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Relationships between sediment caliber and delta shoreline geometry and stratigraphy

Alex Burpee[1], Rudy Slingerland[1], and Doug Edmonds[2]

[1]*Department of Geosciences, The Pennsylvania State University, University Park, PA, 16802*

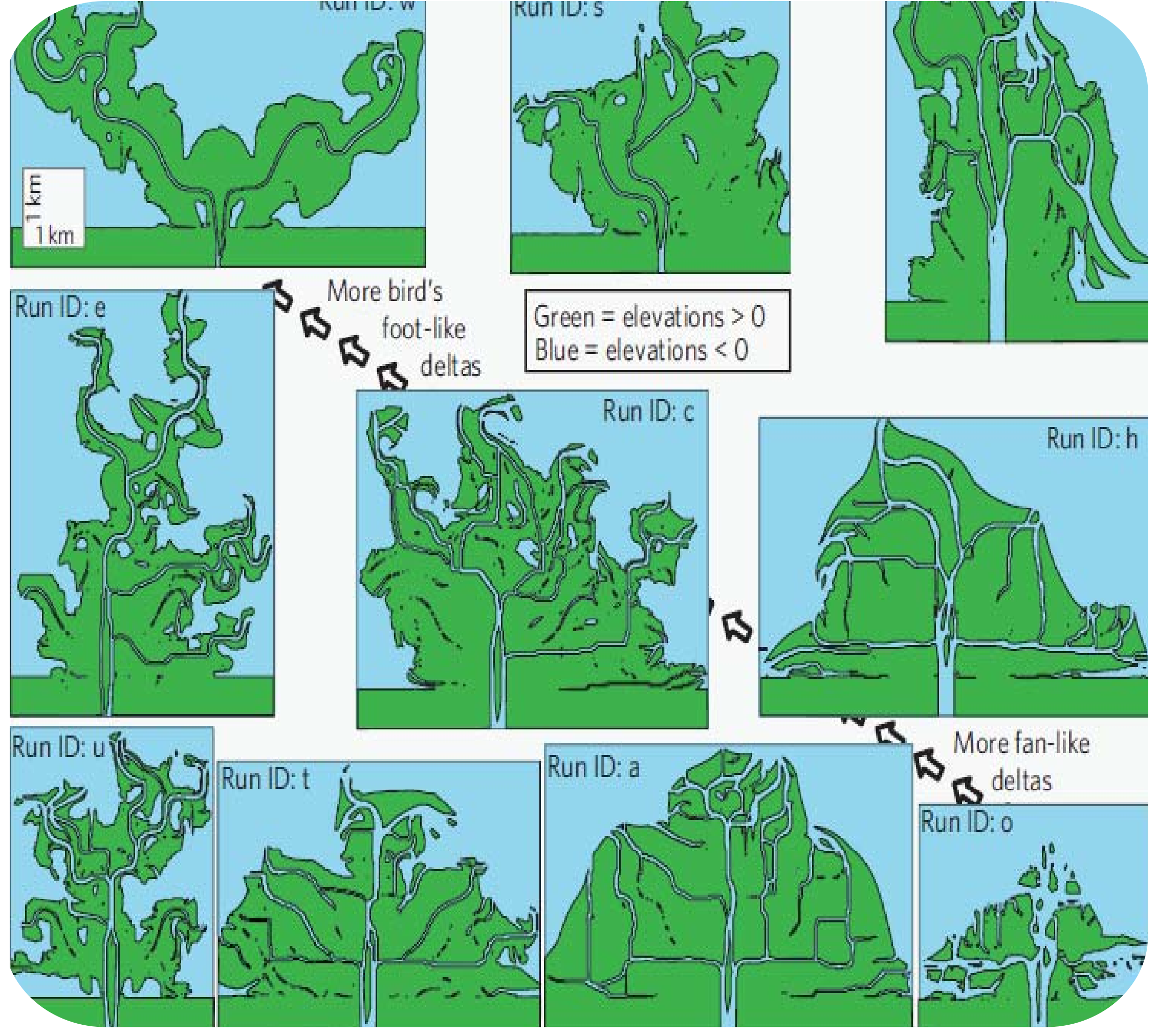
[2]*Department of Geology & Geophysics, Boston College, Chestnut Hill, MA, United States*

