Migrating divides induce drainage reversals toward cliffs and escarpments

Liran Goren (1), Elhanan Harel (1), Eitan Shelef (2), Hanan Ginat (3)

(1) Ben-Gurion University of the Negev, Geological & Environmental Sciences, Beer Sheva, Israel.
(2) University of Pittsburgh, Pittsburgh, PA, United States.
(3) Dead-Sea & Arava Science Center, Tamar Regional Council, Israel.

How to read this display?

Purple text – Read to get the main points

Green text – Read if you are having fun

Brown text – Read only if you are a true fan of fluvial reorganization

This display is based on an open access *Geology* 2009 manuscript.

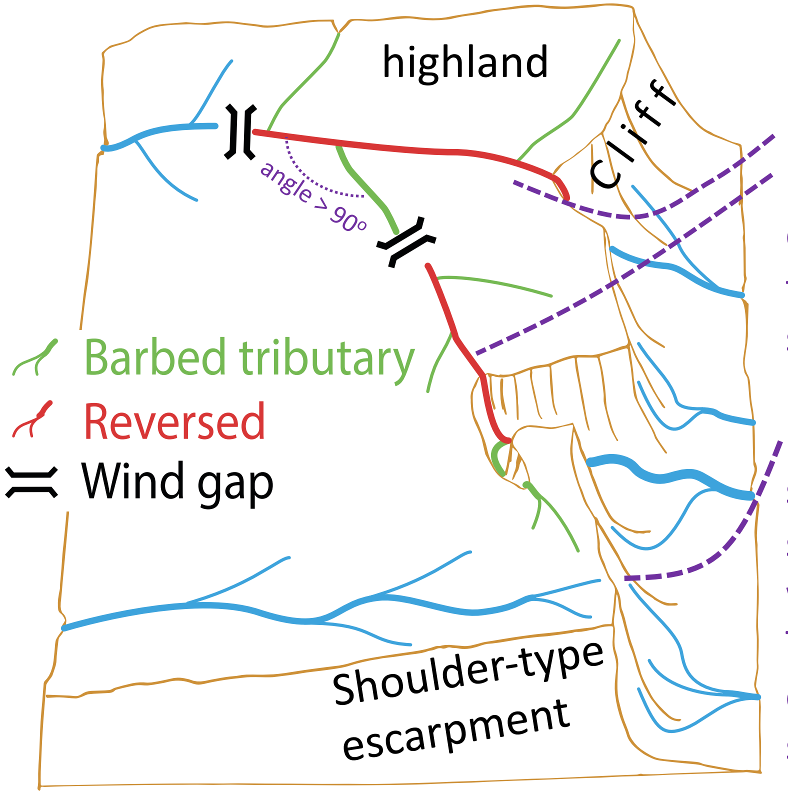
https://pubs.geoscienceworld.org/gsa/geology/article/47/10/928/573170/Drainage-reversal-toward-cliffs-induced-by-lateral

What is drainage reversal?

Drainage reversal is a subcategory of fluvial reorganization. Reversals occur when a channel that used to grade in one direction reverses its gradient by 180°, such that it now drains in the opposite direction and possibly to a different base level.

How can we identify reversals?

1. Barbed tributaries, with junction angle > 90°
2. Valley confined windgap

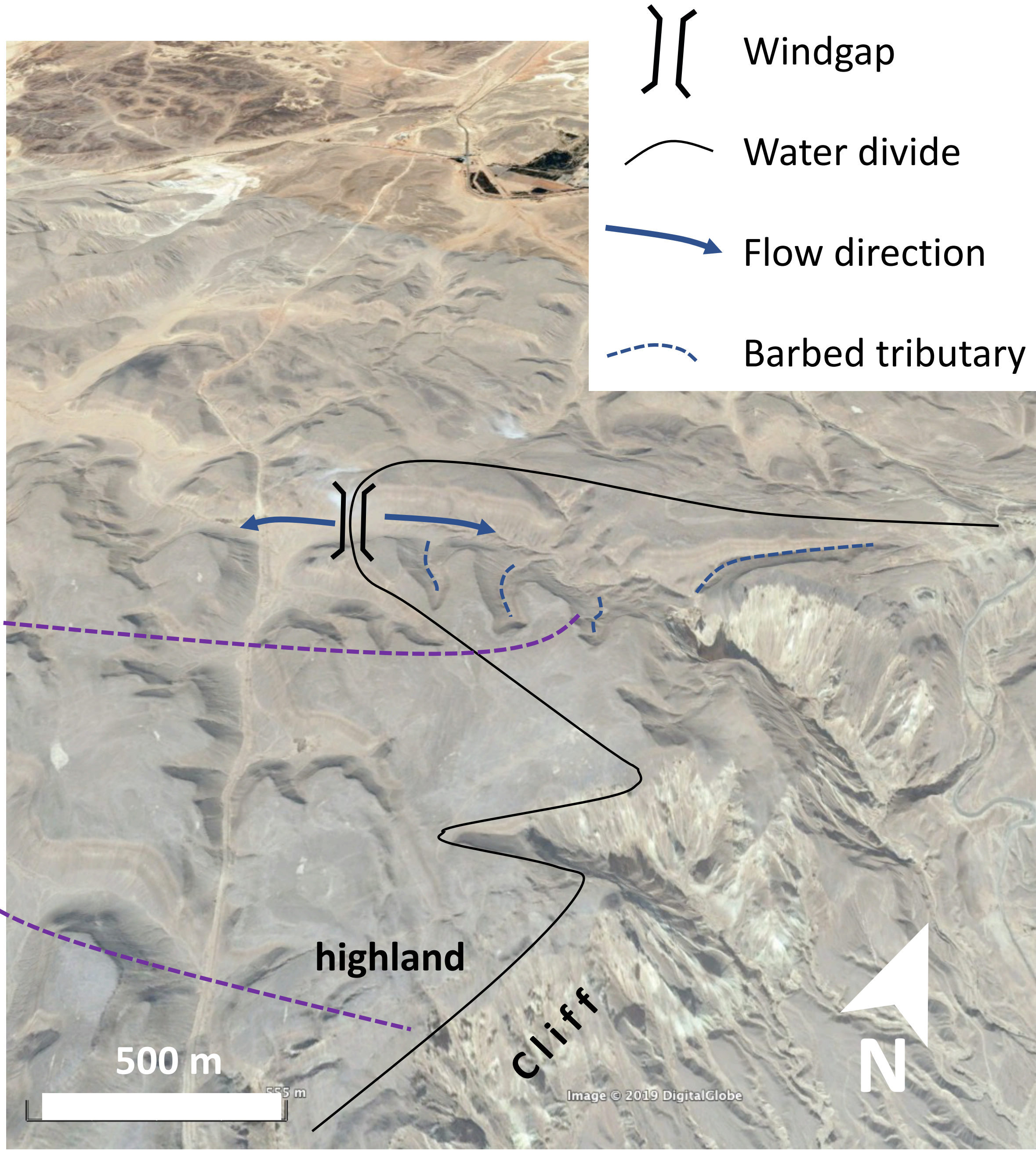


Reversals toward cliffs

Field reports show many examples of drainage reversal toward cliffs and long shoulder-type escarpment.

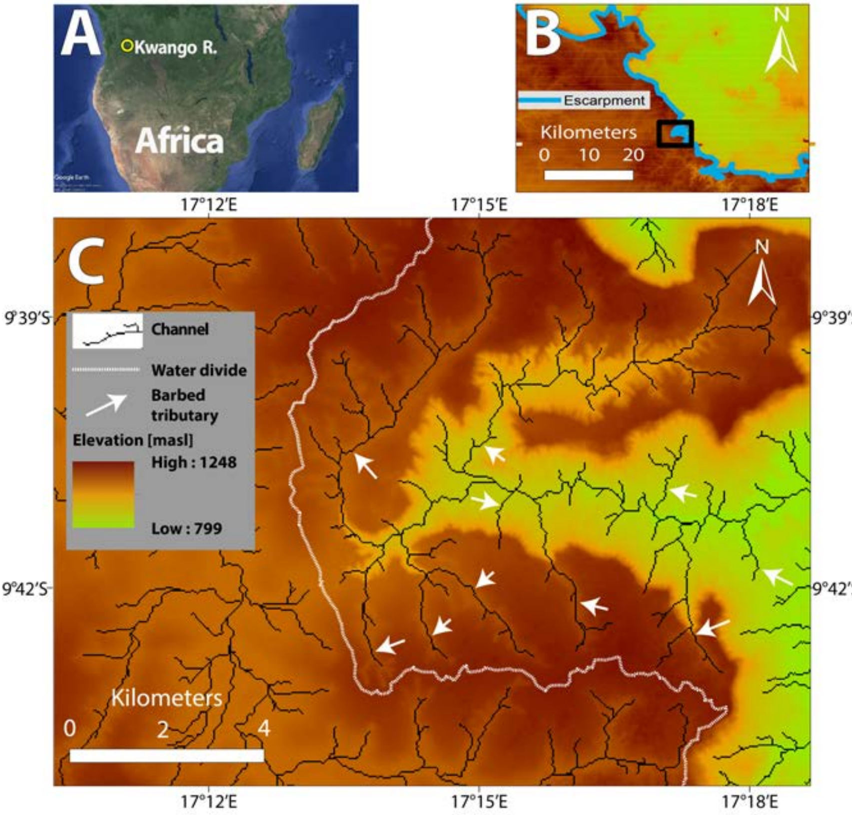
Before reversal occurs, these settings exhibit an inherent slope asymmetry across a water divide.

