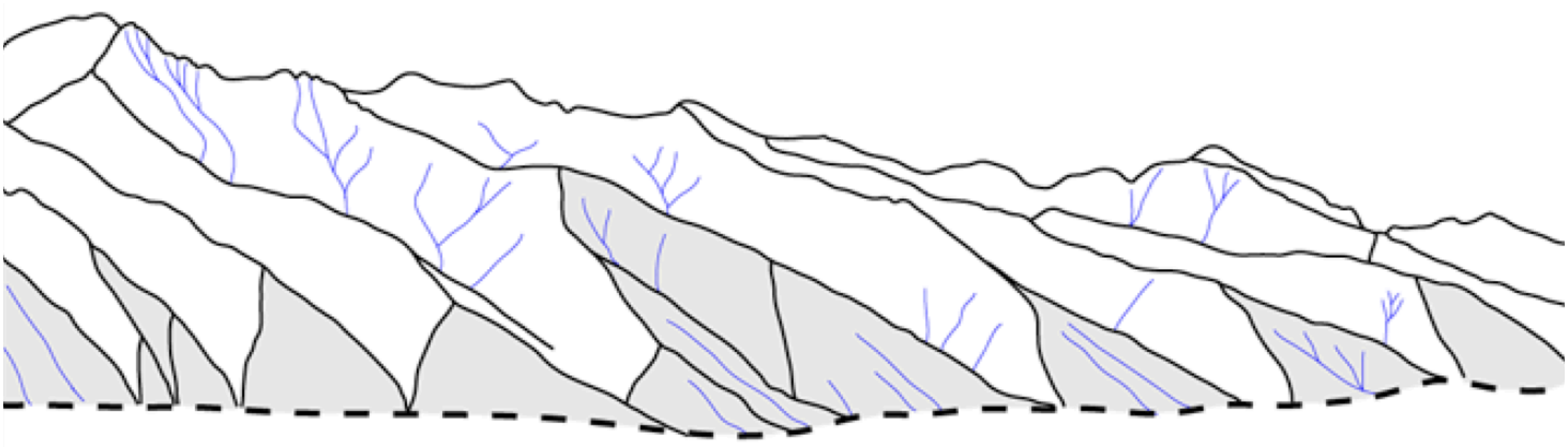
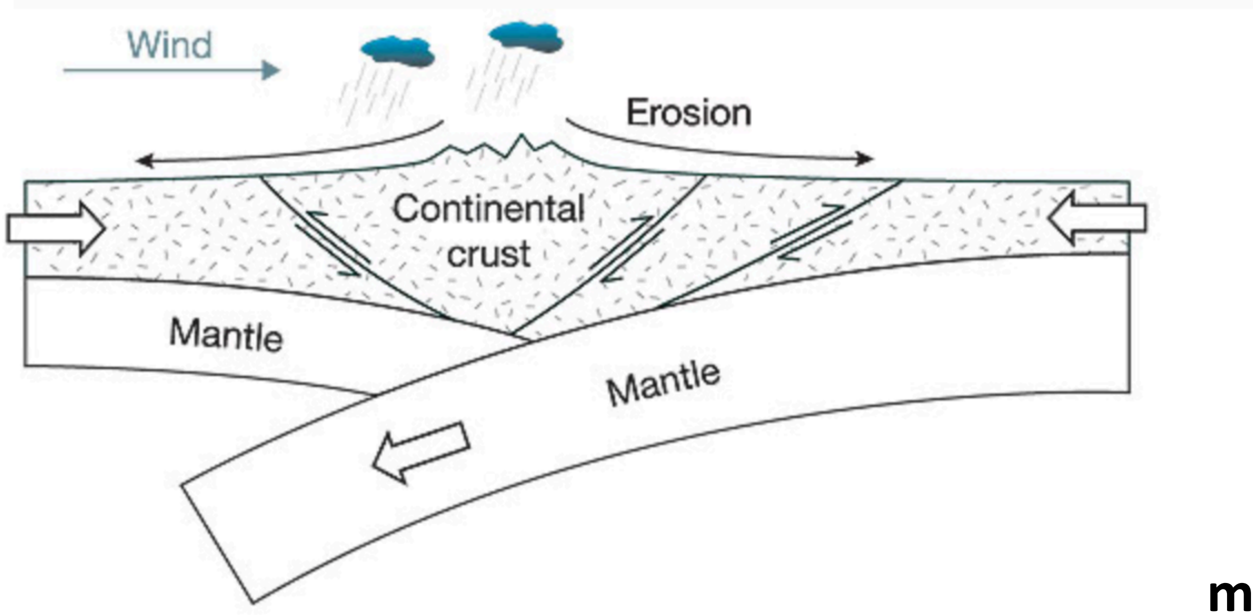
MODES OF EXTENSIONAL FAULTING
CONTROLLED BY SURFACE PROCESSES

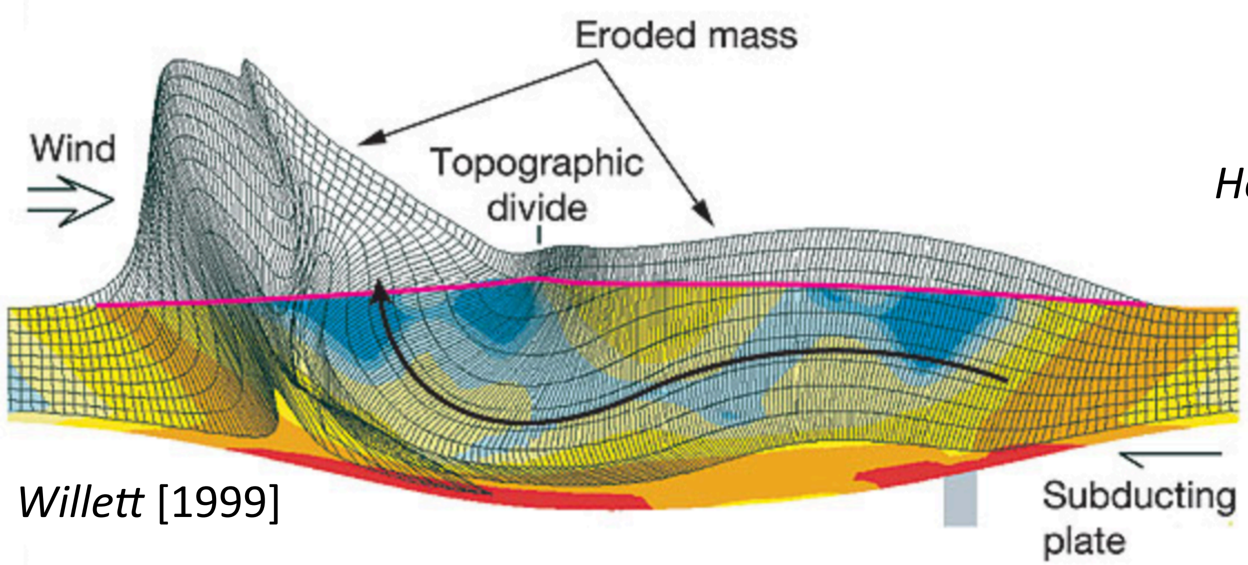


Jean-Arthur Olive[1,2], Mark Behn[2], Luca Malatesta[3]

1 – MIT/WHOI, now LDEO, 2 – WHOI, 3 – Caltech

Feedbacks between tectonics and erosion





Willett [1999]

"Savor the irony should mountains owe their metamorphic muscles to the drumbeat of tiny raindrops."