ABSTRACT

Delft3D morphodynamic modeling of non-uniform turbulent transport and deposition of sediment into a standing body of water devoid of tides and waves shows that sediment caliber plays a major role in determining the shapes, cumulative number of distributaries, and wetland areas of river-dominated deltas. In this study we introduce metrics for quantifying delta shoreline rugosity and clinoform geometry, and explore their variation with sediment caliber. Delta shoreline rugosity is calculated using the isoperimetric quotient, IP = 4 pi A / P^2, where A = area, P = perimeter, and a circle has a value of one. Clinoform complexity is calculated using the uniformity test in circular statistics wherein clinoform dip direction uniformity is the sum of the deviations of dip azimuths from a theoretical uniform distribution. Analysis of fifteen simulated deltas shows that IP increases from 0.1 to 0.5 as the normalized shear stress for re-erosion of cohesive sediment, τ_n, increases from 0.65 to 1. Clinoform dip azimuth uniformity decreases from 300 to 130 with increasing τ_n. Data from outcrops of the Cretaceous Ferron Delta are consistent with these trends. These results imply that changes in sediment caliber delivered to a deltaic coastal system will profoundly change its wetland area, bathymetric hypsometry, and interior stratigraphy.

STATEMENT OF THE PROBLEM

Figure 1: Deltas simulated using Delft3D. Six grain sizes from cohesive clay to noncohesive sand were fed to a basin devoid of waves and tides. Degree of cohesion increases from lower right to upper left.



Even among river-dominated deltas there is a range of planforms (fig. 1) predicted by Delft3D morphodynamic simulations that arise due to variations in grain size (Edmonds and Slingerland 2010). Here we ask the question:

1) What is the link between these planform morphologies and the delta stratigraphy?

OUR APPROACH

- Extract clinoform dip directions from internal chronostratigraphic surfaces recorded in the Delft3D simulated deltas