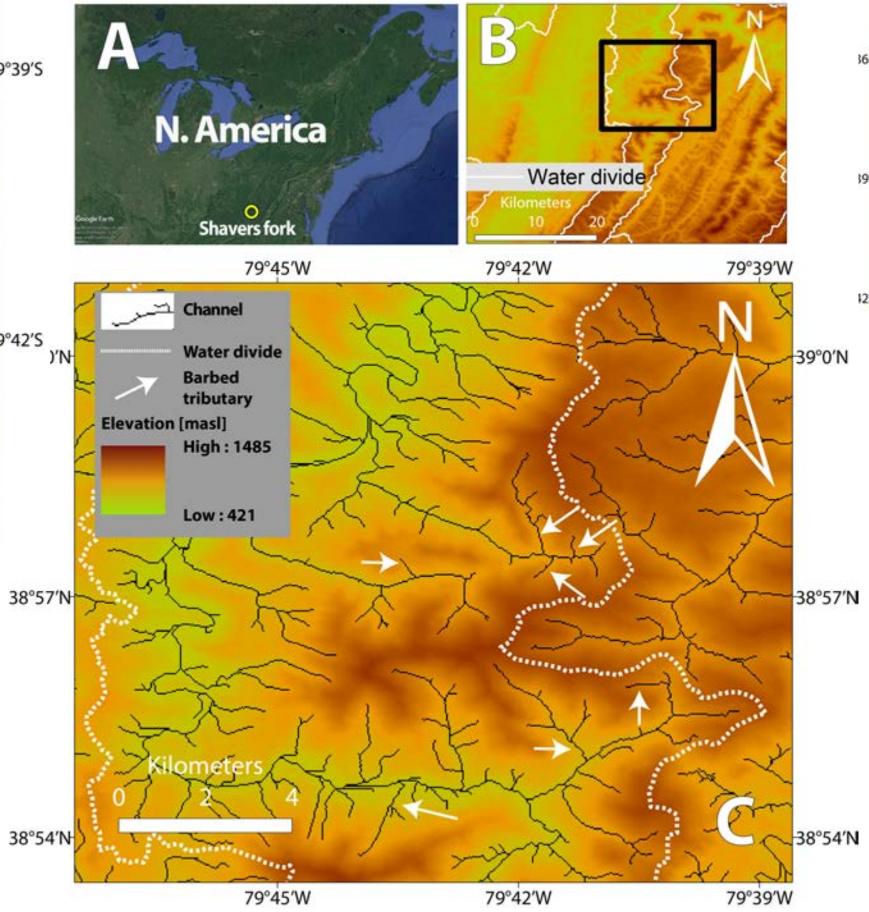
The cliff is steep and the oppositely grading highland side has a low relief.

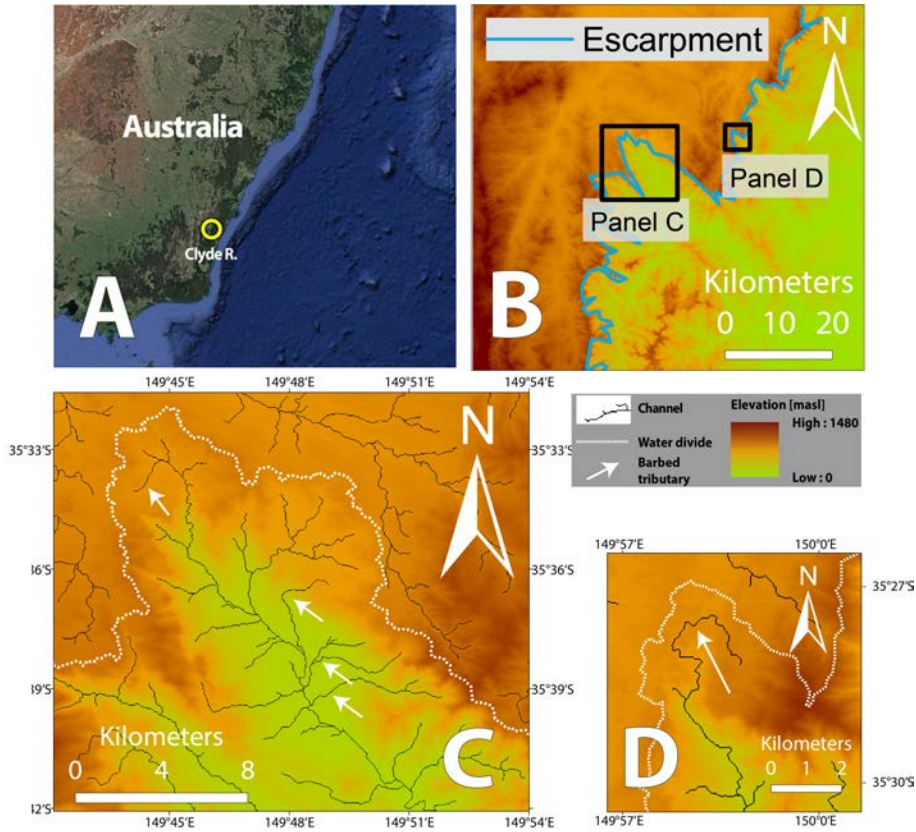


Reversal toward steep escarpments is a common observation

Here are some examples



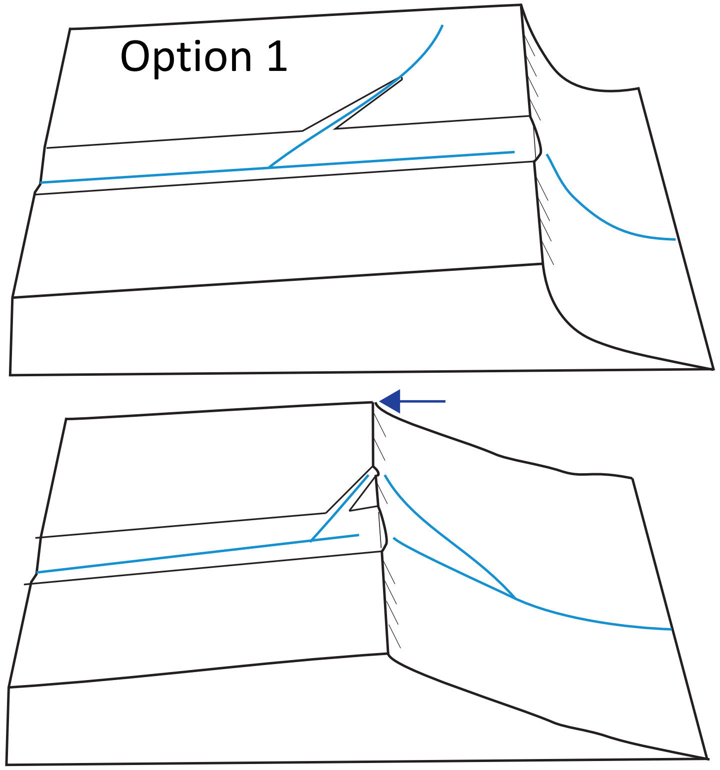




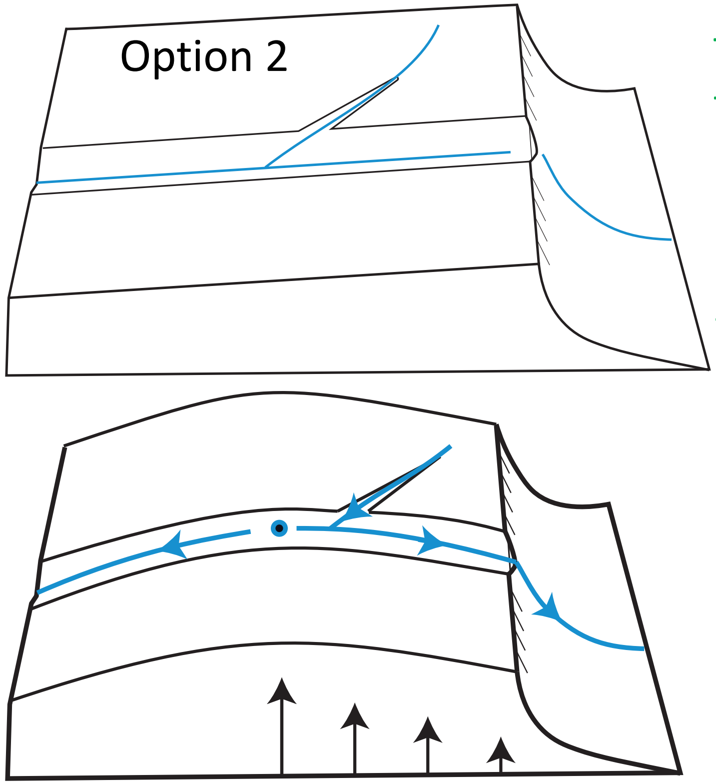
The problem of how reversal develops:

What are the processes and conditions that induce drainage reversal?

Existing models are not always consistent with observations.

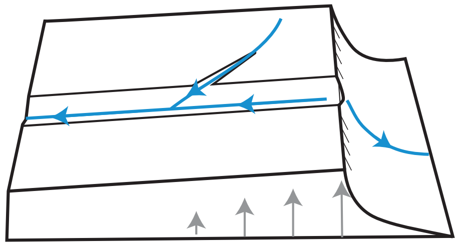


When the cliff and the divide retreat uniformly, the antecedent highland pattern cannot be preserved, and reversal cannot occur.



Tectonic/structural tilt toward the cliff could reverse the drainage. However:

1. Commonly, there is no independent evidence for a tilt; namely, tilt is inferred based on the identification of reversals. (A circular argument)
2. In great escarpments, isostatic adjustment to erosional unloading and the flexural response due to deep-rooted normal faults produce an opposite tilt toward the highlands and away from the cliff, so the tilt is expected to sustain the original flow direction and prevent reversals.

