Modeling Stream Capture and Ridge Migration in Strike-Slip Systems

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Motivation and Background

Strike-slip faults produce characteristic landscape signatures, such as shutter ridges and offset streams, that have been cited as evidence for lateral motion for decades. Geomorphic processes such as stream capture have also long been associated with strike-slip faults. (Wallace, 1968) However, a deep understanding of the landscape processes forced by strike-slip faulting has not yet been fully developed.

Prolonged strike-slip faulting should drive persistent landscape disequilibrium in landscapes where streams drain across a fault. These catchments experience a cycle of gradual stream lengthening followed by abrupt shortening and increased incision caused by stream capture (see **Fig. 1**). (Duvall & Tucker, 2012)

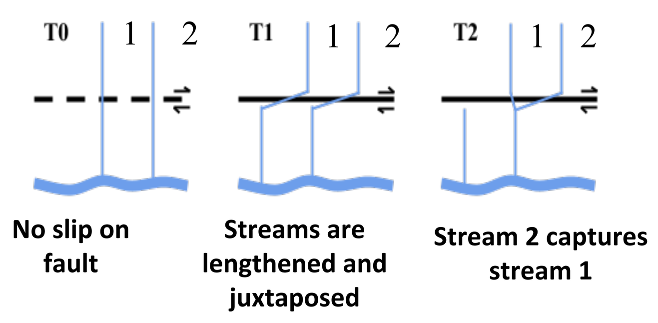

Figure 1. The stream capture cycle along a strike-slip fault.

New research from our group investigates the development and morphology of landscape signatures of strike-slip faulting. This research suggests that strike-slip faulting can cause the ridges separating adjacent drainages to migrate, and that this behavior may be dependent on slip rates and erosion efficiency. (Duvall & Tucker, in review)

Here, we present new experiments and preliminary results as we add more complexity to our models. We model a transpressional setting, where strike-slip motion is combined with differential uplift across a fault. We investigate the effect of this ratio on the production of landscape features and geomorphic processes typically associated with strike-slip fault zones.

Research Questions

- **How is ridge migration in response to strike-slip faulting affected by the ratio of uplift to strike-slip motion on a fault, as in a transpressional setting?**
- **How is stream capture in response to strike-slip faulting affected by:**
  - **Ratio of strike-slip to vertical motion on a fault?**
  - **Sediment supply?**

Model Setup

- We investigate these questions numerically using the Channel-Hillslope Integrated Landscape Development (CHILD) model. (Tucker et al., 2001) CHILD simulates the evolution of topography, given a set of geomorphic transport functions and climatic, tectonic, and lithological characteristics.
- For each of our experiments, we use CHILD to build a 200 x 2000m, one-sided mountain range. Sediment regime and uplift on either side of the fault is varied depending on the experiment.
- The block is uplifted until it reaches a steady-state mean elevation.

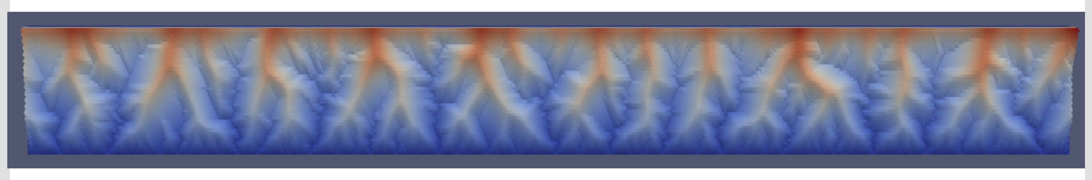

Figure 2. Initial model setup: uplift to steady state mountain range.

- Once the block has reached steady state, a strike-slip fault is broken across it, and whatever uplift regime was used to build the range is maintained.
- We ran a suite of runs with varying ratios of strike-slip motion to differential uplift across the fault. (See **Table 1**.)
  - These runs maintain the same basic parameters as those in earlier work by Duvall and Tucker (in review), but introduce this additional variable.
- All of the runs below have nonlinear hillslope diffusion, with a threshold slope of 0.7, after Roering et al., 1999.

Model Run	Uplift on Uphill Side of Fault	Differential Uplift Across Fault	Horizontal Slip Rate	Uplift/ Advection Ratio	NAE
1	1 mm.yr	0	1 mm/yr	1	6.22
2	1.25 mm/yr	0.25 mm/yr	0.75 mm/yr	1.67	3.50
3	1.5 mm/yr	0.5 mm/yr	0.5 mm/yr	3	1.56
4	1.75 mm/yr	0.75 mm/yr	0.25 mm/yr	7	0.039
5	2 mm/yr	1 mm/yr	0	n/a	0

Table 1. Input parameters for CHILD model runs investigating ratios of differential uplift to strike-slip.

