Understanding the impacts of autogenic processes on fluvial sediment accumulation using a 2-D diffusive sediment transport model

Duke UNIVERSITY

Candise L. Henry[1] and Lincoln F. Pratson[1]

[1] Division of Earth and Ocean Sciences, Nicholas School of the Environment, Duke University

Background and Objective

Classical sequence stratigraphy defines sequences and systems tracts based on allogenic controls (eustasy, sediment supply, and subsidence) on accommodation for sediment accumulation. However, more recent findings have shown that autogenic processes (e.g., channel avulsion, delta lobe switching, sediment storage and release) can complicated this by affecting where and how much sediment accumulation occurs. The goal of our work is to explore how fluvial sediment accumulation is affected by streamwise versus cross-stream biases in sediment transport related to autogenic processes.

A. Passive margin depositional environment with principal controls on stratal architecture

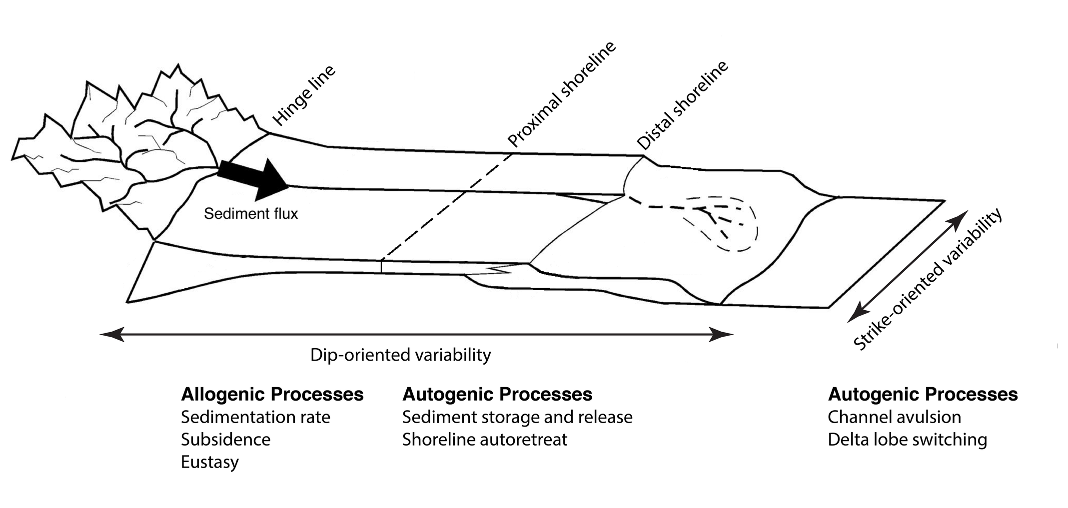


Figure A. While both allogenic and autogenic processes control along-dip (streamwise) stratigraphic variability, laterally-moving autogenic processes such as channel avulsion, delta lobe switching, and channel migration can create along-strike (cross-stream) variability in sedimentation (Hampson 2006; Straub et al. 2009). Figure modified from Hampson 2006.