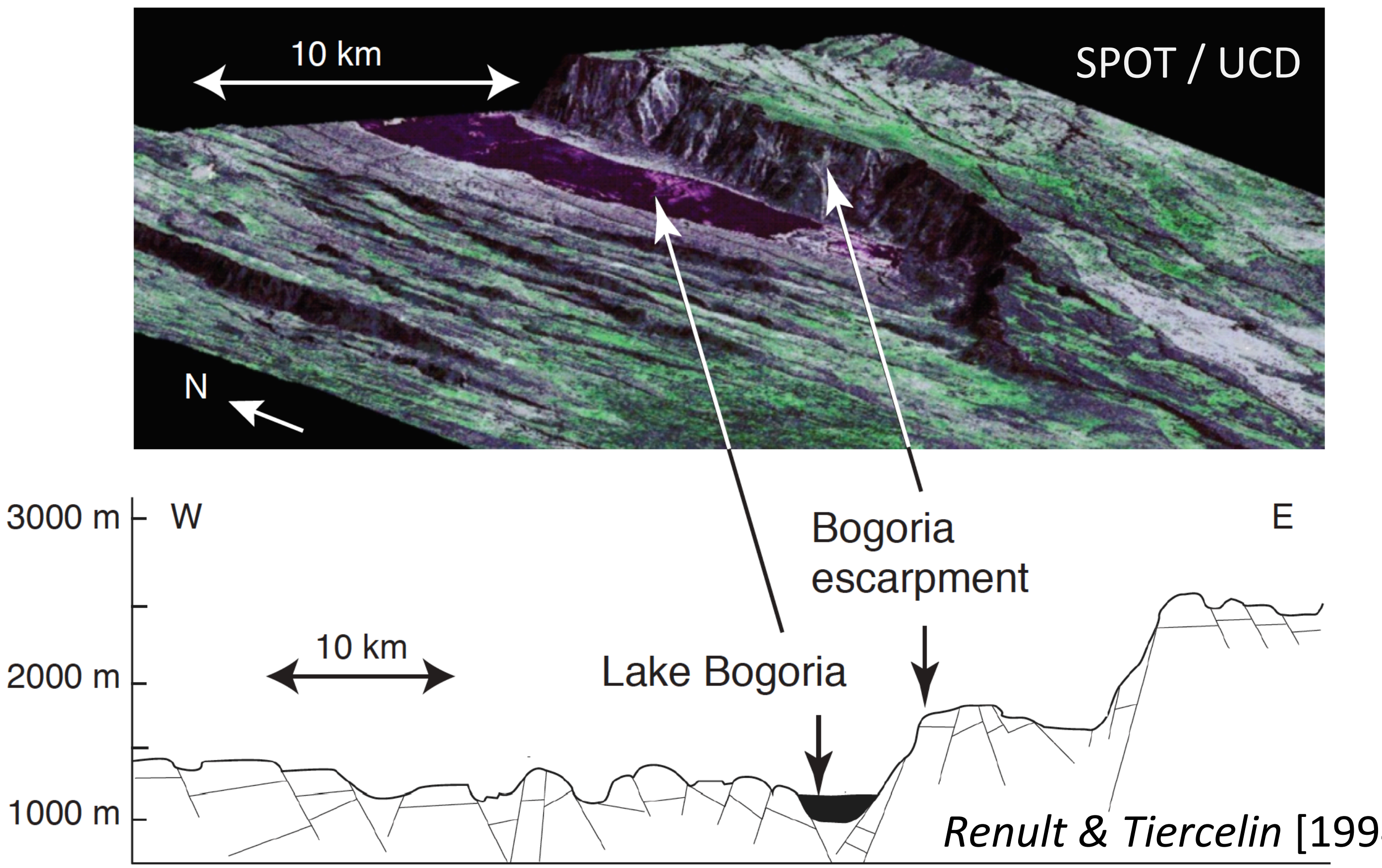
Hoffman and Grotzinger [1993]

Diversity of (subaerial) normal fault styles

SHORT-LIVED FAULTS → LONG-LIVED DETACHMENTS

fault life span

↑ Baringo-Bogoria half-graben (Kenya)
East African Rift - Eastern Branch



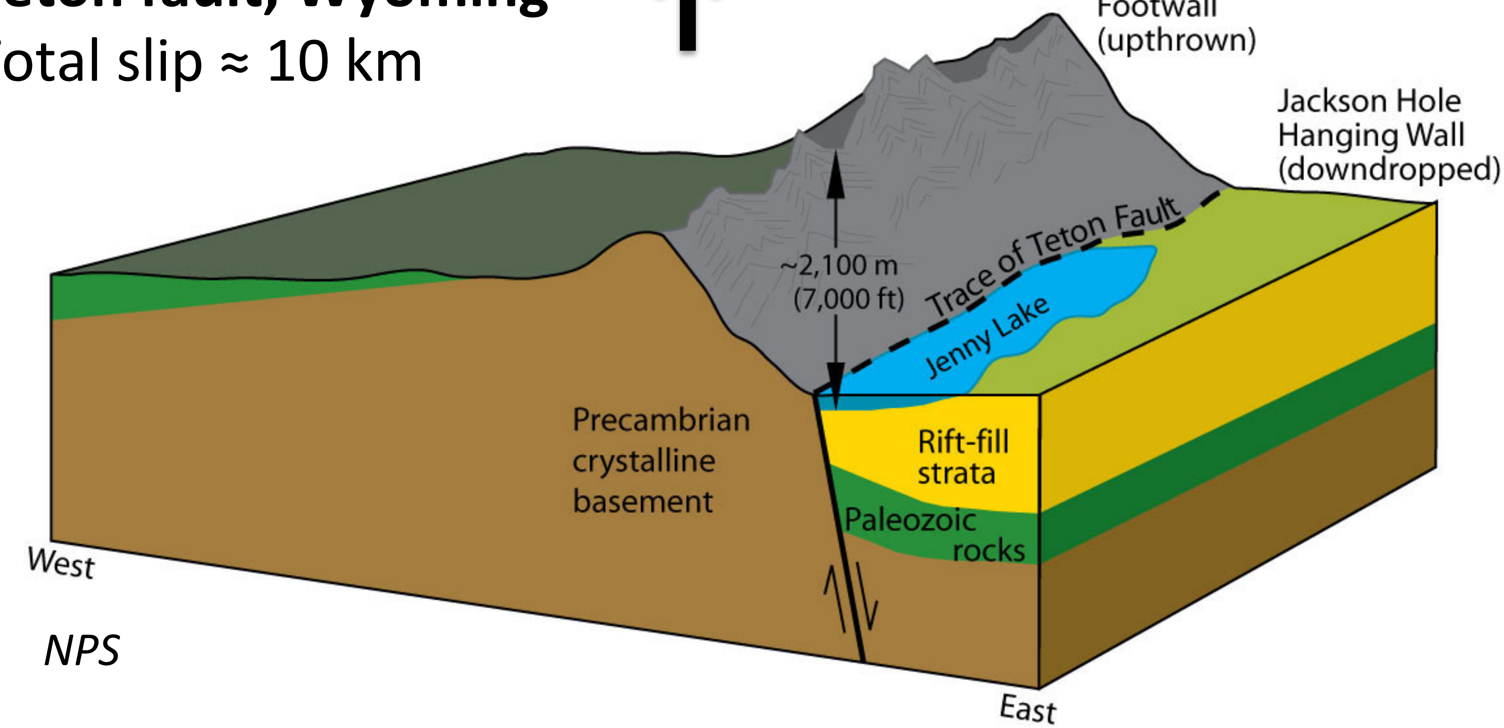
Renult & Tiercelin [1994]

Diversity of (subaerial) normal fault styles

SHORT-LIVED FAULTS — LONG-LIVED DETACHMENTS

fault life span

Teton fault, Wyoming
Total slip ≈ 10 km



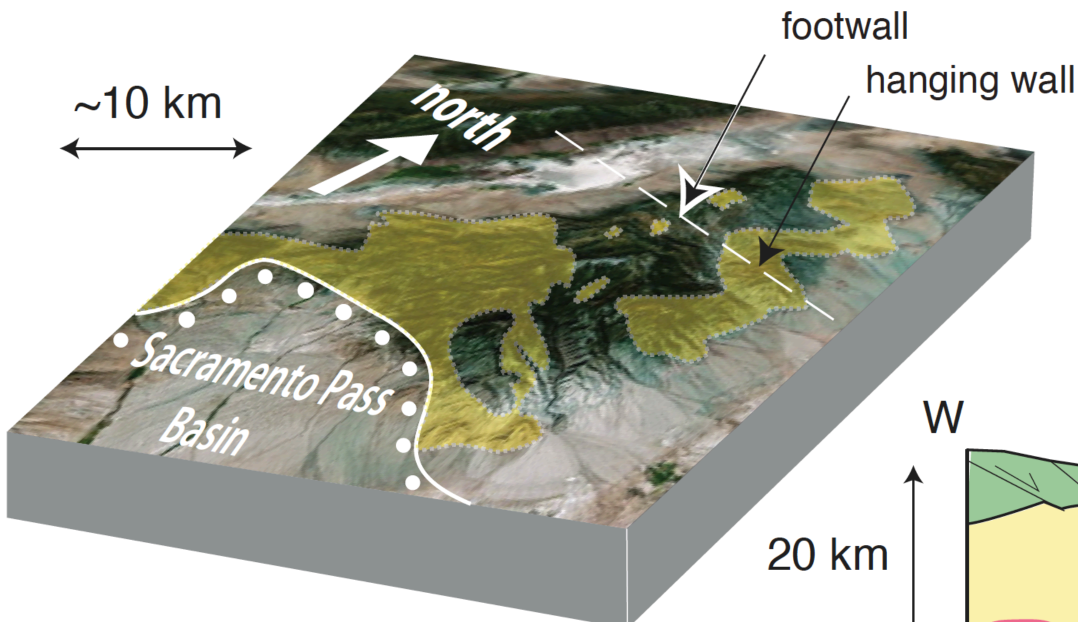
NPS

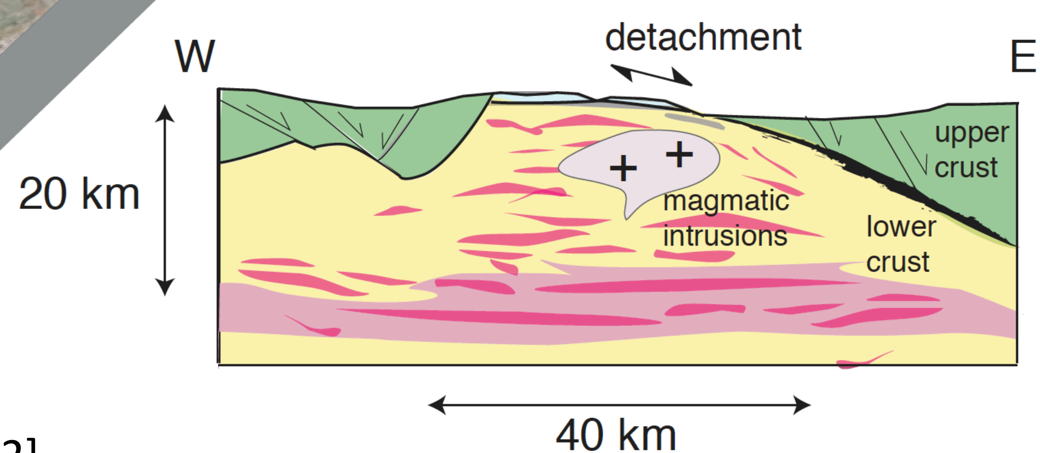
Diversity of (subaerial) normal fault styles

