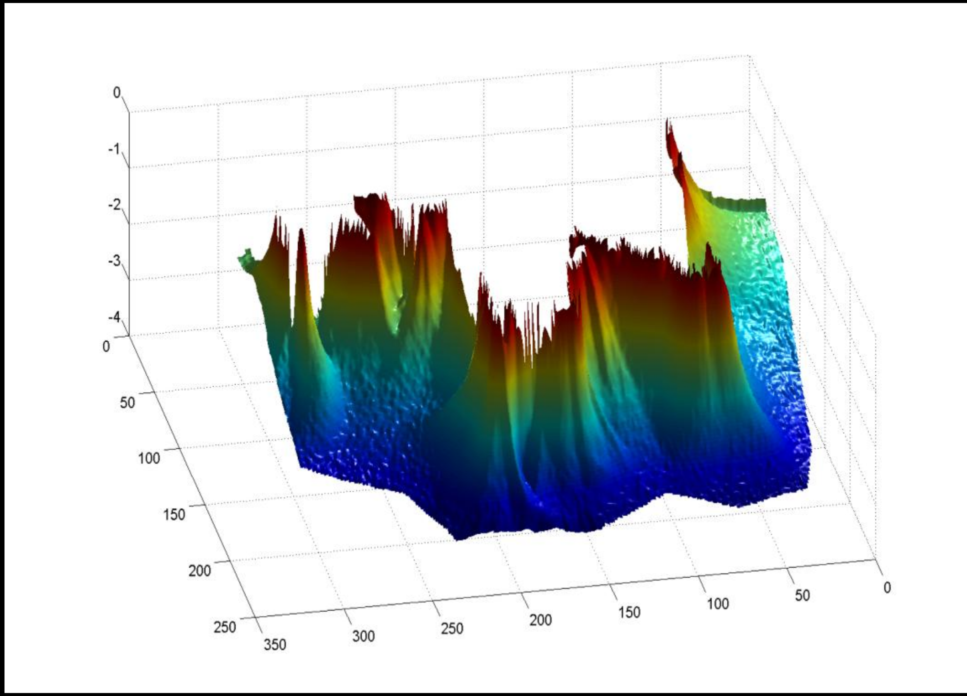
# Results: Clinoform Geometries

Sandy Delta




Mean Dip Magnitude: 15.7 – 16.7º

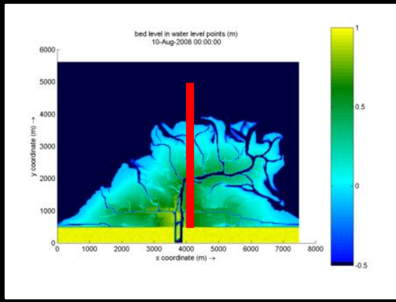
Muddy Delta



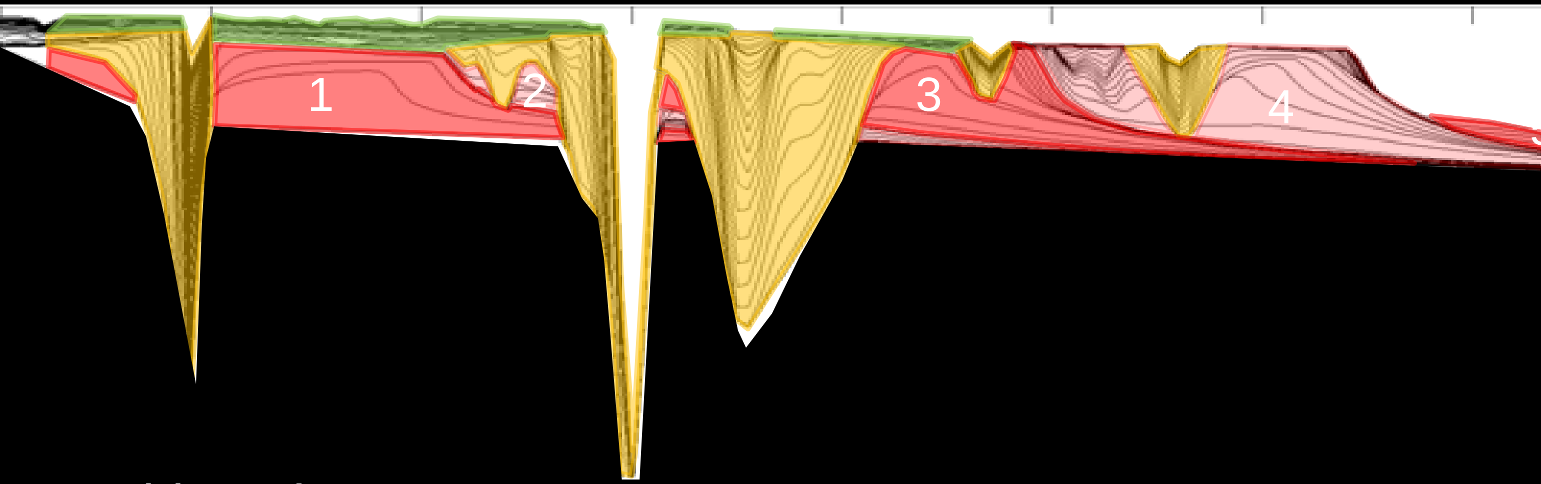

Mean Dip Magnitude: 12.2 – 13.4º

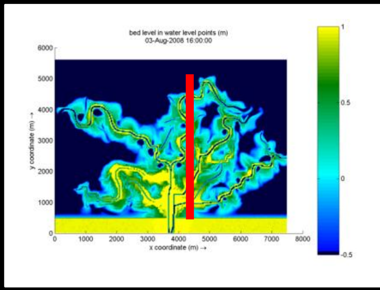
- Sandy delta clinoforms are:
  - less concave
  - steeper (as indicated by t-test)
  - less local variability in dip direction