B. Autogenically-produced cross-stream variability in stratal architecture

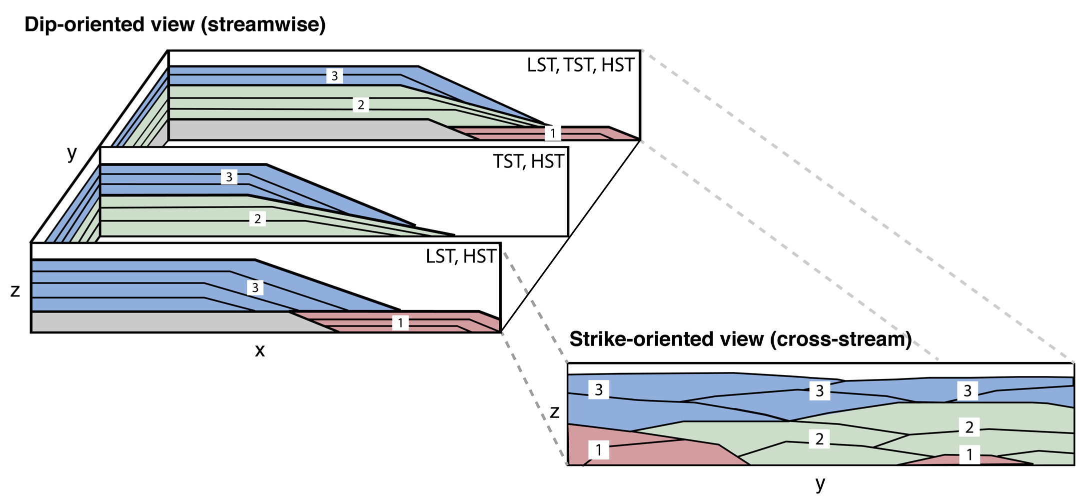


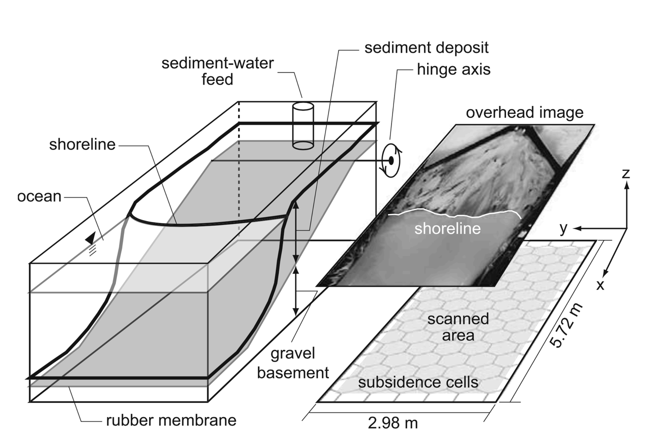
Figure B. Channel avulsion, delta lobe switching, and other autogenic processes can cause cross-stream and vertical variability within a basin in terms of where deposition occurs (Postma 2014). This can impact what is preserved in the final strata, which classical sequence stratigraphy may not predict. Figure modified from Madof et al. 2016.

Methods

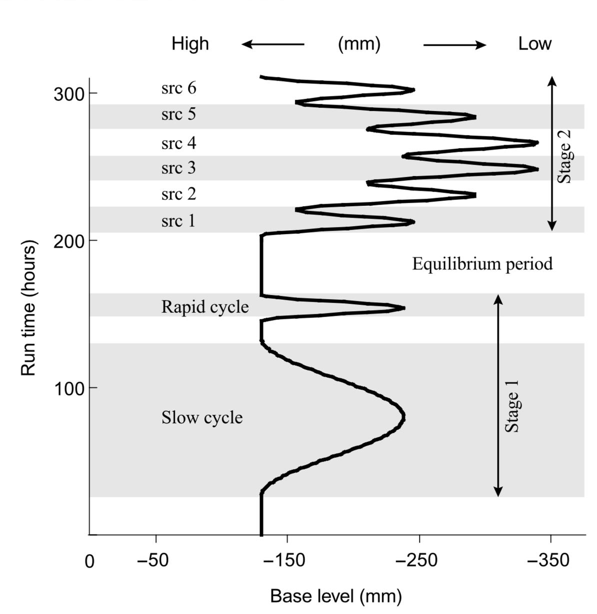
1. Experimental Stratigraphy

- St. Anthony Falls Laboratory Experimental Earthscape Basin run XES-02 (**Fig. A**; Kim et al. 2006, Paola et al. 2001)
- Constant sediment supply and foretilted (downstream-deepening) subsidence profile to simulate passive margin
- Numerous cycles of alternating slow and fast base level change (**Fig. B**; Martin et al. 2009)
- Topographical scans taken 92 times at varying intervals throughout experiment
- Isopach maps derived from topographical scans to determine quantity of deposition and erosion at each time interval within systems tracts