Ridge Migration

- Recent work by Duvall and Tucker (in review) shows that when slip rates are **slow** relative to erosion rates, fault-perpendicular drainage divides upstream of the fault migrate laterally in the direction of the slip of the opposite block.
  - This migration is driven by the growth of new channels from the leading edge of the lengthening trunk stream.
  - This migration allows many ridges to remain unbroken across the fault.
  - Therefore, relief is **high** just upstream of the fault
- On the other hand, when slip rates are **fast**, ridges do not migrate and cannot remain unbroken across the fault.
  - Facets form facing the fault. Therefore, relief is **low** just upstream of the fault.
- This distinction can be quantified by calculating the **Profile Relief Ratio:**

$$PRR = \frac{Relief near fault}{Relief far from fault}$$

- The PRR is around or slightly above **1** in cases with ridge migration, and **less than 1** in cases without.

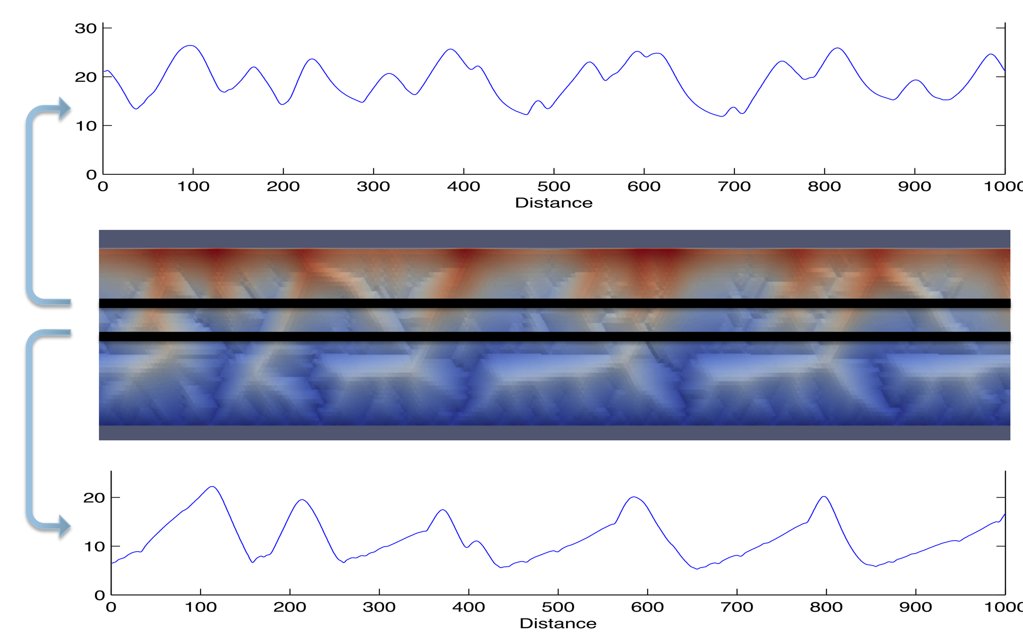

Figure 3. An example of a model run with a PRR of slightly over 1 and that exhibits ridge migration.

- Low horizontal slip rates and high erosive efficiencies both contribute to ridge mobility.
- The dimensionless advection-erosion number (N_{AE}) describes the relative speed of strike-slip motion versus the efficiency with which fluvial and hillslope erosion can adjust to this displacement:

$$N_{ae} = \frac{V^2}{KD}$$

Where V is the horizontal slip rate, K is the rate coefficient for fluvial erosion, and D is the rate coefficient for hillslope erosion.

- Plotting N_{AE} versus PRR (**Fig. 4**) shows that, as N_{AE} increases, PRR declines from its maximum around 1 as ridge migration declines.
- In previous experiments, ridge migration was observed only when N_{AE} was below ~1.