SHORT-LIVED FAULTS → LONG-LIVED DETACHMENTS

fault life span

Northern Snake Range (Nevada)



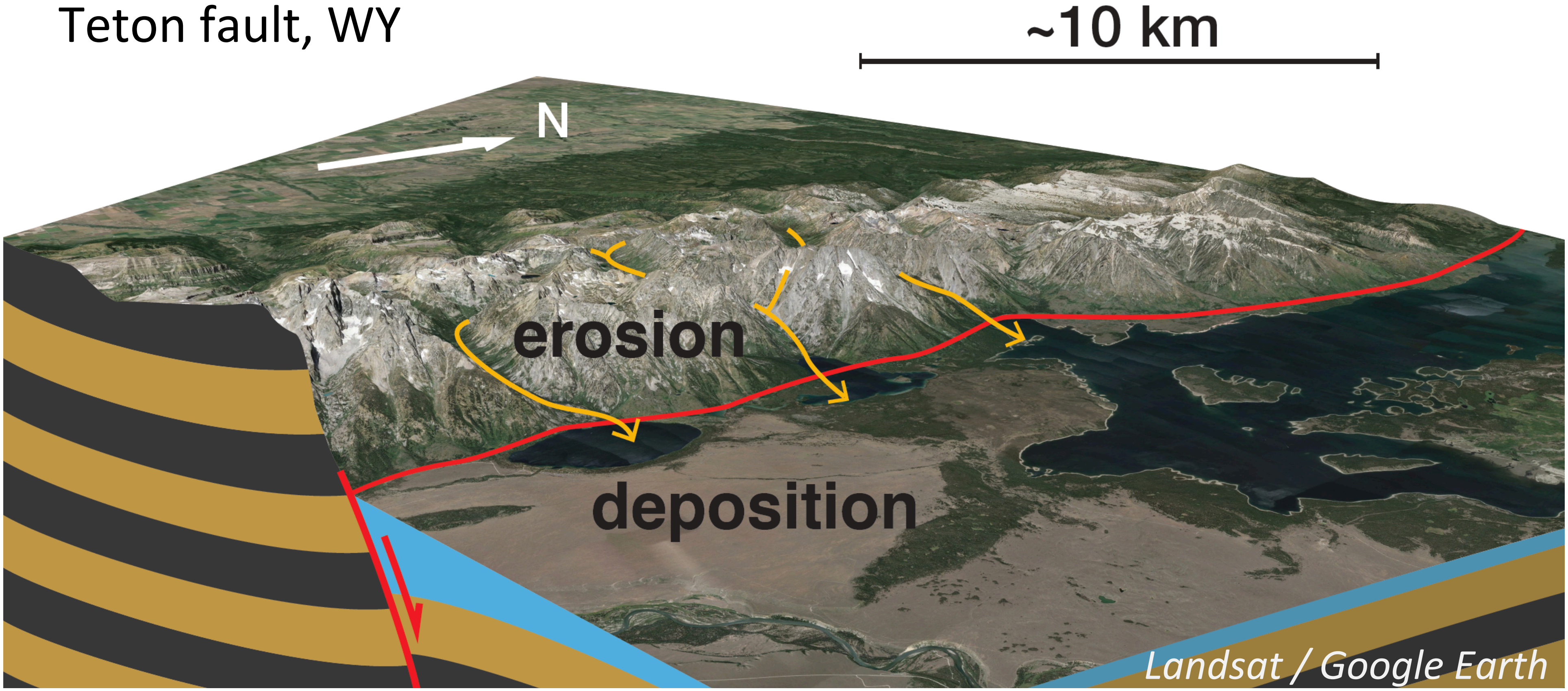


Miller et al. [1983]; *Whitney et al.* [2012]

Normal faulting vs. surface processes

Surface processes redistribute mass and topographic loads on a growing fault. **Can they affect fault life span ?**

Teton fault, WY

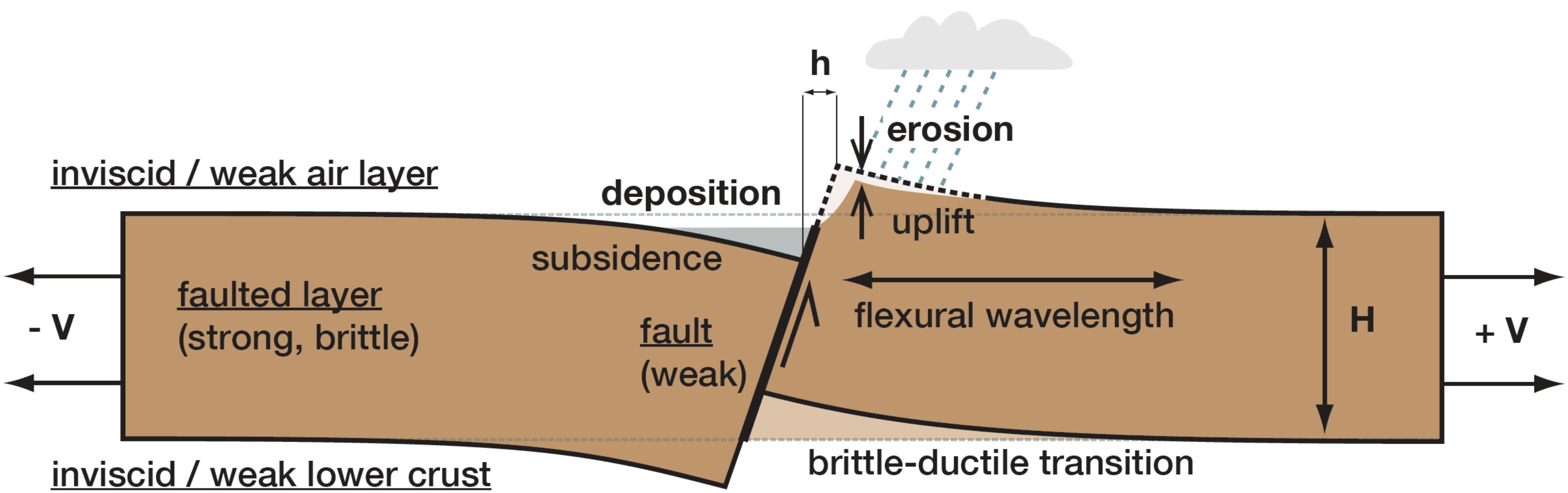


Coupled geodynamics – surface model

<u>Geodynamic model (visco-elastic-plastic flow with FD/PIC):</u>

Strong brittle layer (thickness **H**) with seeded fault subjected to stretching at half-rate **V**. Fault evolution monitored as offset **h** increases.

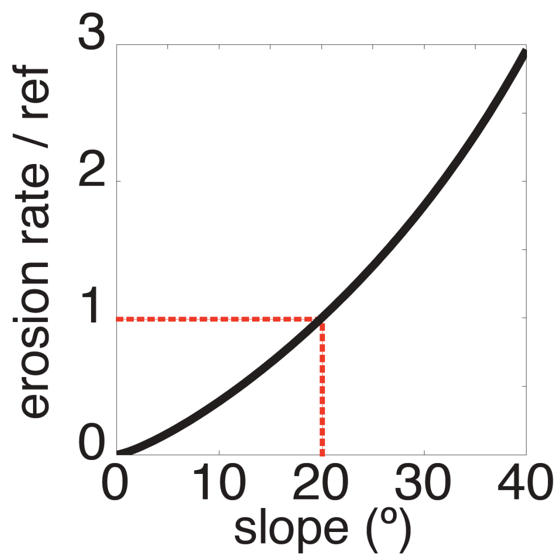
Numerical simulations conducted with the **SiStER** code (***Si****mple* ***St****okes with* ***E****xotic* ***R****heologies*).



