Sediment Supply to Rivers

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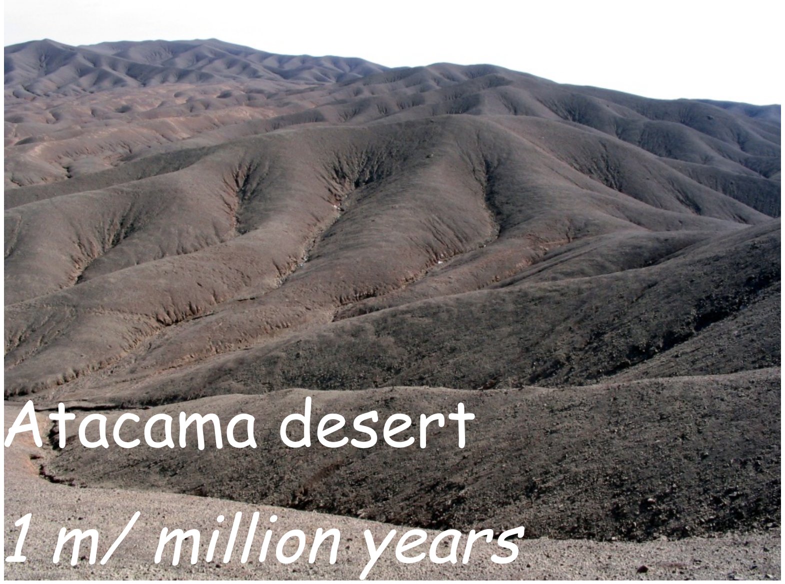
S 2 S N U

Coastal Range, Taiwan

5000 m/ million years

Oregon Coast Range

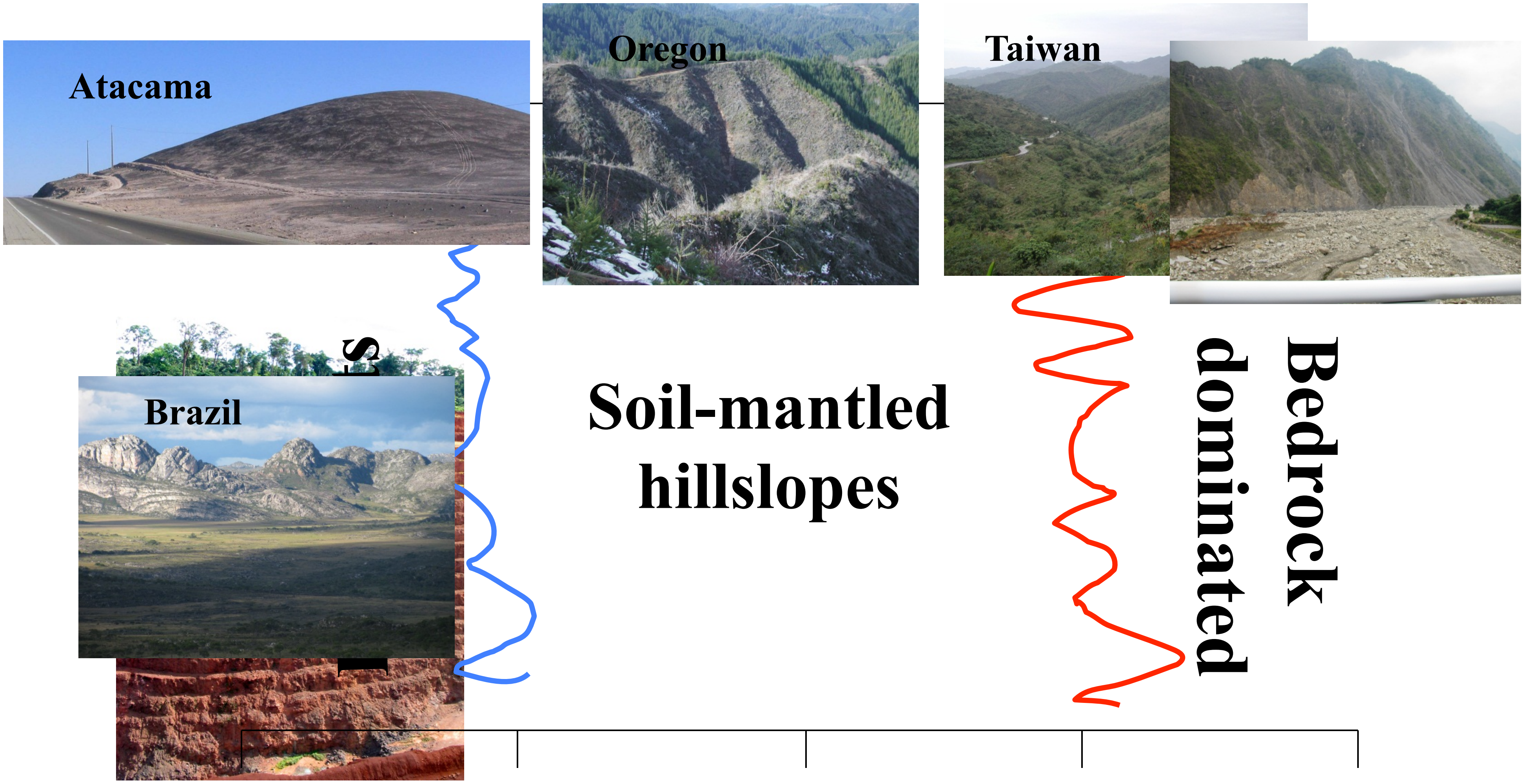
100 m / million years



Atacama desert

1 m/ million years

Brazil, quartzite 5 m/million years, schist 9 m/million years



Soil-mantled hillslopes

Bedrock dominated

0.001 0.01 0.1 1 10

Uplift or channel incision rate (setting landscape erosion rate)

mm/yr

Primary Methods :

direct
↓
inferential

- 1) ***direct measurement on hillslopes*** (landslide inventories, creep measurements, surface erosion pins and troughs, topographic surveys and construction of sediment budget) (1 to 100 years)
- 2) ***local cosmogenic nuclide measurement*** (of exposed rock, bedrock at base of soil, sand in channels) (typically 10^3- $10^{5 \text{ years}}$)
- 3) ***sediment load of streams by direct sampling or in reservoirs*** (most relevant to hillslopes in steep catchments with little or storage; spatially averages) (1- 10's years
- 4)***catchment cosmogenic nuclide measurement*** (of exposed sediment in channels) (typically 10^3- $10^{5 \text{ years}}$)
- 5) ***thermochronometry*** (rock samples and detrital samples; larger spatial scale, longer time frame) ($10^{6 \text{ years}}$)

Little data on grain size entering channels

Rarely are measurements made to test mechanistic theories

Sediment supply, erosion, uplift, exhumation, and denudation

Surface Uplift = Rock Uplift – Exhumation

(relative to geoid) (relative to geoid) (relative to surface)

Common language: Erosion = Denudation = Exhumation

If Rock uplift is exactly balanced by erosion, no surface uplift = steady state landscapes

Sediment supply is Erosion (L/t) x surface area.

Little is know about grain size….

England and Molnar, 1990,
Geology

Terminology

Weathering-limited landscapes:

erosion rate is set by the rate at which bedrock breaks down to mobile material

Detachment- limited landscapes:

erosion rate is limited by resistance to erosion of mobile material

Transport-limited landscapes:

erosion rate is limited by the rate of transport of readily transportable material

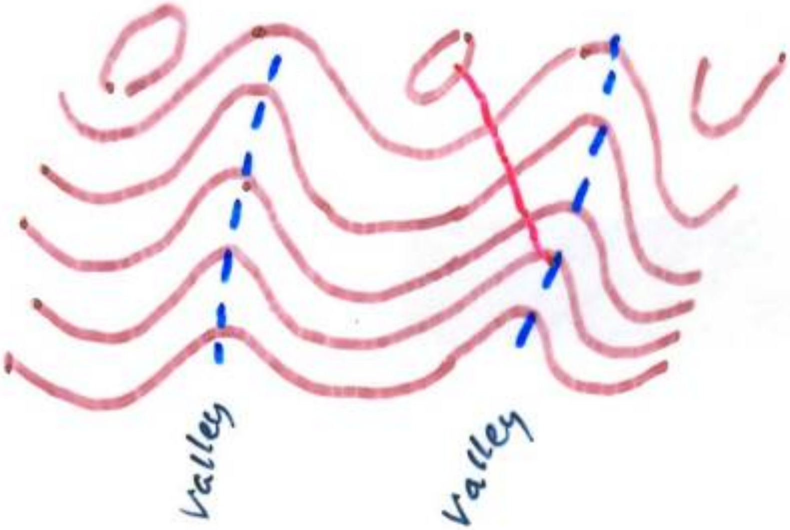
What controls sediment supply to rivers in uplands catchments?

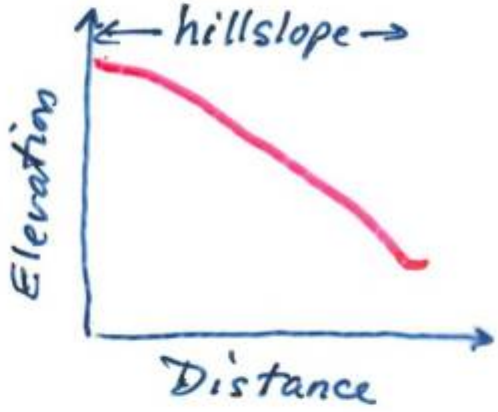
Key concept- *the hillslopes and channels are coupled*.

Channel incision ultimately drives hillslope erosion, but transients happen: for example

- pulses of channel incision
- climate shifts that alter topographic-climate erosion relationship (some call this “erosional efficiency”)
- exhumation of lithology of varying resistance to erosion

What's a hillslope?