# Results: Stratigraphy

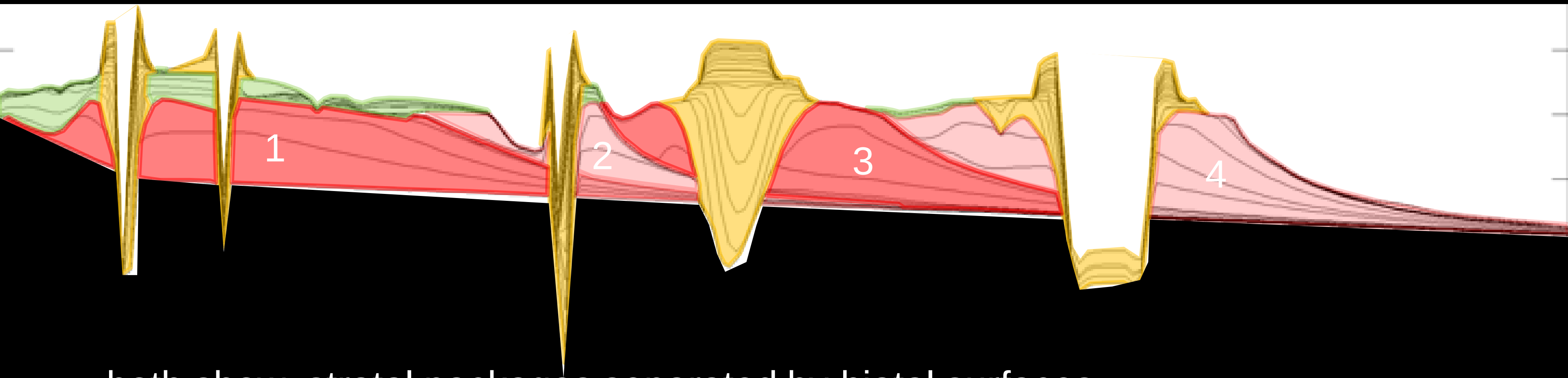


Sandy Delta



Muddy Delta

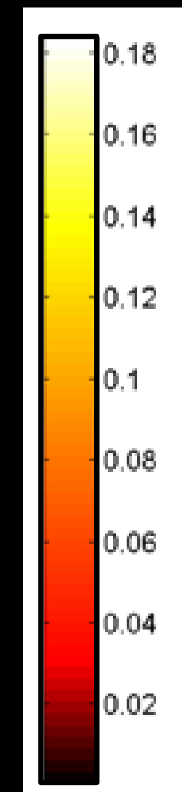


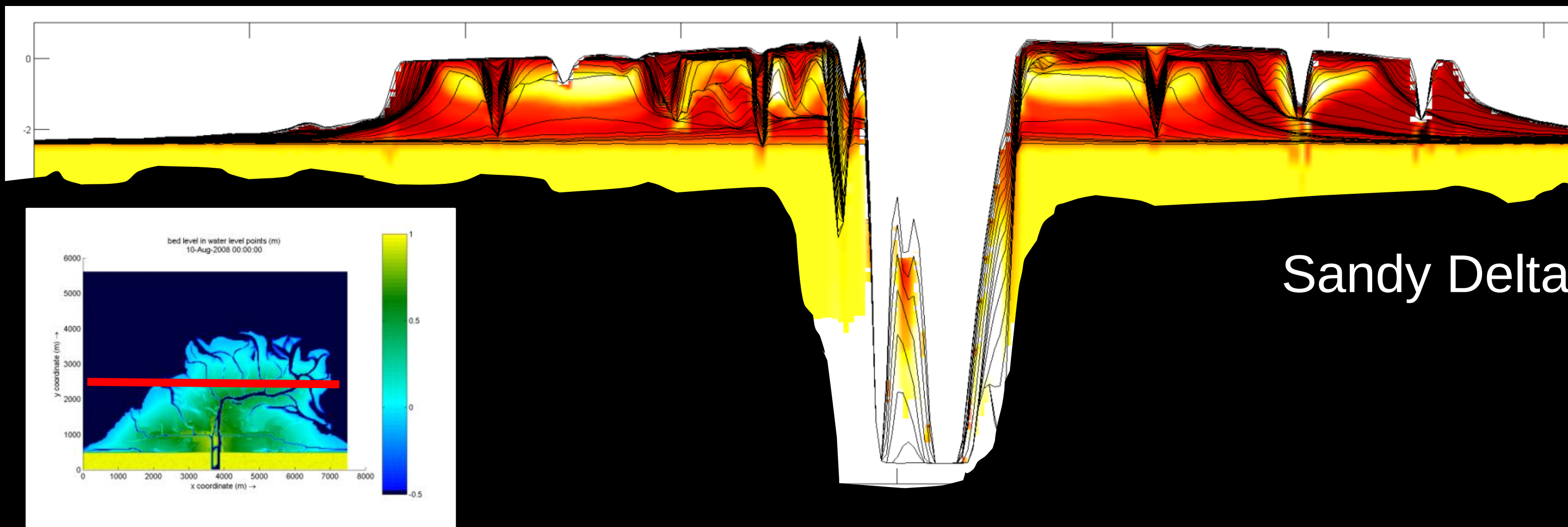

-- both show stratal packages separated by hiatal surfaces