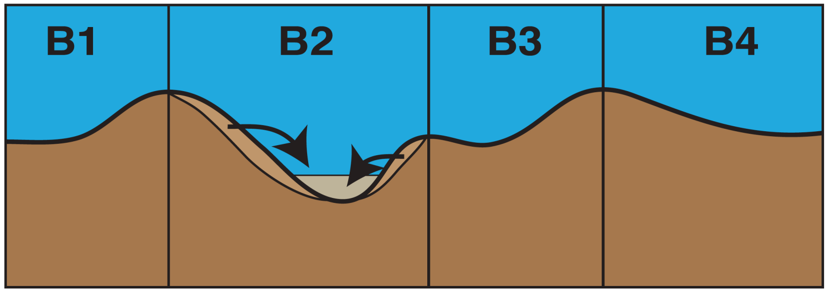
Coupled geodynamics – surface model

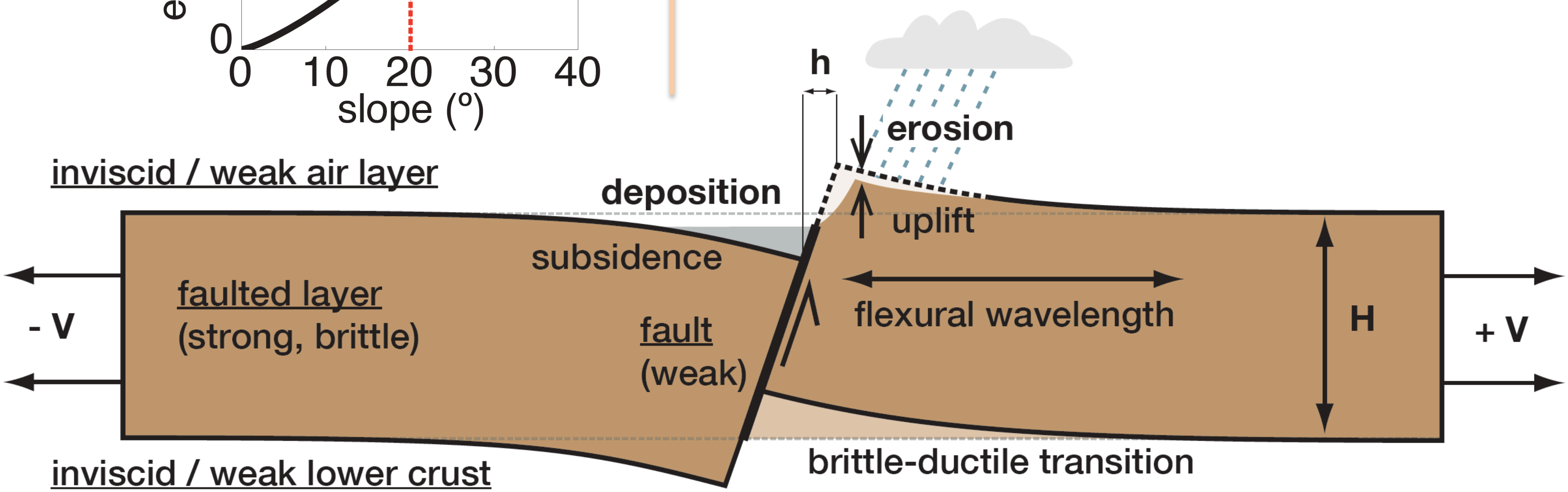
Surface evolution model (upper boundary condition):

Step 1: **erode** material



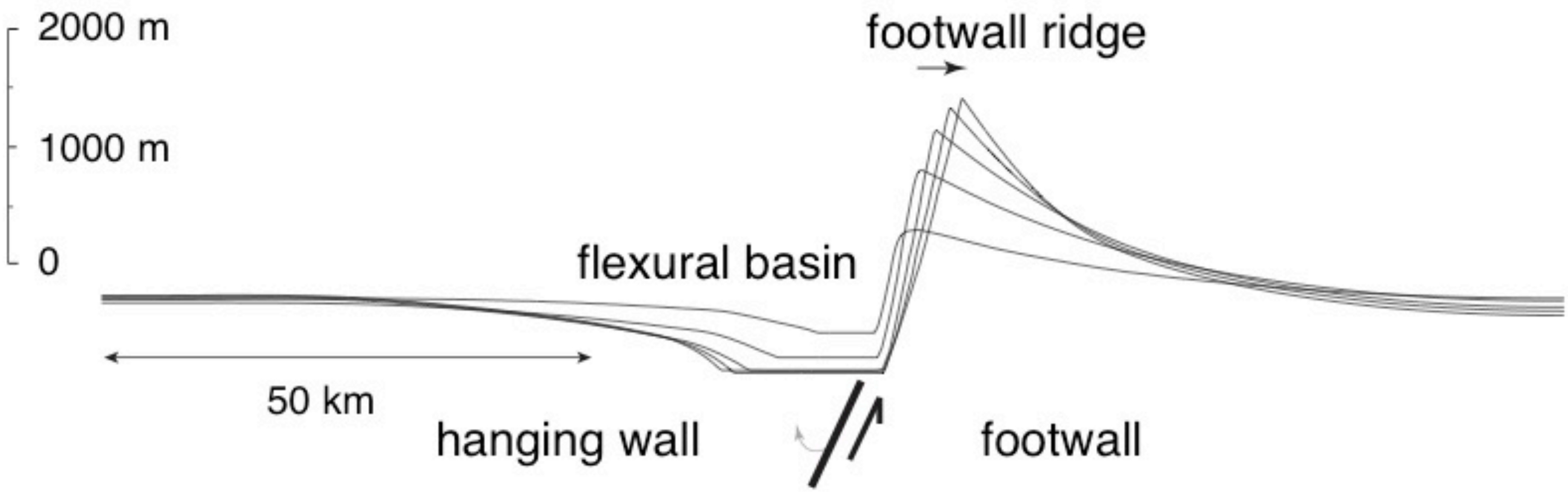
Step 2: **deposit** material flat in corresponding watershed





Fault growth with erosion and sedimentation

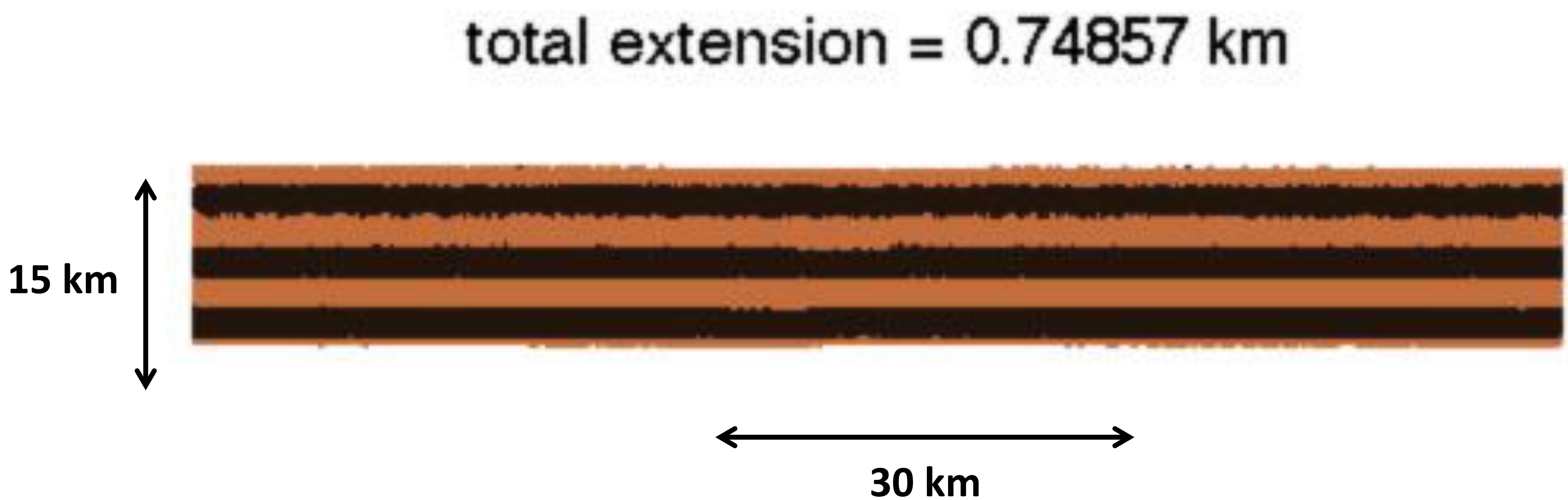
Fault growth is accompanied by



- Flexure of the footwall and hanging wall
- Rapid rotation of the fault plane down to 30-45º.
- Erosion of the footwall block, ridge migration, deposition in flexural basin.