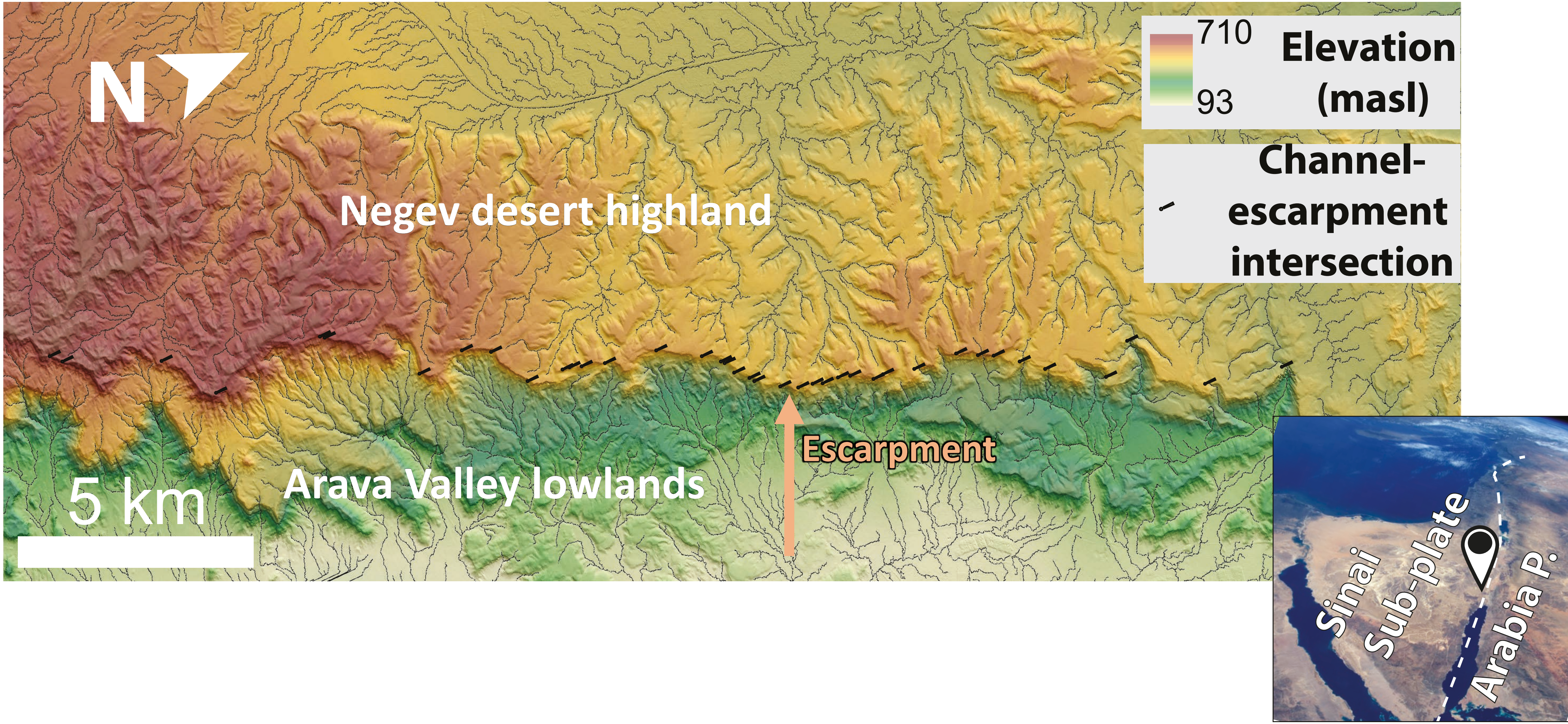


A general model to explain reversals is still missing. Coming up with such a model is the goal of this work.

Our field area

is located along the Arava escarpment that separates the Negev desert highland from the Arava Valley.

The escarpment is part of the Sinai-Arabia transtensional plate boundary.



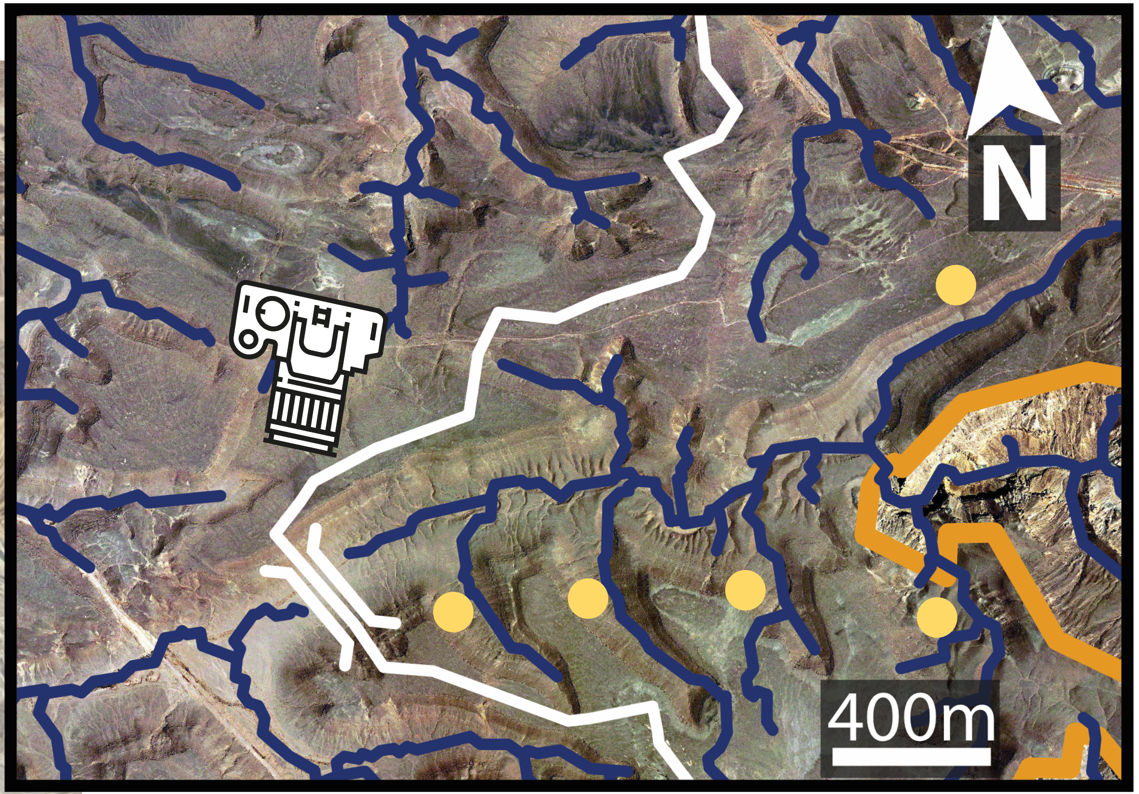
Identifying reversed drainages:

The main water divide deviates from the cliff and loops around channels.

We see:

1. Barbed tributaries

Wadi Grofit



Cliff

Barbed tributaries

Orientation of the photo in the next slide

Identifying reversed drainages:

The main water divide deviates from the cliff and loops around channels.

We see

2. Valley confined windgap

Wadi Itro N.

Identifying reversed drainages:

The main water divide deviates from the cliff and loops around channels.

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2. Valley confined windgap

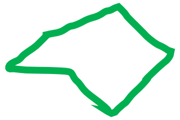
Identifying reversed drainages:

The main water divide deviates from the cliff and loops around channels.

We see:

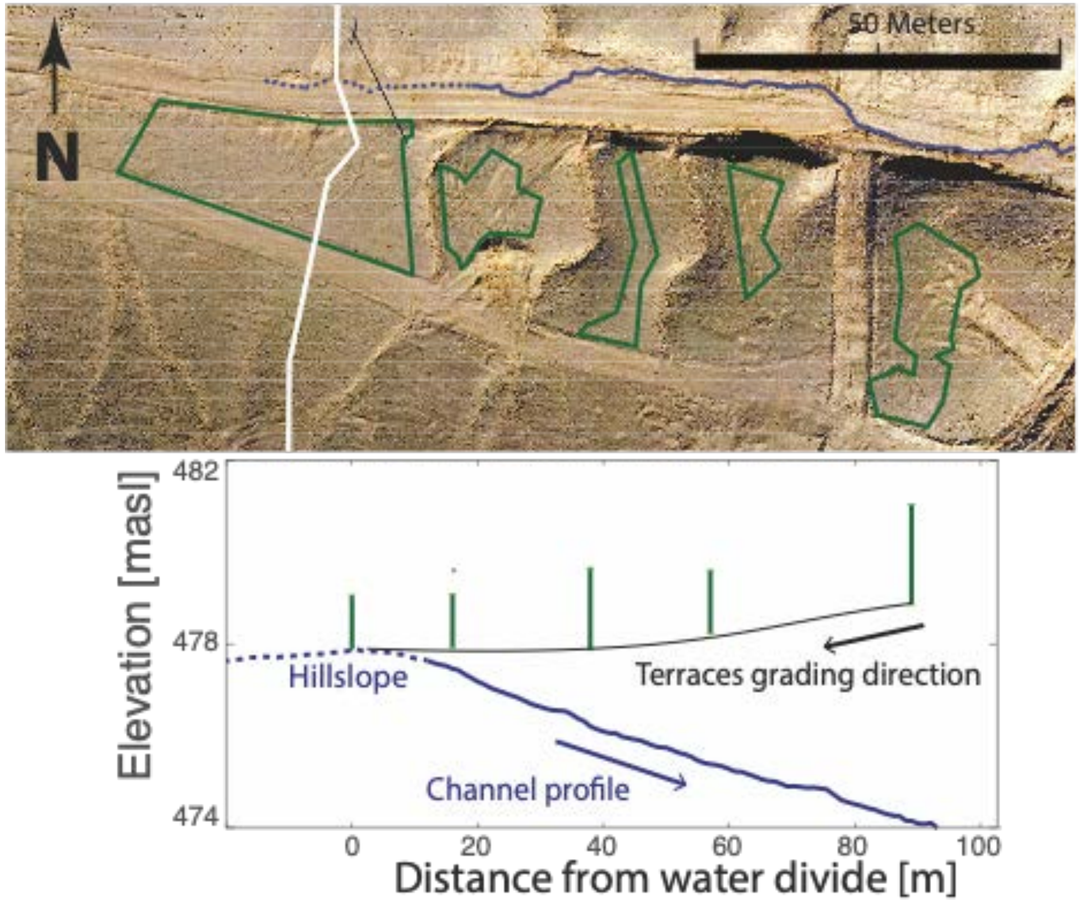
3. Terraces that grade opposite to the active channel drainage direction.

The terraces are interpreted as the channel bed of the antecedent valley.