-- clinoform concavity, dip magnitudes, and topset stratigraphy differ

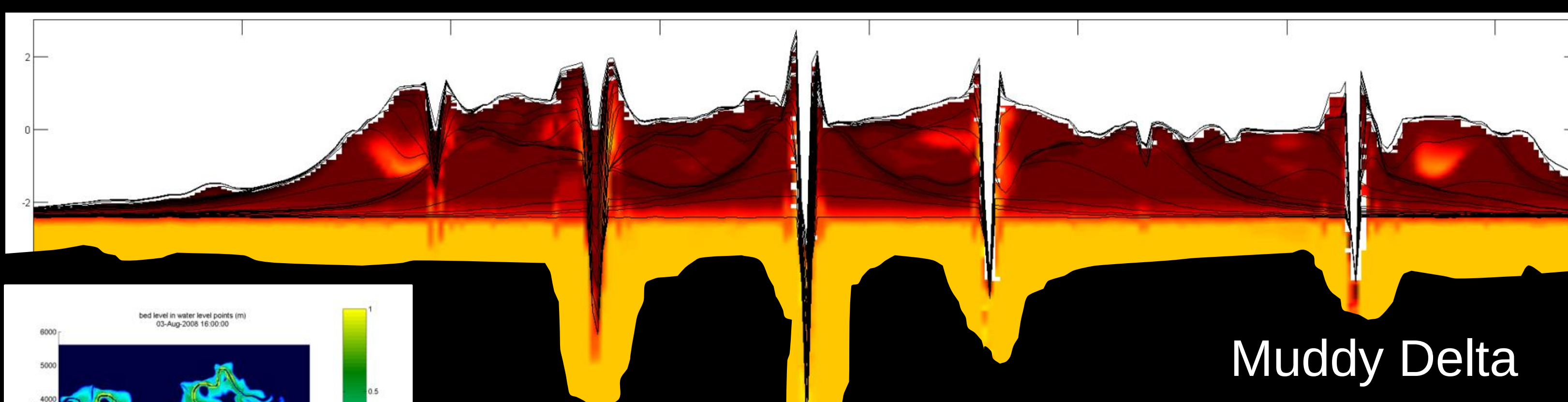
# Results: Delta Facies

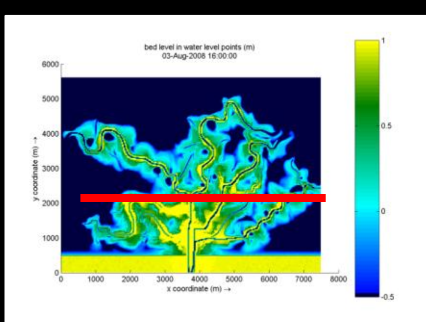
D50 (mm)