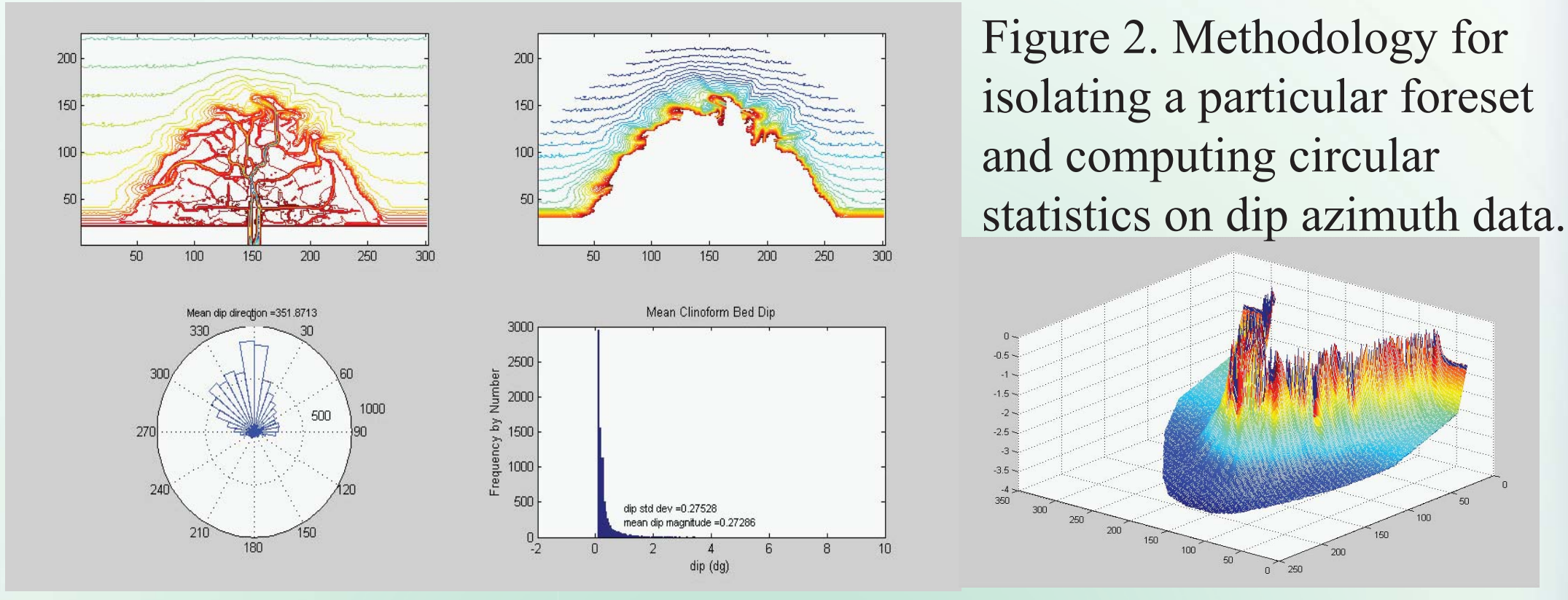


Figure 2. Methodology for isolating a particular foreset and computing circular statistics on dip azimuth data.

Variability of dip direction is measured using the uniformity test for circular statistics (Jones, 2006) which provides a comparison of the theoretical CDF of a uniform distribution to that of the data:

$$U^2 = \sum_{i=1}^{N} \left[U_i - \bar{U} - \frac{i-1/2}{N} + \frac{1}{2} \right]^2 + \frac{1}{12N}$$

where $\bar{U}$ is the simple mean of the U_i. A larger U indicates a less likely uniform distribution.

- Extract shoreline rugosity (complexity or sinuosity) by using the isoperimetric quotient (IQ), a measure of the shape that gives the greatest area (A) for a given perimeter (P):

$$IQ = (4\pi A) / P^2$$

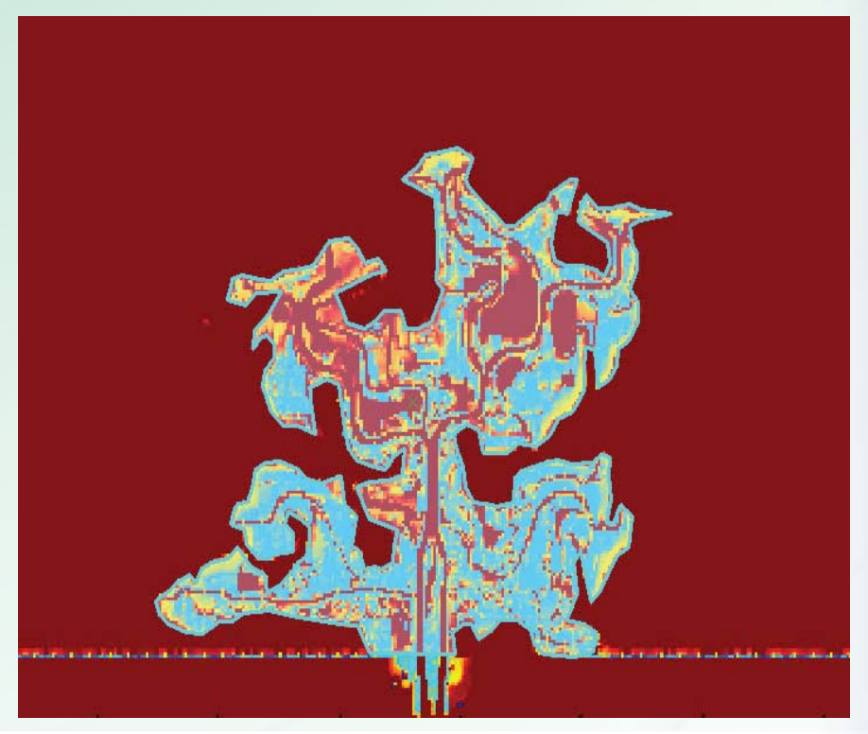


Figure 3. This delta has the most rugose shoreline of all the synthetic deltas in this study, with an IQ = 0.10

RESULTS

Shoreline rugosity increases with an increasing normalized critical shear stress for erosion of cohesive mud (τ_N) and is a lesser function of the amount of cohesive sediment delivered to the head of the delta (Q_{sr}).