A. Experimental set-up for XES-02



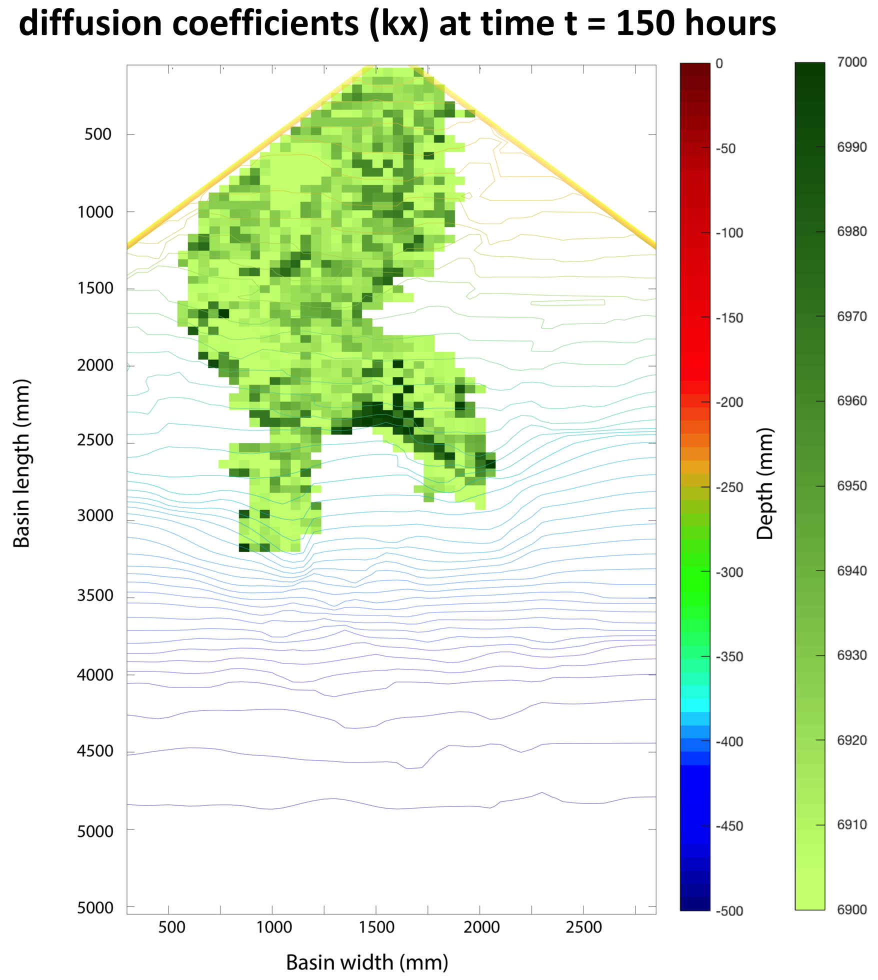
B. XES-02 base level



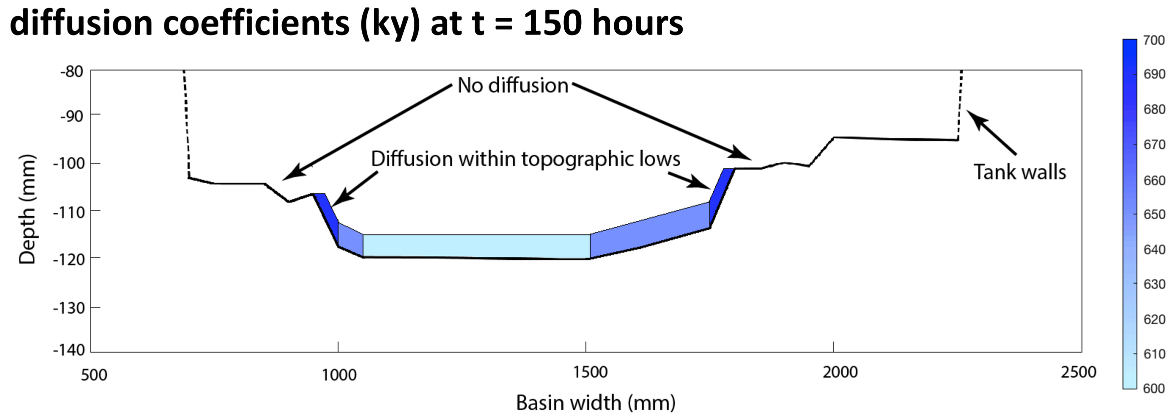
2. 2-D Diffusive Sediment Transport Model