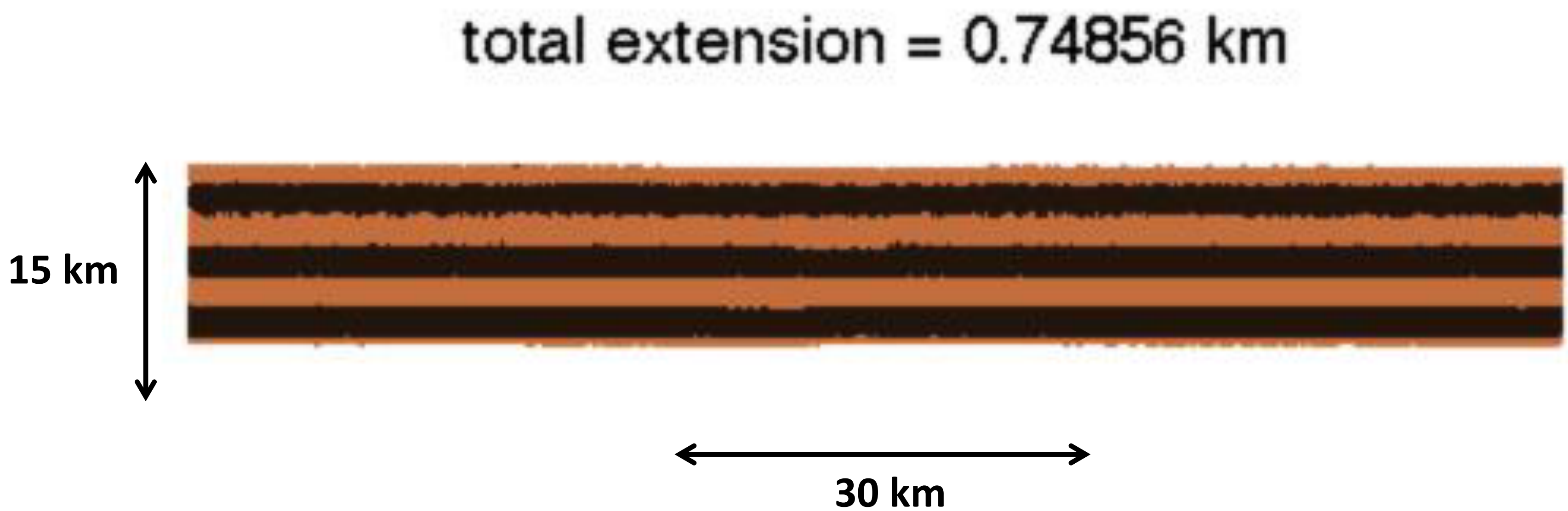
Sequence of faulting with **slow** erosion

Extending a **15 km thick** layer at **2 mm/yr** (full rate).
Ref. erosion rate = **0.05% of fault slip rate**.

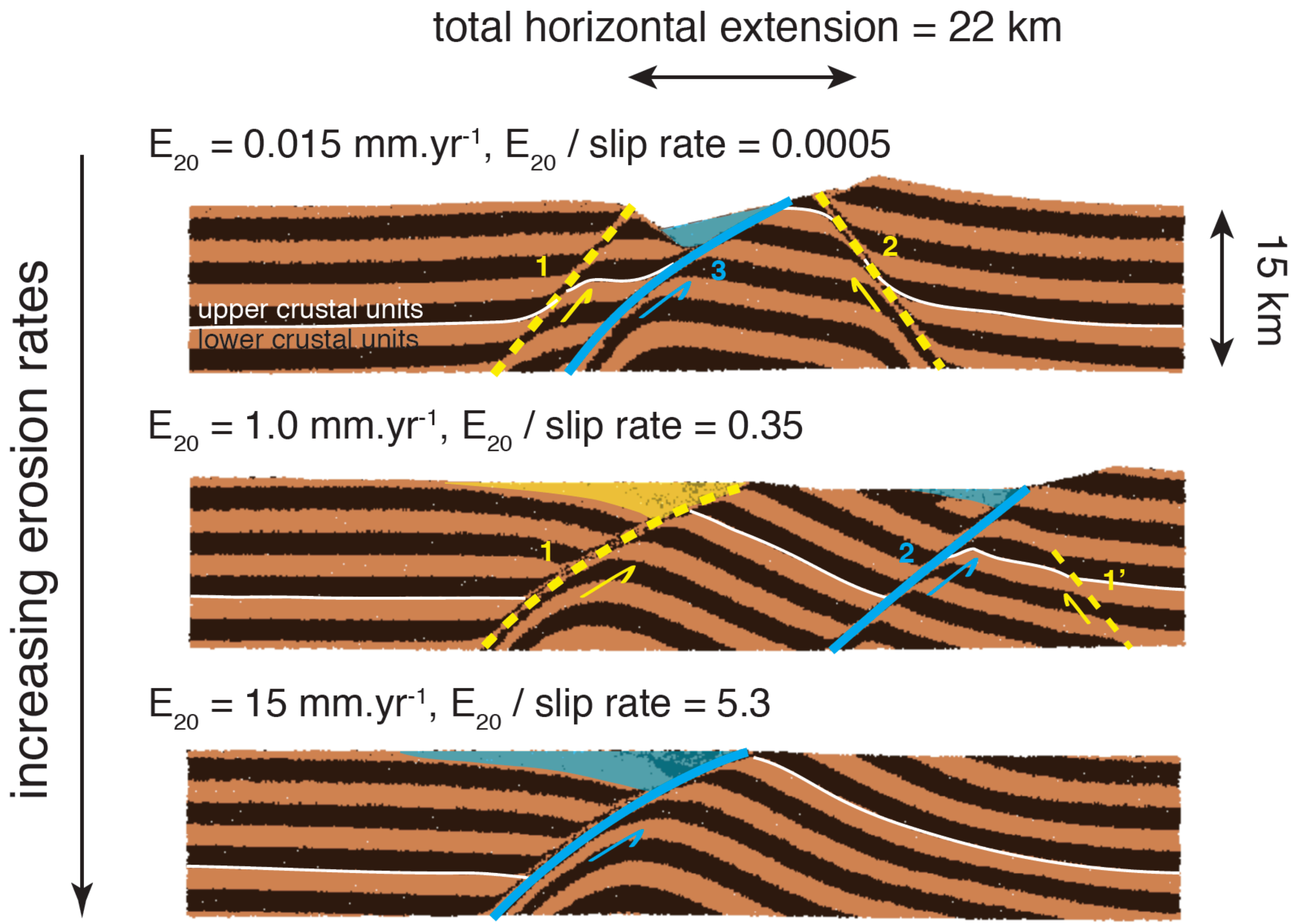


Sequence of faulting with **fast** erosion

Extending a **15 km thick layer** at **2 mm/yr** (full rate).
Ref. erosion rate = **35% of fault slip rate**.

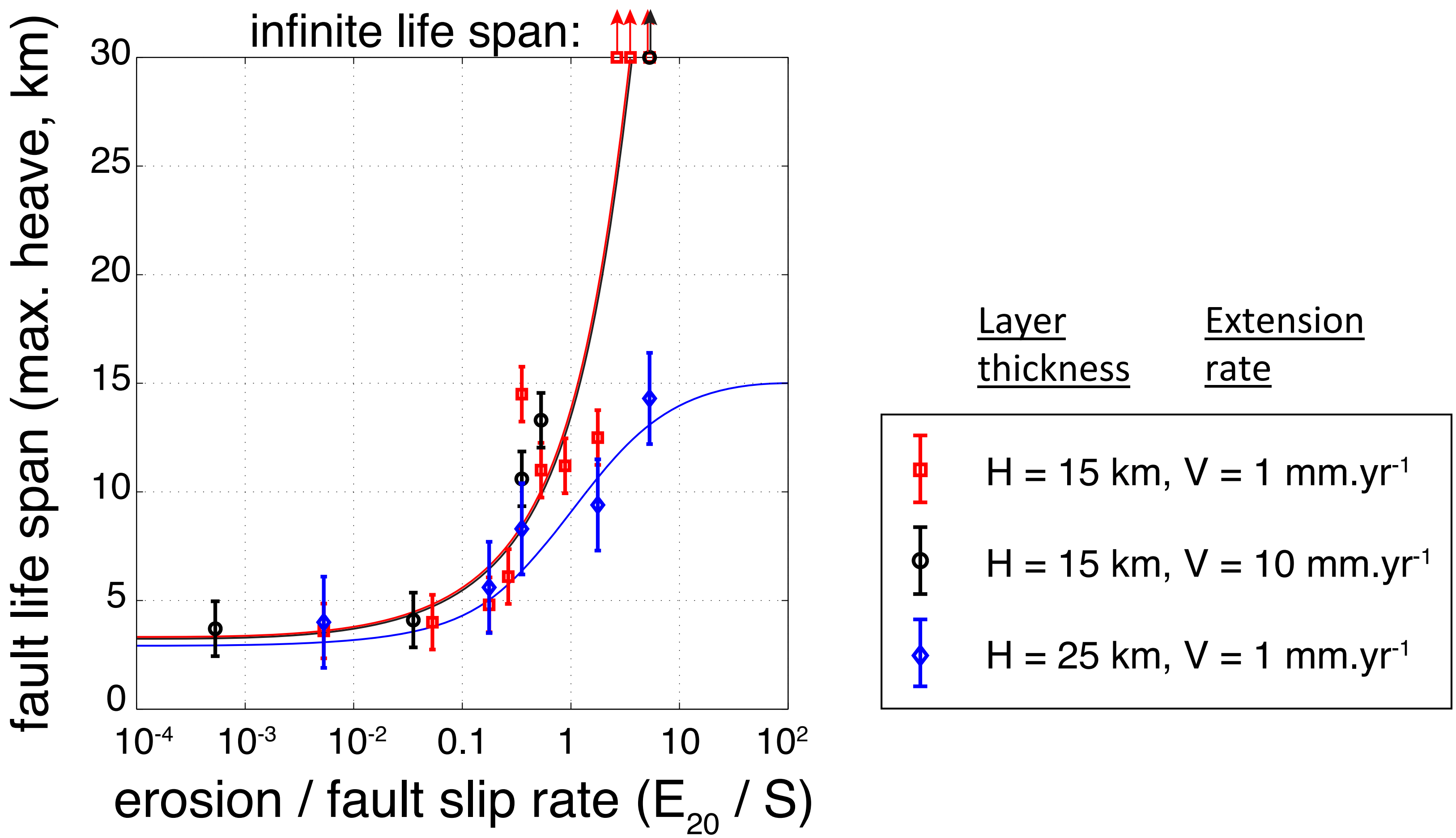


Faster surface processes = longer-lived faults



Faster surface processes = longer-lived faults

Surface processes **further enhance** fault life span
in **thinner** faulted layers for a given erosion / slip rate.