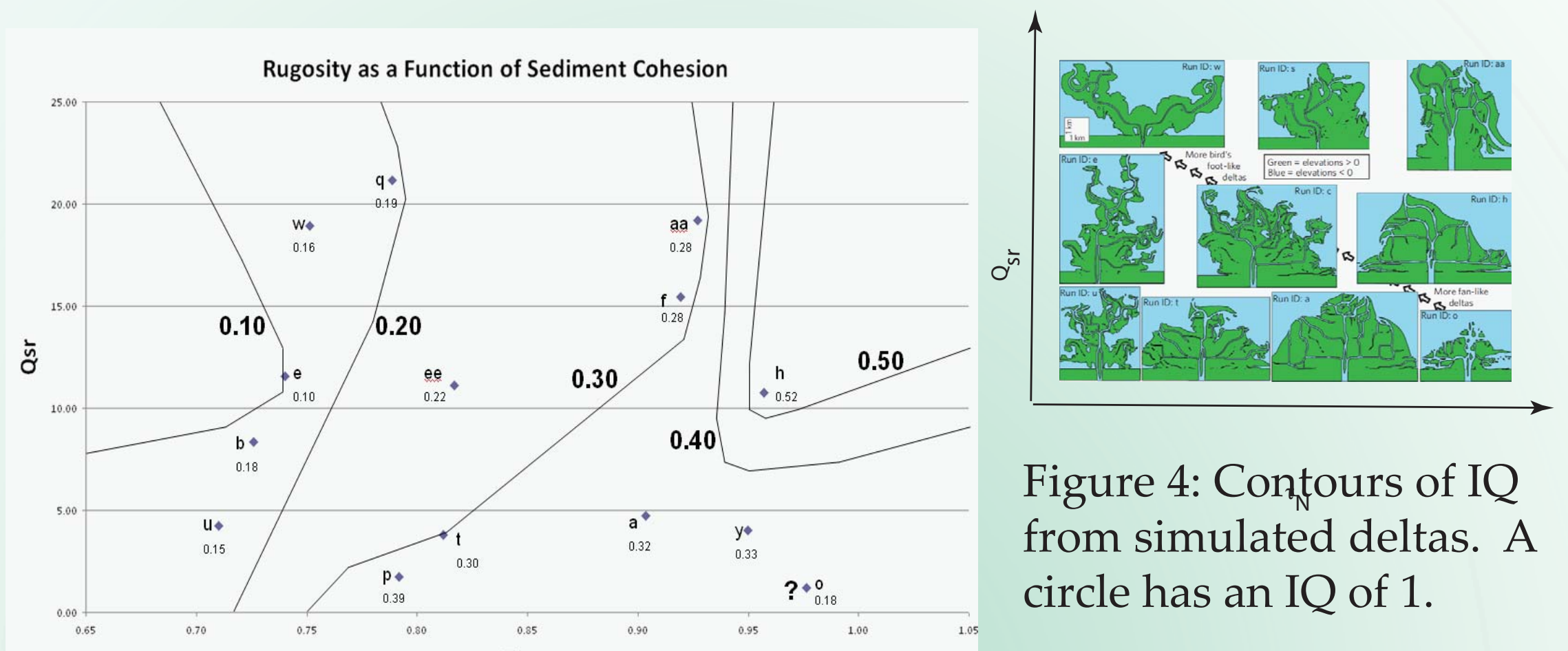


Figure 4: Contours of IQ from simulated deltas. A circle has an IQ of 1.