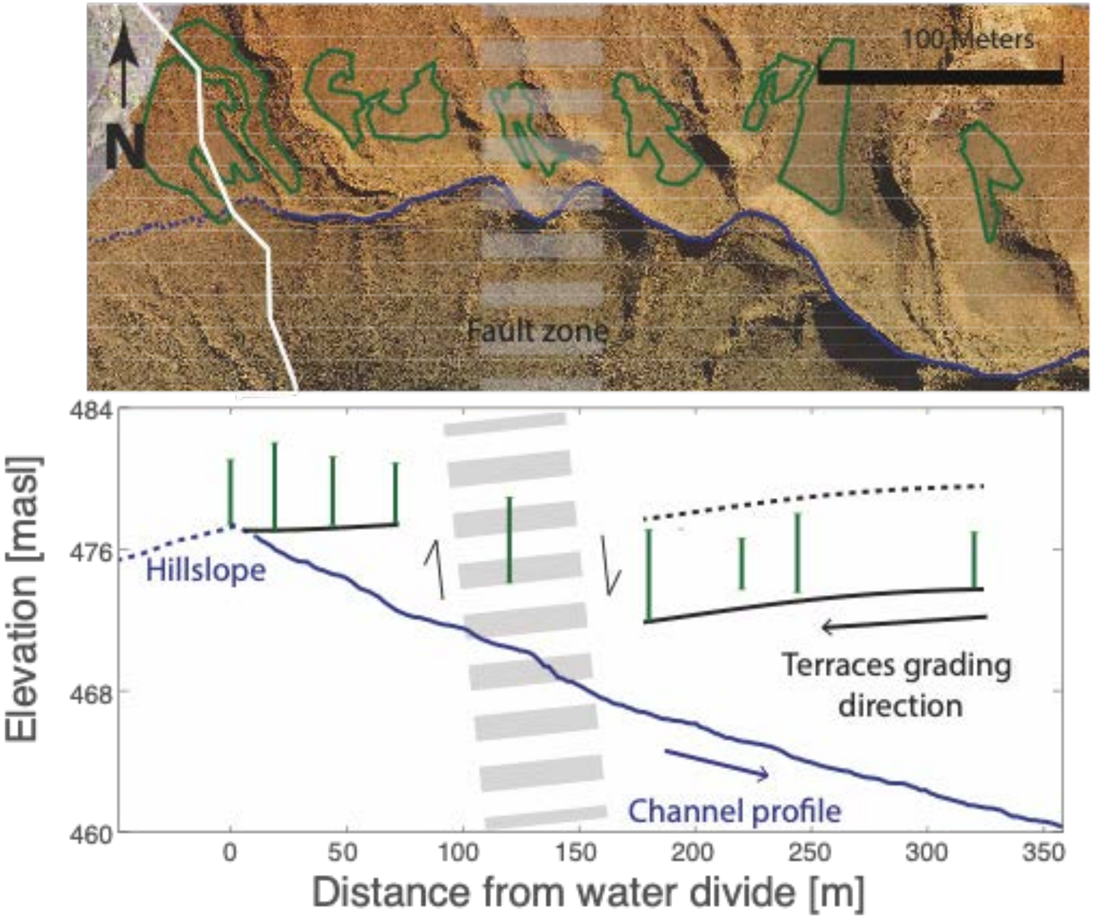


Green polygons are terraceses presrved in the antecedent valleys

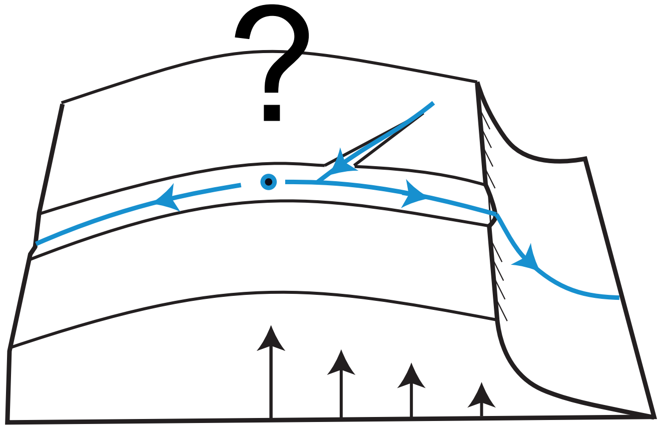
Wadi Shaharut

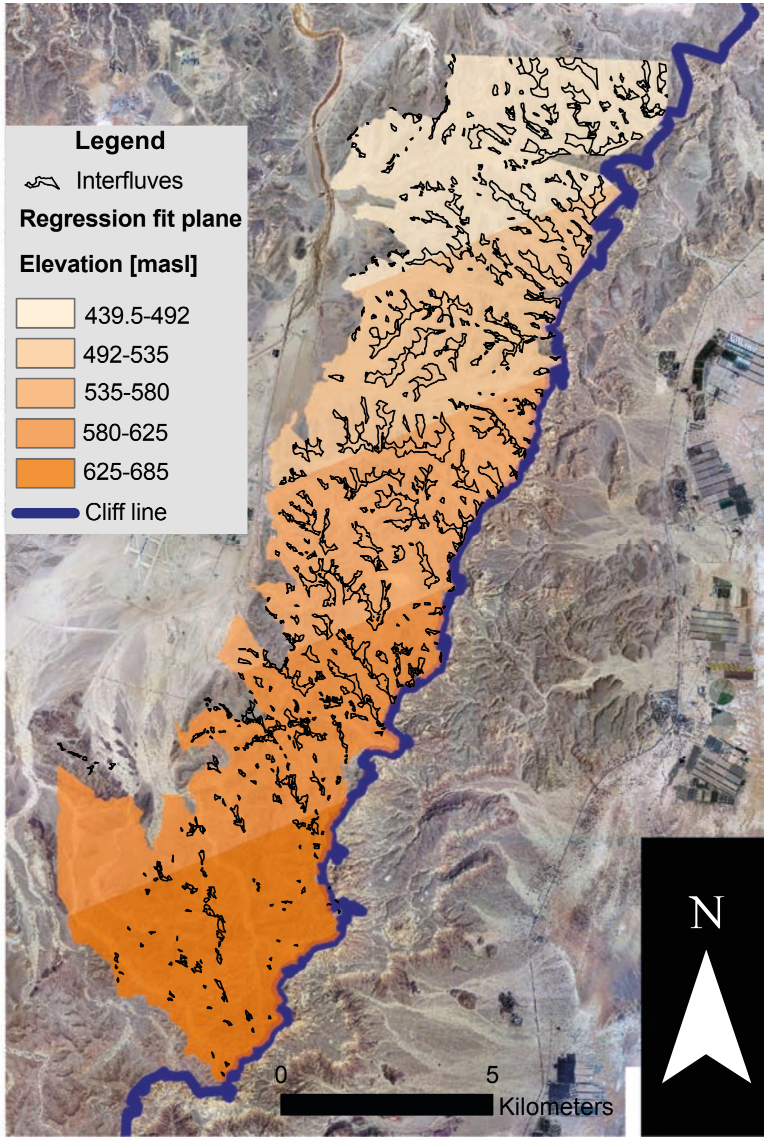


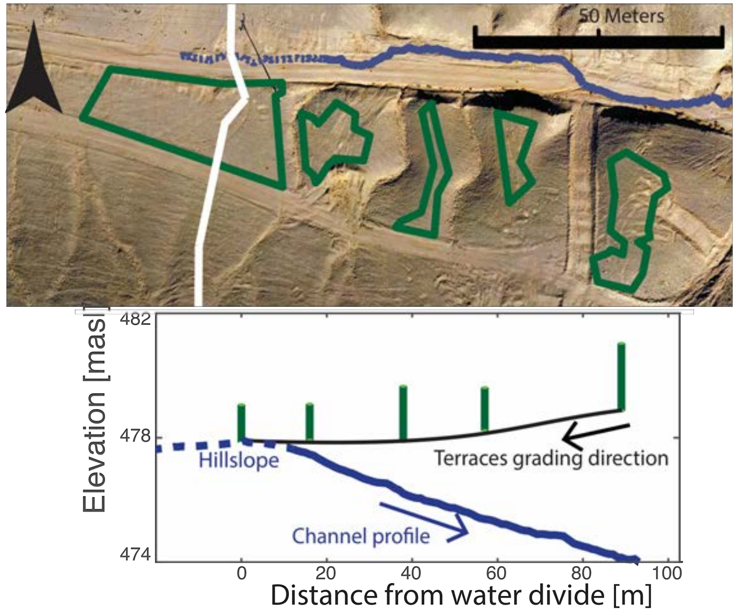
Wadi Itro N.



Could tectonic tilt toward the Arava escarpment explain the observed reversals?

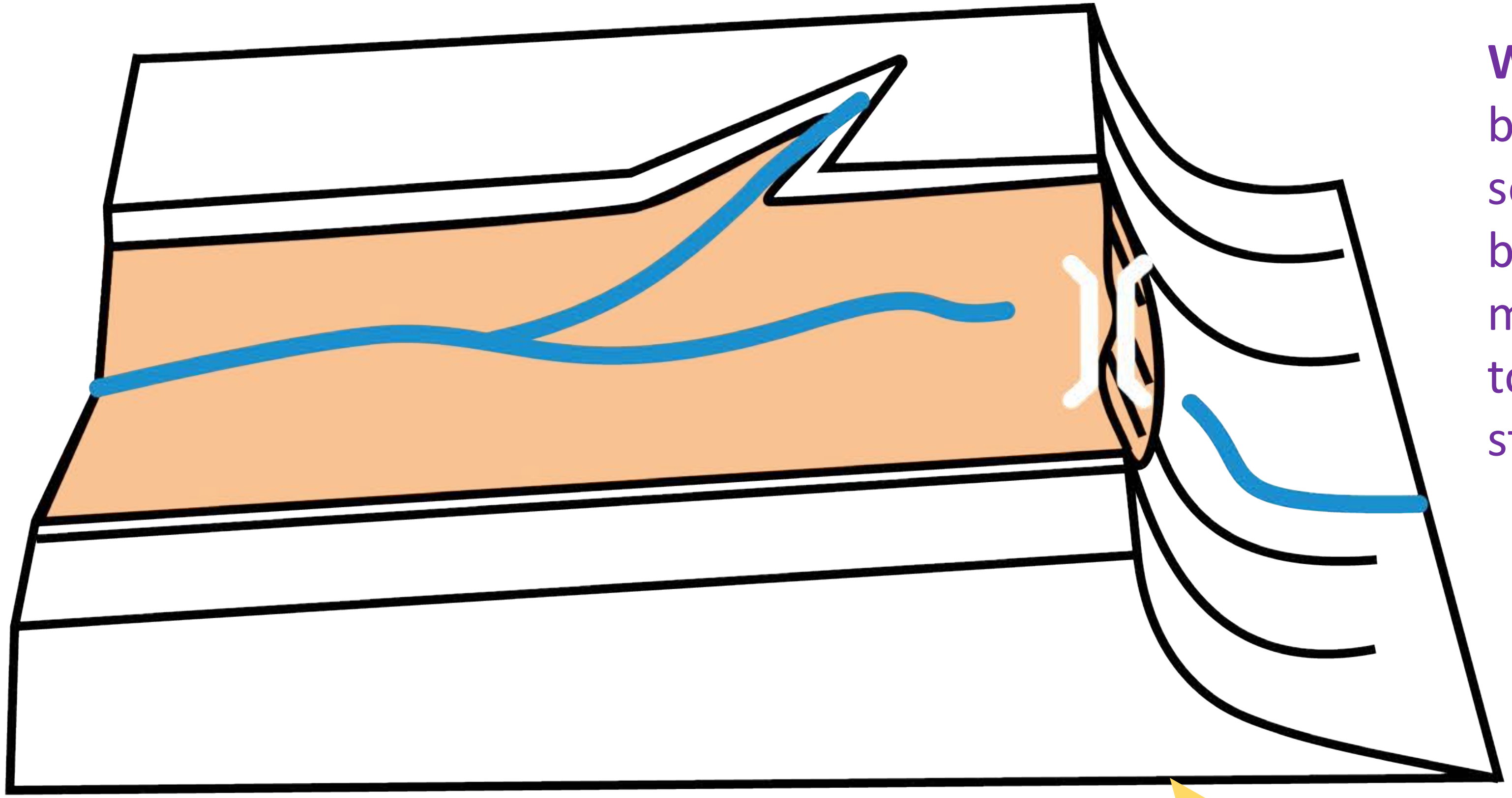






Not entirey:
The general grading of the highland is to the northwest and not to the east.