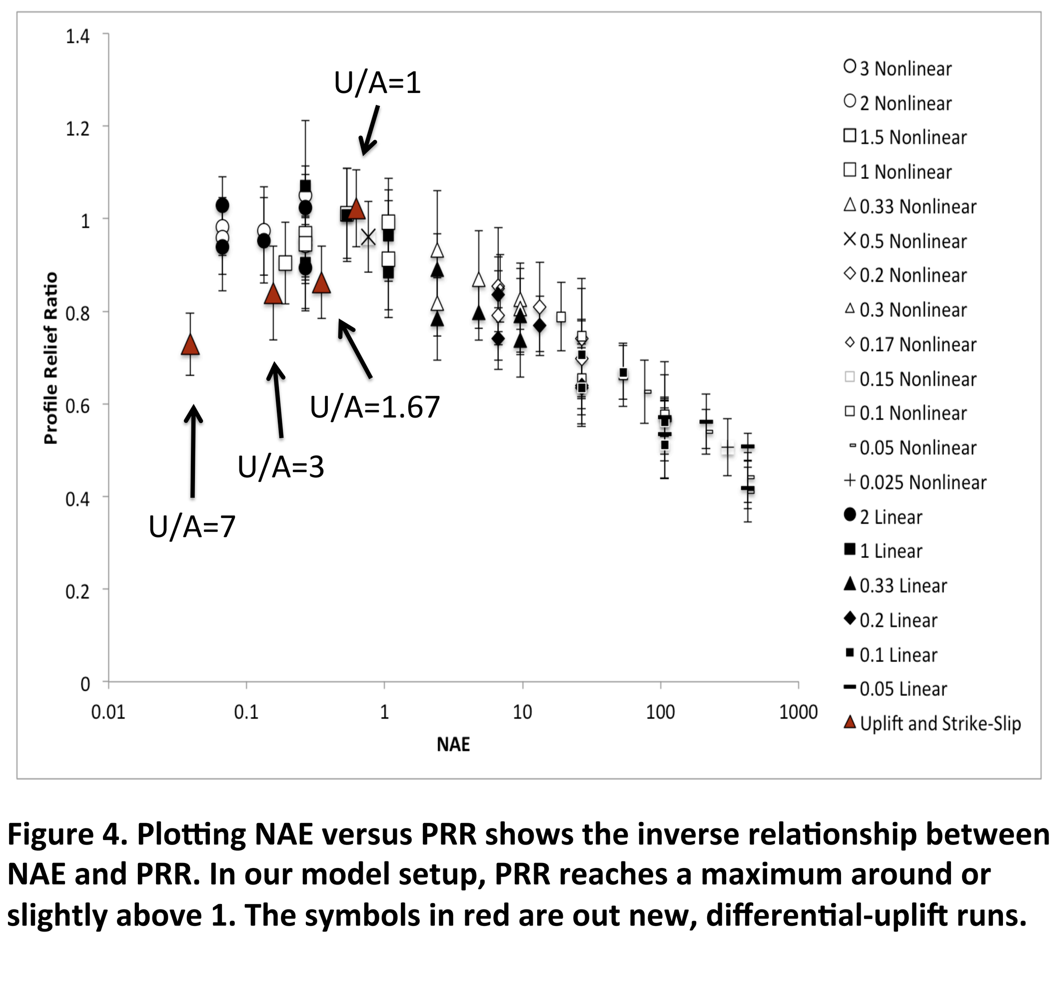

Figure 4. Plotting NAE versus PRR shows the inverse relationship between NAE and PRR. In our model setup, PRR reaches a maximum around or slightly above 1. The symbols in red are out new, differential-uplift runs.

Effects of Differential Uplift on Ridge Migration

- The low relief ratios observed in the slow strike-slip/high uplift cases suggest that this migration may be diminished when strike-slip motion is a very minor component of slip.
- However, ridge migration **was** observed in all differential uplift cases that involved some component of strike-slip, even those in which the uplift rate was seven times the strike-slip rate.
- Future work will seek to better quantify the degree of ridge migration in transpressional situations where uplift may affect relief.

Stream Capture

Effects of Uplift-Advection Ratio on Stream Capture

- Stream capture (in addition to ridge migration) still occurred in even our slowest-horizontal-slip runs.
- However, the rate of stream capture slowed down in runs with a very low rate of strike-slip relative to uplift (~1:7).