Clinoform dip direction variation decreases (U values from the uniformity test increase) as a function of both increasing normalized critical shear stress for erosion of cohesive mud (τ_N) and amount of cohesive sediment delivered to the head of the delta (Q_{SR})

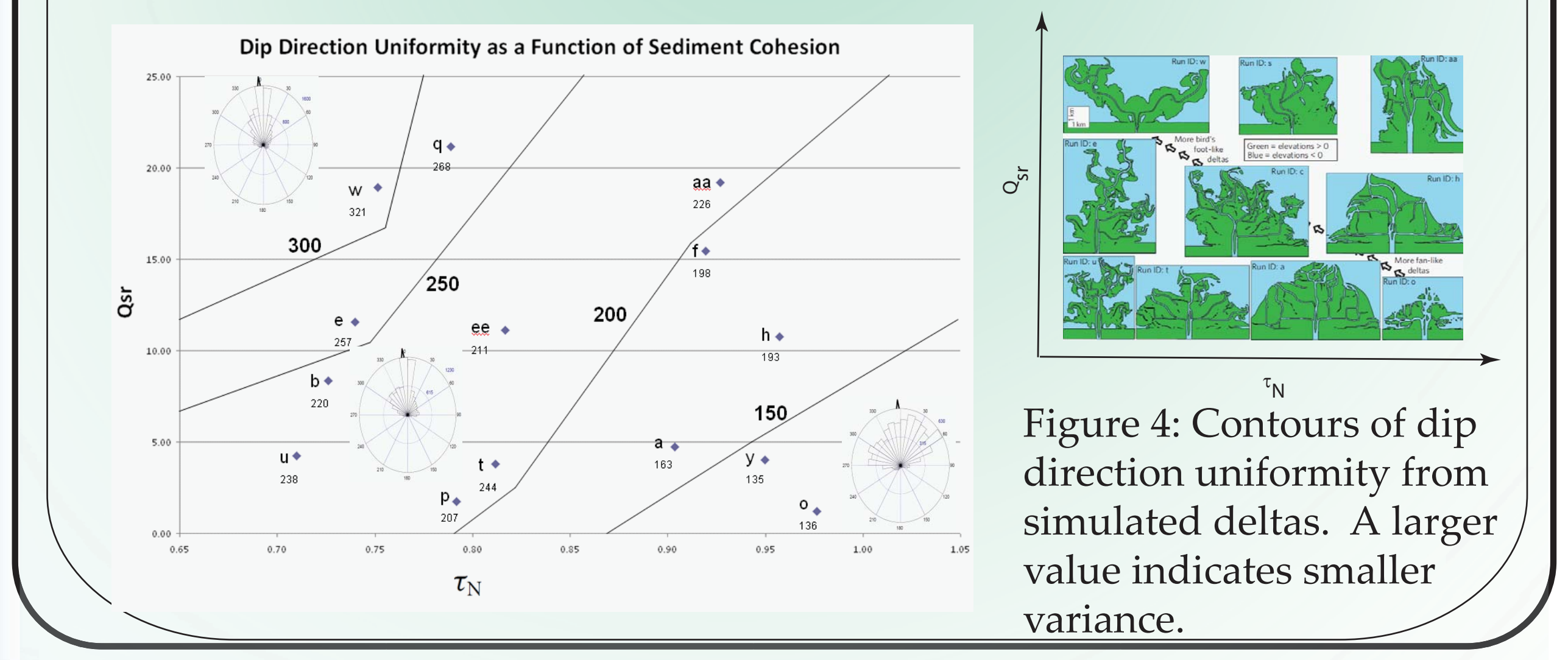


Figure 4: Contours of dip direction uniformity from simulated deltas. A larger value indicates smaller variance.

RESULTS

Sandbody shape and connectivity also depend upon the ratio of cohesive to noncohesive sediment fed to the delta