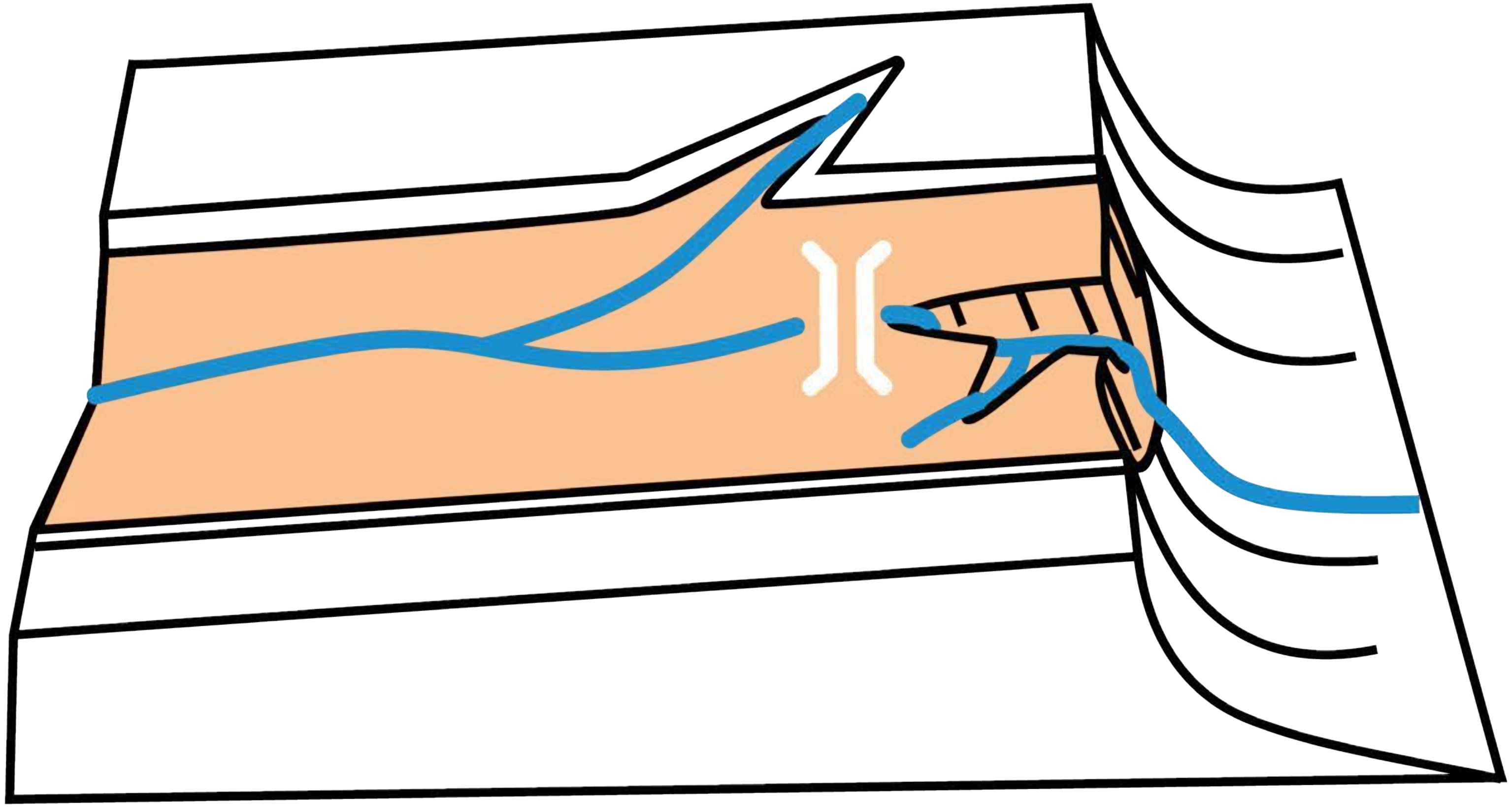
Not entirey:
Tectonic tilt, if applies, is not sufficient to reverse the gradeint of the terraces.



We propose a new reversal mechanism, based on differences in erodibility between soft sediments that fill the valley and hard bedrock interfluves. Under the new mechanism, the divide preferentially migrates toward the highland along paleo-valleys, but sticks to the cliff along the interfluves.

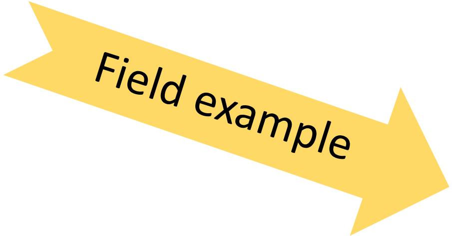
Stage 1:

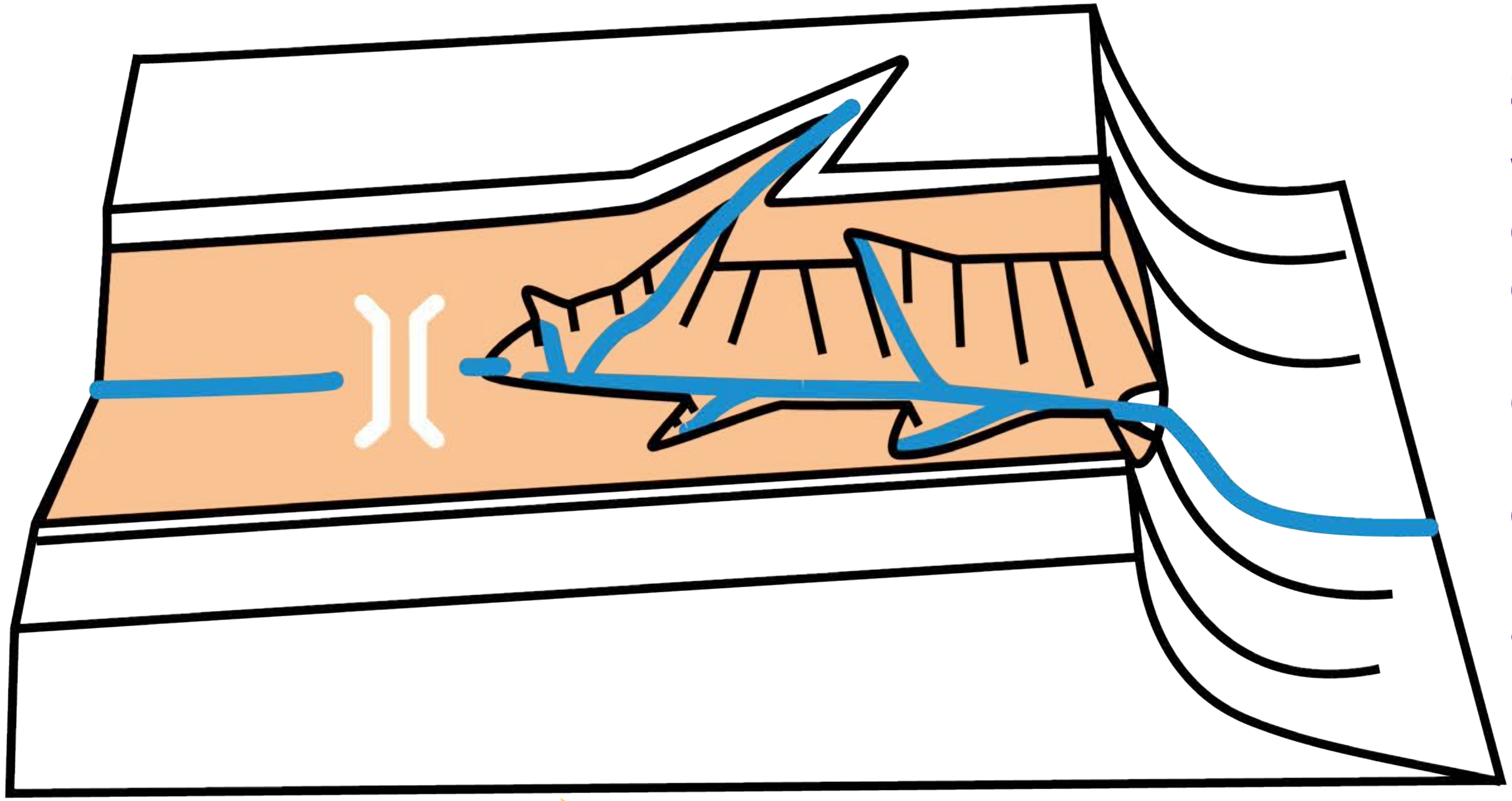
During cliff (escarpment) retreat, highland antecedent channels are truncated, and sediment-filled saddles form on the cliff. The source for valley fill may be relict fluvial sediments of the antecedent drainage or colluvium deposits from the local hillslope. The slope asymmetry between the two sides of the divide promotes hillslope processes that cause sediment transport of the erodible fill toward and down the cliff, and divide migration toward the highland.