Sandy Delta



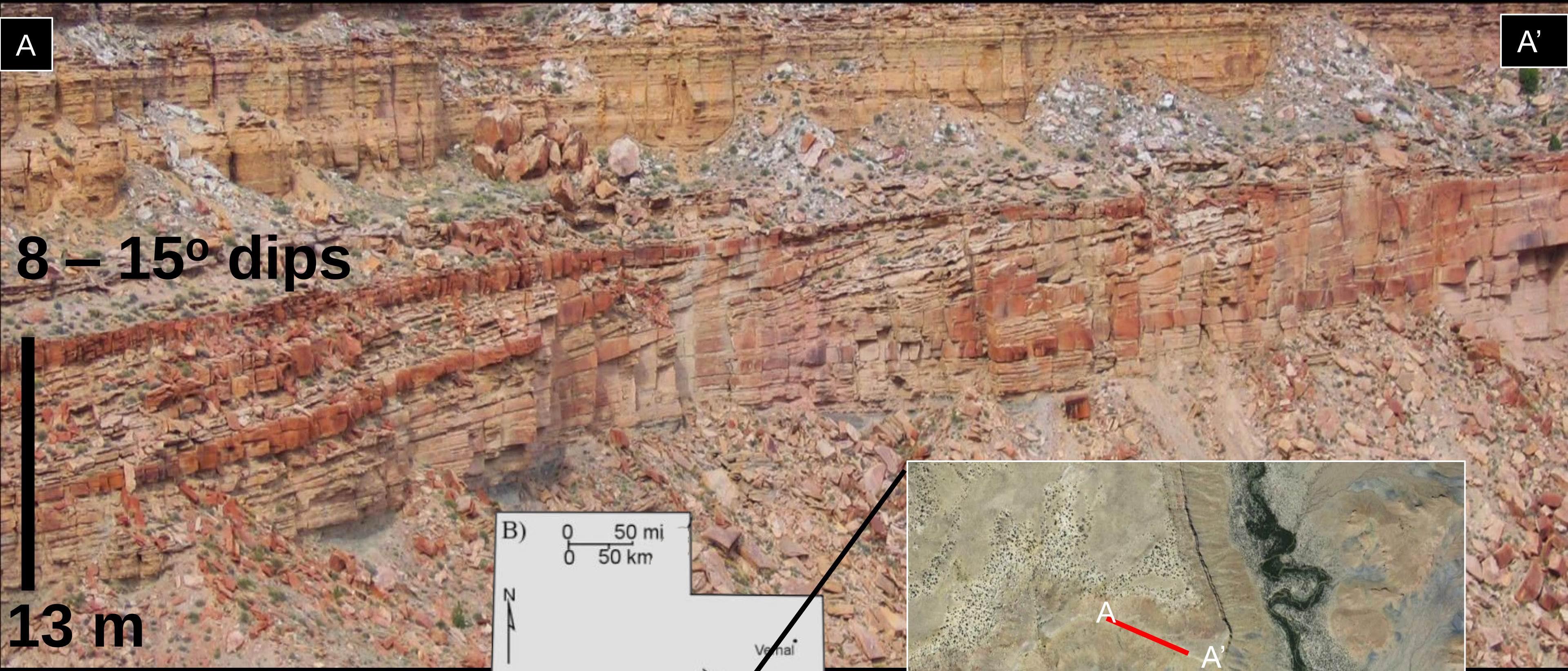


Muddy Delta

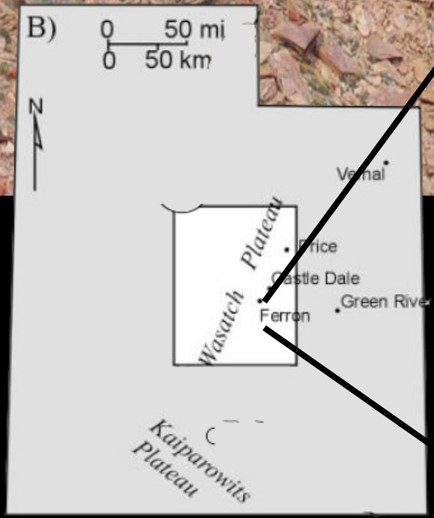
-- sandy delta simpler with sheet sands higher in section