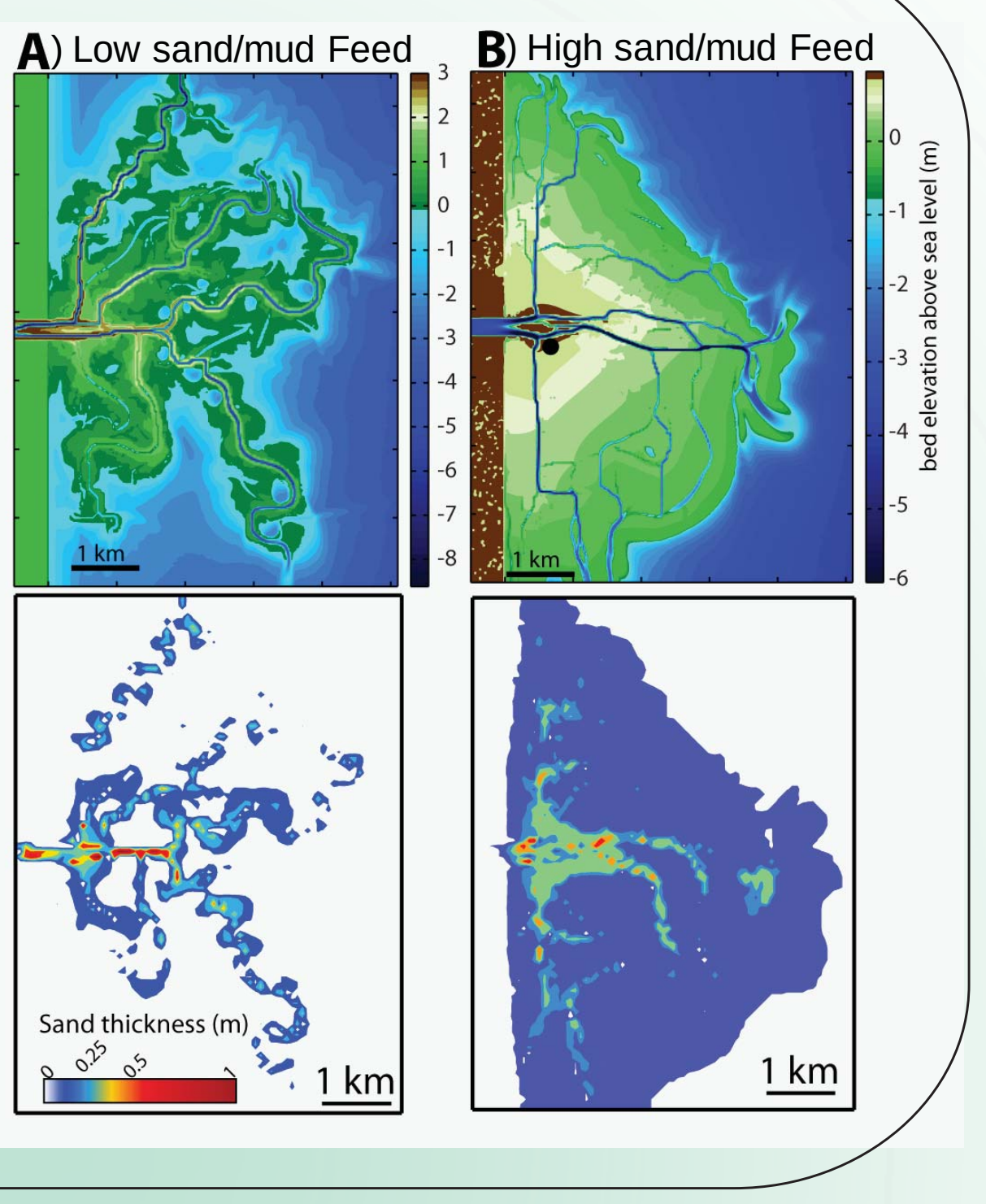


Figure 5: Planform (top) and net sand thickness (bottom) for two different sediment feed types.

Sandy deltas contain steeper clinoforms (top), in contrast to muddy deltas (bottom)