Stage 2:

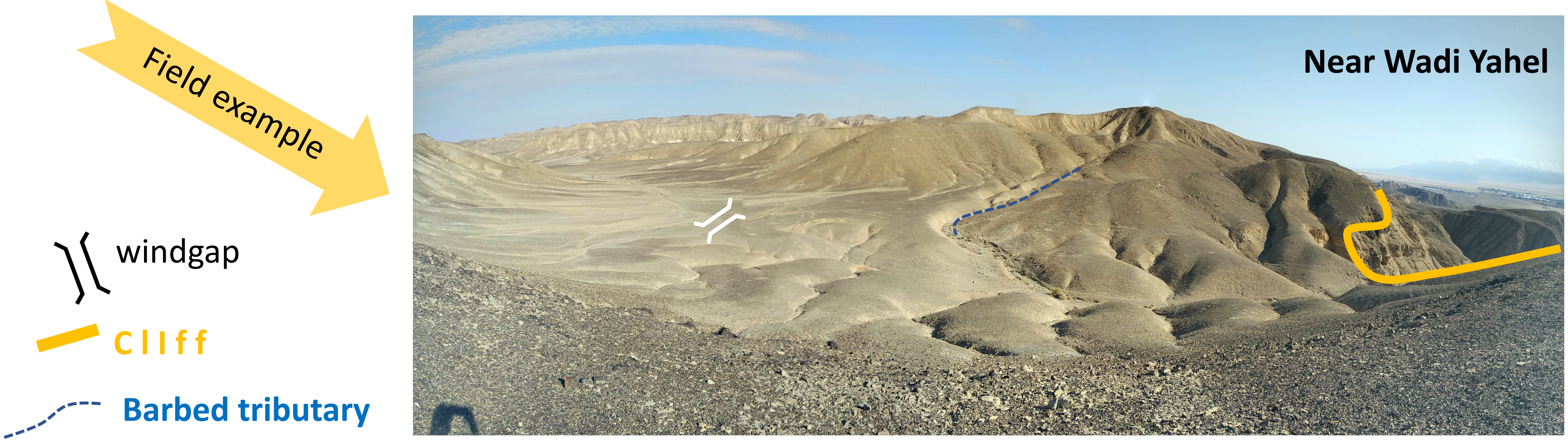
A reversed segment is formed within the antecedent valley, bounded between the migrating divide and a waterfall that crosses the cliff. The fluvial incision within the erodible fill preserves the slope asymmetry across the migrating divide and promotes further migration.

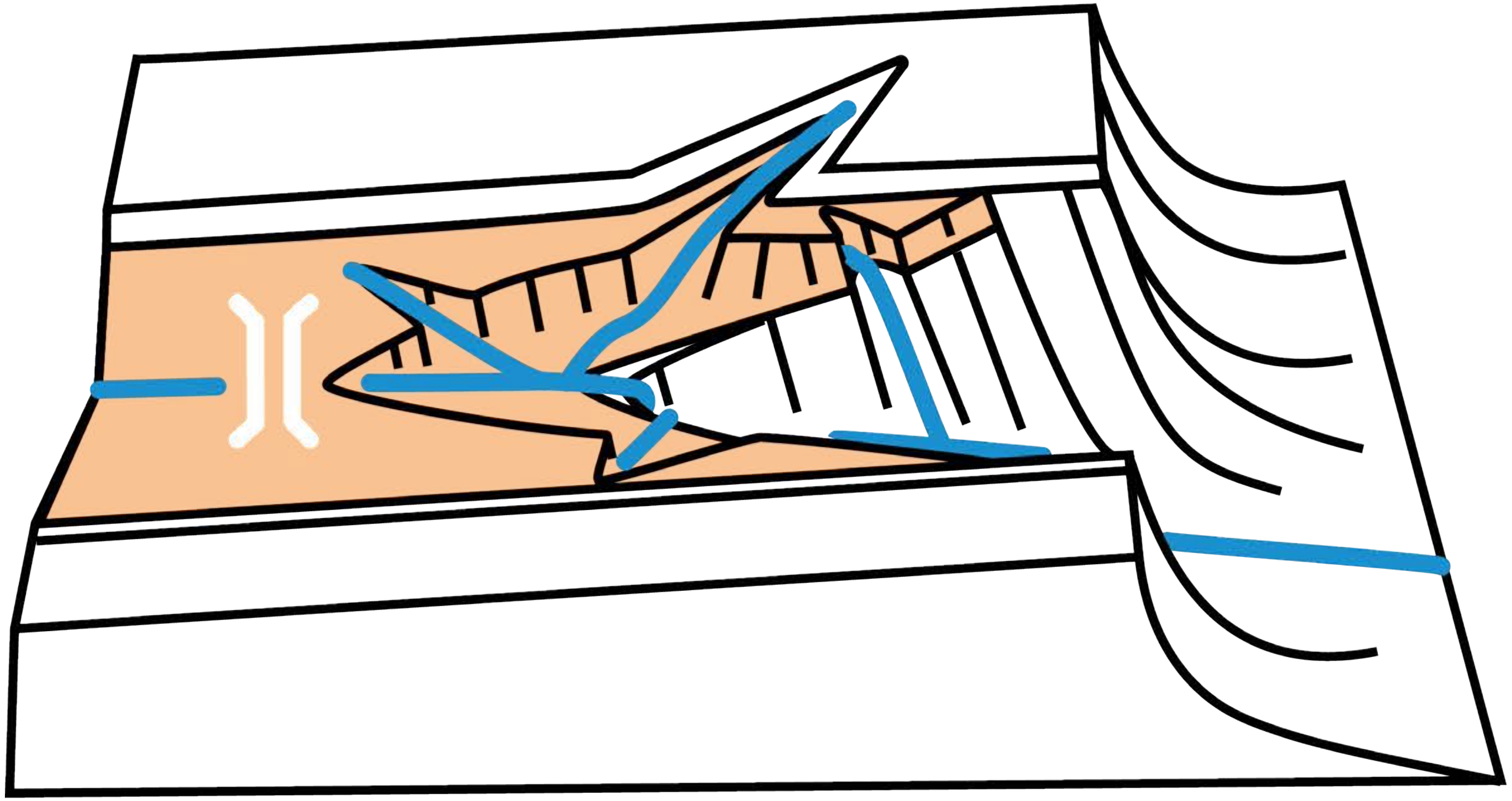




Stage 3:

When the divide transverses a tributary confluence, the tributary joins the reversed channel and forms a barbed morphology. The barbed tributary is captured toward the new drainage direction, and it significantly increases the discharge along the reversed channel segment, potentially allowing rapid incision and maintaining the slope asymmetry across the divide.





Stage 4:

As divide migration continues along the valley, the enhanced discharge of the reversed basin causes the waterfall to retreat and to embay the cliff.

Field example

windgap

Cliff

Barbed tributary

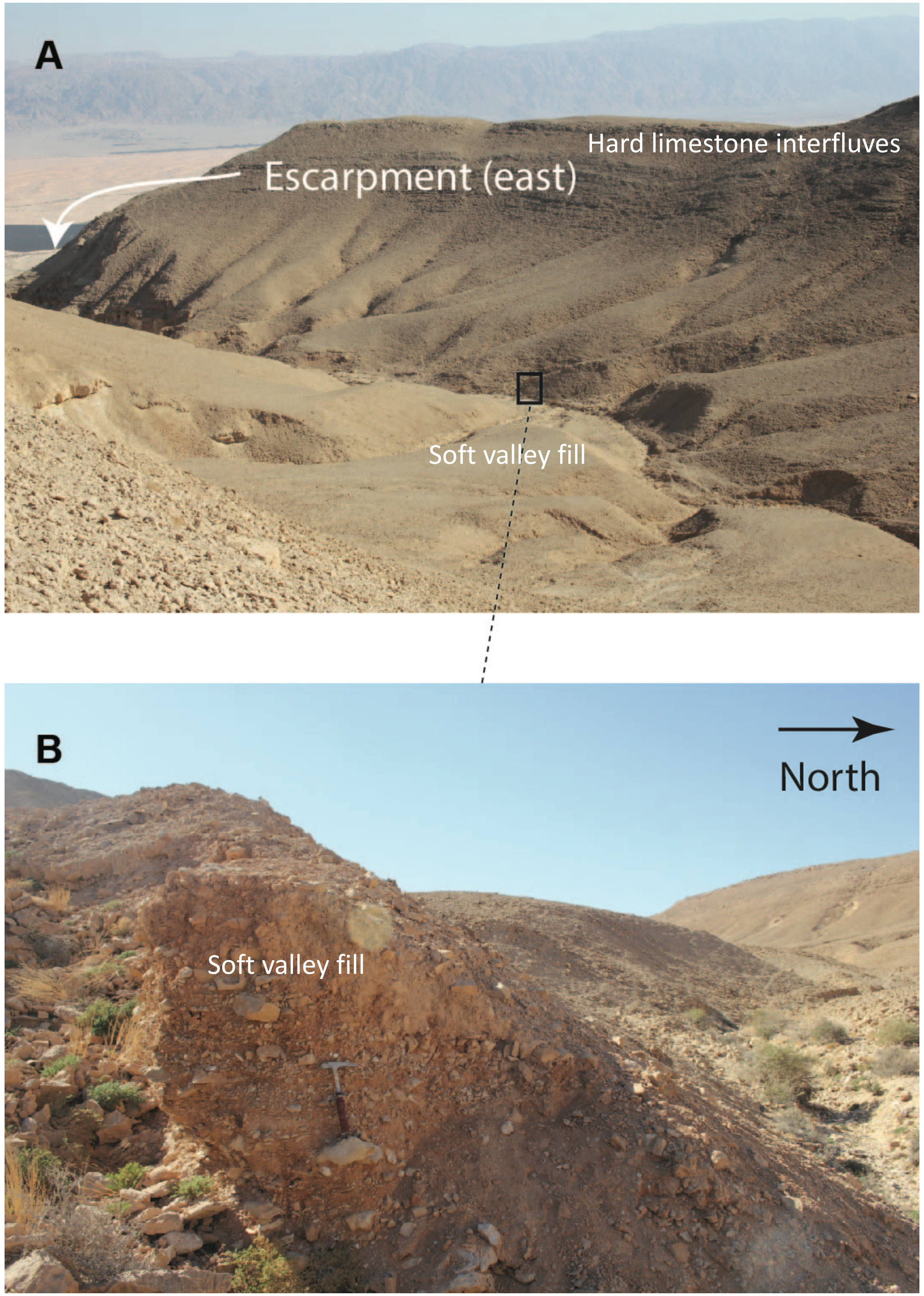
To test the applicability of the preferential divide migration mechanism in our field area, we extract two predictions from the model, and we test whether they apply to our setting.