Force balance on a growing normal fault

How to keep a normal fault active ? [*Forsyth*, 1992]

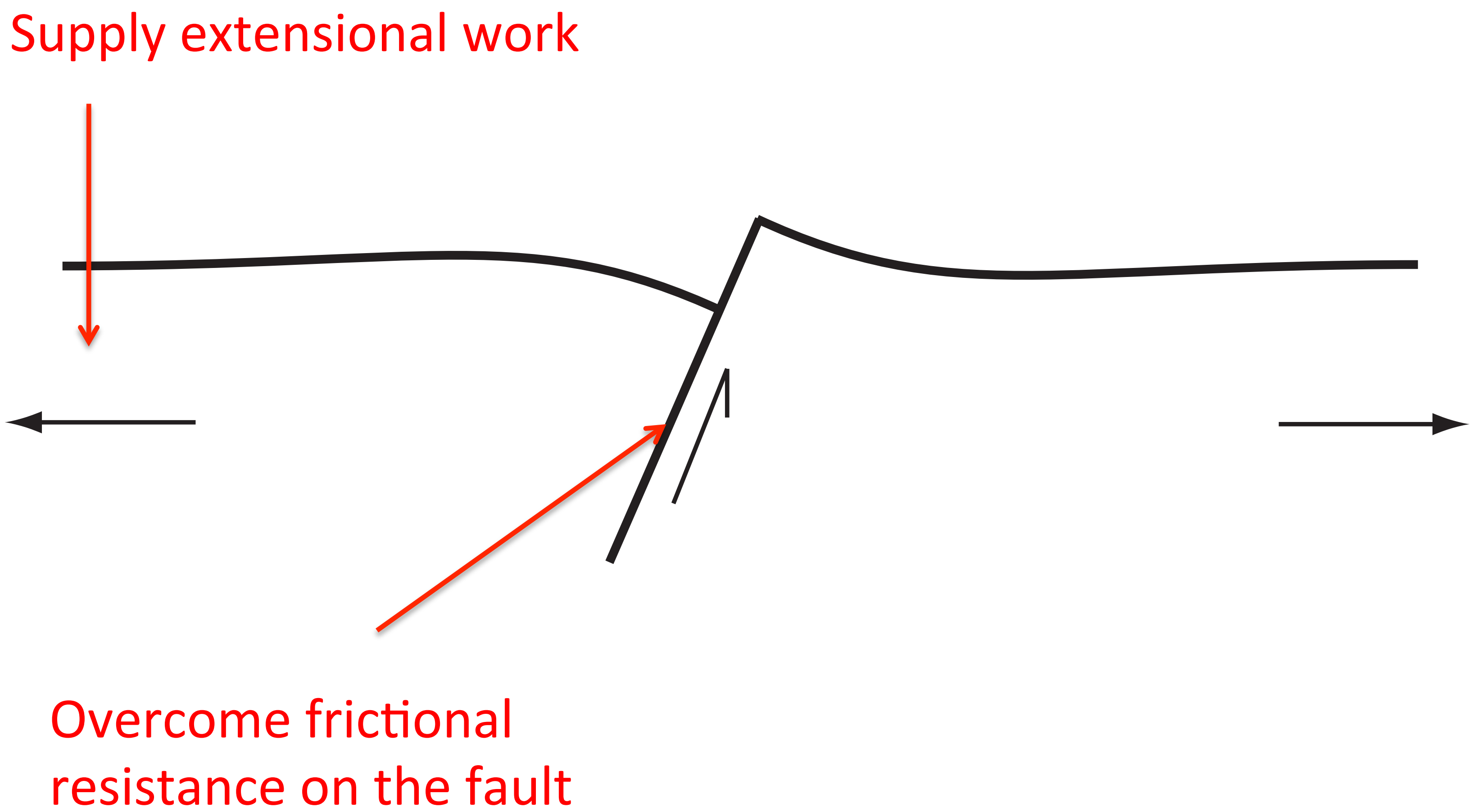
Force balance on a growing normal fault

How to keep a normal fault active ? [*Forsyth*, 1992]

Supply extensional work

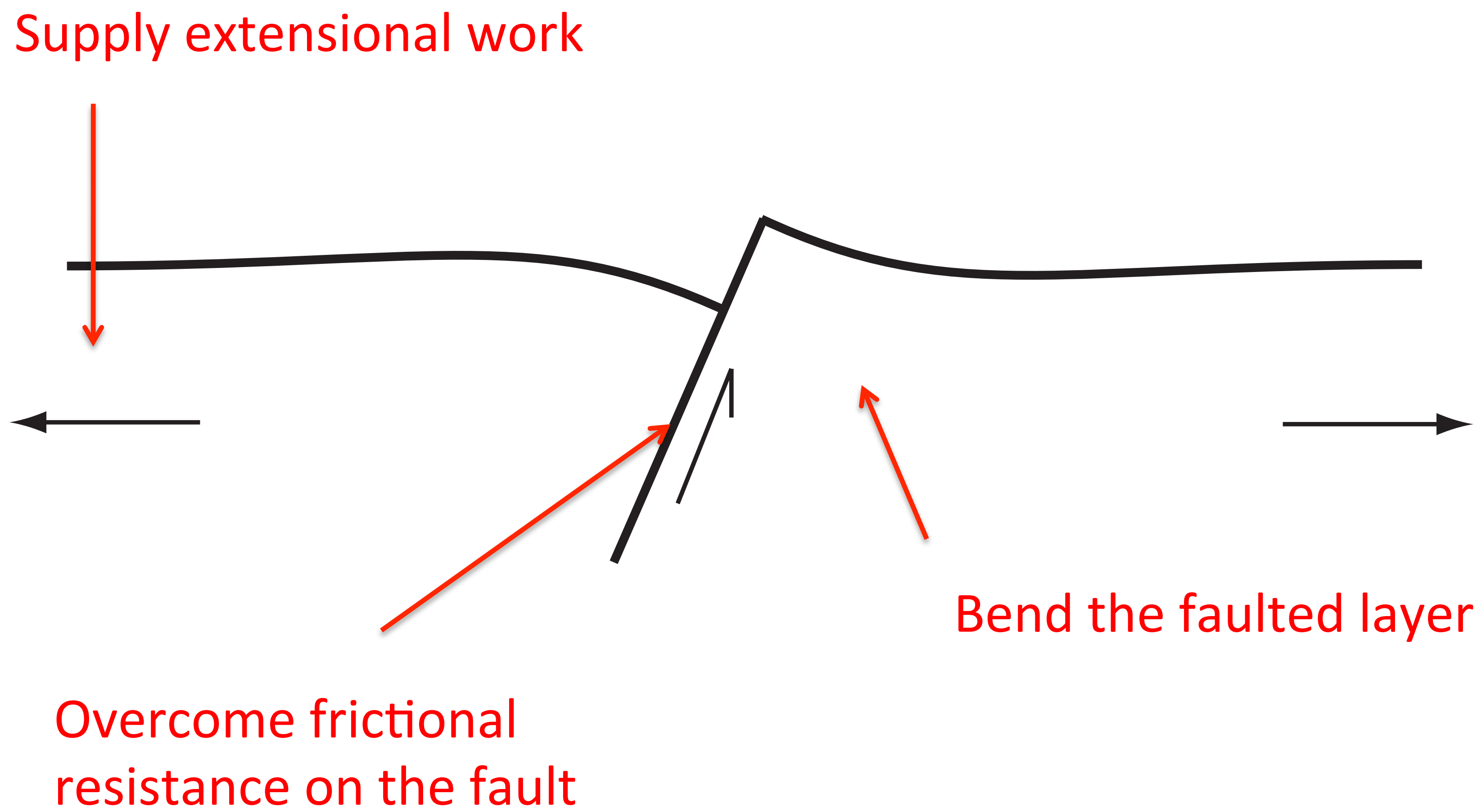
Force balance on a growing normal fault

How to keep a normal fault active ? [*Forsyth*, 1992]