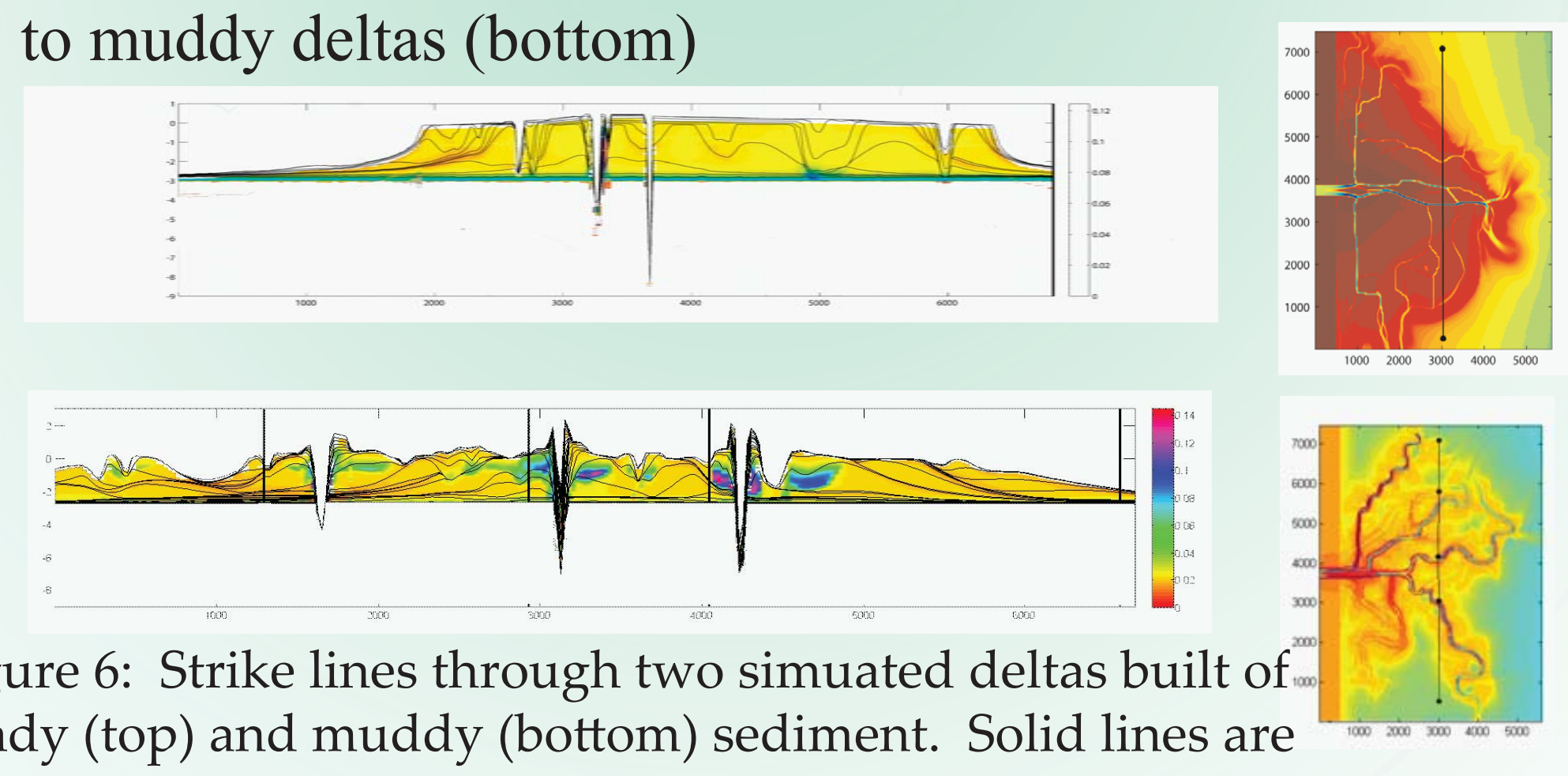


Figure 6: Strike lines through two simuated deltas built of sandy (top) and muddy (bottom) sediment. Solid lines are isochrons; colors reflect grain size from sand (red) to clay (yellow).

CONCLUSIONS

These results indicate that the caliber of sediment delivered to a deltaic coastal system plays a significant role in setting delta planform and consequently clinoform dip angles, dip variability, and sand body shapes and connectivity.

Recently Bose et al. (3011) suggested that the global sand/mud ratio of sediment delivered to the World's sedimentary basins has changed significantly through geologic time. If true, then the World's deltas should also have changed in the manner suggested here. The more common presence of braid-delta systems during the Precambrian than in Phanerozoic time may be confirmation of this fact.