Prediction 1:
Preconditions for the preferential migration mechanism are:
- Extreme slope asymmetry across the divide.
- Erodibility differences: erodible valley fill and hard bedrock interfluves.

✓

Extreme slope asymmetry across divides is the defining characteristic of shoulder-type escarpments and cliffs.
Extreme slope asymmetry is widespread in the Arava escarpment.

The reversed channels in our field area incise into erodible valley fill made of colluvial-alluvial sediments. These could be the alluvial sediments of the antecedent, larger basin that existed before the truncation by escarpment retreat, and/or colluvial sediments that accumulated from hillslope erosion that could not be evacuated due to reduction in transport capacity, stemming from the loss of drainage area due to this truncation.



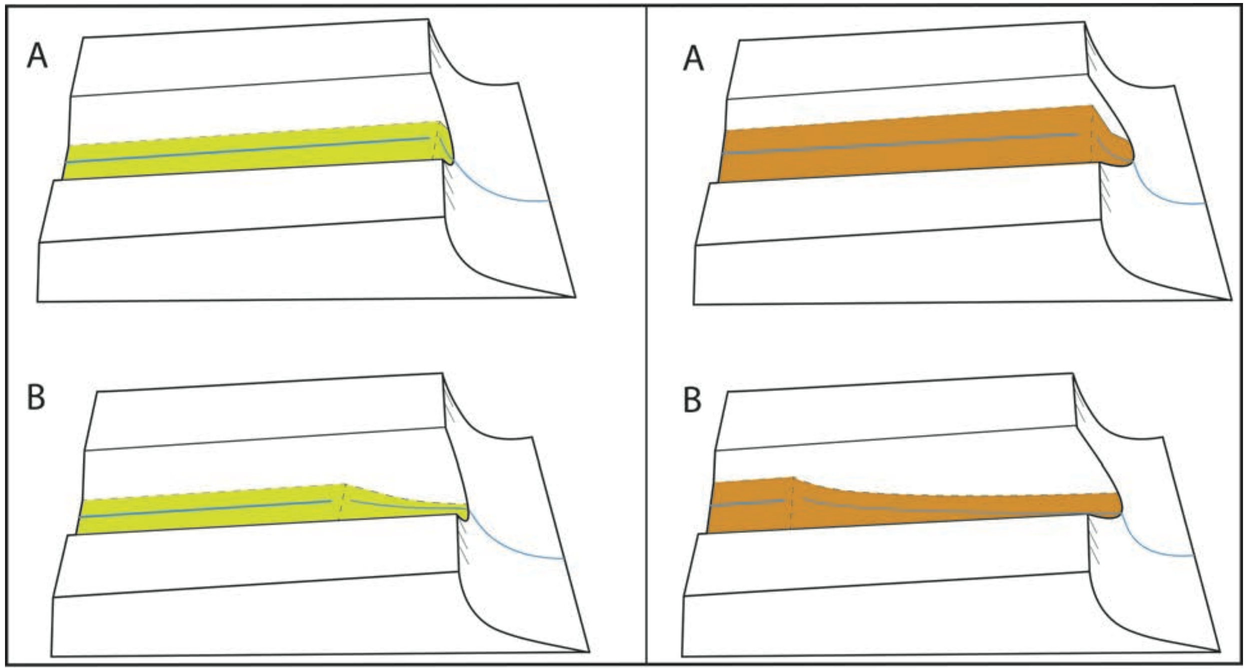
To test the applicability of the preferential divide migration mechanism in our field area, we extract two predictions from the model, and we test whether they apply to our setting.

Prediction 2:

The thicker the fill, the longer should be the reversed segment.

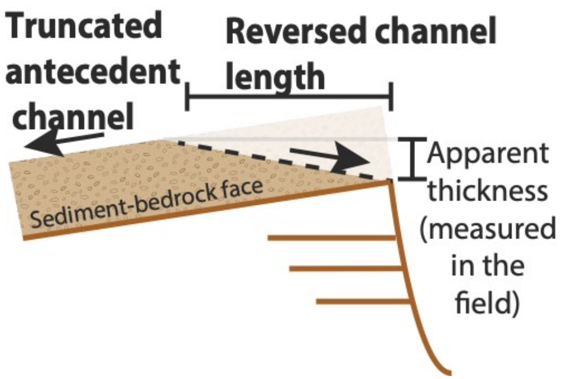
Thin fill → short reversed segment

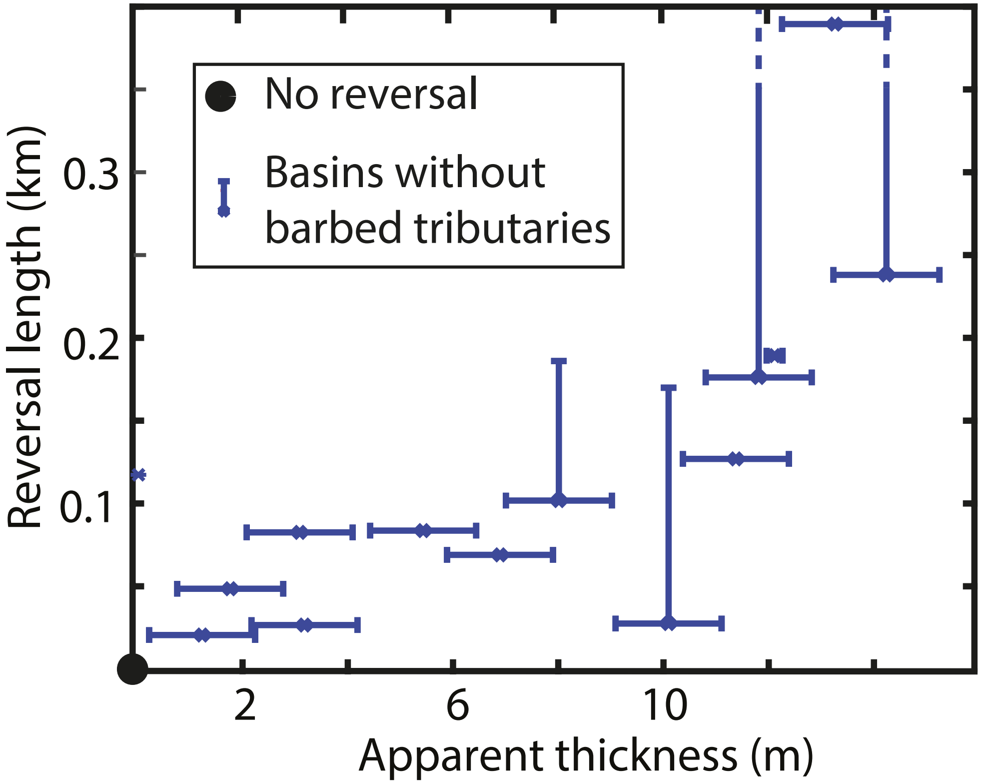
Thick fill → long reversed segment



✔

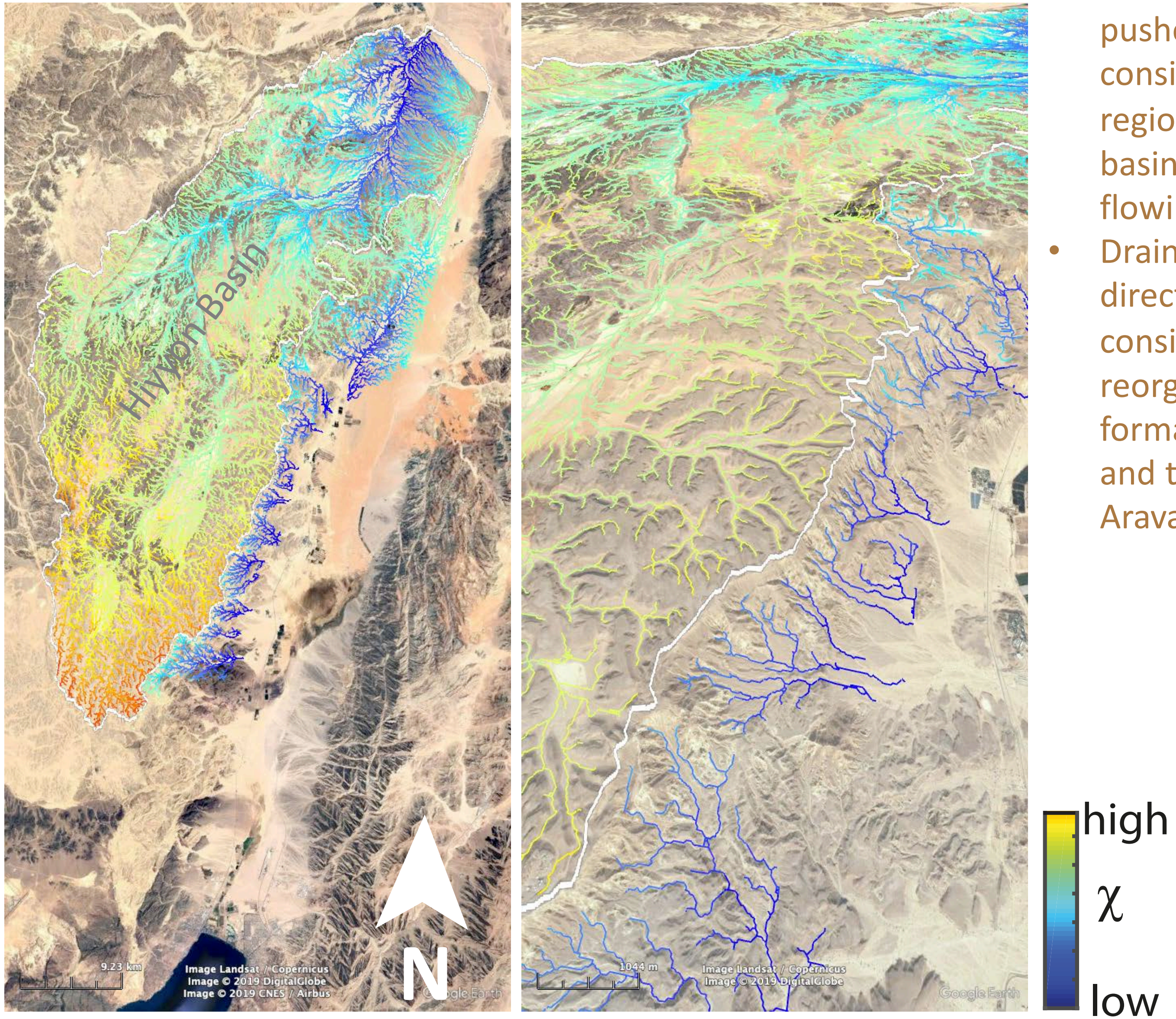
We measure a positive correlation between the thickness of the erodible sediment fill and the length of the reversed segment between the windgap and the cliff.