-- muddy delta more architecturally complex with shoestring sands

# Comparison with Ferron Kf-1 Parasequence Set at Ivie Creek

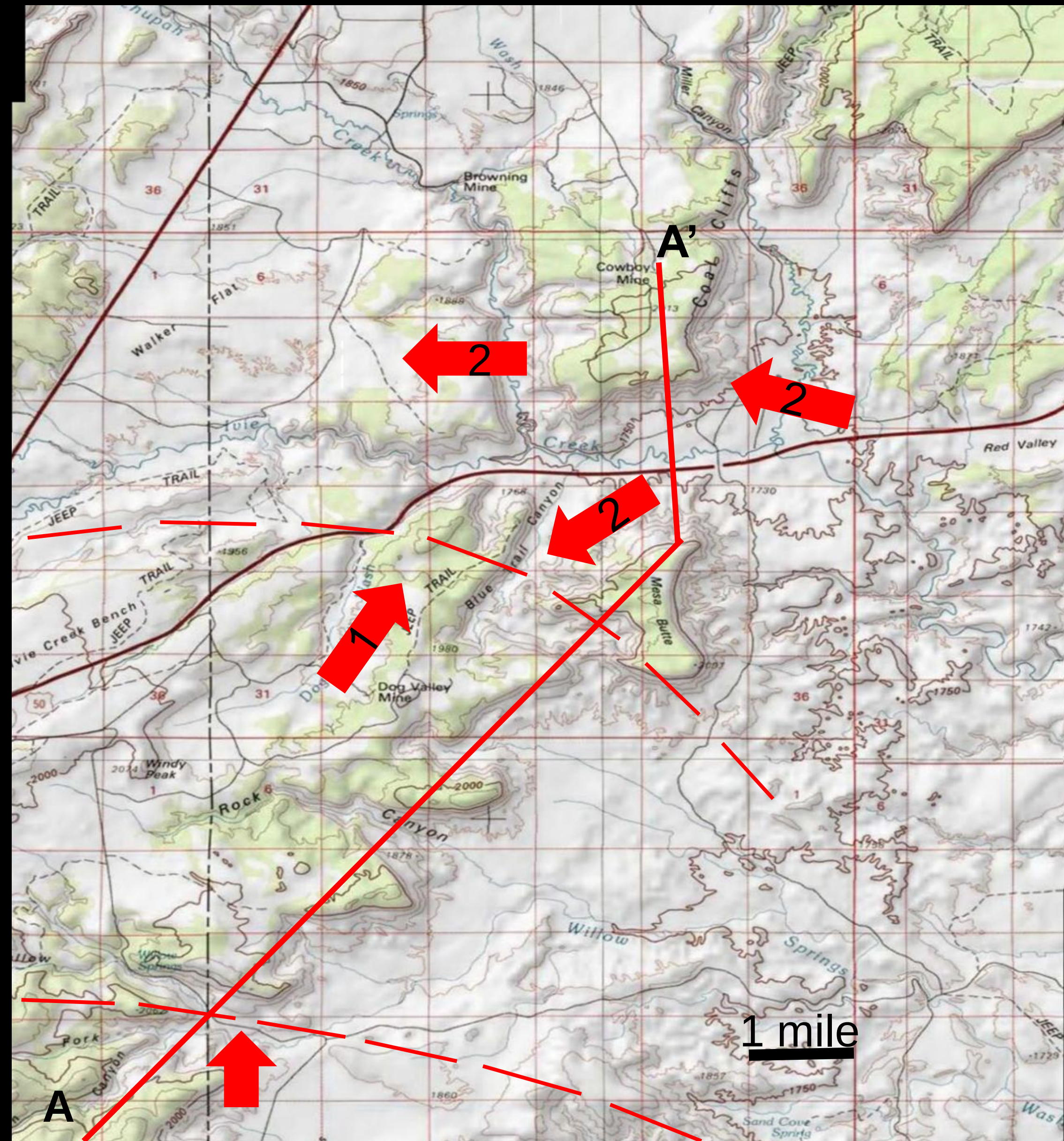



Steep, sandy foresets

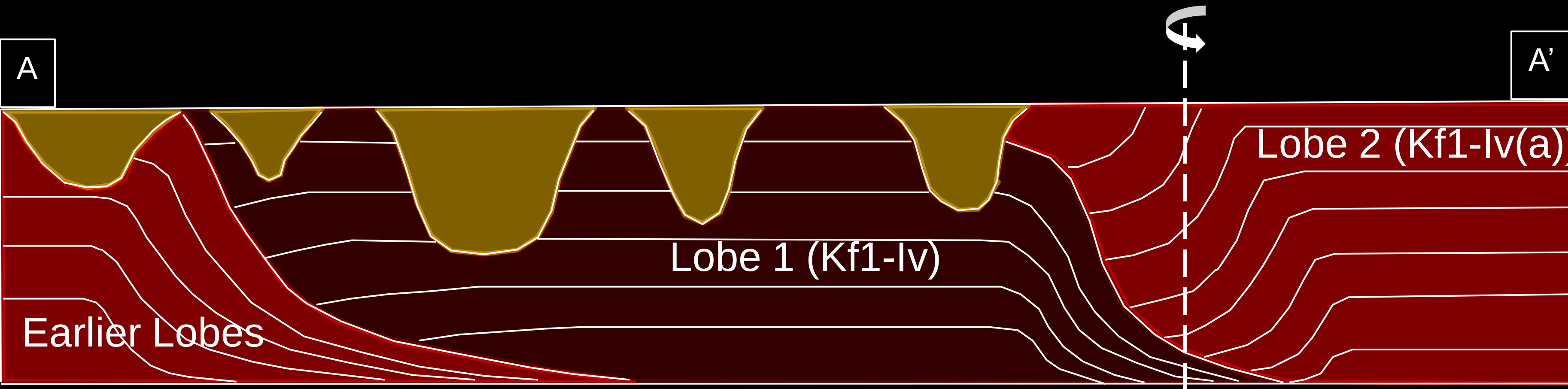


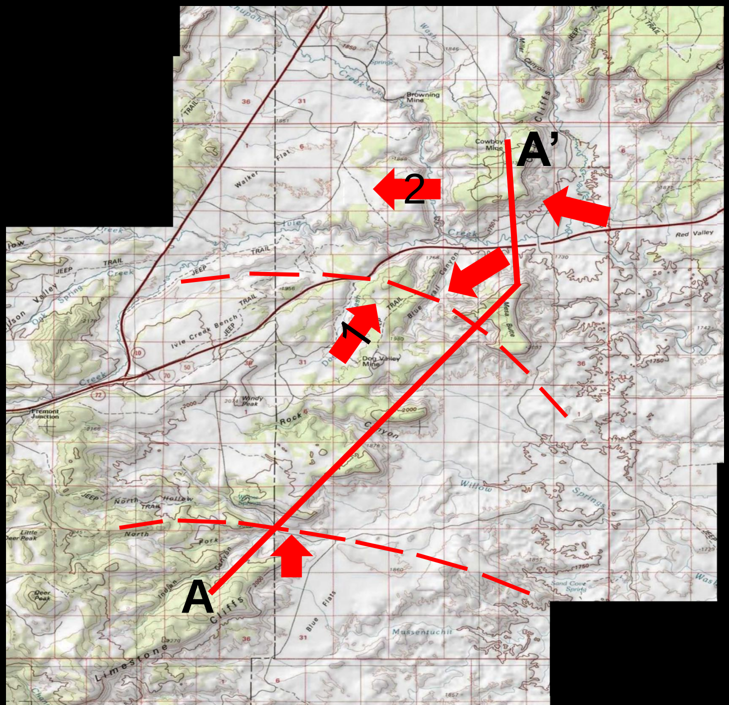

# True Dip Directions at Ivy Creek

- -- Lobe boundaries are defined by dip directions and lap relationships
- -- Dip directions determined by apparent dips on two intersecting planes
- -- Two lobes, 1 prograding NE; 2 prograding W & SW, onlapping 1