- Based on Kaufman et al. 1991 with 2-D initial and boundary conditions from XES-02
- Deposition is determined by diffusion coefficients (kx, ky; mm^2/s), where:
  1. Diffusion increases with cell steepness;
  2. Streamwise diffusion (kx) is greater than cross-stream diffusion (ky; compare diffusion coefficients in **Figs. C and D**);
  3. No diffusion occurs outside of topographic lows (kx = ky = 0).
- Diffusion coefficients are approximated following above rules and by minimizing area and volumetric differences between modeled and XES-02 isopachs
- Diffusion is set to occur multiple times over each of XES-02's 92 scan intervals, depending on length of each scan interval
- **Figures C and D** show just one of the multiple diffusion runs that would comprise each of XES-02's 92 scan intervals

C. Aerial view of basin topography with streamwise diffusion coefficients (kx) at time t = 150 hours



D. Cross-sectional view of basin topography with cross-stream diffusion coefficients (ky) at t = 150 hours



Results

Comparisons between XES-02 and 2-D diffusive transport model (kx/ky = 10)

A. Area and volume comparisons

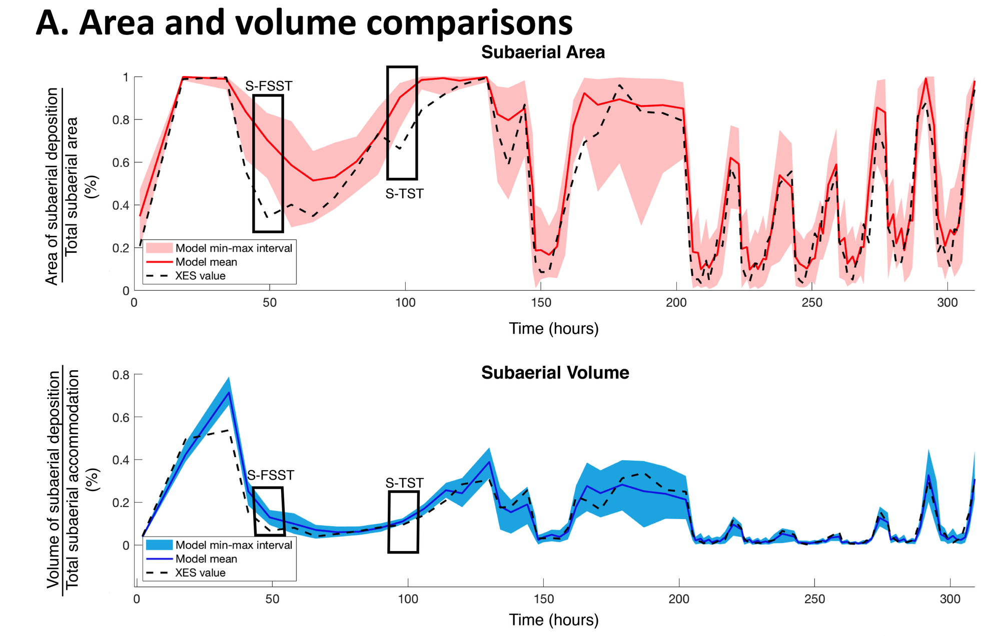
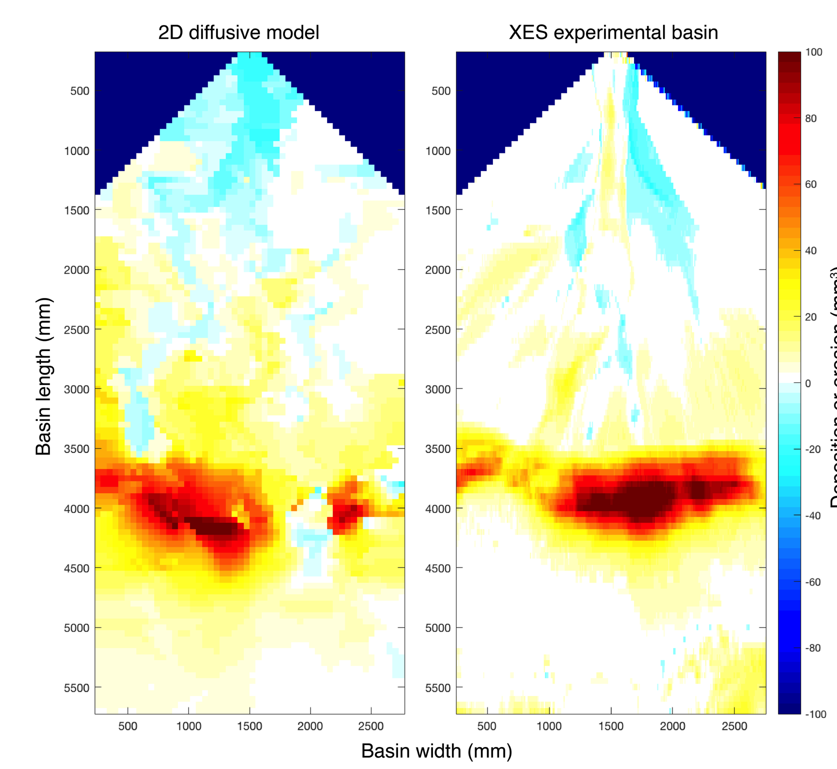
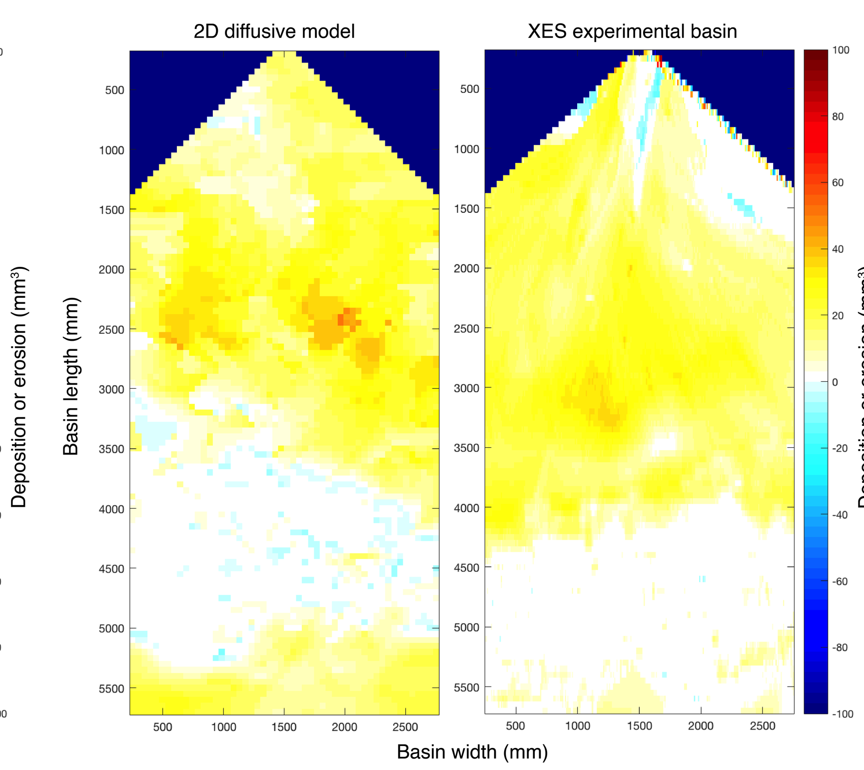