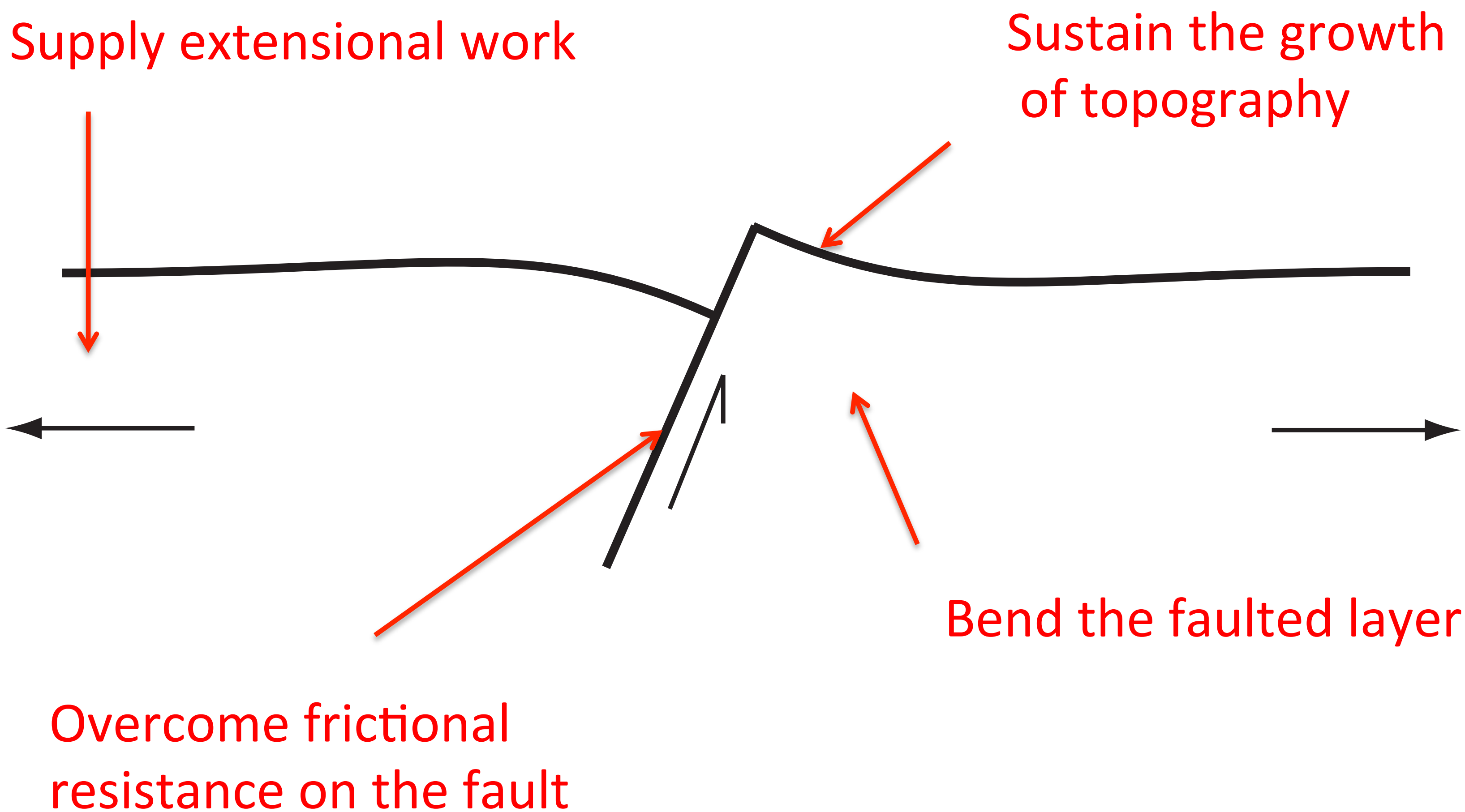
Force balance on a growing normal fault

How to keep a normal fault active ? [*Forsyth*, 1992]

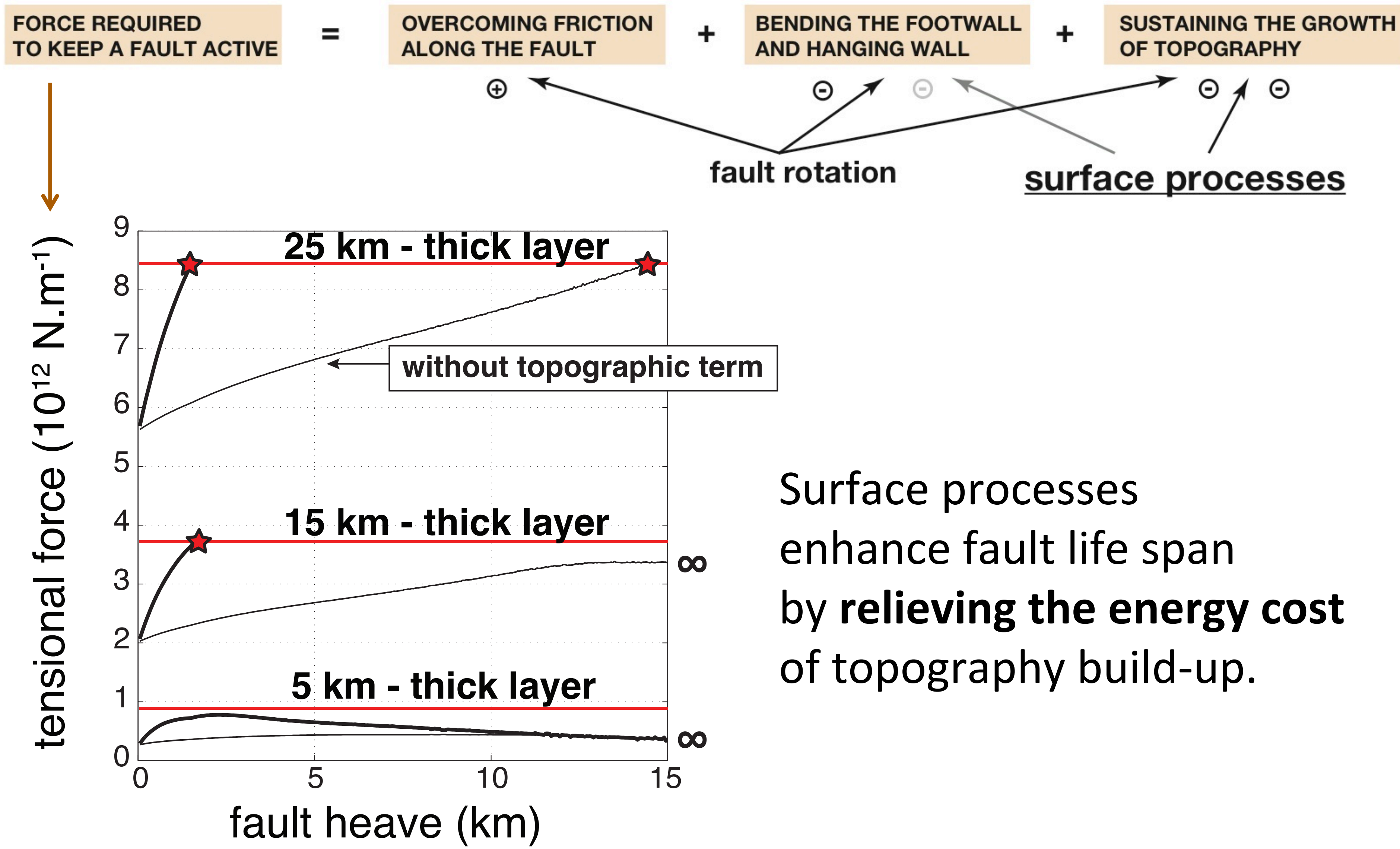


Force balance on a growing normal fault

How to keep a normal fault active ? [*Forsyth*, 1992]



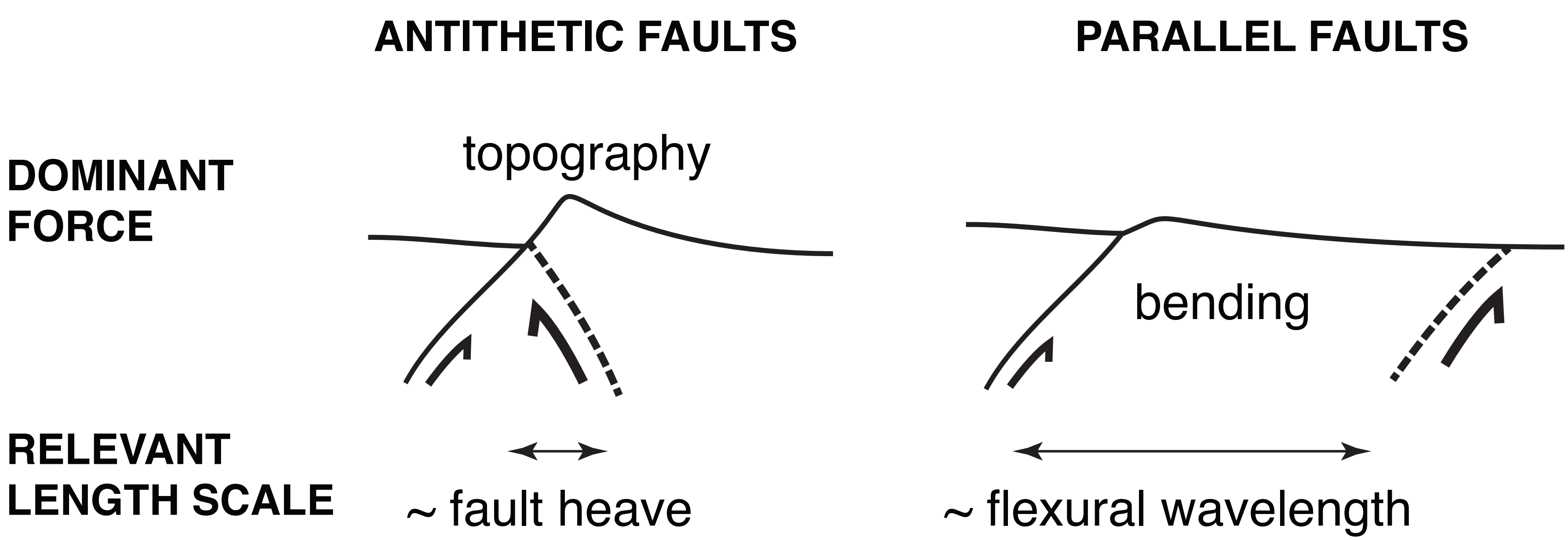
Topographic forcing on fault life span



Surface processes
enhance fault life span
by **relieving the energy cost**
of topography build-up.