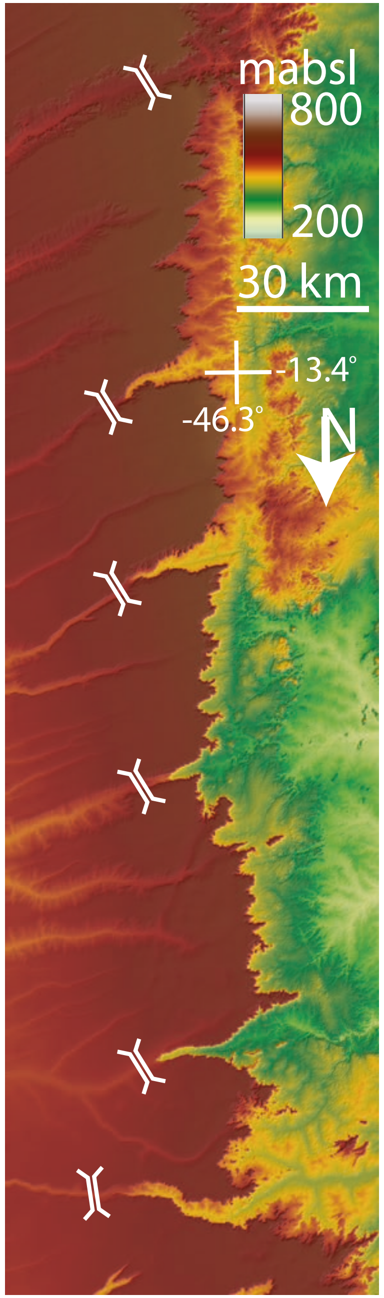
Regional landscape evolution implications

χ map of the southwestern Arava escarpment



- In the Arava escarpment, drainage reversal pushes the main water divide westward, consistent with the predictions of local and regional χ maps, which show that east-flowing basins should grow at the expense of west-flowing basins.
- Drainage area increase in basins that drain directly to the Arava Valley (eastward) is consistent with the general trend of drainage reorganization in response to the Miocenic formation of the Arabia-Sinai plate boundary and the introduction of a new base level – the Arava Valley.

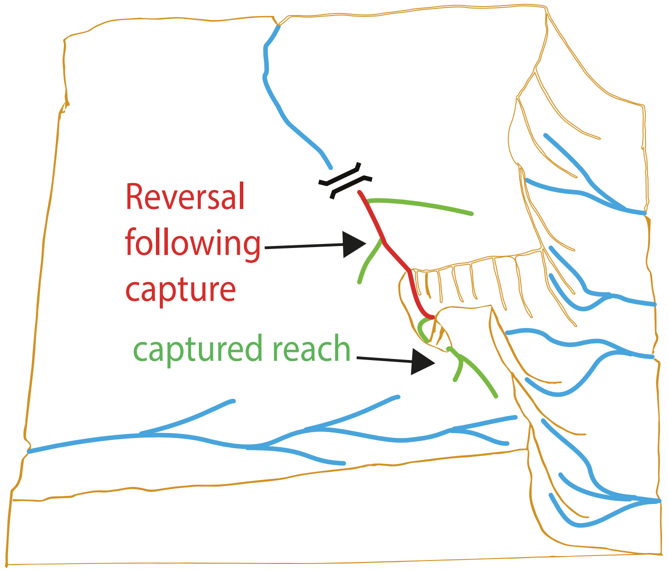
The brazilian example



- Drainage reversals change the discharge, sediment flux, and erosive power across escarpments, and could alter the dominant escarpment retreat mechanism from cliff retreat to fluvial knickpoint retreat. This means that reversals control the long term evolution of escarpments and explain the extreme variability in escarpment preservation and morphology, i.e., increased sinuosity of the cliff.

Implications for landscape evolution

- A waterfall in a river profile that includes a highland reversed segment could be wrongly interpreted to mark a change in uplift rate. It is, therefore, critical to identify the reversed segment as a signature of local reorganization.
- Our mechanism is also applicable to reversals following capture events. When a highland channel is captured to flow across a cliff, extreme slope asymmetry forms between the cliff and the antecedent valley. **Initially, the divide coincides with the cliff.** The head of the antecedent valley, just downstream of the capture point, is likely filled with erodible sediments without the capacity to transport them, potentially promoting reversal toward the cliff and migration of the divide away from the cliff. **The cliff and the divide do not coincide any more.**



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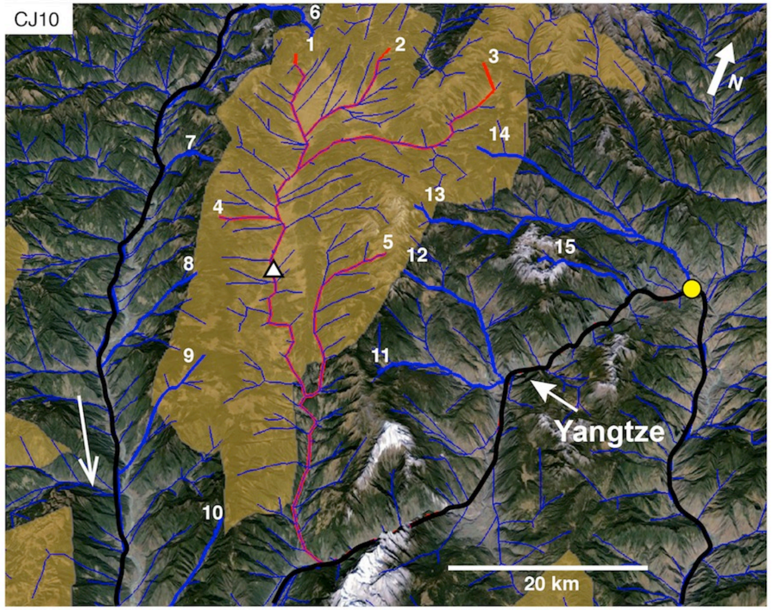

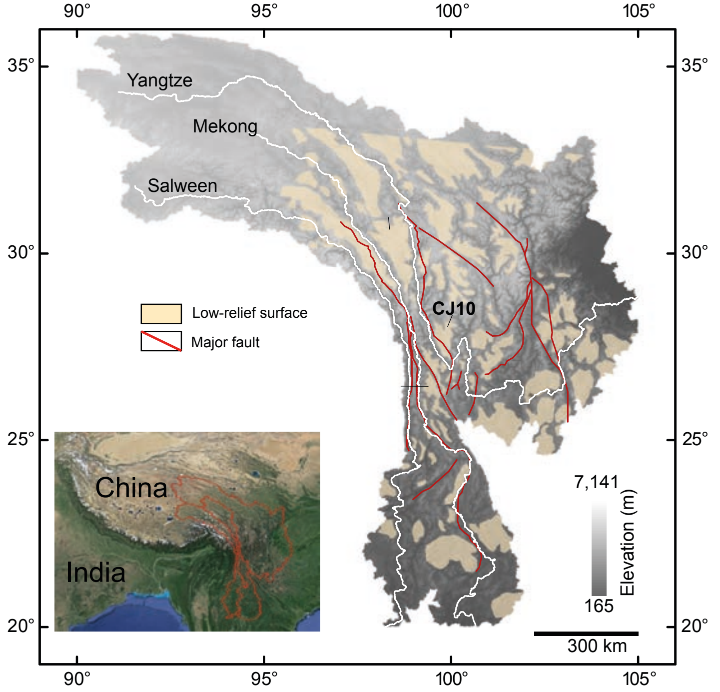

(Yang et al. 2015)

The coincident between divide and cliff has been used as important evidence in a recent discussion about the formation of low-relief high-elevation surfaces.

Two models were proposed:

1. Preservation - Antecedent low relief surface is being uplifted by tectonic forces. River profile shows a migrating knickpoint (a cliff). The divide is at the head of the antecedent river and far away from the cliff. Namely, divide and cliff are not coincident. (i.e., rivers 9 and 14 in the figure above) (Clark et al. 2006, Whipple et al. 2017)
2. Piracy – Simultaneous cliff and divide retreat and capture events decrease drainage area in victim basins. As a result, erosive power and transport capacity reduce, leading to dynamic flattening of the victim basins. Here, the divide and the cliff are assumed to coincide. (rest of blue rivers above) (Yang et al. 2015, Willett 2017)

Our reversal mechanism shows that following cliff retreat or capture, the divide can be pushed toward the highland, such that the cliff and the divide are not coincident anymore.

This means that the coincident between cliff and divide should not necessarily be used as a decisive observation to differentiate between the two models.

Summary

- Flow reversal toward cliffs and escarpments is a common phenomenon.
- The processes that induce flow reversal are not trivial.
- We propose that preferential divide migration within antecedent valleys can induce reversals.
- It requires extreme slope imbalance across a divide (as occurs in cliffs and shoulder-type escarpments), and lateral lithologic differences: erodible lithology within the channel and harder rocks in the interfluves.
- New reversal mechanism means that a relatively thin layer of soft valley fill can tip the fluvial system toward a drastic drainage change, influencing large scale patterns of escarpments morphology and evolution

Dear Fellow Reorganization Hunter,

Do you know of drainage reversals that agree or disagree with the model we propose?

Are you willing to share their location with us?

Please leave a comment or email us at: gorenl@bgu.ac.il