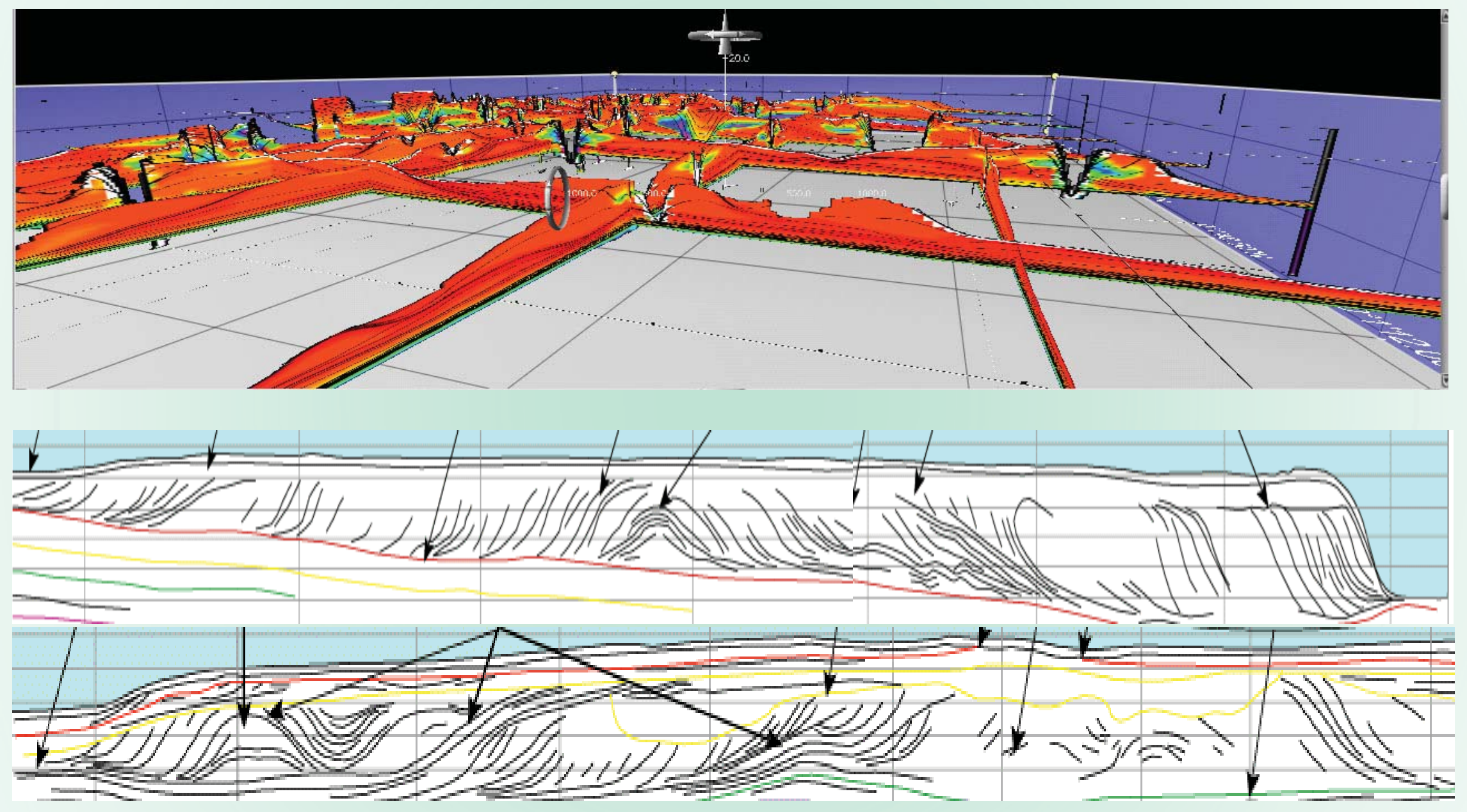


Figure 7: Top: Simulated seismic fence from a Delft3D muddy delta; Bottom: seismic lines through the Appalachicola shelf-edge Pleistocene delta, Gulf of Mexico (McKeown et al., 2004)

REFERENCES

Bose, P. K., P. G. Eriksson, et al. "Sedimentation patterns during the Precambrian: A unique record?" Marine and Petroleum Geology In Press, Corrected Proof.

Edmonds, D. and R. Slingerland (2010). "Significant effect of sediment cohesion on delta morphology." Nature Geoscience 3(2): 105-109.

Jones, T., A. (2006). "MATLAB functions to analyze directional (azimuthal) data—I: Single-sample inference." Computers & Geosciences 32: 166-175.