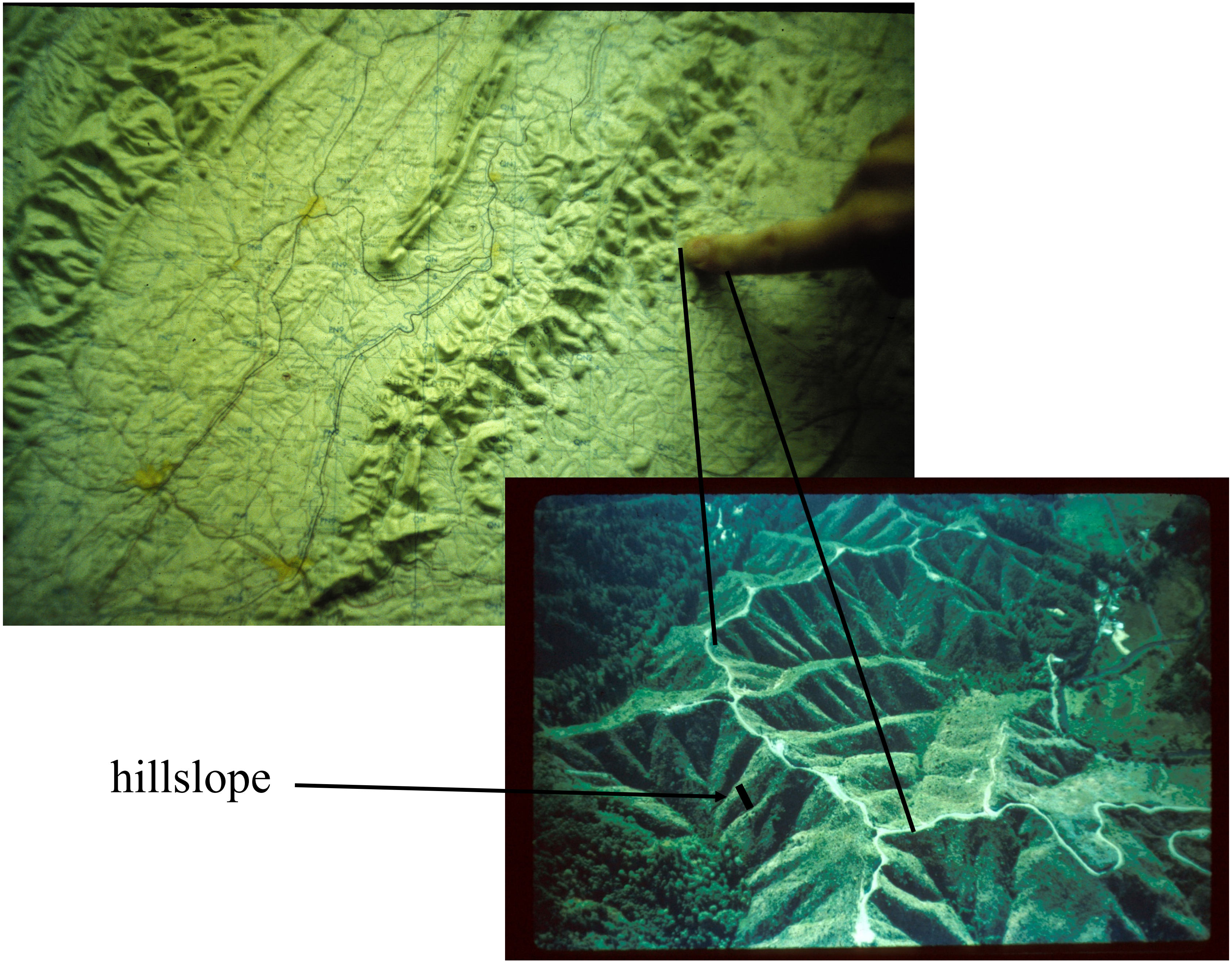


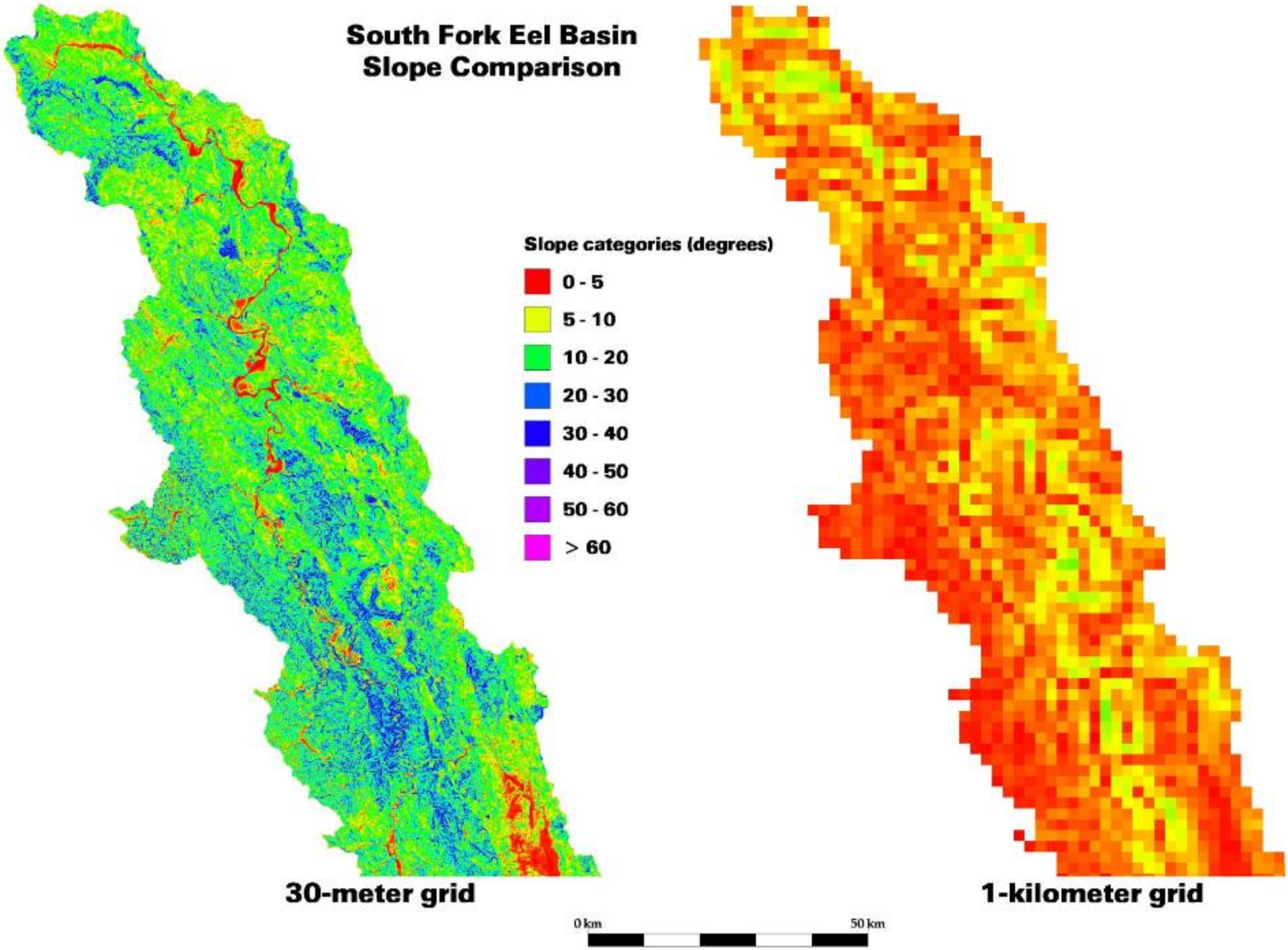


Valley = Convergent topography

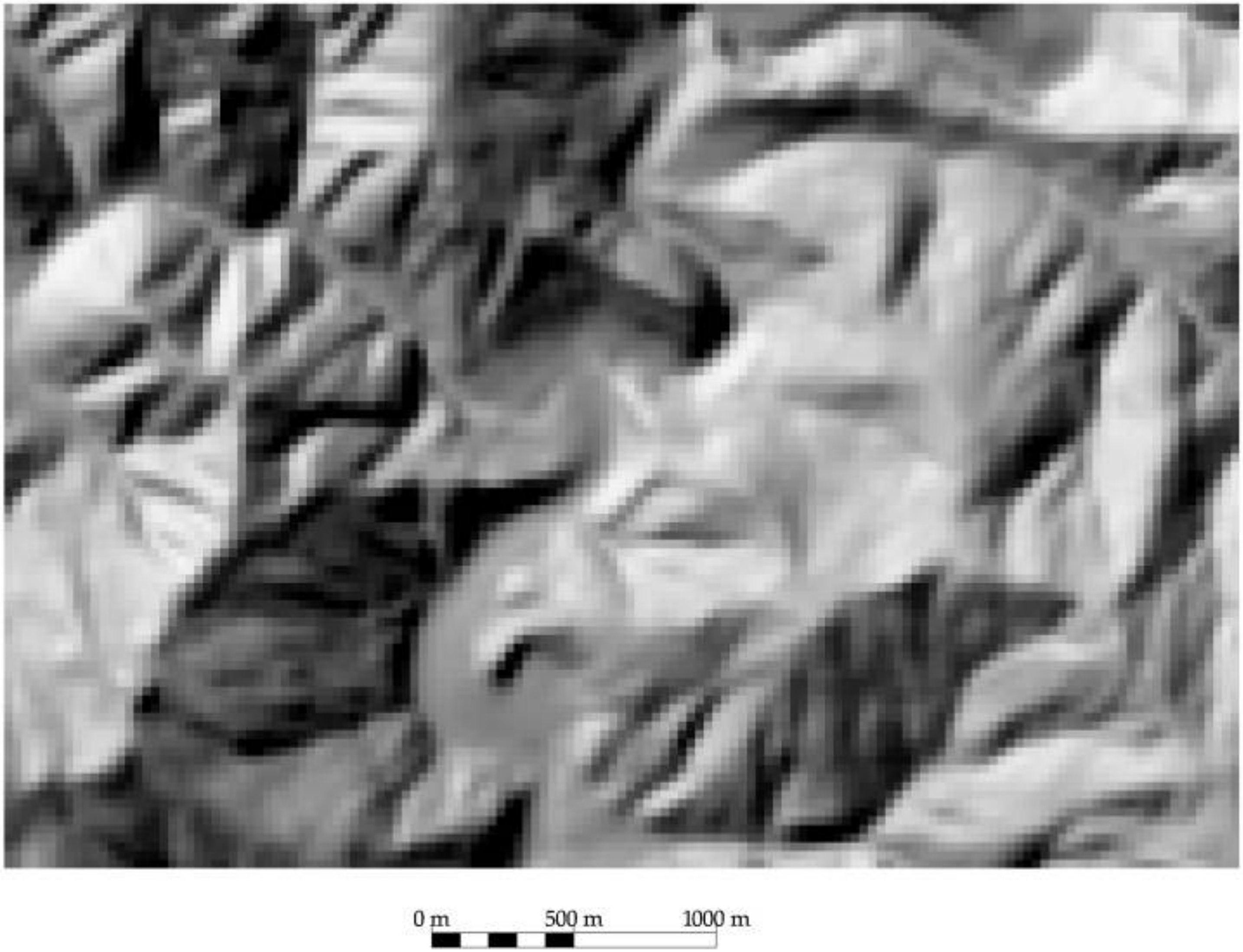
Hillslope = Planar and divergent topography bordering a valley (e.g. Dietrich & Montgomery, 1998)