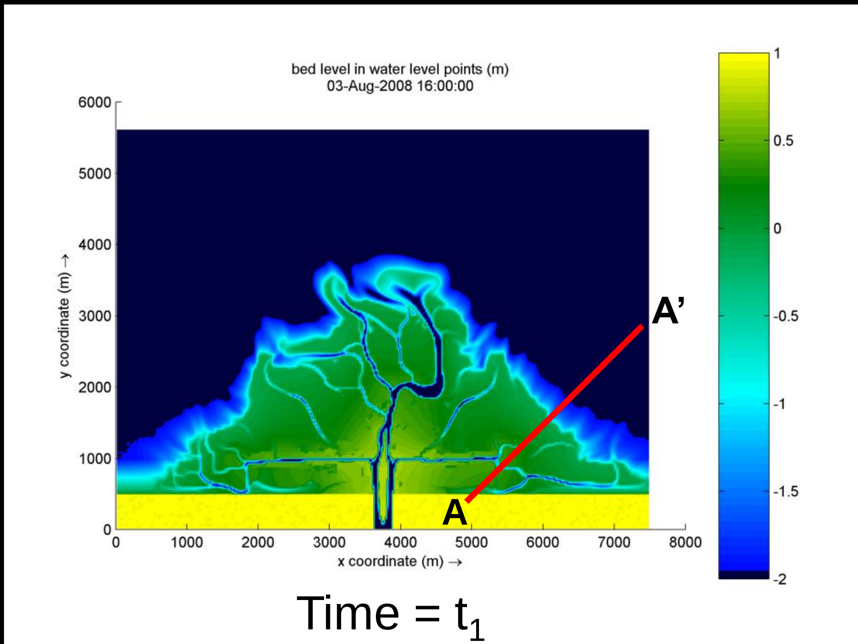


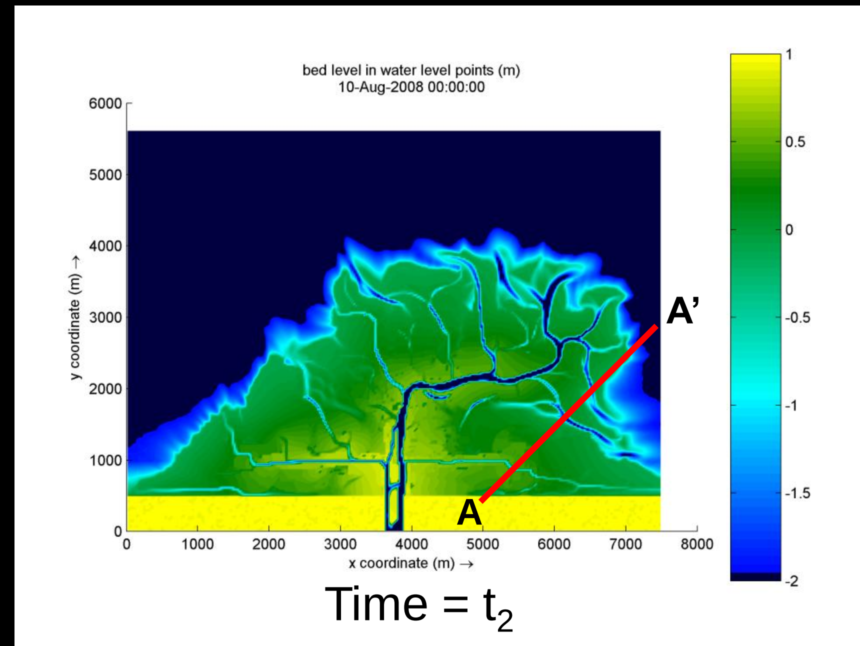
# Upper Ferron Last Chance Delta Kf-1 Parasequence Set

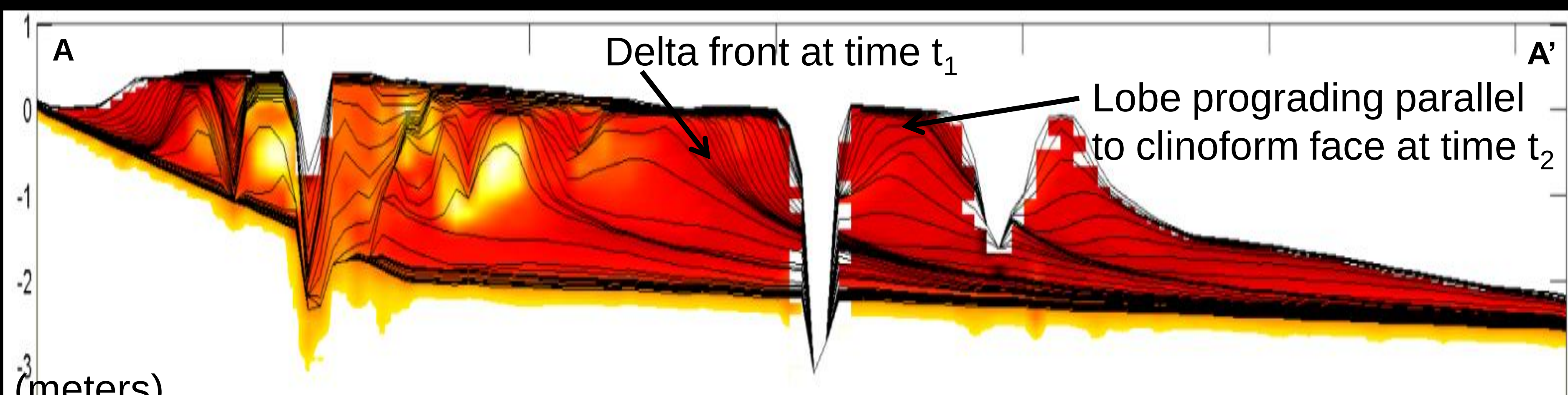


# Possible Explanation



# Conclusions

- Grain size is a major determinant of delta shape.  Elongate deltas with rugose shorelines and topographically rough floodplains are created if the incoming sediment is highly cohesive. Fan-like deltas with smooth shorelines and flat floodplains are created by less cohesive sediment
- These shapes create relatively unique lobe and clinoform geometries
- Thus by knowing the sediment properties of an ancient delta, one can predict the expected clinoform geometries
- The Ferron Kf-1 delta most likely looked like this: