Investigating the Role of Near-Fault Relief and Vertical Uplift in Strike-Slip Landscape Development

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Motivation and Background

Strike-slip faults produce distinctive landscape features such as shutter ridges and offset streams. Continual lateral offset on a fault can produce a cycle of stream lengthening and capture, as shown in **Figure 1**. These features and processes have been used to determine activity and slip rates of faults. (Wallace, 1968, Hubert-Ferrari et al., 2002)

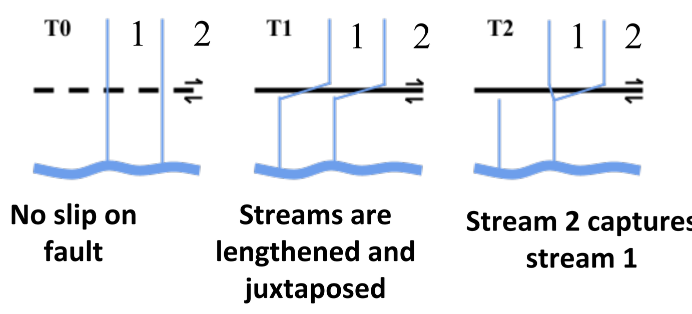

Figure 1. The stream capture cycle along a strike-slip fault.

This cycle of stream lengthening and shortening induces ongoing transience in the landscape, causing knickpoints in channels and beheaded channels and wind gaps visible in plan form. However, stream captures shorten stream offsets, reducing the first-order "landscape signature" of a strike-slip fault. When viewing a landscape at a single moment in time, it can be difficult to find conclusive evidence of stream capture, and thus to determine whether observed stream offsets are the direct result of offset on a fault or whether they have been altered by capture. (Walker and Allen, 2012)

In real-world settings, the landscape signature of strike-slip faults is often not very dramatic. Walker and Allen (2012) note that on the Kuh Banan Fault in Iran, offsets are not as long as expected. In our field area, the right-lateral Marlborough Fault System in New Zealand, channel offsets are relatively short and often not present (**Figure 2**).

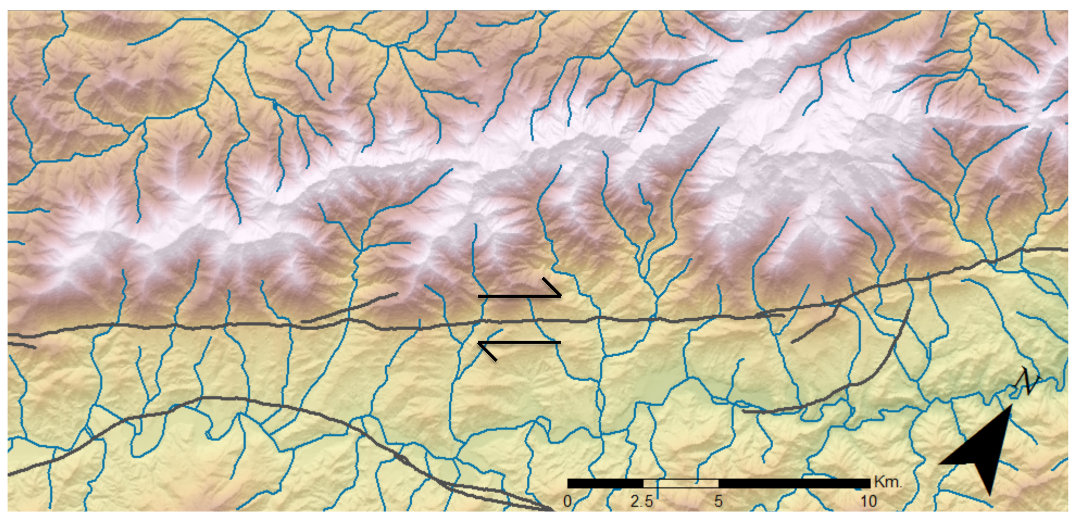

Figure 2. Clarence Fault, Marlborough Fault System, South Island NZ. Although this fault is actively slipping at 5 mm/yr, many streams flowing across it do not show offsets.

Here we investigate the role of shutter ridges, which are areas of high relief transported laterally on the downhill side of the fault. Is relief in this area necessary to create stream offsets? Without shutter ridges, does stream capture happen more often and erase offsets?

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.
- We use CHILD to build a 200 x 2000m, one-sided mountain range. Uplift on either side of the fault is varied in different runs.
- Once the block has reached steady state, a strike-slip fault is created through the range while maintaining the differential uplift.

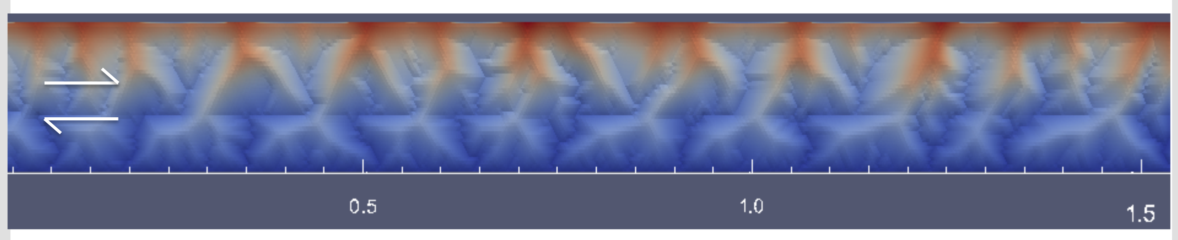

Figure 3. Example CHILD model run.

Model Run	Uplift on Uphill Side of Fault	Uplift on Downhill Side of Fault	Horizontal Slip Rate	Uplift/ Advection Ratio
1	1 mm/yr	0.1 mm/yr	1 mm/yr	0.1
2	1 mm/yr	0.2 mm/yr	1 mm/yr	0.2
3	1 mm/yr	0.3 mm/yr	1 mm/yr	0.3
4	1 mm/yr	0.4 mm/yr	1 mm/yr	0.4
5	1 mm/yr	0.5 mm/yr	1 mm/yr	0.5
6	1 mm/yr	0.6 mm/yr	1 mm/yr	0.6
7	1 mm/yr	0.7 mm/yr	1 mm/yr	0.7
8	1 mm/yr	0.8 mm/yr	1 mm/yr	0.8
9	1 mm/yr	0.9 mm/yr	1 mm/yr	0.9
10	1 mm/yr	1 mm/yr	1 mm/yr	1

Table 1. Input parameters.

Research Questions

- **How do the height and length of shutter ridges affect the frequency of stream capture?**
- **In the Marlborough Fault System, do shutter ridges control stream offsets?**

Modeling Results

- We tracked individual shutter ridges through time and recorded the number of stream capture events that breached each one.

Effects of Shutter Ridge Relief on Stream Capture

- A higher shutter ridge is more of an obstacle to stream capture.
- When relief downhill of the fault is greater, stream capture happens **less often** and stream offsets are **longer**.

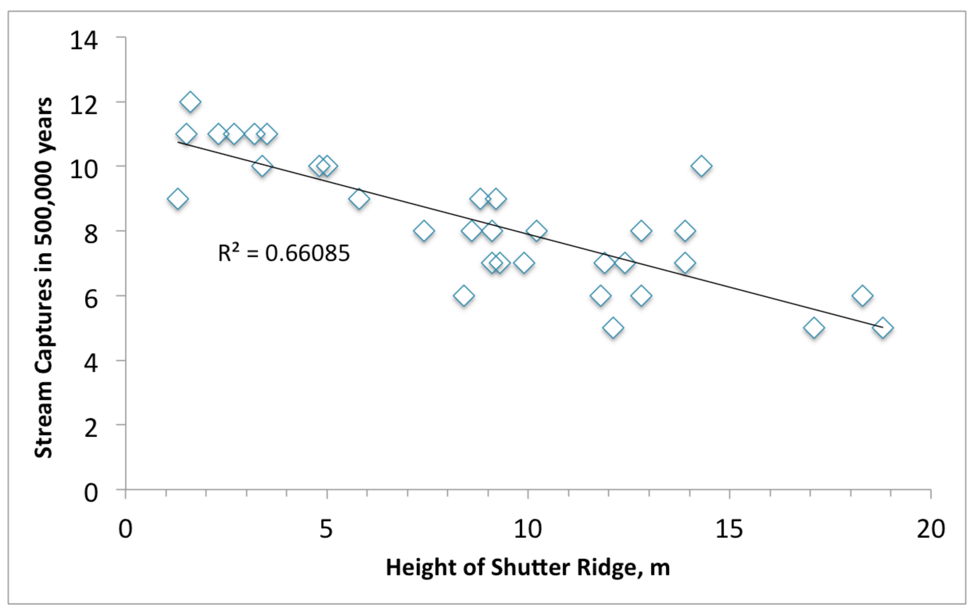

Figure 4. The number of stream captures occurring around shutter ridges of different heights in 500,000 years, the time it takes the fault to slip 500m.

Effects of Shutter Ridge Length on Stream Capture

- Stream capture happens **less often** around longer shutter ridges and stream offsets are **longer**.
- Longer shutter ridges effectively increase the drainage spacing near the fault, causing adjacent streams to be juxtaposed less often.
- However, shutter ridge length has **less** of an effect on stream capture frequency than shutter ridge height does.

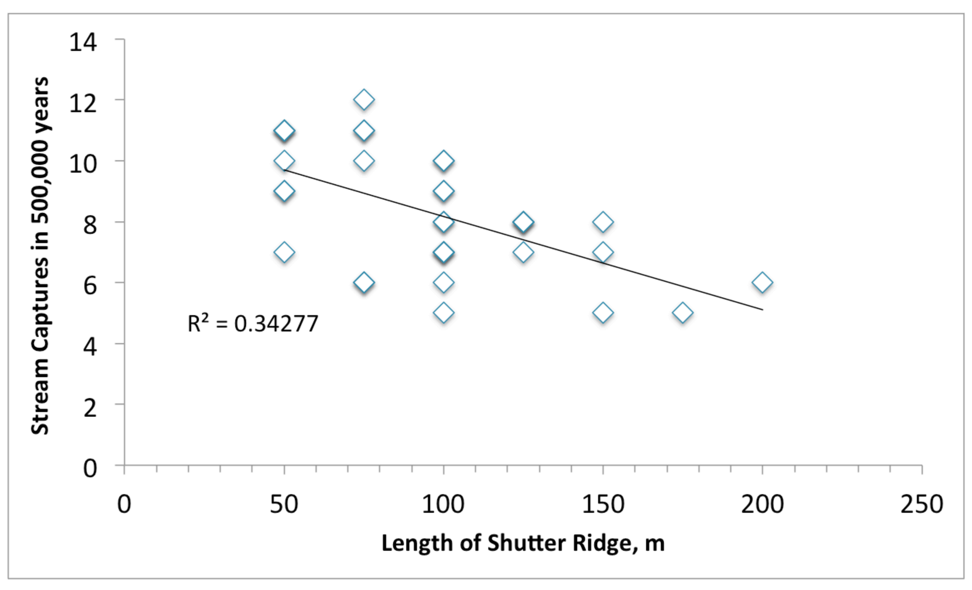

Figure 5. The number of stream captures occurring around shutter ridges of different lengths.

Effects of Uplift Downhill of the Fault on Stream Capture

- Uplift below the fault is negatively correlated with the overall frequency of stream capture.
- Our ongoing research will separate this effect from the effect of relief below the fault by testing pre-existing, non-uplifting shutter ridges and lithologically controlled shutter ridges.

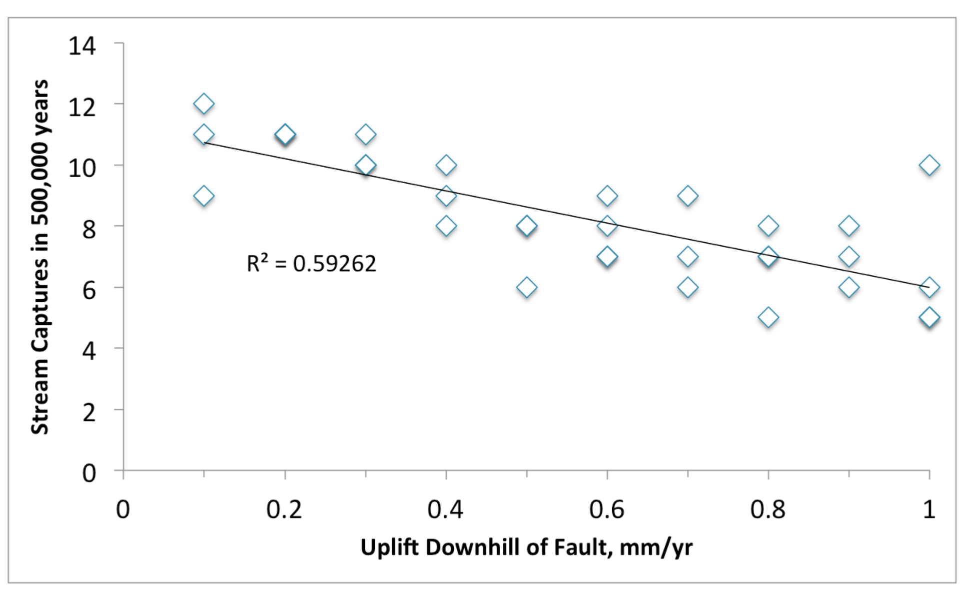

Figure 6. The number of stream captures occurring in model runs with different amounts of uplift downhill of the fault.