= Landform that has statistically planar or divergent topography


hillslope

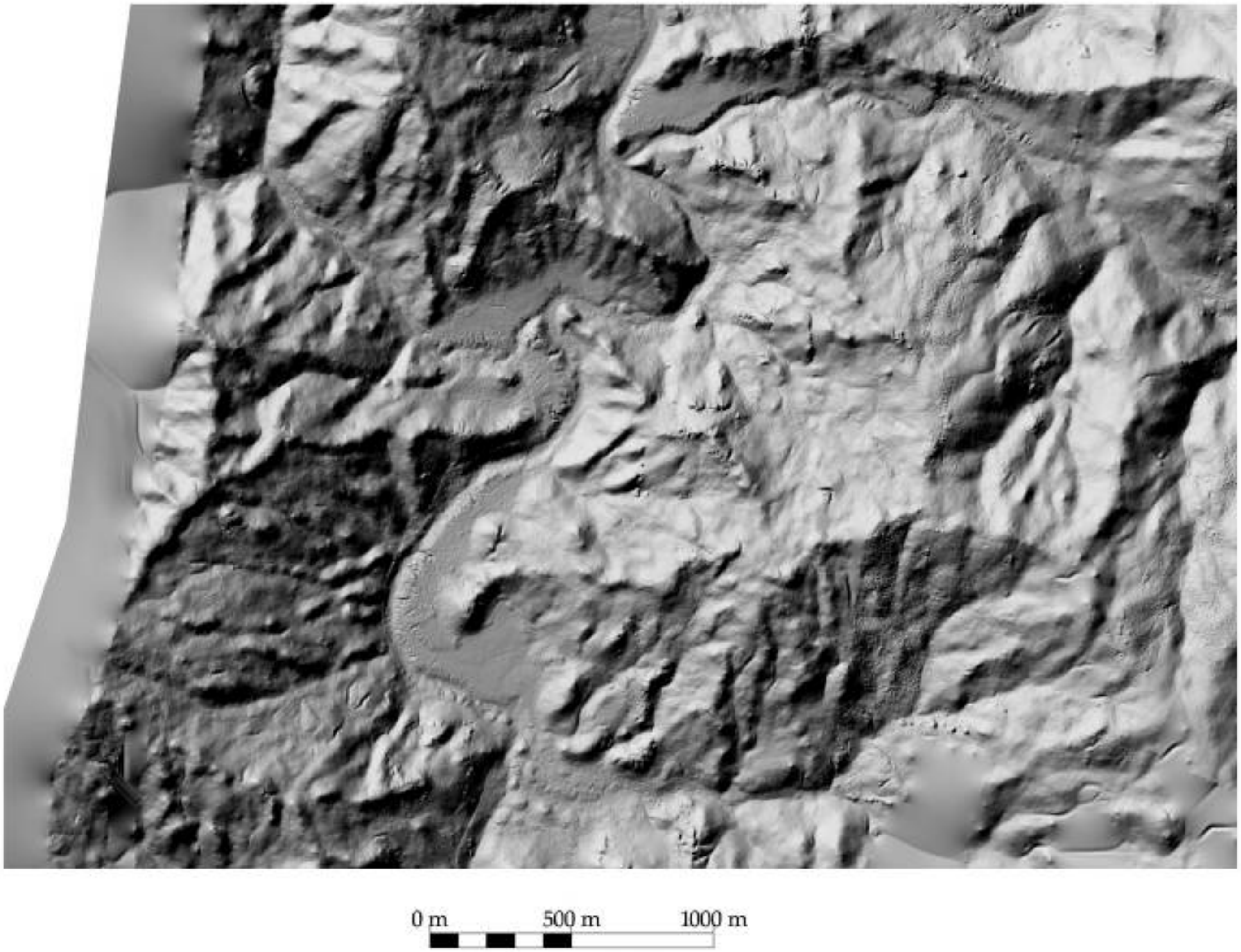

South Fork Eel Basin
Slope Comparison
Slope categories (degrees)
0 - 5
5 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
> 60
30-meter grid
1-kilometer grid
0 km
50 km

Eel River (detail), CA
Shaded Relief, Cell Size: 30qm
09/04/02, Source: USGS



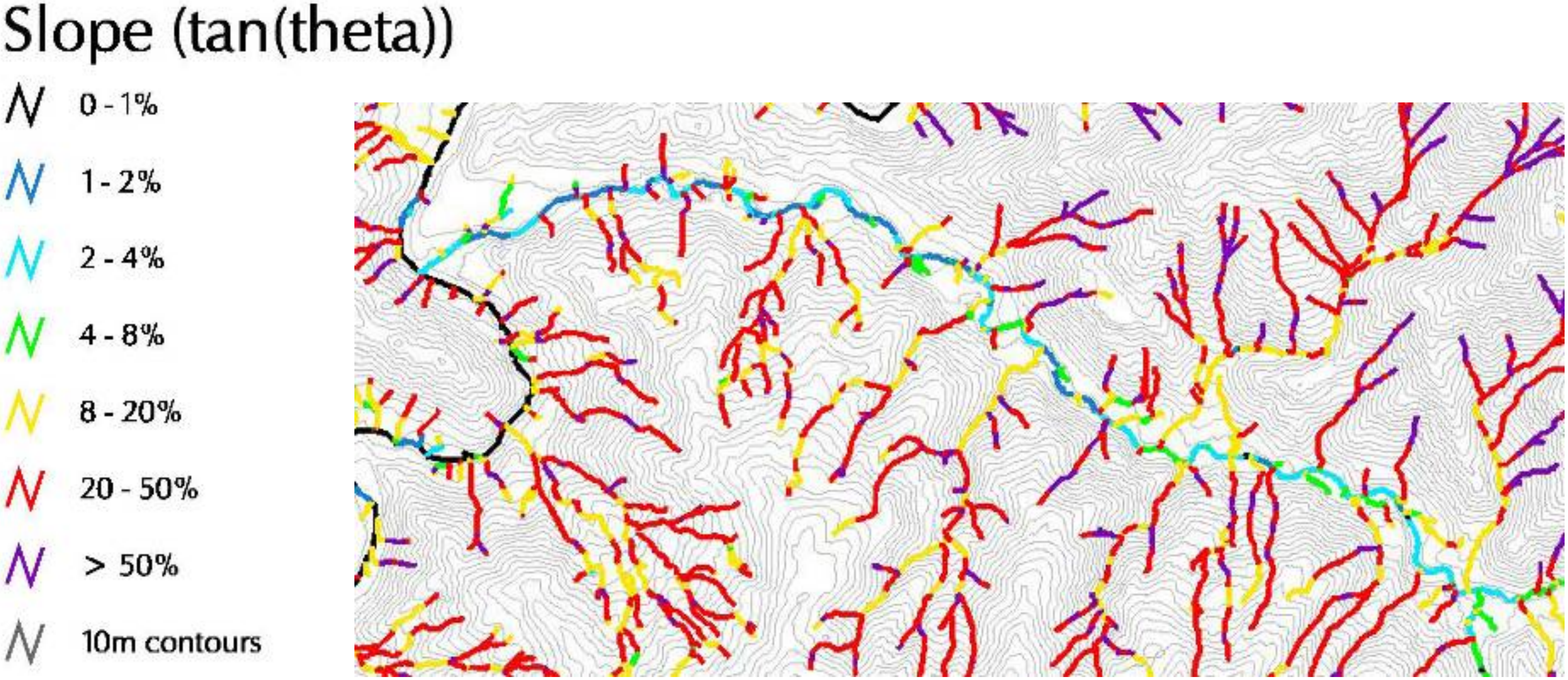
Scale: 1 to 20000

Eel River (detail), CA
Shaded Relief, Cell Size: 2m
09/04/02, Source: Lidar



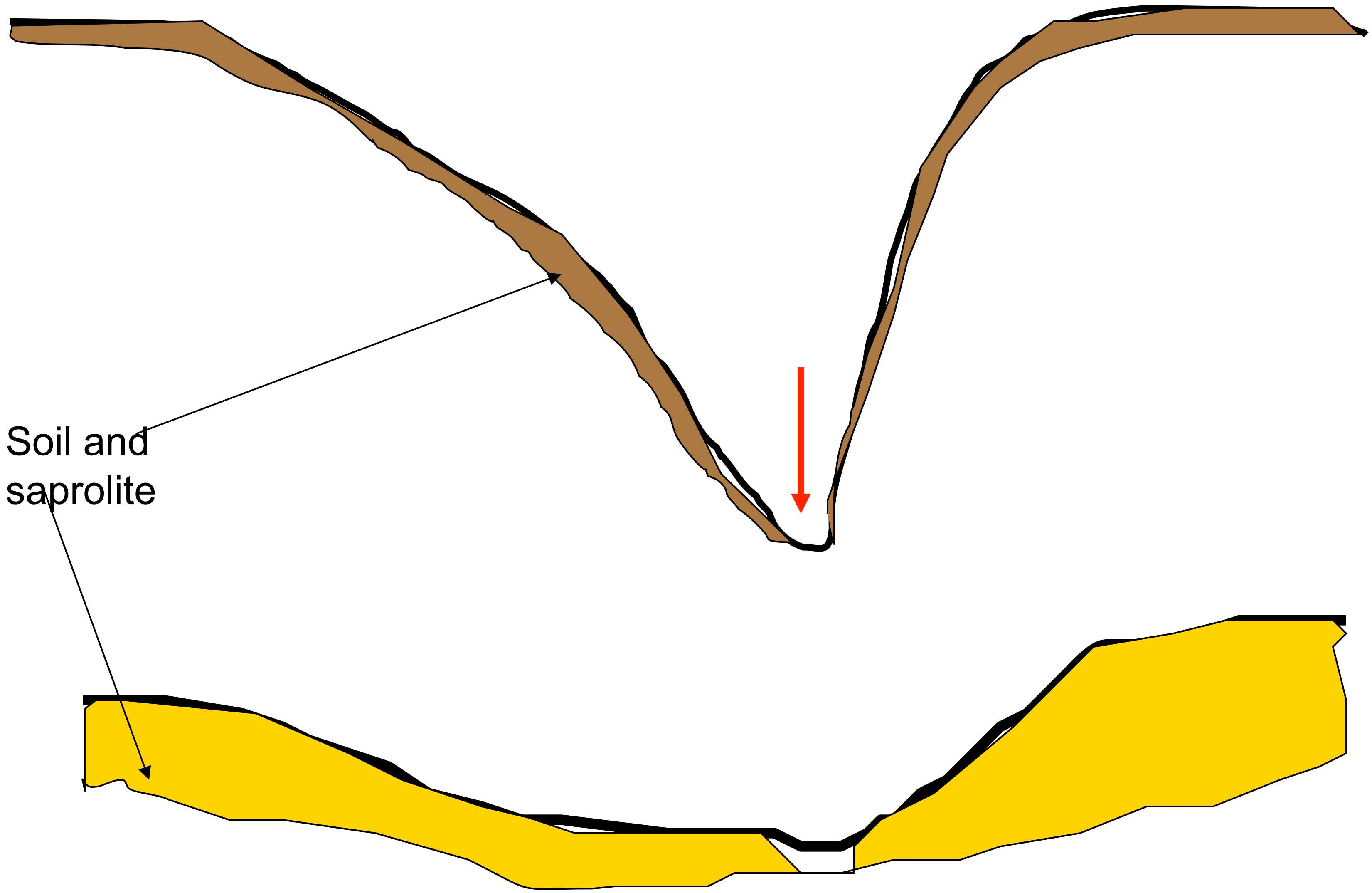
Scale: 1 to 20000

A channel is a drainage feature with distinct banks.



Elder Creek channel slope from ALSM data

Channel incision drives hillslope erosion: it is the boundary condition



Cross section across a ridge and valley. For identical climate, vegetation, precipitation, and rock type, the upper section is experiencing higher channel incision rates and, with that, coarser, fresher material is entering the channel, and at a higher rate.

What controls erosion rates?

- “Tectonics” (U)
- “Topography” (T)
- “Climate” (C)
- “Lithology” (L)
- “Landuse” (Not considered here)

E = F (C,U,L,T) ?

NOT THIS!

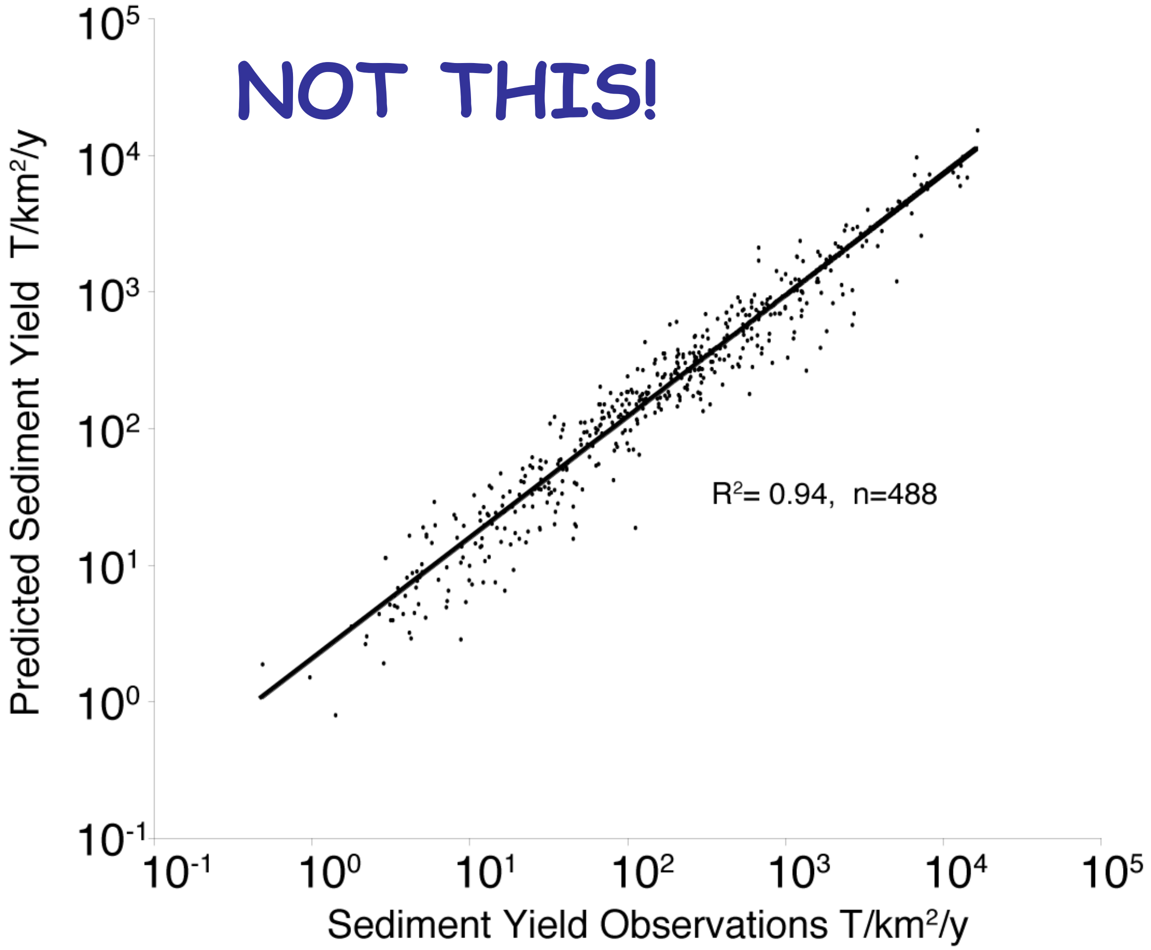


Fig. 10 Syvitski & Milliman

Qs = sediment load (M/t)

ω = a constant

Q = water discharge (km^3/yr)

A = drainage area (km^2)

R = maximum relief (km)

T = basin averaged temperature (in degrees)

I = glacier factor

L = basin average lithology factor

T_E =trapping efficiency of reservoirs

E_h = human influence factor

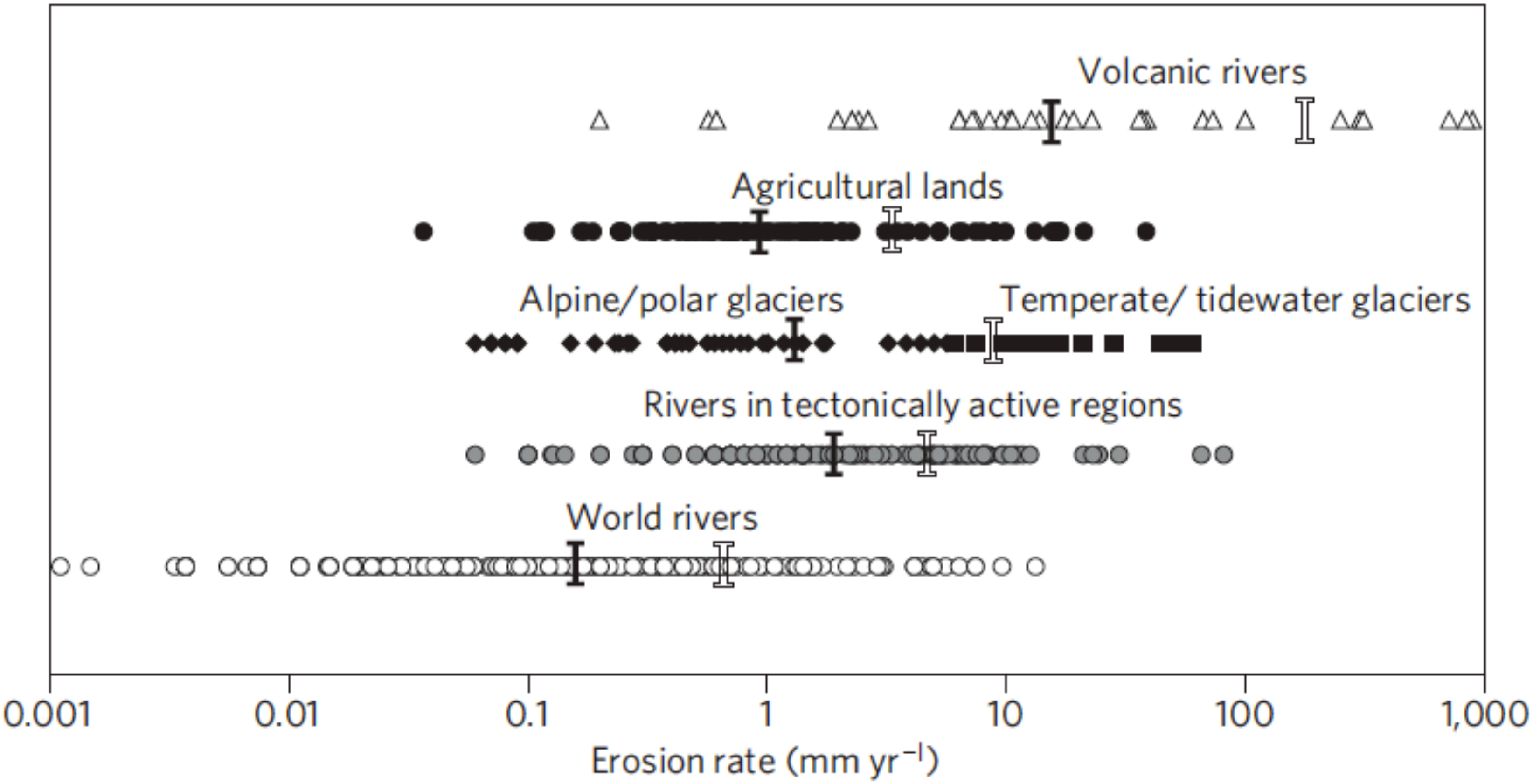
$$Q_s = \omega B Q^{0.31} A^{0.5} R T \quad \text{for } T \geq 2°C$$

$$Q_s = 2 \omega B Q^{0.31} A^{0.5} R \quad \text{for } T < 2°C$$

$$B = I L (1-T_E) E_h$$

Syvitski and Milliman, in press

This is sediment discharge to the ocean- not sediment flux from hillslopes



Koppes and Montgomery Nature Geoscience 2009

“Tectonics”

Active (Whipple (2009: frictional narrow mountain belts; large, hot orogens)

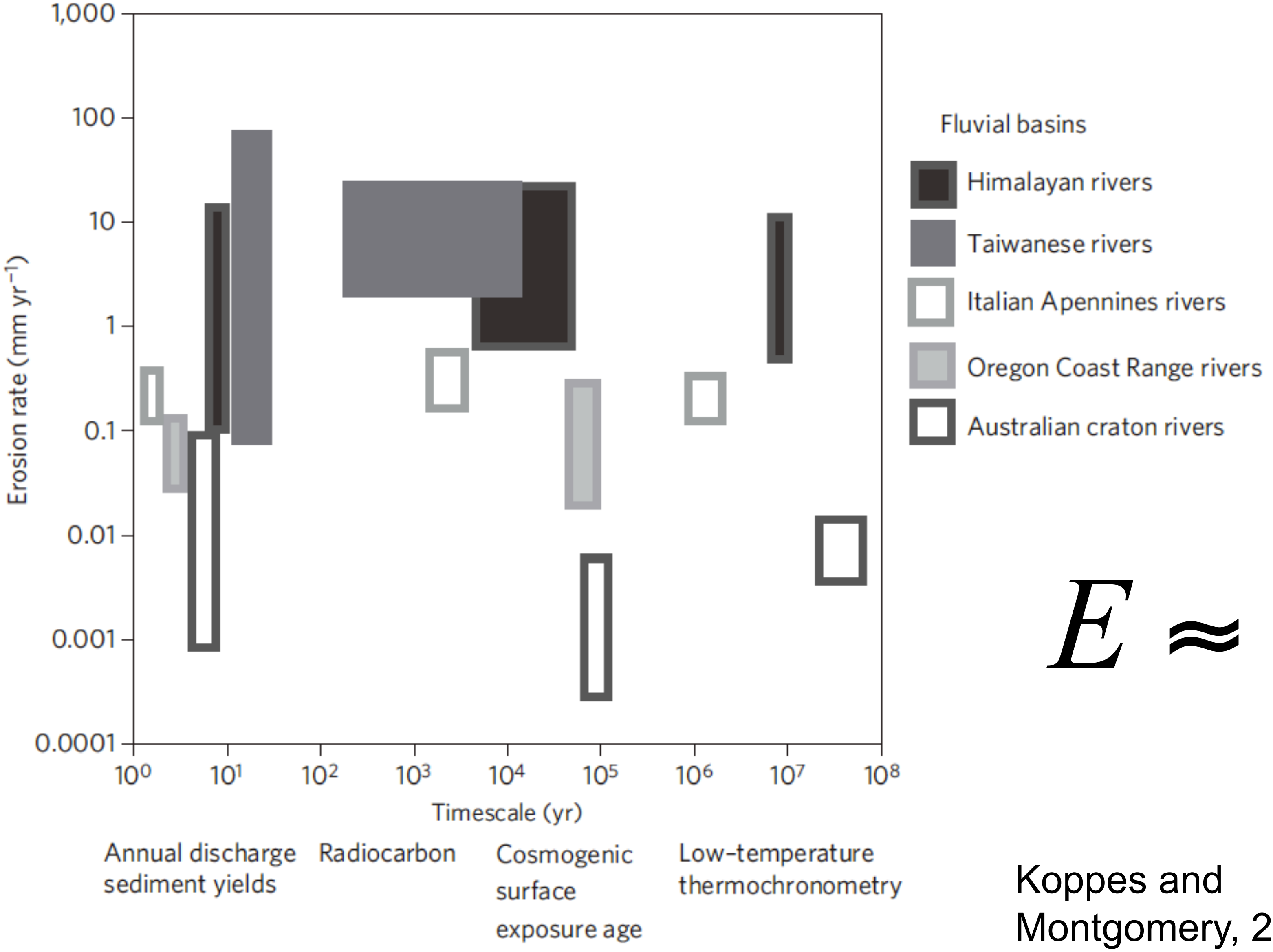
Hyperarid

Inactive

Let’s pick a tectonic setting (rate of uplift) and look for erosional dependency on climate, topography and lithology

Note: “tectonics” could include earthquake-driven erosional events

Active tectonics and erosion



$$E \approx U$$

Koppes and Montgomery, 2009

Active tectonics and erosion

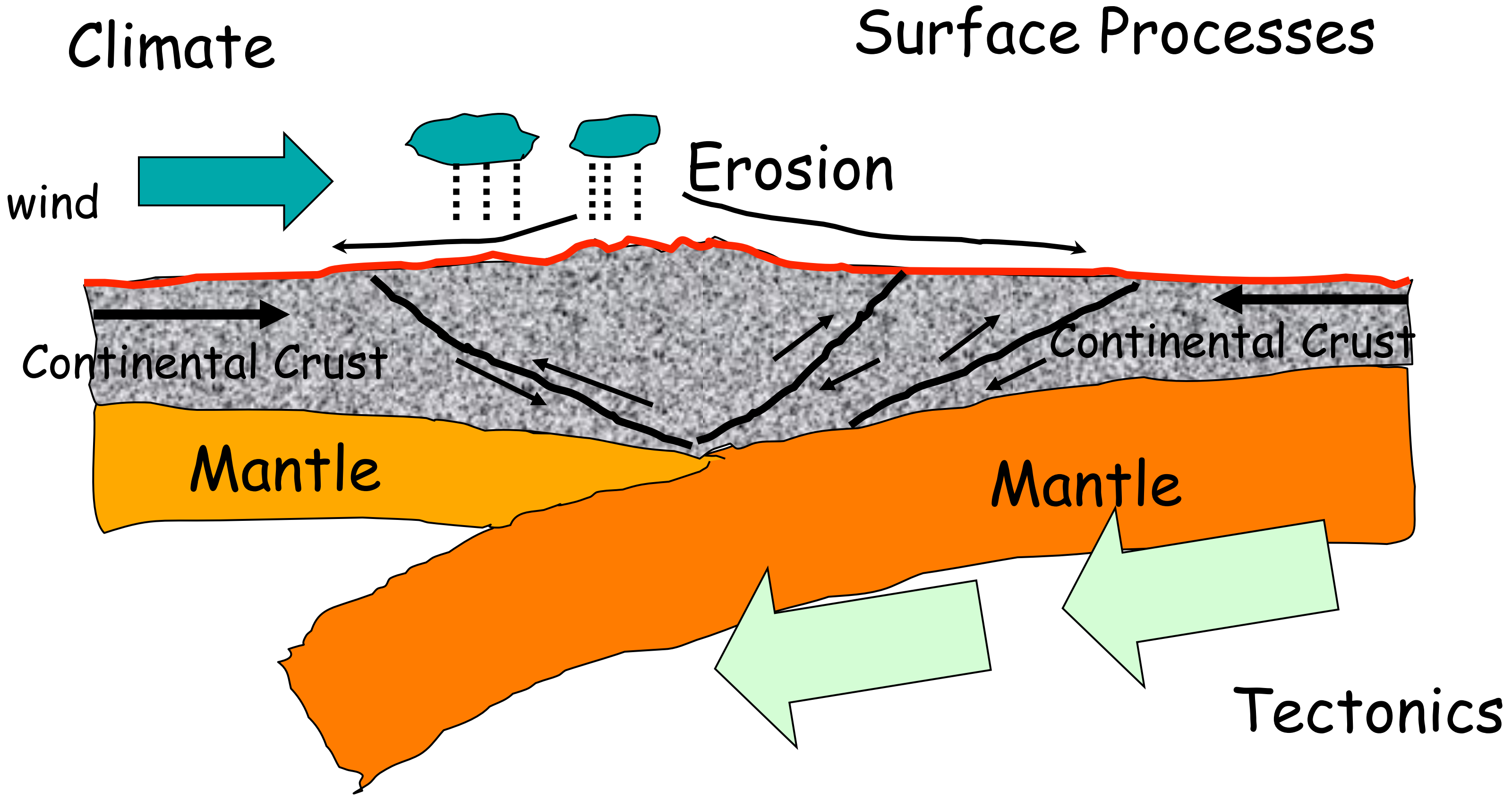
$$E \text{ € } \quad U$$

This interaction may act through precipitation influence on erosion.