Figure A. The upper panel shows the comparison of percent subaerial coverage (depositional area over total subaerial area) between the diffusive model and the XES basin, and the lower panel shows the comparison of the percent of volumetric subaerial accommodation that is filled. Kx and ky values were determined by fitting modeled deposition and erosion to the XES-02 isopachs (kx/ky = 10). The lighter areas indicate the minimum and maximum values from 100 model iterations, while the darker red and blue lines indicate the mean area and volume of these runs, respectively. The dotted black line shows that the XES basin values generally fall within the model's range, suggesting that the diffusive model reasonably simulates the XES basin. The greatest discrepancies after the basin equilibrates occur during S-FSST and S-TST.

B. Slow cycle falling stage (S-FSST)



C. Slow cycle transgression (S-TST)



Figures B, C. Isopachs of the 2-D diffusive transport model and XES basin during S-FSST and S-TST (marked boxes in Fig. A) show where area and volume discrepancies occur in the basin. In both systems tracts, the 2-D model allows for greater subaerial deposition compared to the XES basin. Further analysis will examine the cause and impacts, if any, of these discrepancies.

Discussion

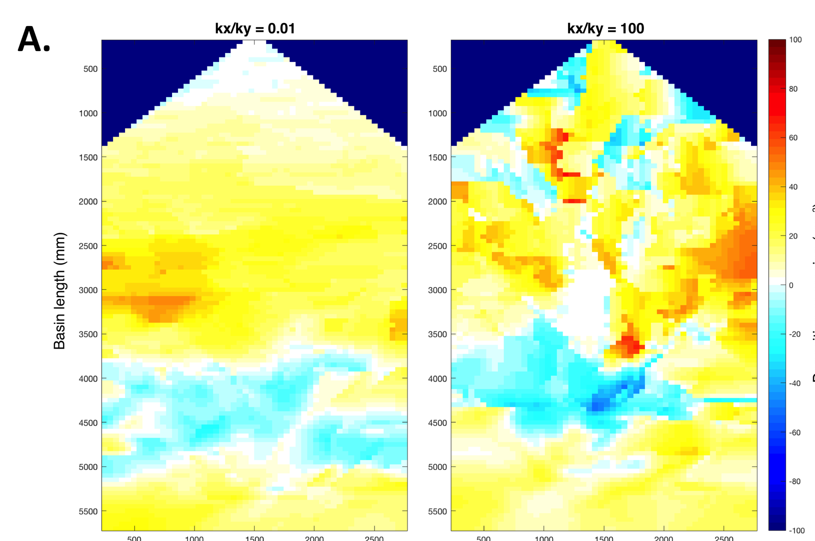
$\frac{kx}{ky}$ **= 0.01 Endmember**

Subaerial deposition produced by laterally-moving processes (ky) form *more quickly* than the deposition produced by streamwise processes (kx)

$\frac{kx}{ky}$ **= 100 Endmember**

Subaerial deposition by laterally-moving processes (ky) form *more slowly* compared to the deposition produced by streamwise processes (kx)

A.



B.

