

MEASURABLE IMPACT OF RIVER INCISION ON RIFT TECTONICS

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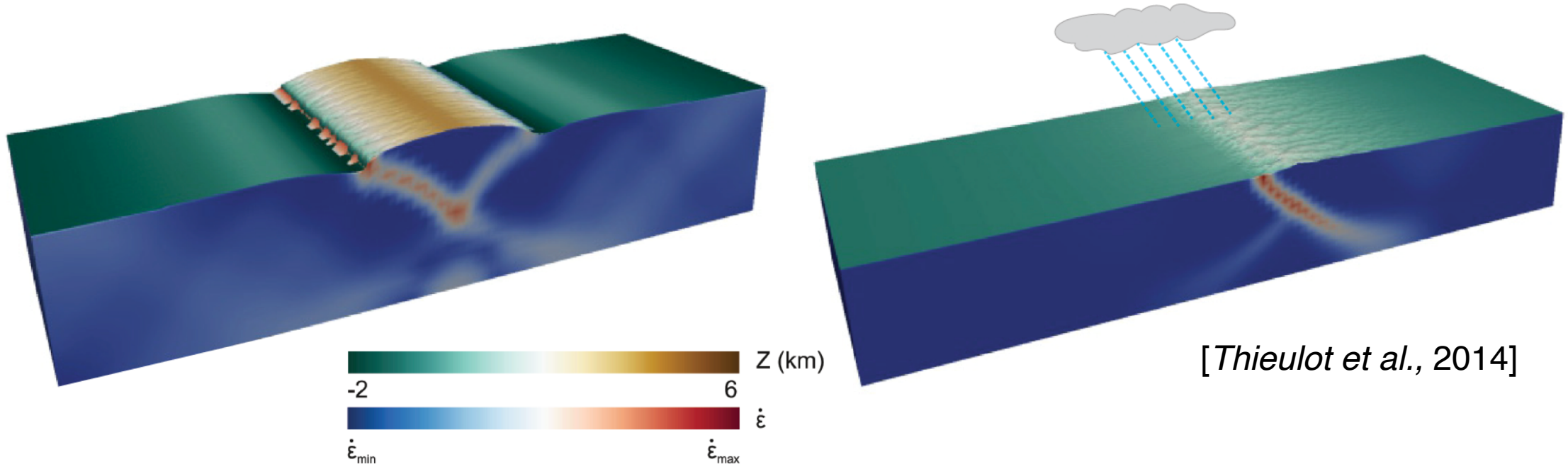
Luca Malatesta[2], Mark Behn[3], and Roger Buck[4]

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SURFACE PROCESSES PROMOTE STRAIN LOCALIZATION

Most tectonic models agree:



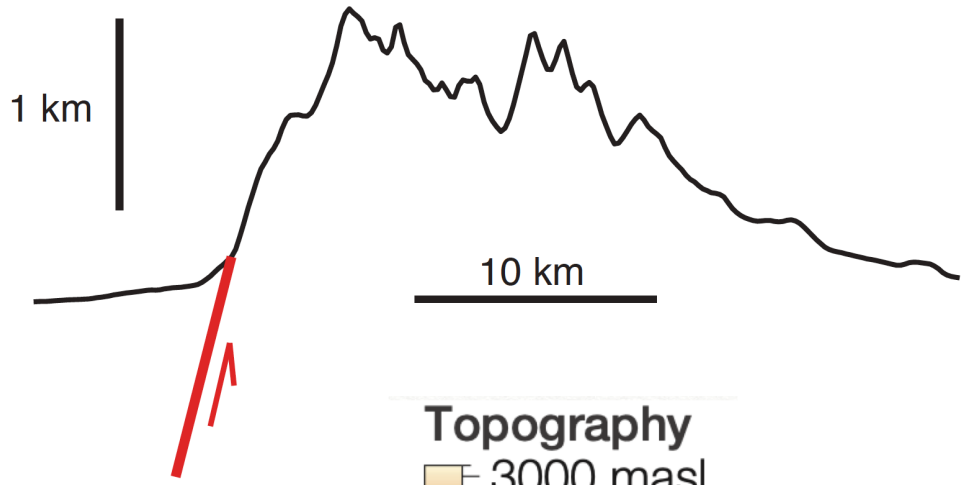
[*Thieulot et al.*, 2014]

- How **efficient** do surface processes need to be to impact tectonic evolution?
- What is a **realistic range** of river erosion efficiency?
- Can we find evidence for a modulation of tectonic evolution by erosion **in real systems**?

HALF-GRABENS AS NATURAL LABORATORIES

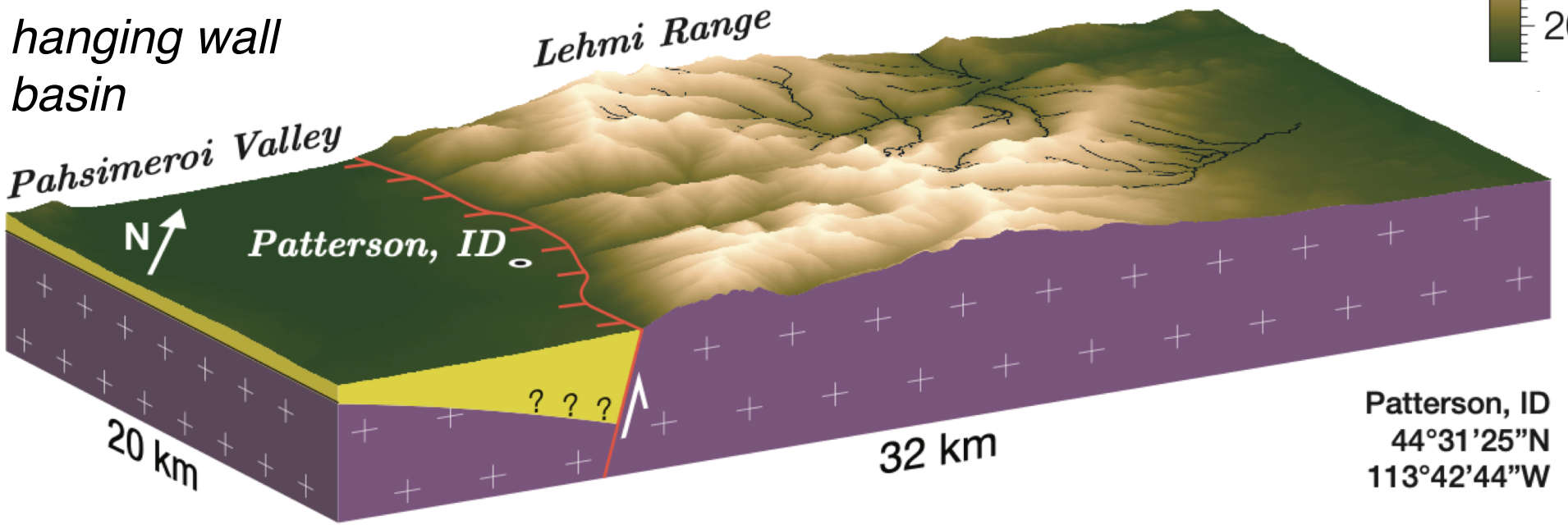
<u>All the key ingredients within 10s of km</u>:

- Strain localized on a master fault,
  until new fault cuts hanging wall or footwall.
- Up- and down-warping of the faulted blocks.
- Topography build-up vs. surface processes:



rivers incise footwall range

sediments fill hanging wall basin



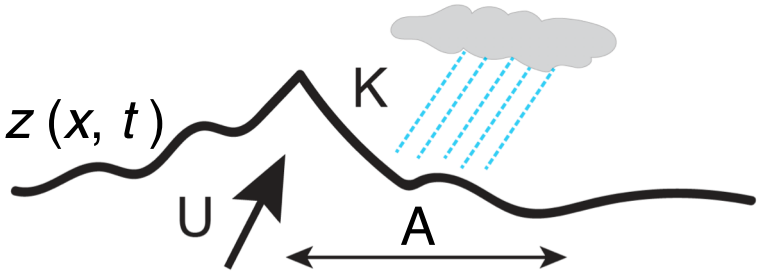
Lemhi Range, Basin & Range, Idaho USA

Patterson, ID
44°31'25"N
113°42'44"W

MODELING RIVER EROSION

Change in local elevation =

$$\frac{\partial z\,(x,t)}{\partial t} = \boxed{U\,(x,t)} - \underbrace{K\,(x,t)\,A^m\,(x,t)\,S^n\,(x,t)}$$