hence

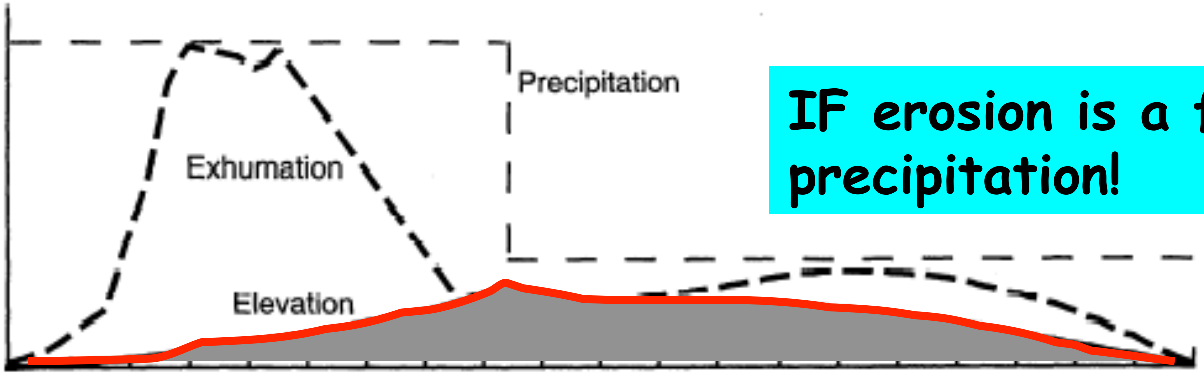
$$E = U = F(C)$$

Linkages among climate, tectonics, surface processes and topography

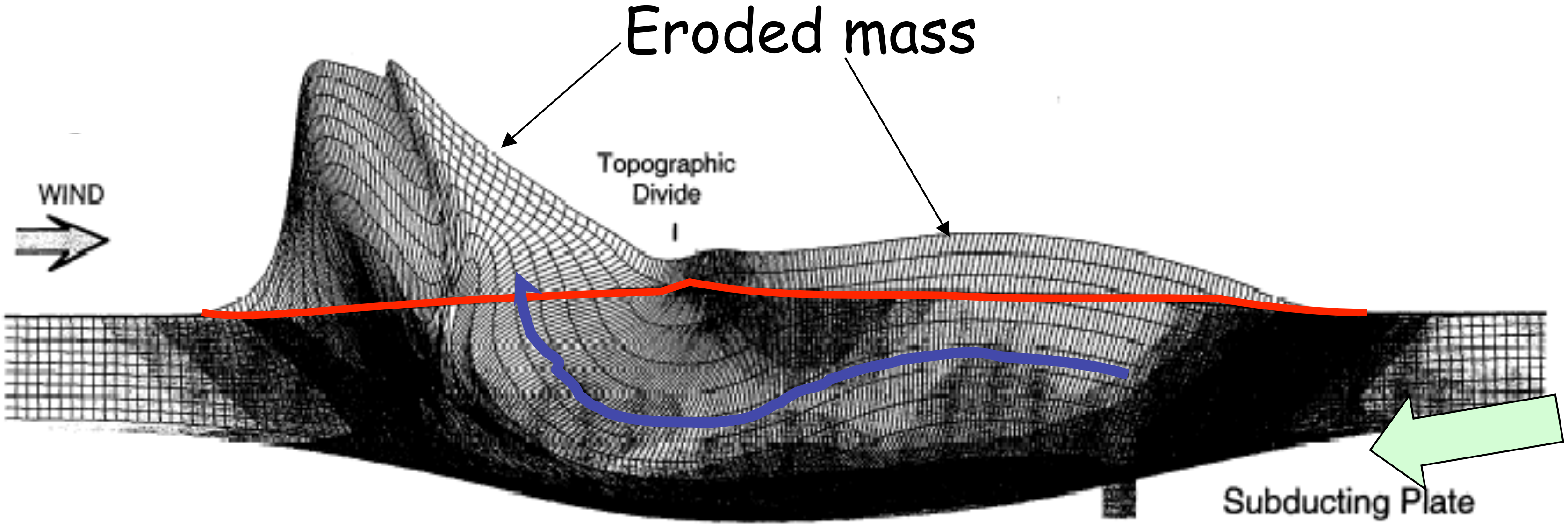


Modified from Willett, 1999

Effect of precipitation-driven erosion on tectonics



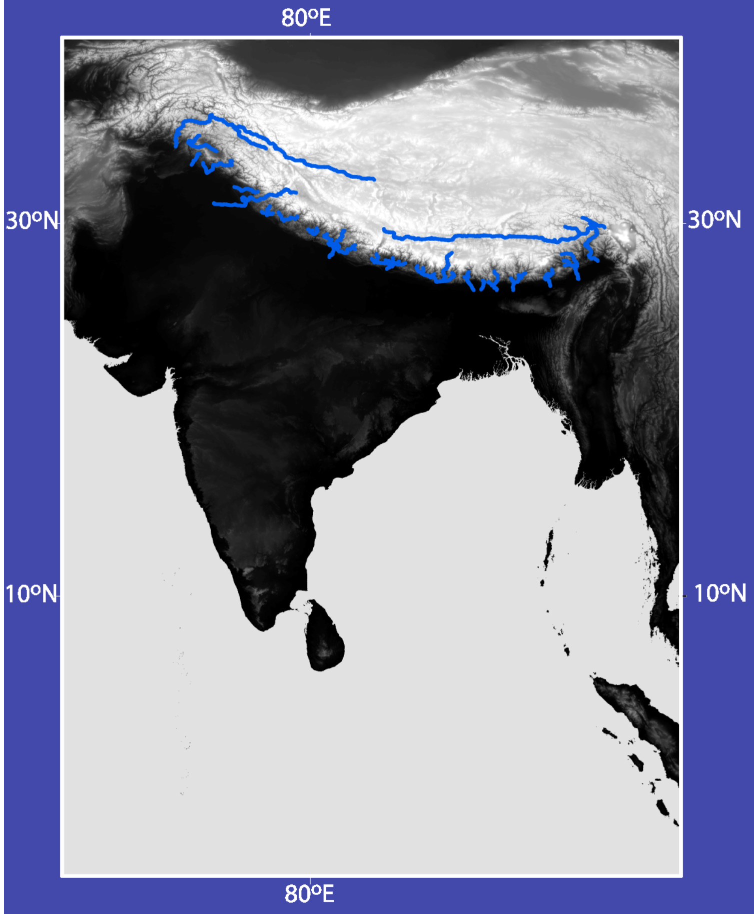
IF erosion is a function of precipitation!

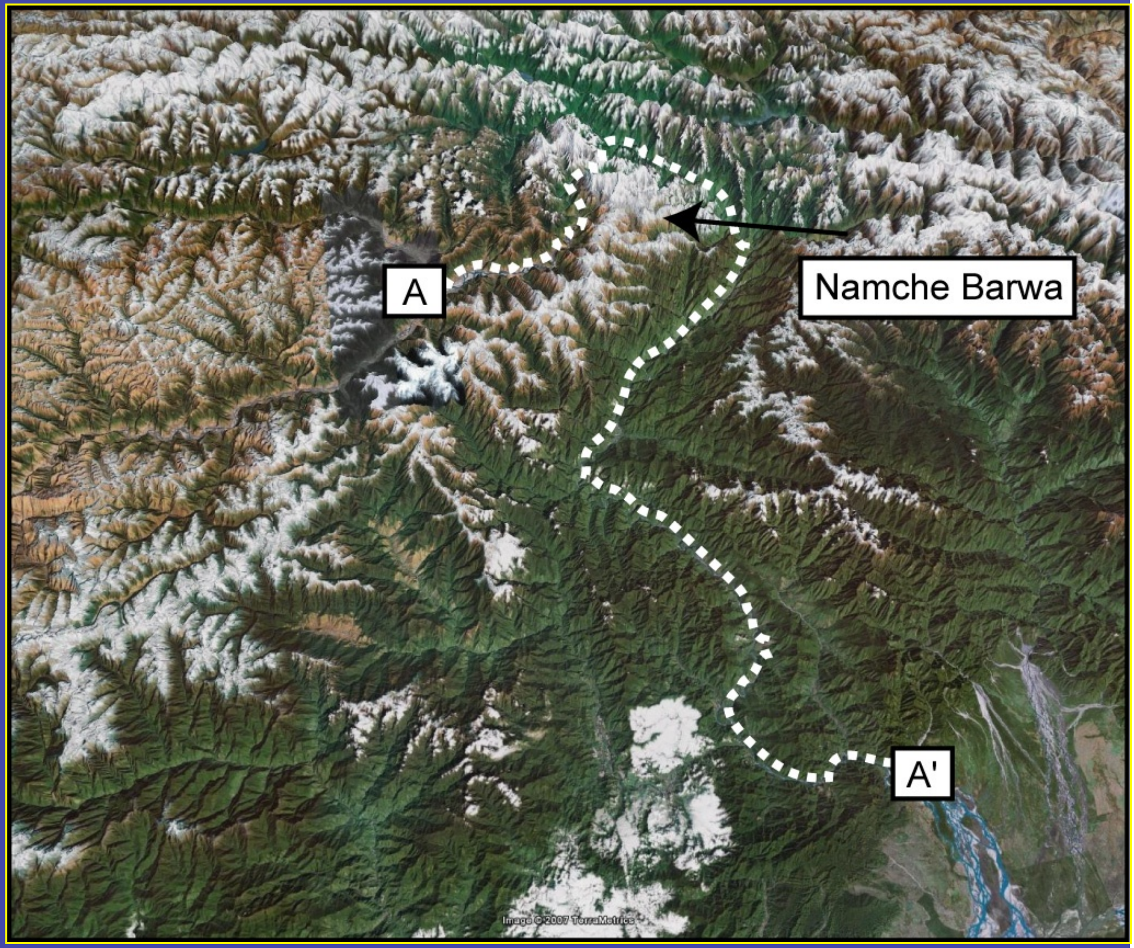


Willett, 1999

The water draws the rock to it.