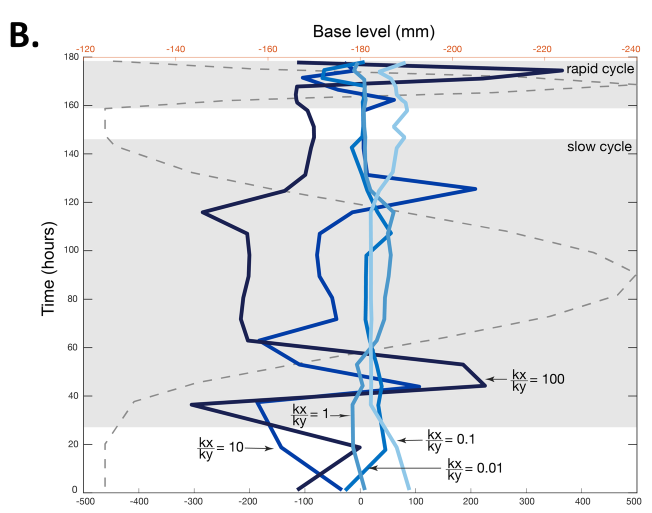
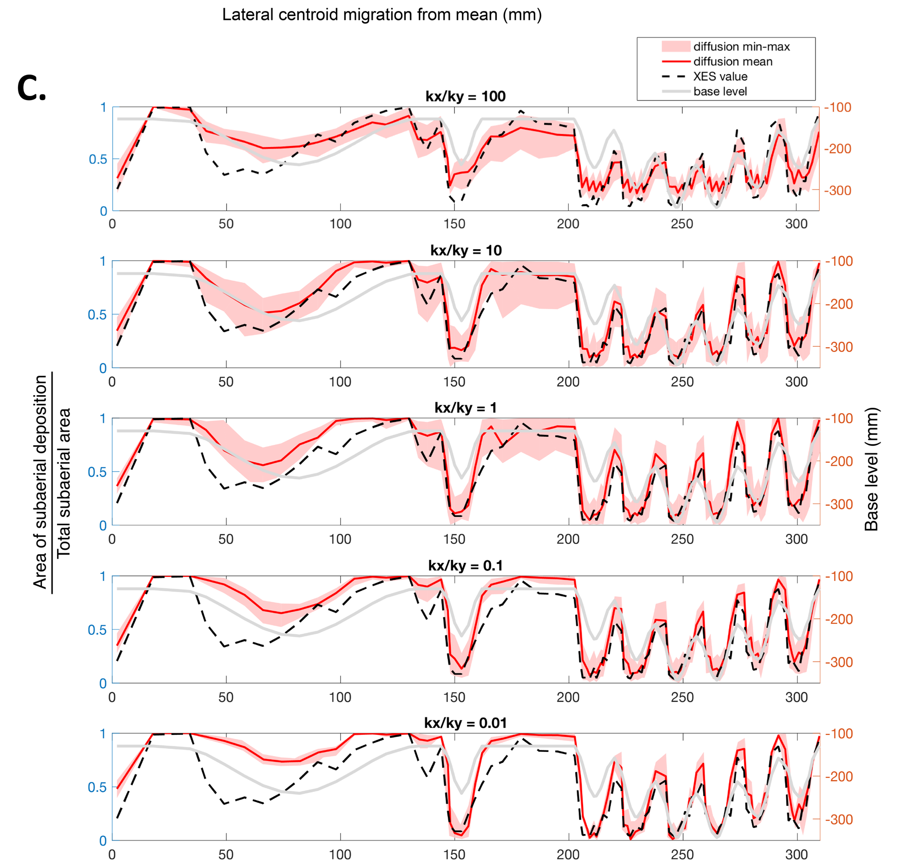
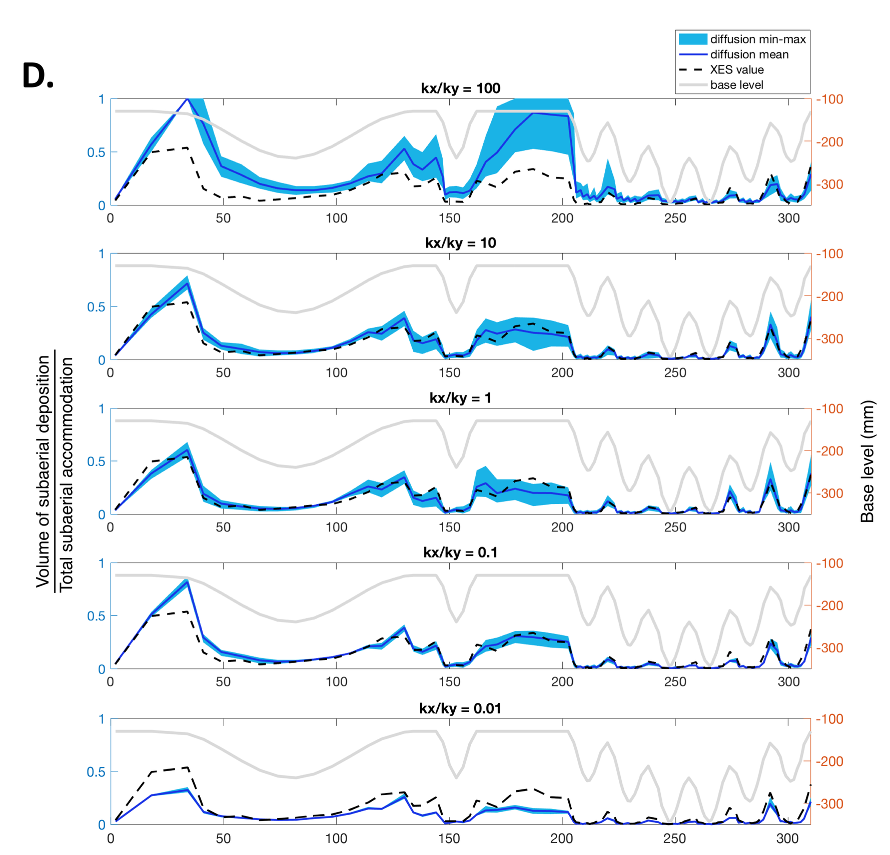