Implications for the geometry of the 2nd fault

Topography build-up favors the formation of an **antithetic second fault** in the vicinity of the initial fault.



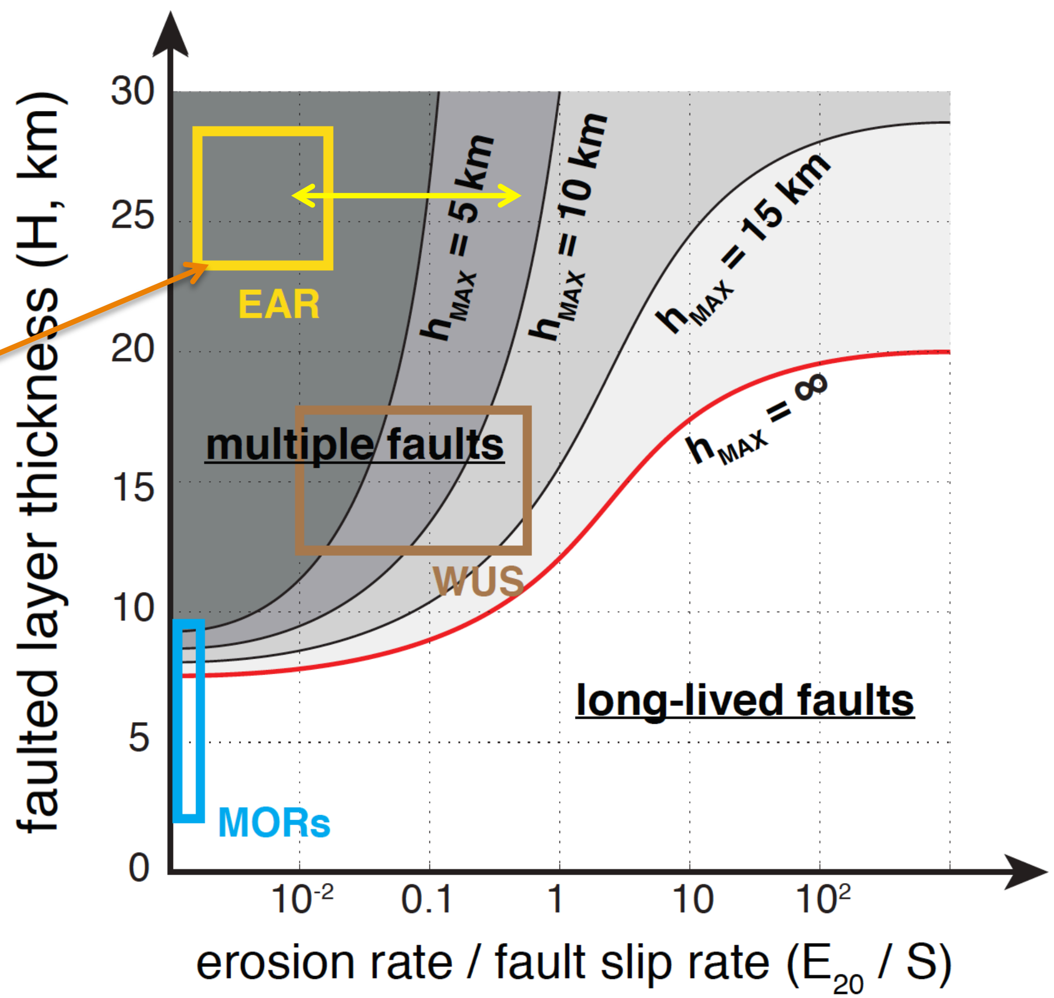
When **surface processes suppress topography**, internal **bending** controls the location and geometry of the 2nd fault.

Implications for rift dynamics

Surface processes **enable the large offsets (10+ km)** observed on major range-bounding normal faults.

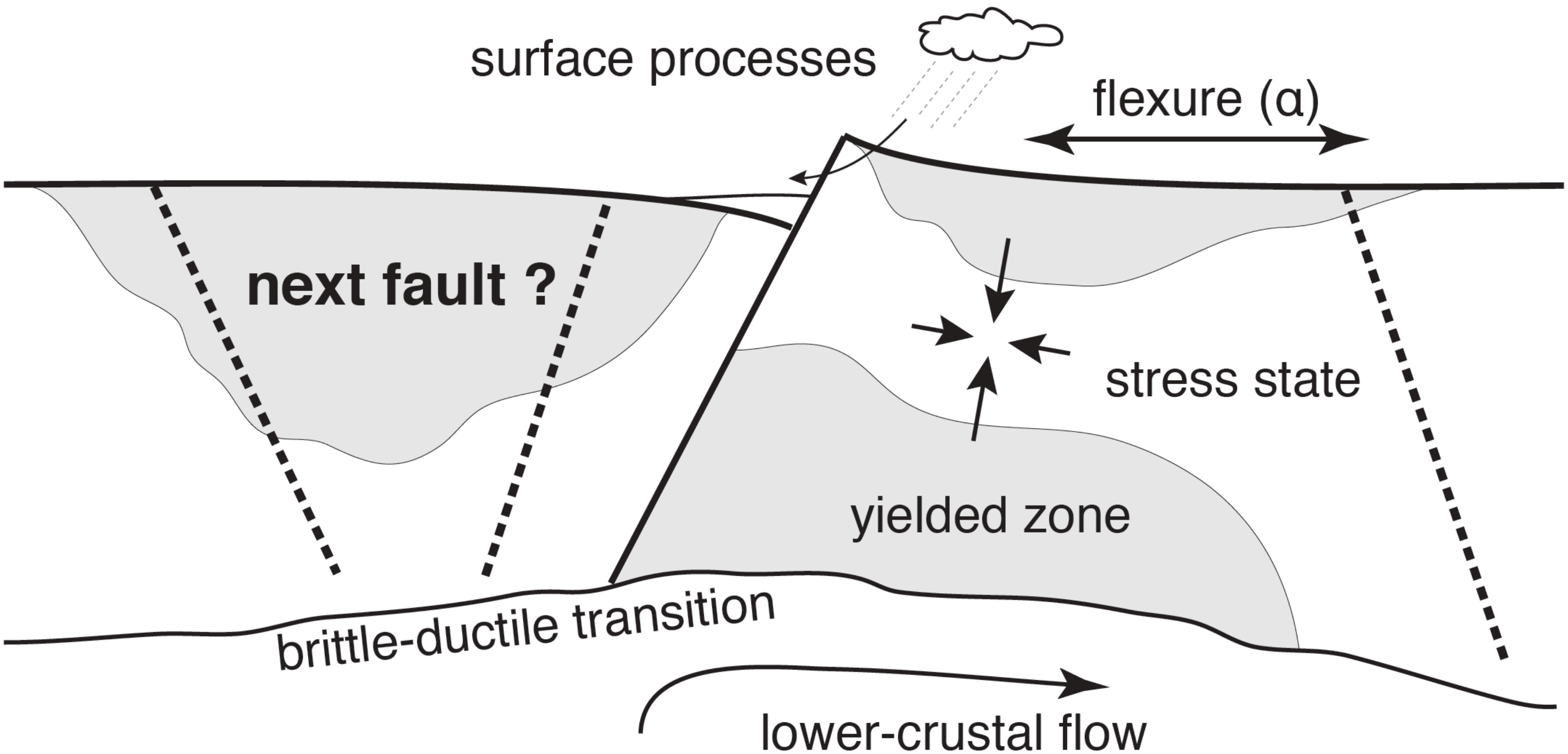
(These would otherwise be difficult to achieve in 15 km-thick brittle upper crust)

Rwenzori Mountains (Uganda)



Future directions

- **Top-down** vs. **bottom-up** controls on rift dynamics ?



- Improved models of **sediment deposition** for load redistribution
- **Model, meet data**: mechanical vs. geomorphological observables