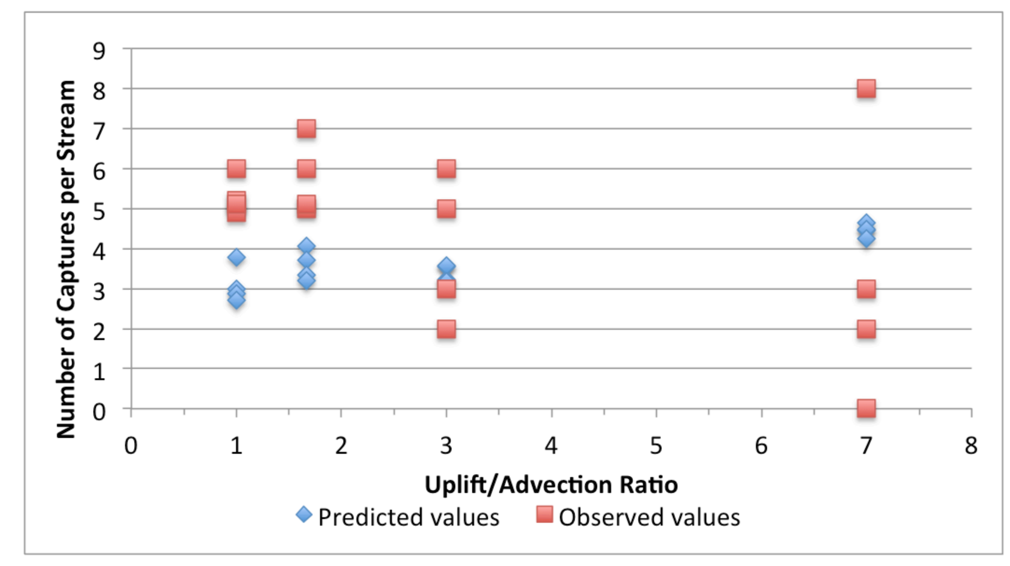

Figure 5. The number of stream captures occurring on certain streams in the model runs, during the time it takes each run's fault to slip 500m. These values are compared to predicted values, which are simply the number of times streams are expected to be juxtaposed, based on the drainage spacing of the model.

Effects of Sediment Supply on Stream Offsets and Capture

- We found that a higher sediment supply increased the frequency of stream capture.
- The mechanism for this difference was that transport-limited streams were unable to sustain offsets as long as those of the detachment-limited rivers, and therefore were juxtaposed with other streams more often.

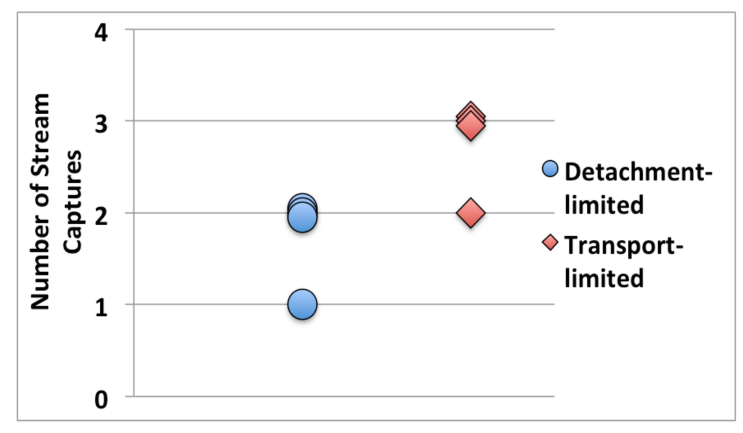

Figure 6. Number of captures over 50 time steps (100,000 years) for detachment- and transport-limited model runs.

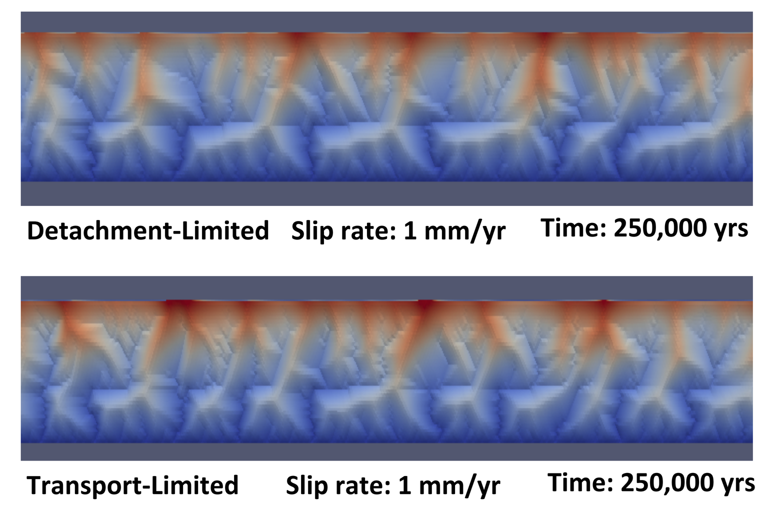

Figure 7. In the detachment-limited case, rivers flowing along the fault are able to sustain longer offsets than rivers in the transport-limited case are.

Discussion

- Even a small proportion of lateral motion on a fault produces landscape signatures of strike-slip faulting, such as ridge migration and stream capture.
- The continuation of this work will test more cases, including higher rates of differential uplift and lower rates of strike-slip.
- Ongoing work by this research group is also investigating patterns of uplift in the right-lateral Marlborough Fault System of New Zealand, as well as the morphology and sediment load of the streams there, in order to determine how these characteristics interact to produce this landscape.

Acknowledgements and References

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