Figure A shows isopachs for two model runs during a slow cycle transgression: one where kx/ky = 0.01 (left) and one where kx/ky = 100 (right). When kx/ky = 0.01, such that cross-stream processes are greater and faster than streamwise processes, sediment accumulation occurs nearly uniformly in as a thin deposit across the entire shelf. However, when kx/ky = 100, sediment transport moves more longitudinally (streamwise) and sediment accumulation is much less uniform both in terms of area and volume. **Figure B** shows how the subaerial depositional center (centroid) from one run for each of the kx/ky ratios migrates laterally (cross-stream) through time. As kx/ky increases, the centroid shifts cross-stream more dramatically, demonstrating how lateral sediment transport has greater impact on fluvial deposition when it is relatively slow compared to streamwise sediment transport. **Figures C and D** show the subaerial area and volume comparisons, similar to Figure A in the Results section, between 5 kx/ky ratios. As the kx/ky ratio gets smaller, more of the fluvial area is filled during the rapid transgression and highstand (as in Fig. A) and more erosion occurs during rapid falling stage and lowstand. During the slow cycle, the fluvial area coverage for all ratios are fairly similar perhaps because all cross-stream diffusion occurs relatively quickly compared to the slow base level change. The volume comparisons suggest that as kx/ky decreases, the volume of fluvial deposition decreases. This is likely due to the constant deposition and erosion that occurs with greater cross-stream sediment transport, where the fluvial deposits are widespread but thin.

C.



D.



Conclusions

1. 2-D diffusive sediment transport can produce lateral channel movements and fluvial deposits that compare reasonably well with those found in the experimental basin.

2. Results confirm previous work that when cross-stream sediment transport (e.g., by avulsions or other laterally-moving autogenic processes) is dominant within a basin, fluvial deposition tends to be widespread but does not necessarily occupy significant vertical space. However, when streamwise sediment transport (e.g., RSL) dominates, there is much more variability in the quantity and pattern of sediment accumulation.

Further Work

1. We will use the diffusivity coefficients and ratios to quantitatively relate the cross-stream sediment transport rate to the RSL and sediment supply rates, in order to better understand and constrain the impacts of laterally-moving autogenic processes relative to allogenic processes on fluvial sediment accumulation.

2. We will then attempt to reconcile those results with how systems tracts are interpreted.

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