Comparison to Field Sites

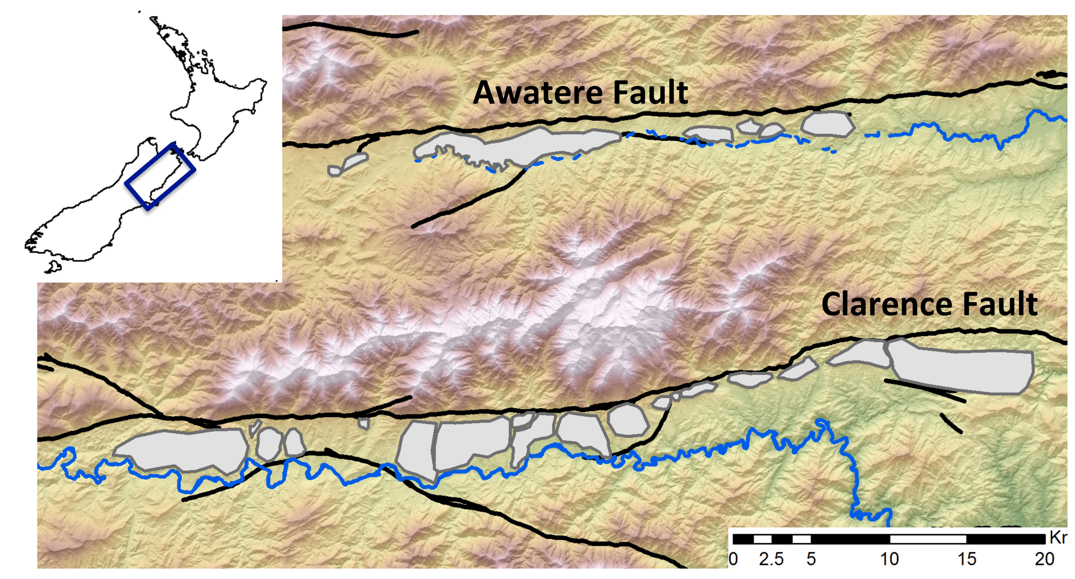

Figure 7. Shutter ridges are a common feature in the Marlborough Fault System of New Zealand, but they are not ubiquitous.

Effects of Relief on Offset Length

- We found a modest positive correlation between relief downhill of the fault and stream offset length.

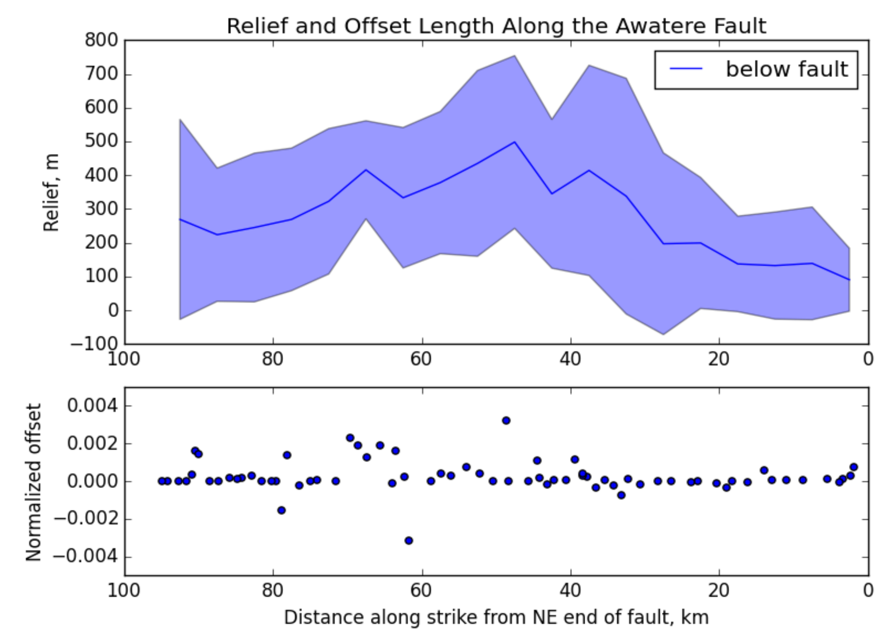

Figure 8. Relief downhill of the Awatere Fault plotted along strike against lengths of channel offsets. Shaded band is 95% of relief values. Channel offsets are normalized against stream drainage area. Positive offsets are in the direction predicted by slip on the fault and negative offsets are in the opposite direction.

Discussion

- Shutter ridges are important for generating the long channel offsets that are considered characteristic of strike-slip fault zones.
- In the absence of shutter ridges, or where they are not high-relief features, stream capture is frequent and channels can re-arrange often. This situation can dampen the landscape signature of the fault.
- Many real-world landscapes still show even fewer and shorter stream offsets than we have been able to produce in the model.
- The presence or length of offset channels does not necessarily reveal a fault's activity or slip rate.
- Future work on this project will compare the effectiveness of different types of shutter ridges in creating long channel offsets. Many of the shutter ridges in the Marlborough Fault System are lithologically controlled – does an erodibility contrast create a more effective shutter ridge?

Acknowledgements and References

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