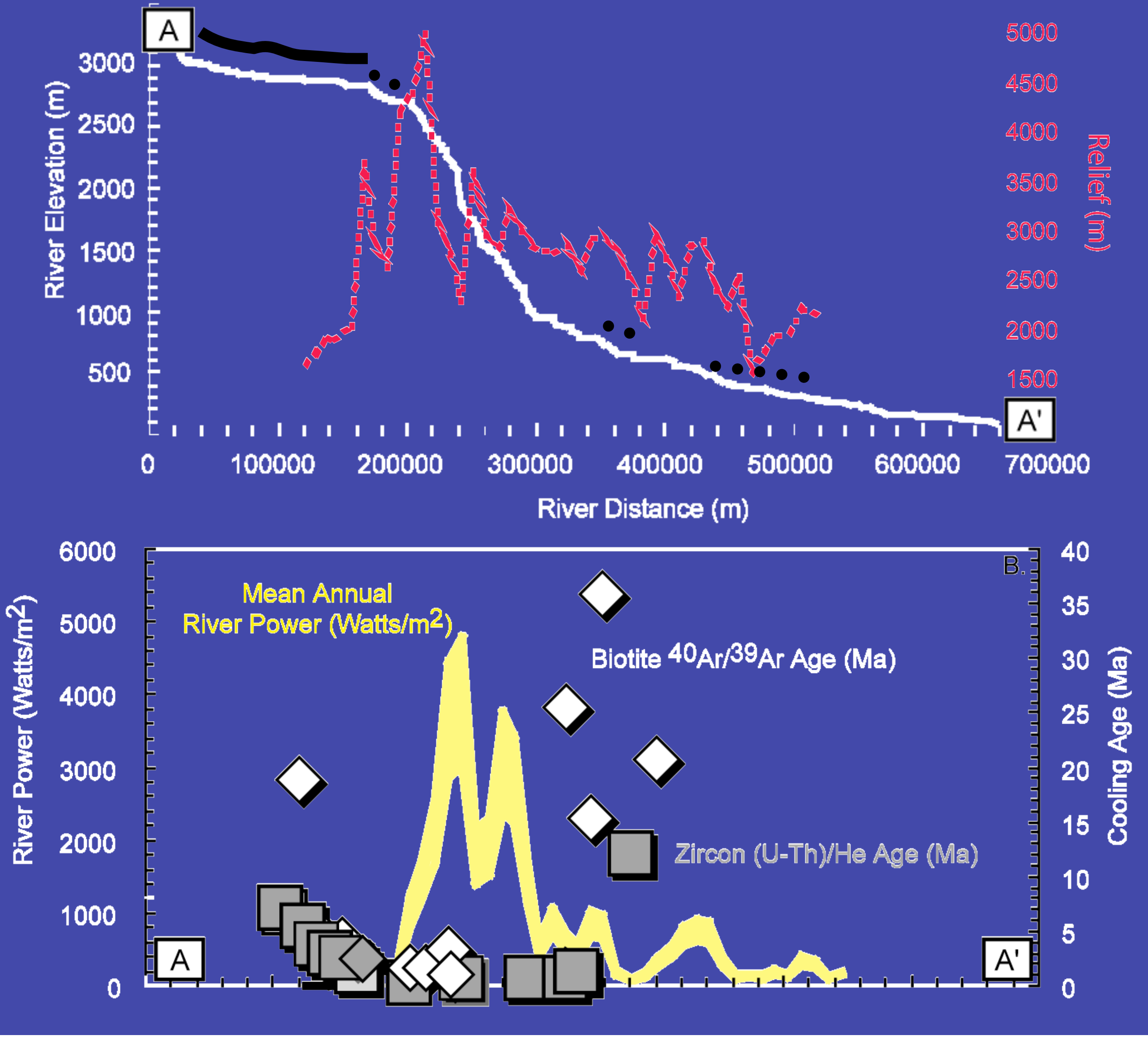
Fluvial Transect Through the Massif



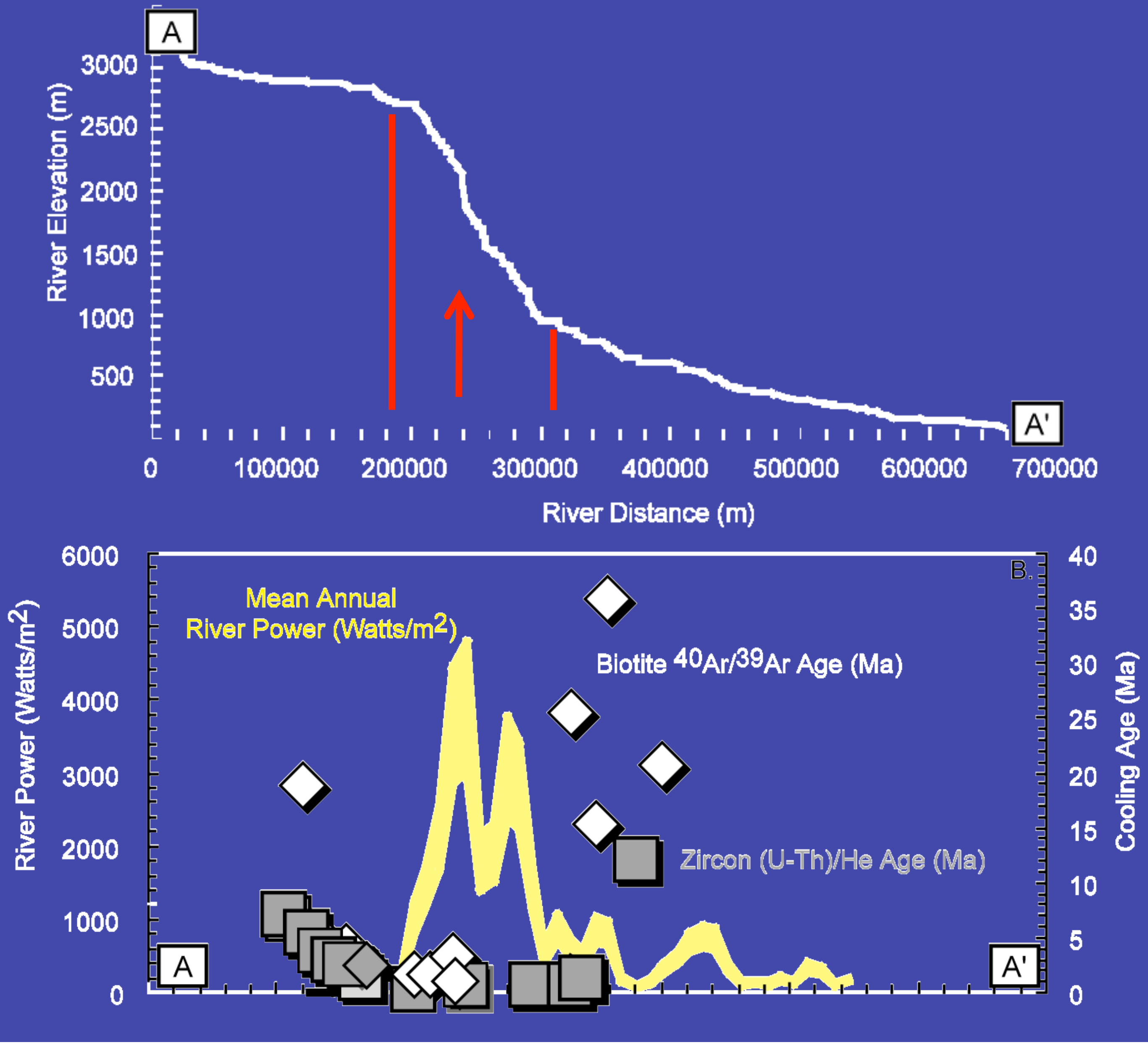


Fluvial Transect Through the Namche Barwa-Gyala Peri Massif

Finnegan, et al. 2008

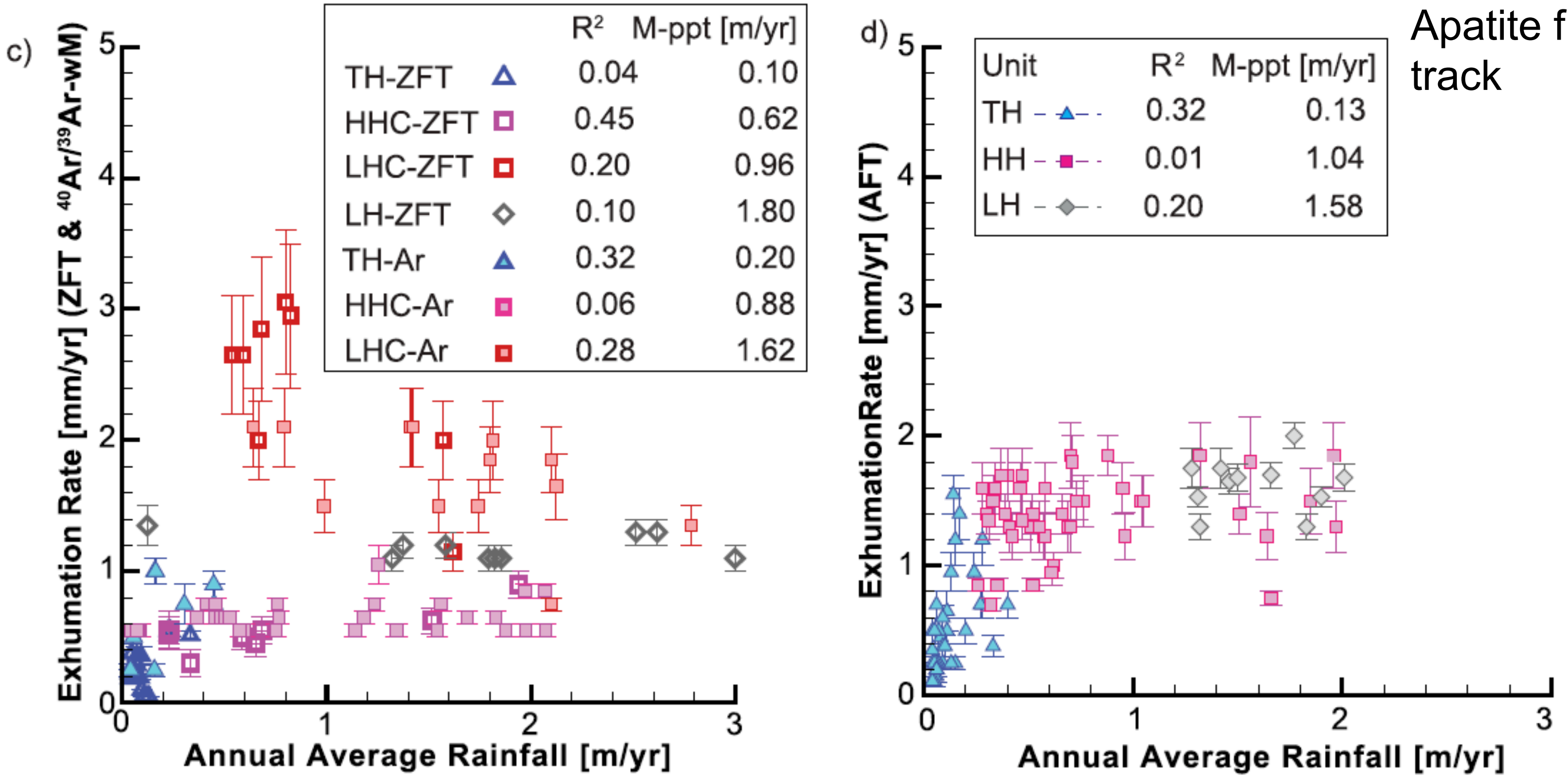


Fluvial Transect Through the Namche Barwa-Gyala Peri Massif



Active tectonics and erosion

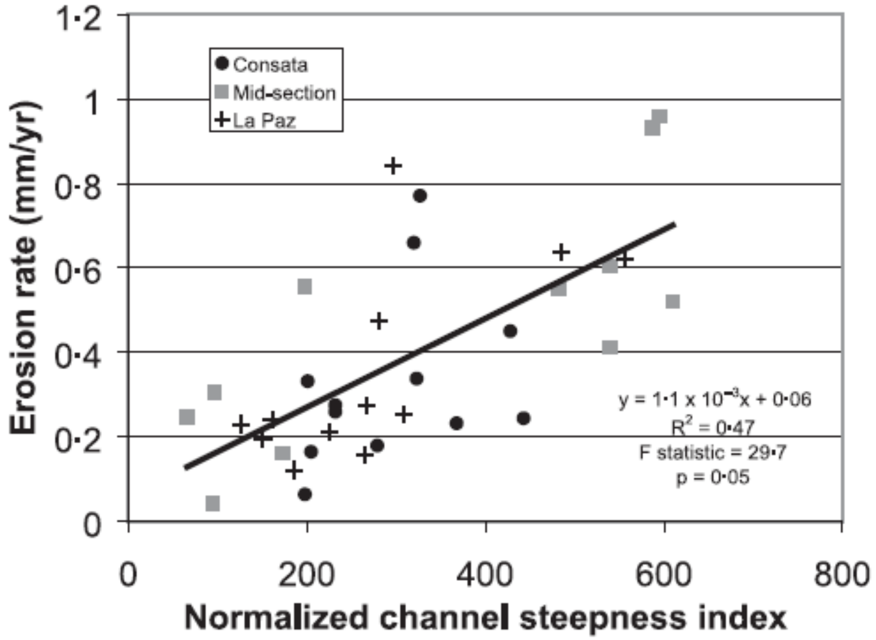
$E \neq F(P)$ **For 1000's to million years time scale**