Tectonic uplift

Local incision rate *(faster for steeper slope **S**, with more water flowing)*
Parameters:
- erodibility (**K**)
- drainage area (**A**)
- exponents (**m**, **n**)

At steady state:

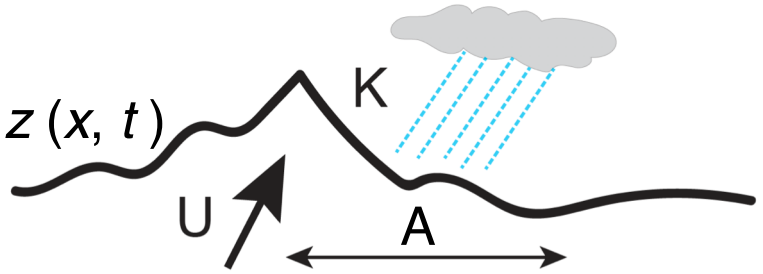
$$\left|\frac{\partial z\,(x)}{\partial x}\right| = \left(\frac{U\,(x)}{K\,(x)\,A^m\,(x)}\right)^{\frac{1}{n}}$$

$$z\,(x) = z_b + \int_{x_b}^{x} \left(\frac{U\,(x)}{K\,(x)\,A^m\,(x)}\right)^{\frac{1}{n}} dx$$

Can we calibrate these coefficients against real landscapes?

QUANTIFYING THE EFFICIENCY OF RIVER EROSION

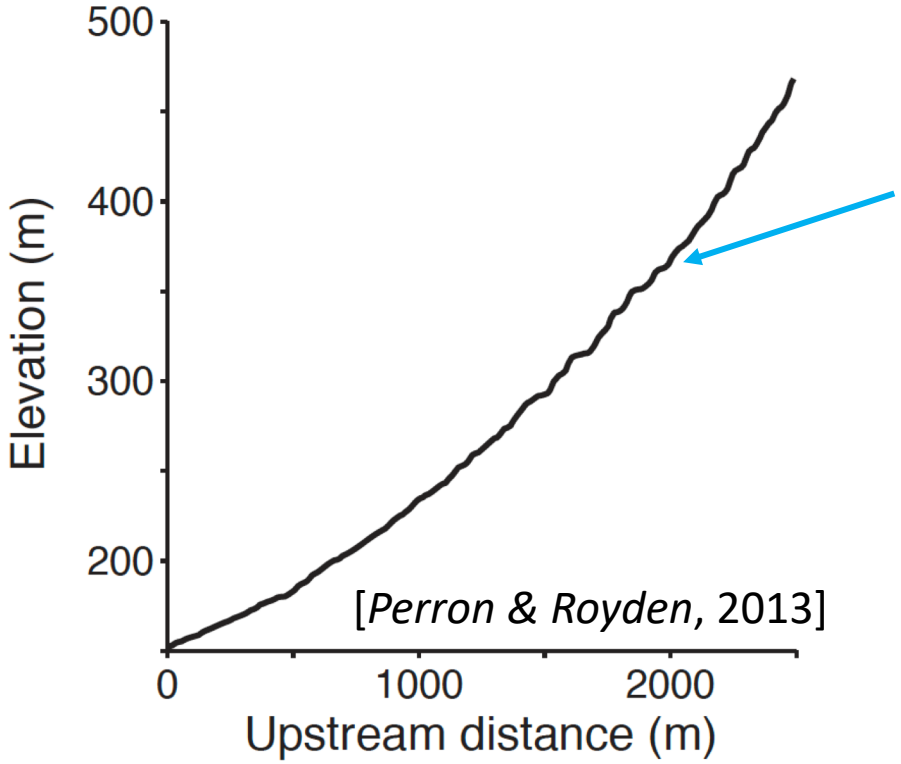
Equilibrium river profile



At steady state:

$$\left|\frac{\partial z\,(x)}{\partial x}\right| = \left(\frac{U\,(x)}{K\,(x)\,A^{m}\,(x)}\right)^{\frac{1}{n}}$$

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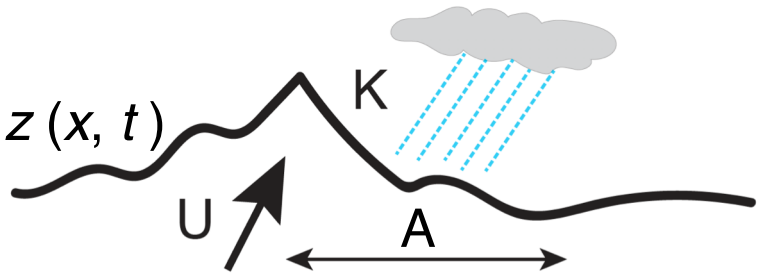
Contains information on the efficiency of erosion relative to tectonic uplift

River concavity reflects:

- **Upstream decrease in drainage area**
- **Shape of uplift function**
- Spatially-variable erodibility

QUANTIFYING THE EFFICIENCY OF RIVER EROSION

Equilibrium river profile



Assume:

$$A(x) = A_0 A^*(x) \qquad U(x) = U_0 U^*(x)$$

Constant $K = K_0$ *known uplift "shape"*

Define upstream distance corrected for changes in drainage area and uplift rate:

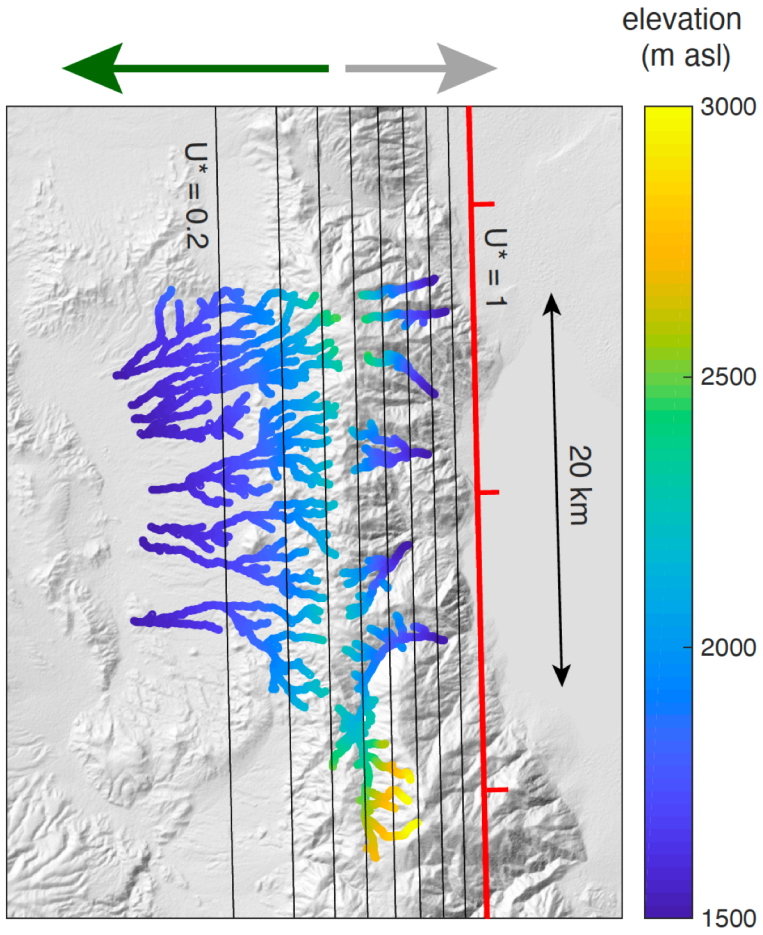
$$z(x) = z_b + \left(\frac{U_0}{K_0 A_0^m}\right)^{\frac{1}{n}} \underbrace{\int_{x_b}^{x} \left(\frac{A_0 U^*(x)}{A^*(x)}\right)^{\frac{m}{n}} dx}_{\chi_U}$$

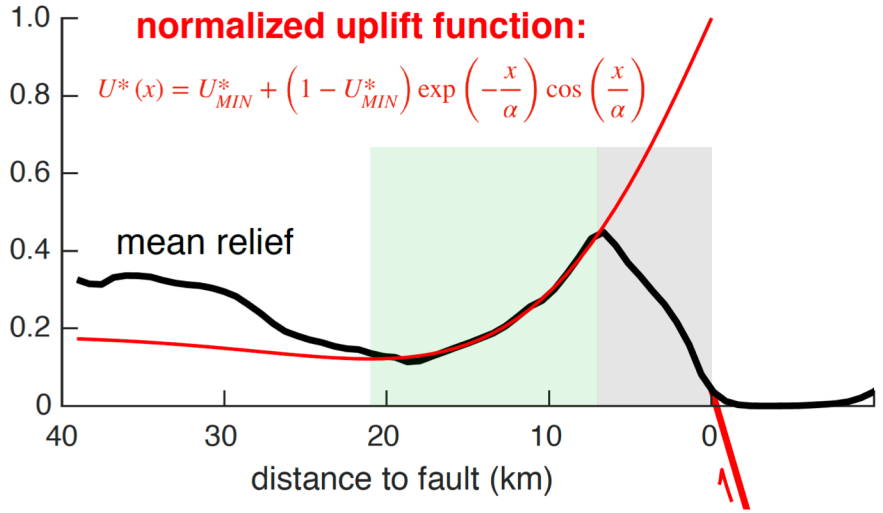
Plots of river elevation vs. **corrected upstream distance** have slopes equal to 1 / **dimensionless erosional efficiency** *EE*:

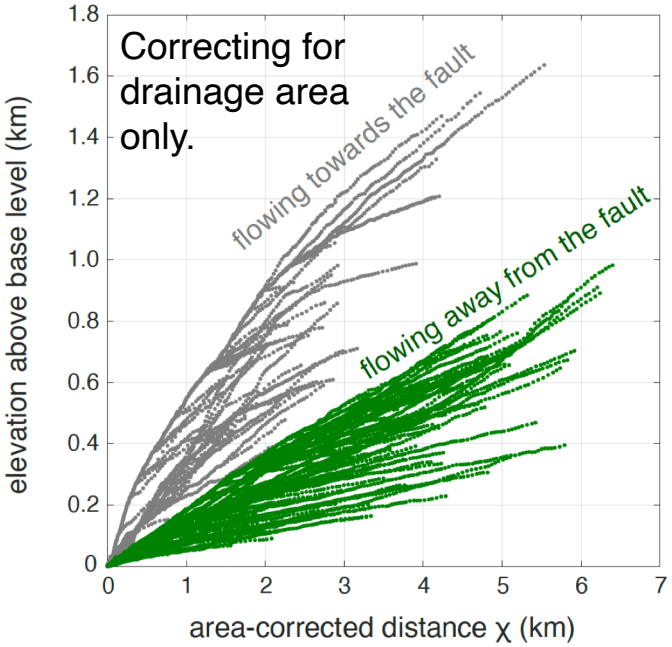
$$EE = \left(\frac{K_0 A_0^m}{U_0}\right)^{\frac{1}{n}}$$

APPLICATION TO THE WASSUK HALF-GRABEN (NV, USA)

Target rivers flowing away from master fault:

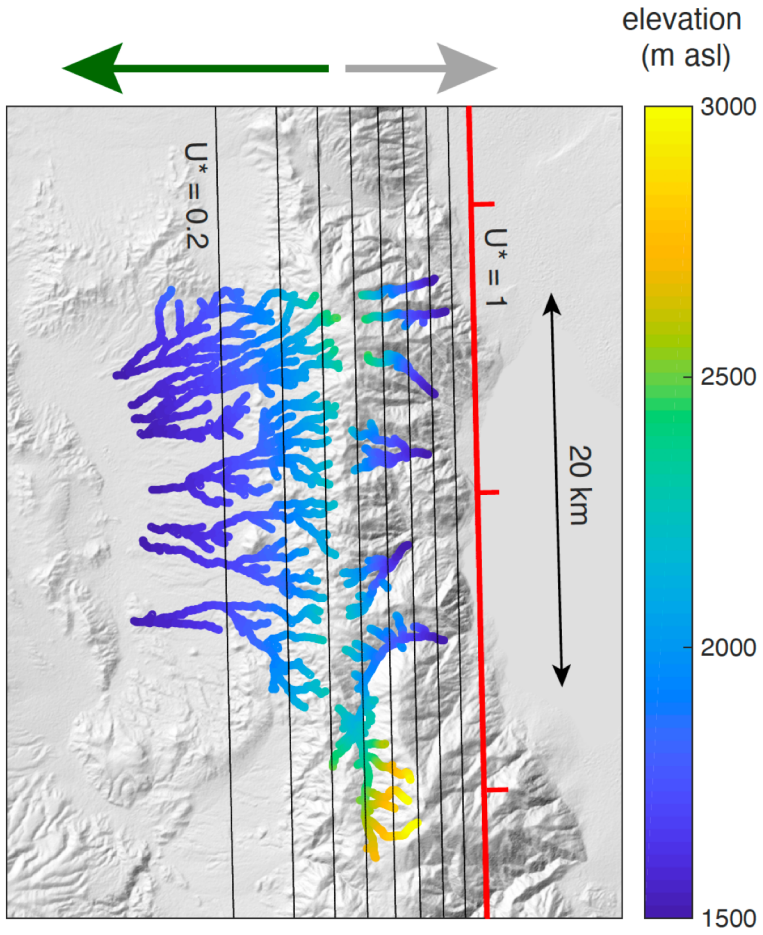


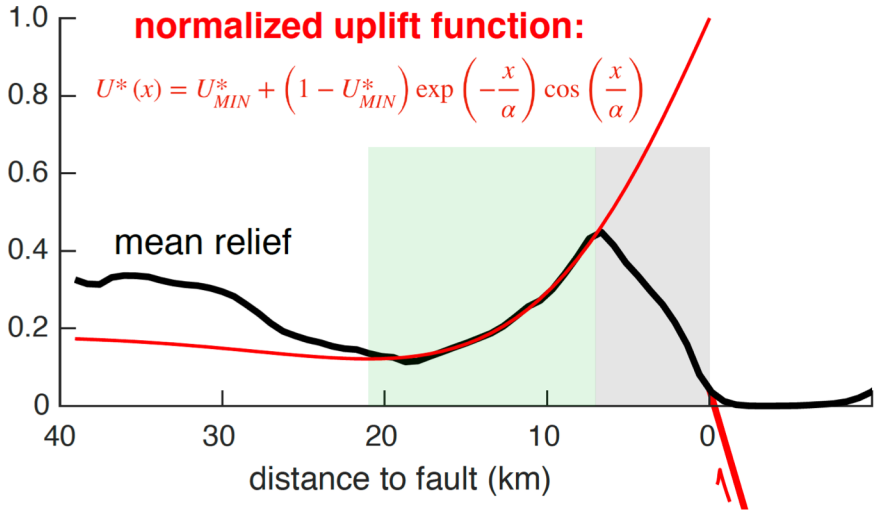


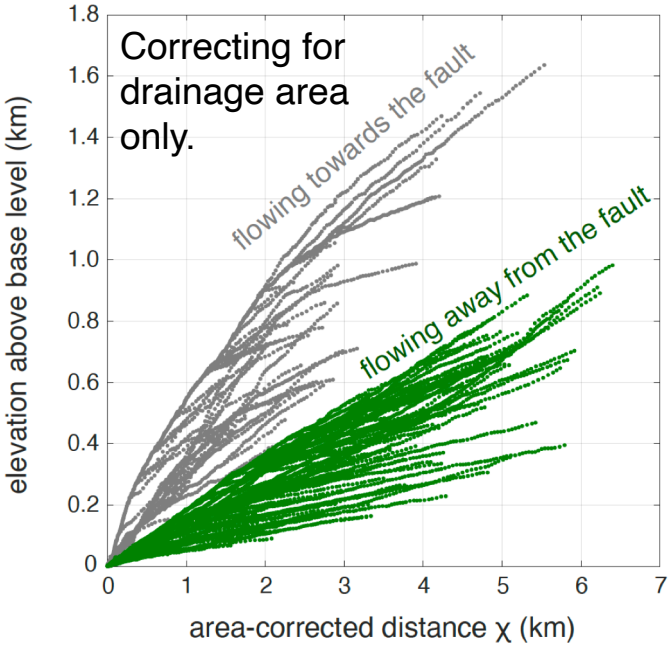


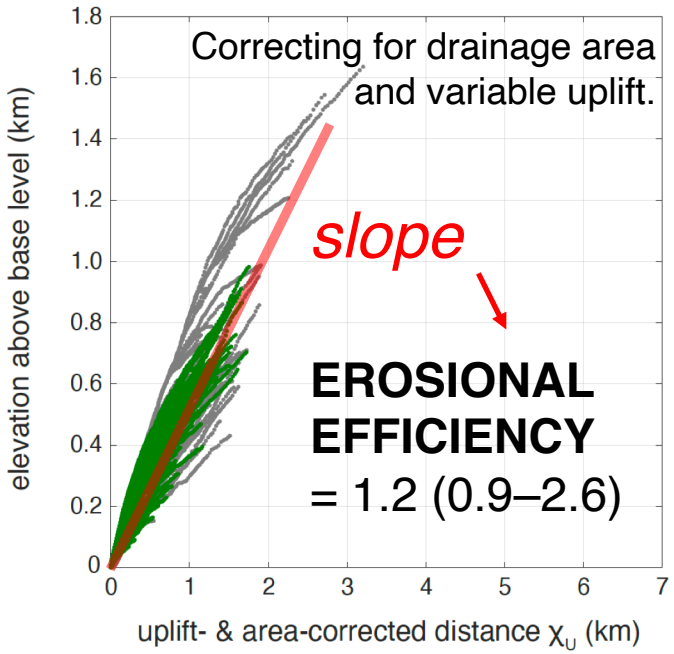
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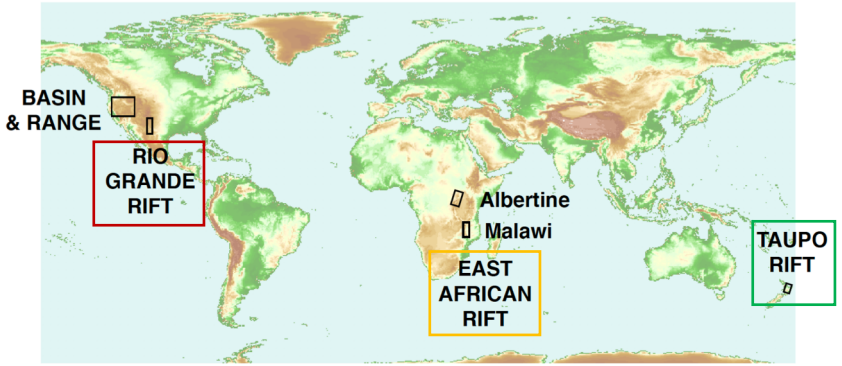




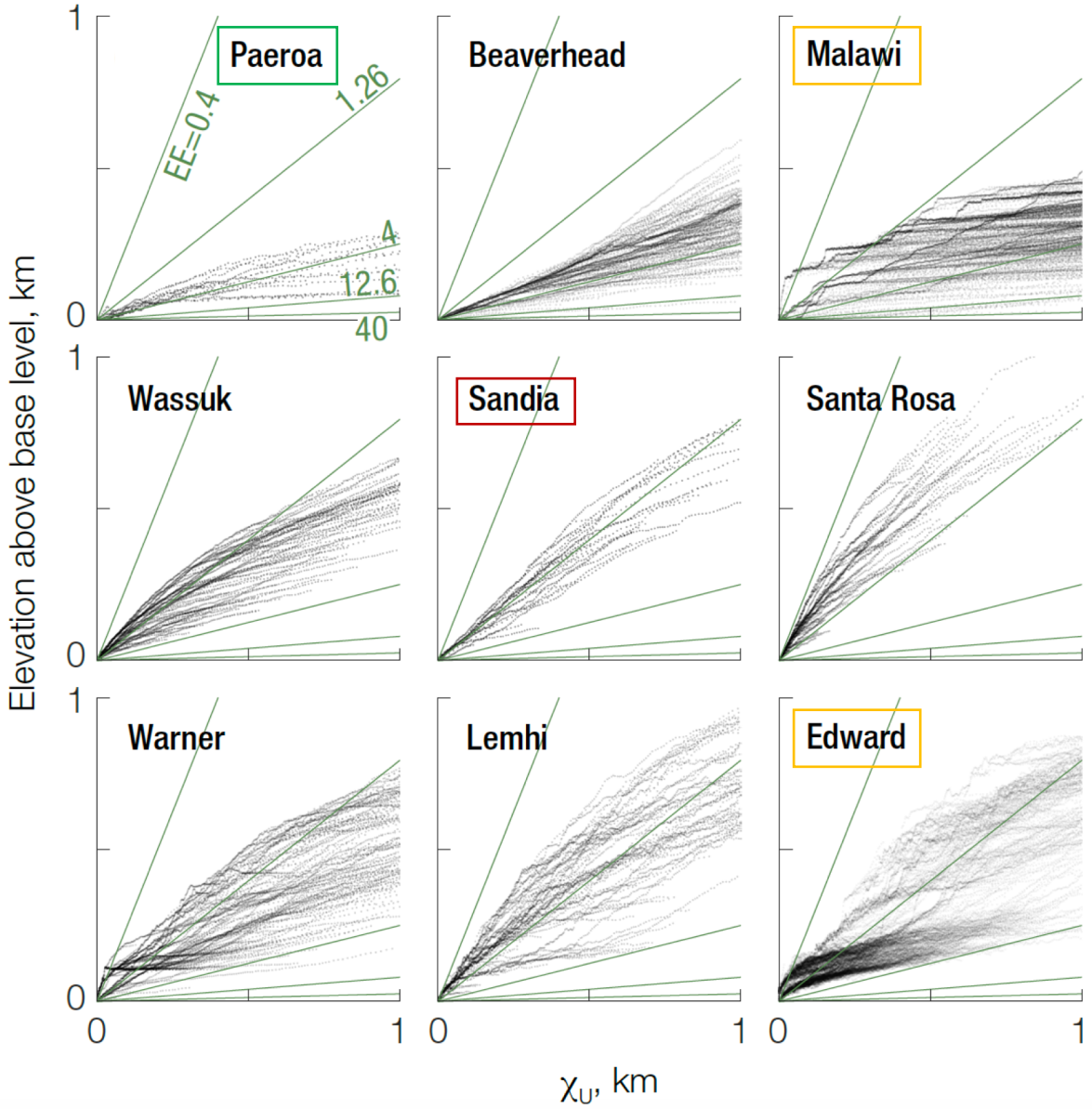




EROSIONAL EFFICIENCIES ACROSS RIFTS

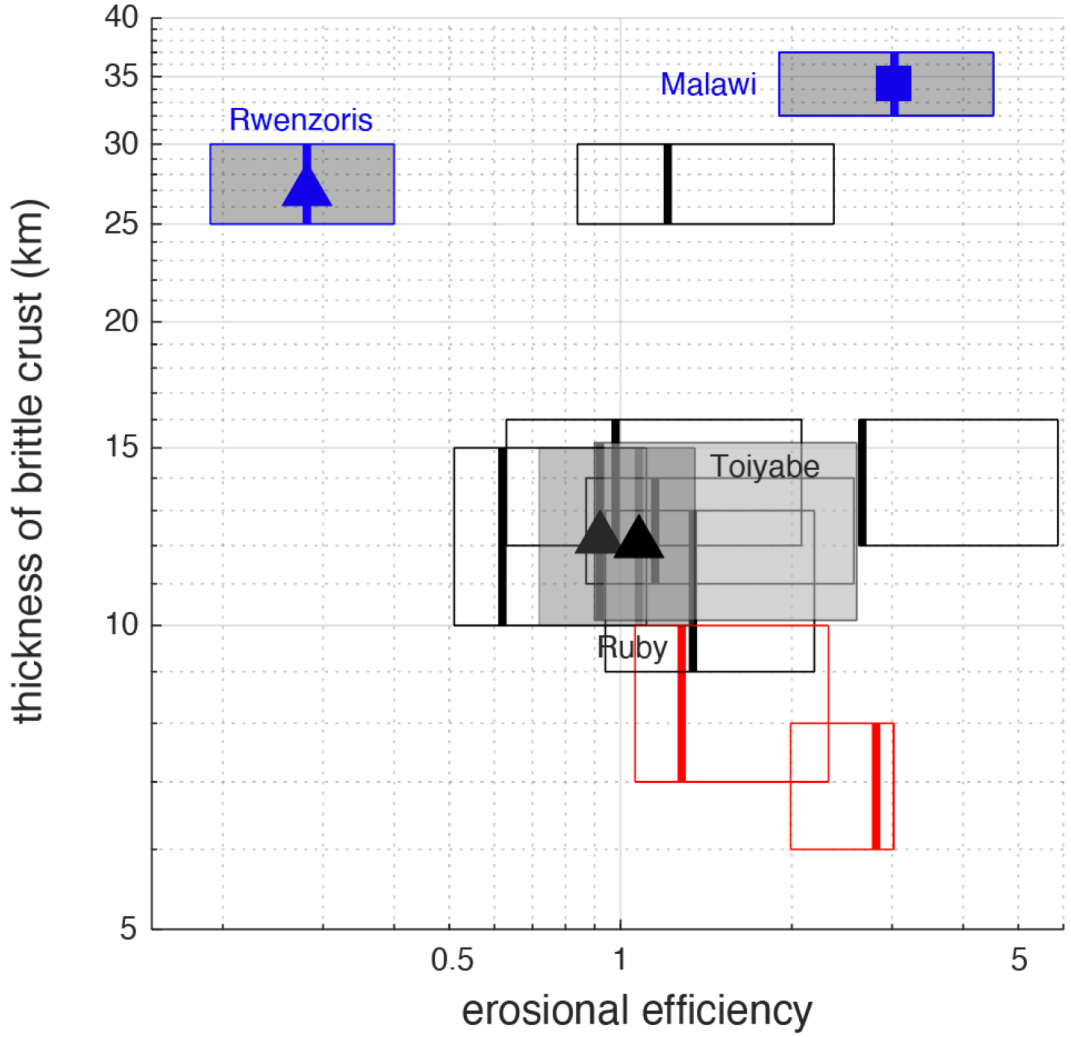


Applying this method to half-grabens across rift settings yields global range of erosional efficiencies:
~0.5–5



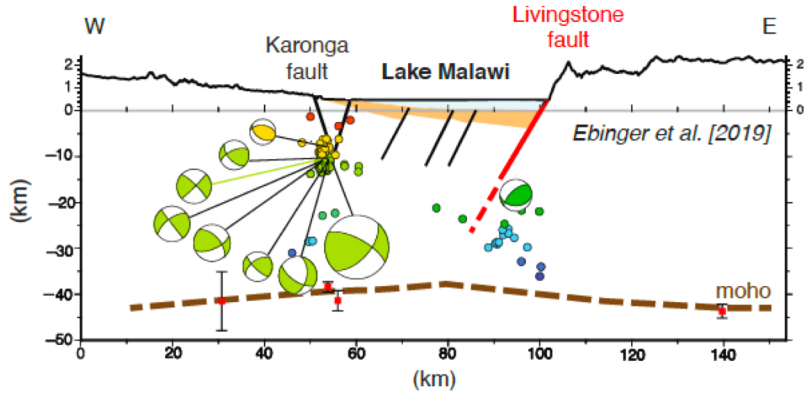
COMPILATION OF EE & STRENGTH ACROSS RIFTS

Using seismogenic thickness as proxy for upper crustal strength.

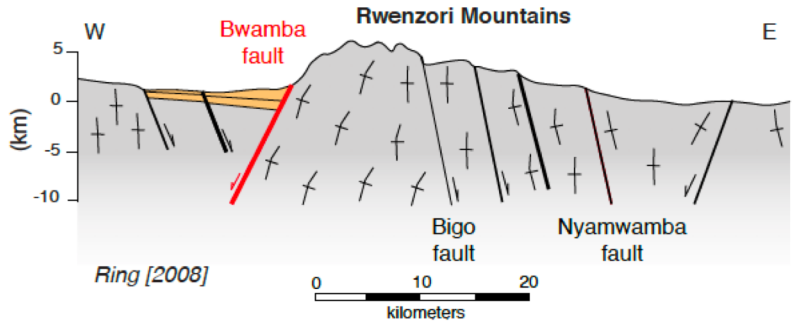


GROWING HALF-GRABEN

HANGING WALL SNAPPING



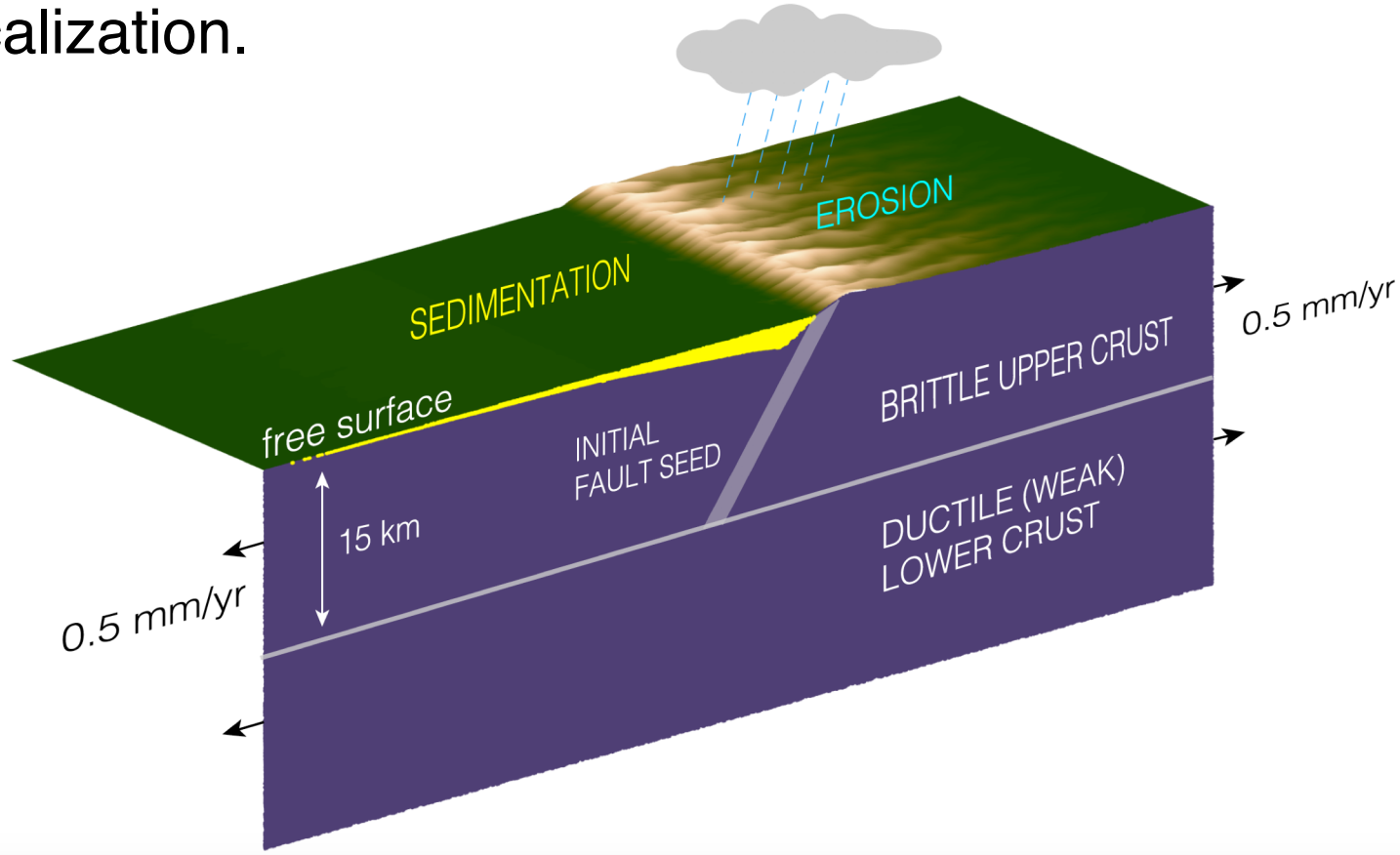
FOOTWALL SNAPPING



NUMERICAL SIMULATIONS

Visco-elasto-plastic deformation model fully coupled with river incision model + sedimentary infilling of subsiding areas.

Master fault initially seeded, focus on half-graben evolution and subsequent strain localization.

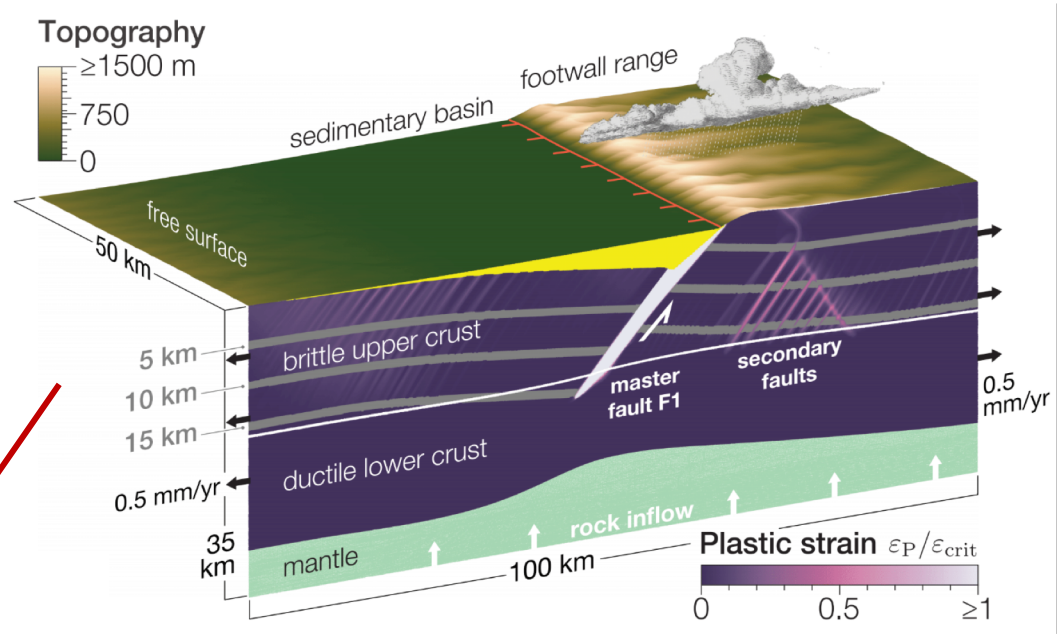


Parameters varied:

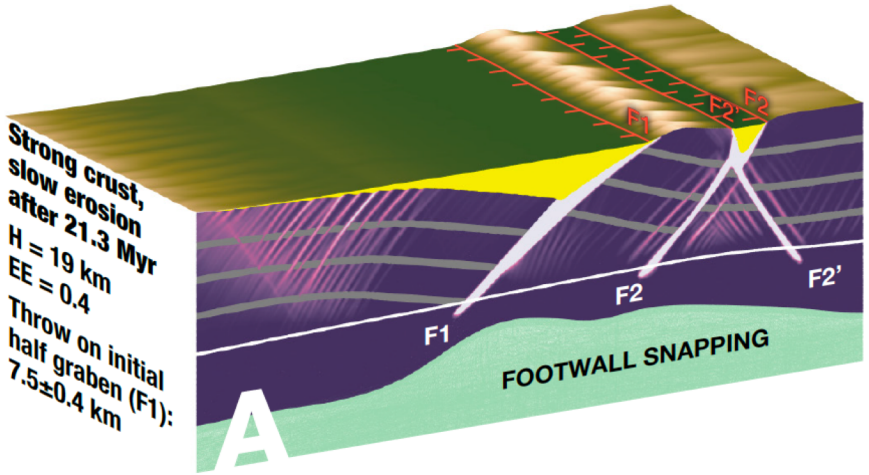
- Thickness of brittle portion of the crust (through thermal regime).
- Efficiency of river erosion within and beyond documented range.

NUMERICAL RESULTS

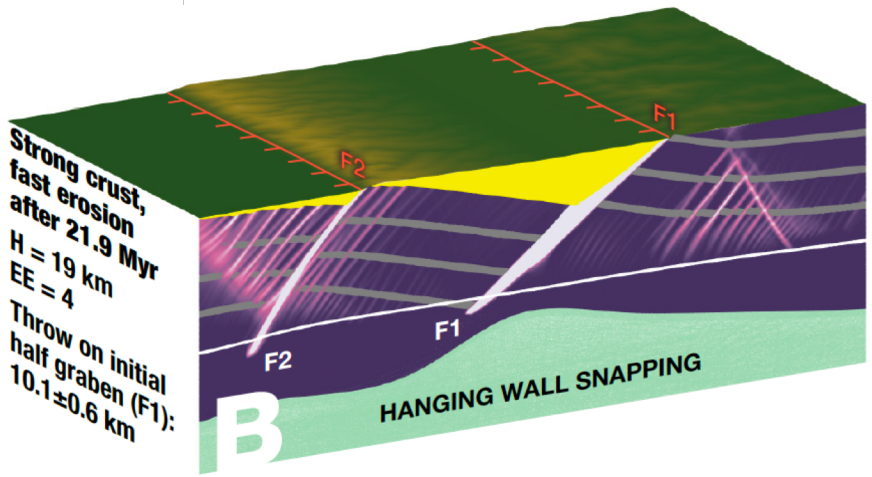
Half-graben grows, then new master fault breaks in footwall or hanging wall (or both) of initial master fault:



Less efficient erosion, weaker crust

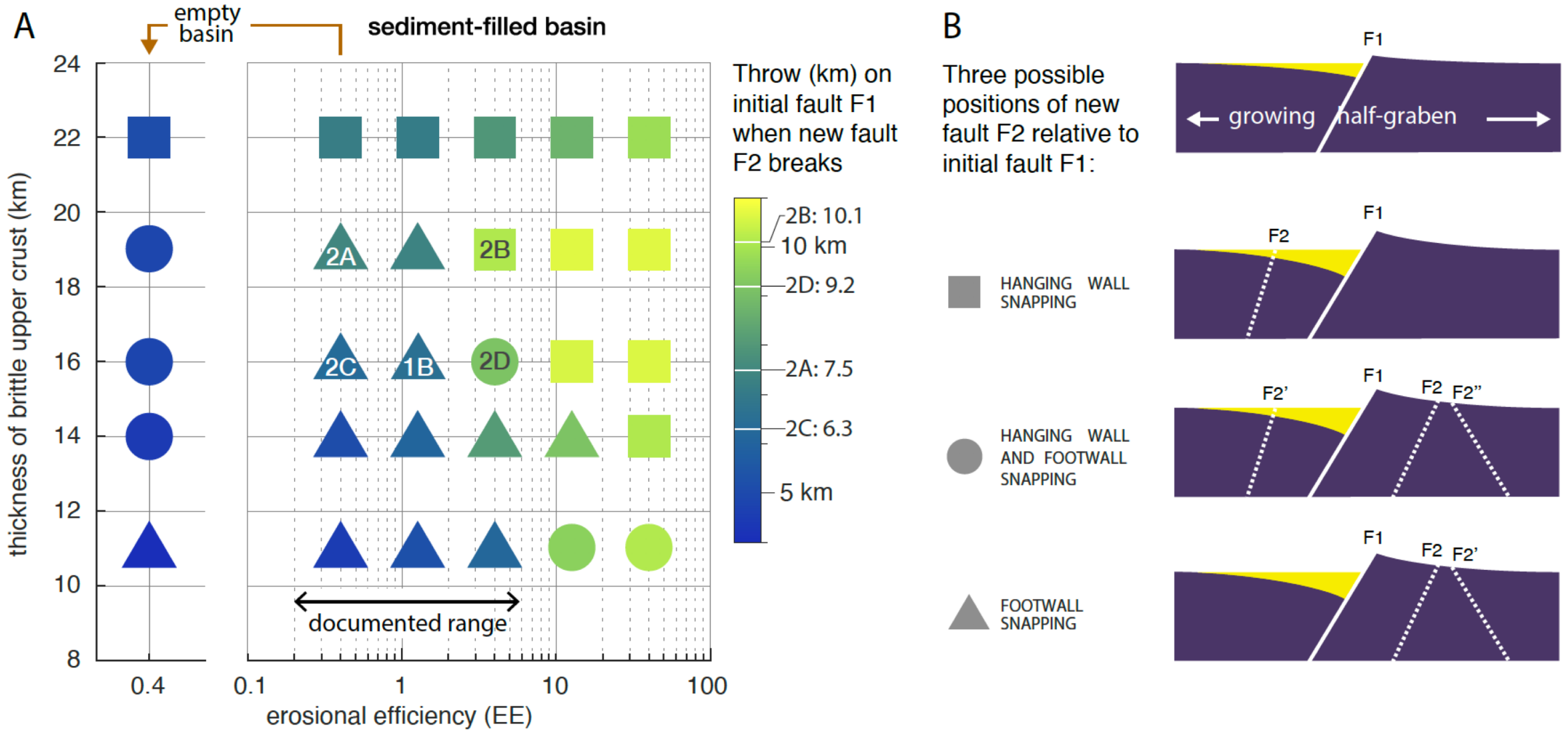


More efficient erosion, stronger crust



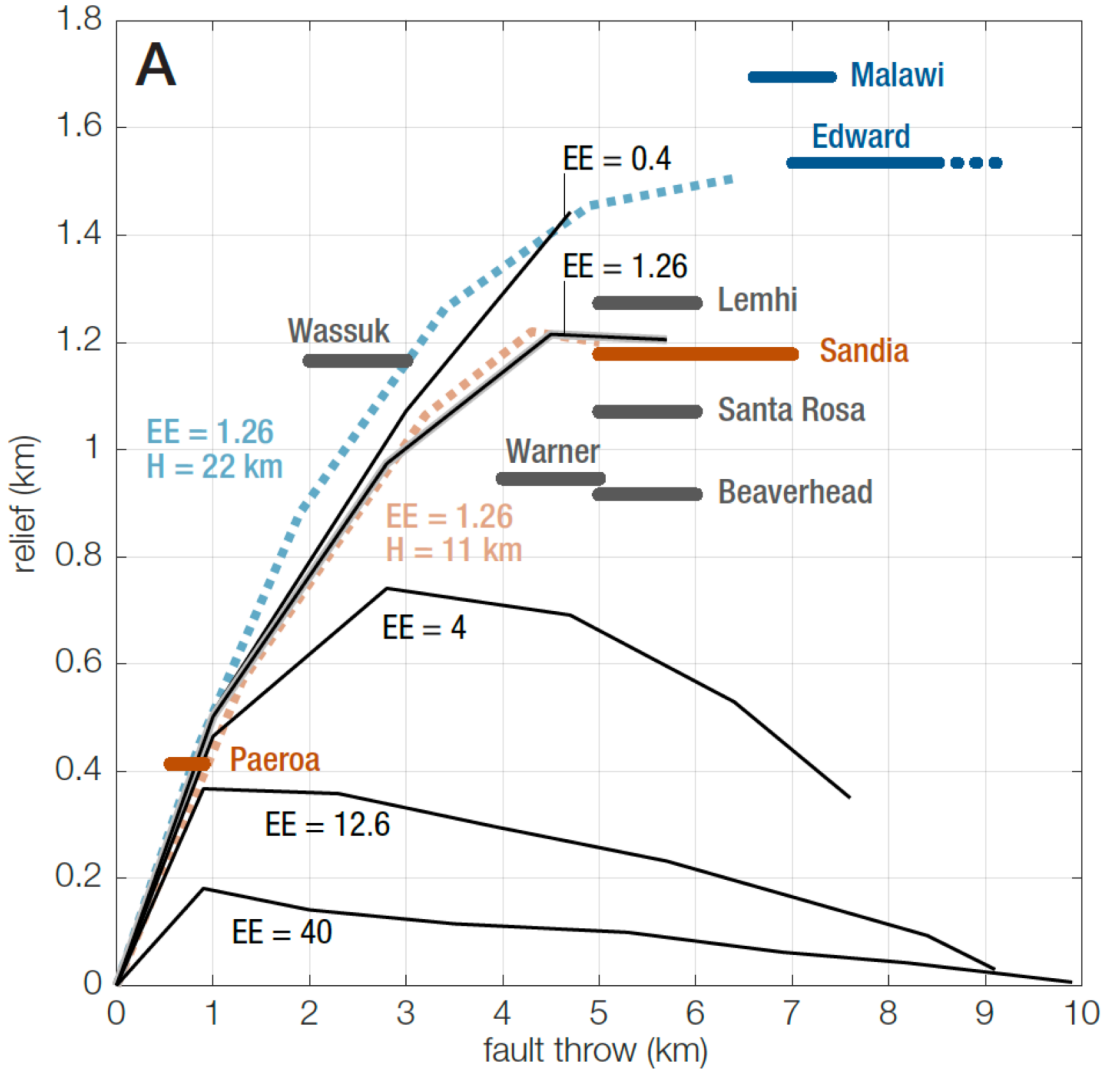
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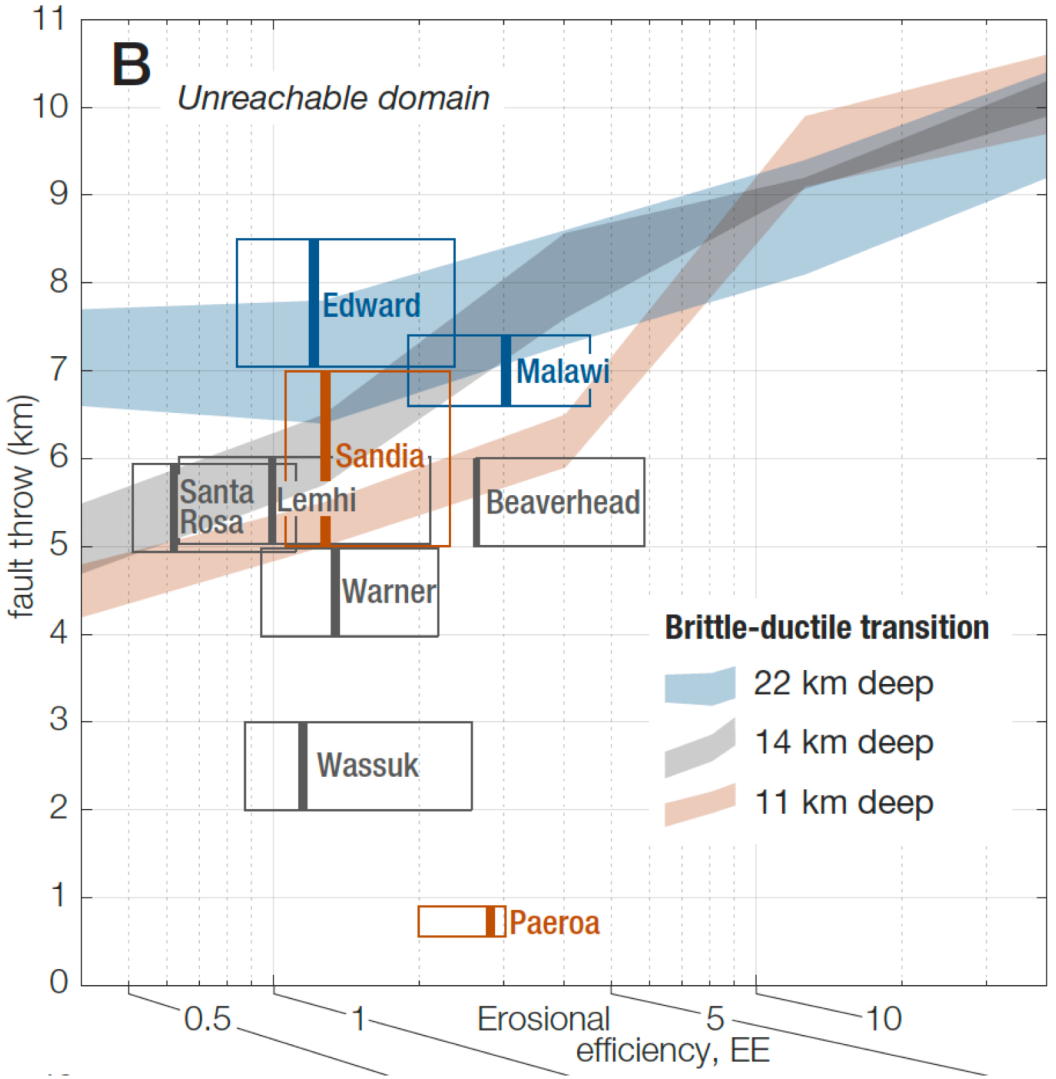
Crustal strength and efficiency of erosion jointly influence rift evolution:



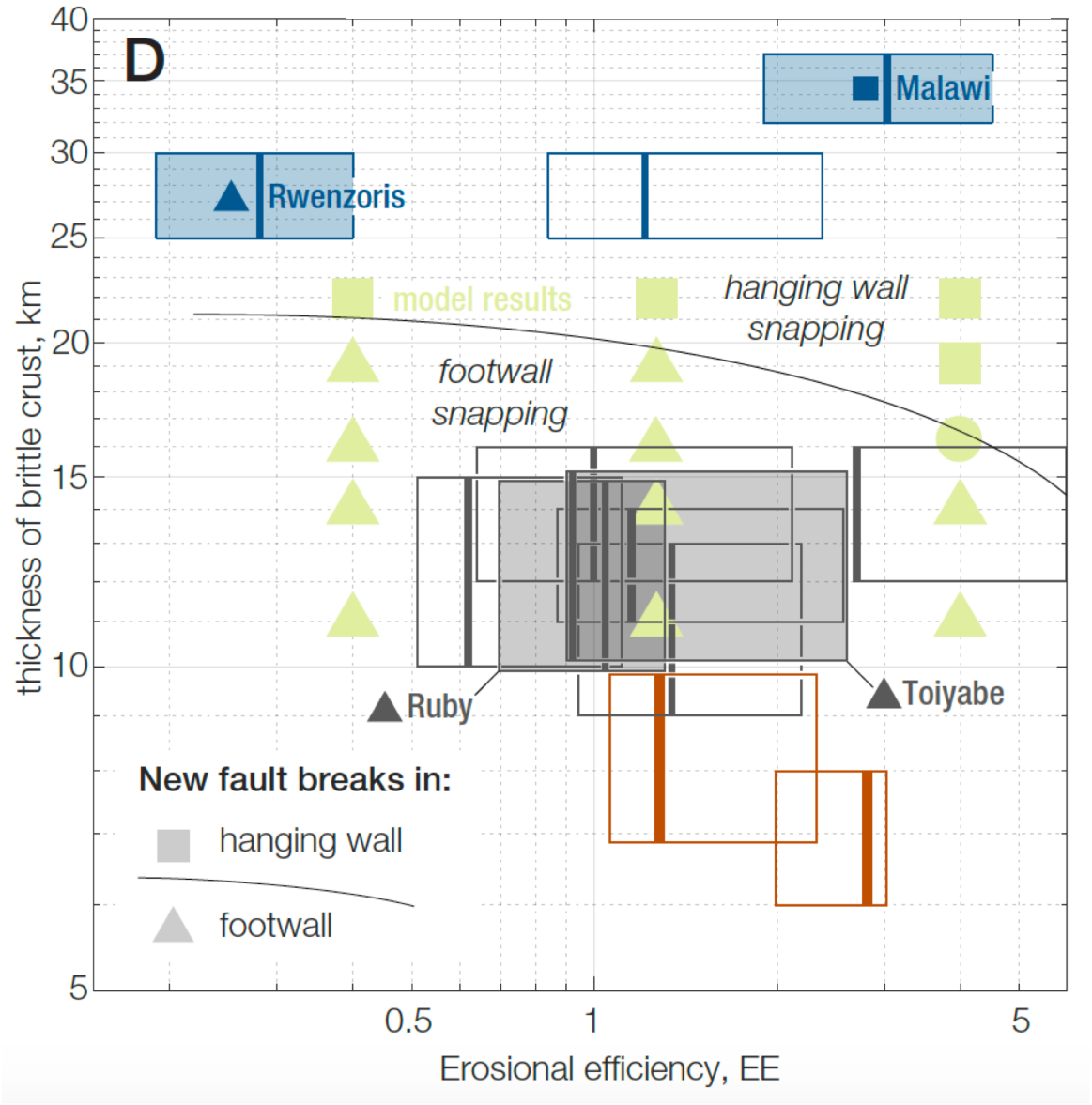
NUMERICAL RESULTS VS. REAL HALF-GRABENS

Models predict reasonable upper bounds on the throw of half-graben master faults:



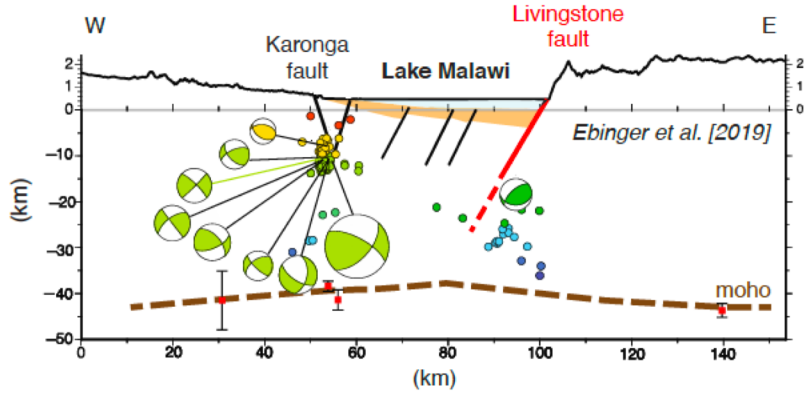


RIFT TECTONICS MODULATED BY EROSION ?

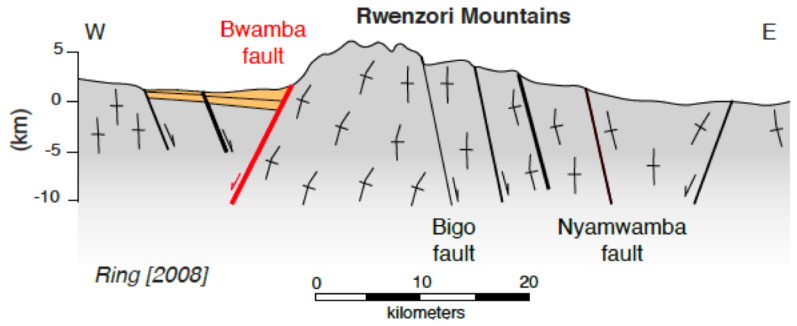


GROWING HALF-GRABEN

HANGING WALL SNAPPING



FOOTWALL SNAPPING



CONCLUSIONS

- Estimates of erosional efficiency through **integral river profile analysis** in up-warped fault blocks, accounting for spatially-variable uplift.
- **Dataset of erosional efficiency**, crustal **strength** and **tectonic styles** across rift zones.
- Models coupling rifting and surface processes show sensitivity to variations in erosional efficiency **within the documented range**.
- Inefficient erosion promotes migration of localized strain into the footwall of half-grabens, **formation of horsts**.