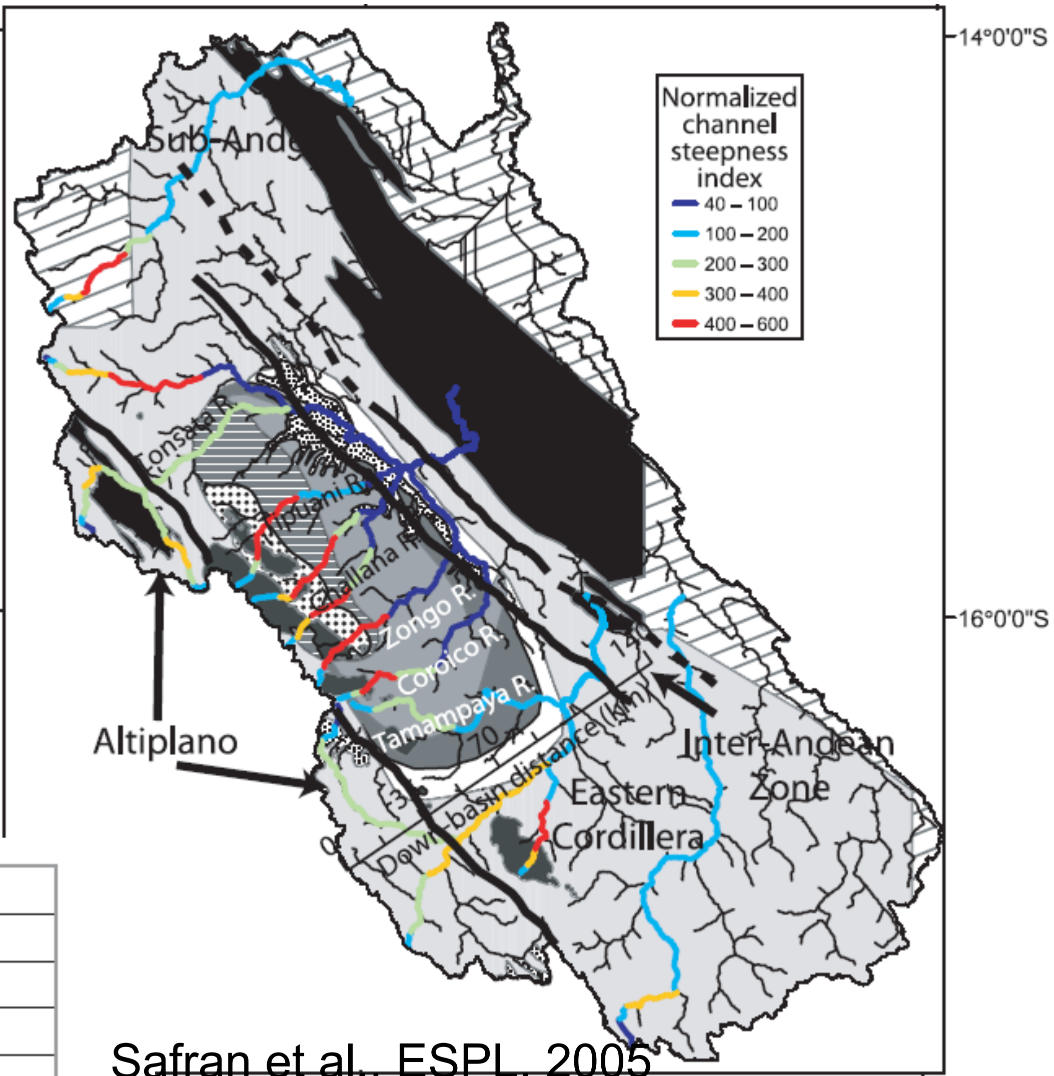
Apatite fission track

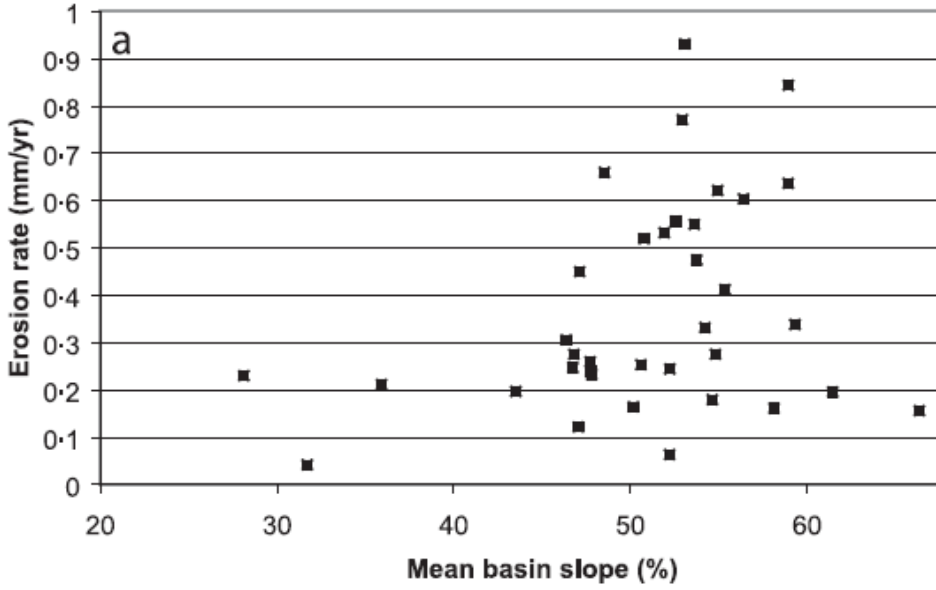
Thiede et al. 2009

ZFT- zircon fission track, Ar- argon dating of mica



$K_s = (S/Sc)A^{-m}$





Safran et al,, ESPL, 2005

Bolivian Andes- no slope or precipitation dependency

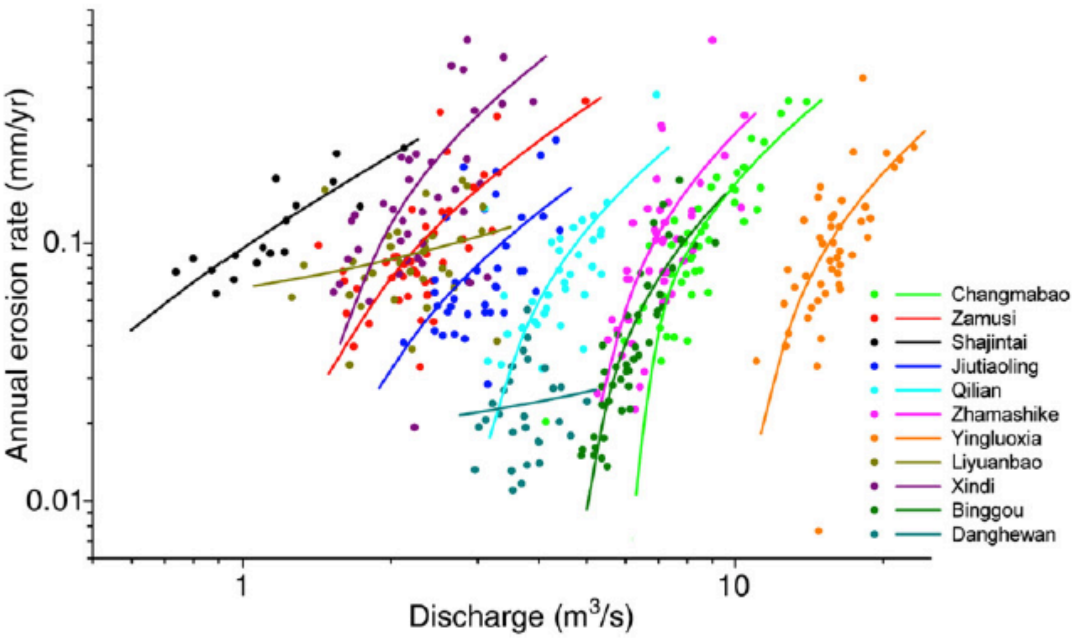
Channel incision is responding to tectonic patterns and drives erosion rates, hillslopes are threshold slopes

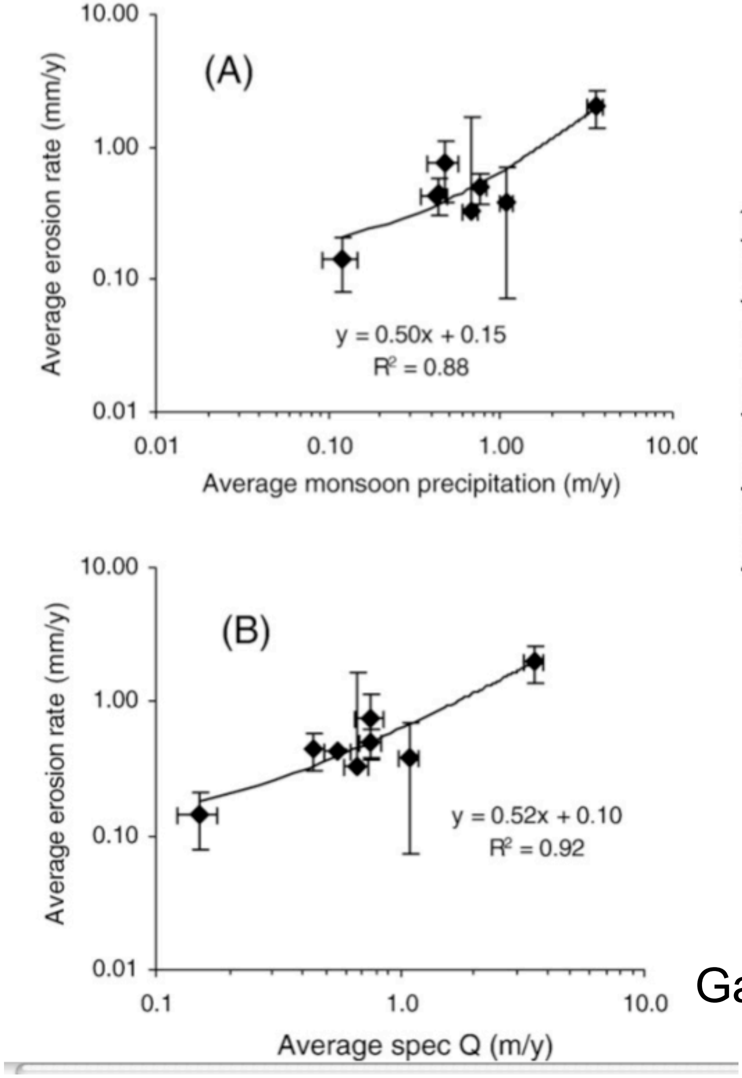
Active tectonics and erosion

$$E = F(P)$$

Contemporary rates

Pan et al. 2010 Qilian Shan Mts.



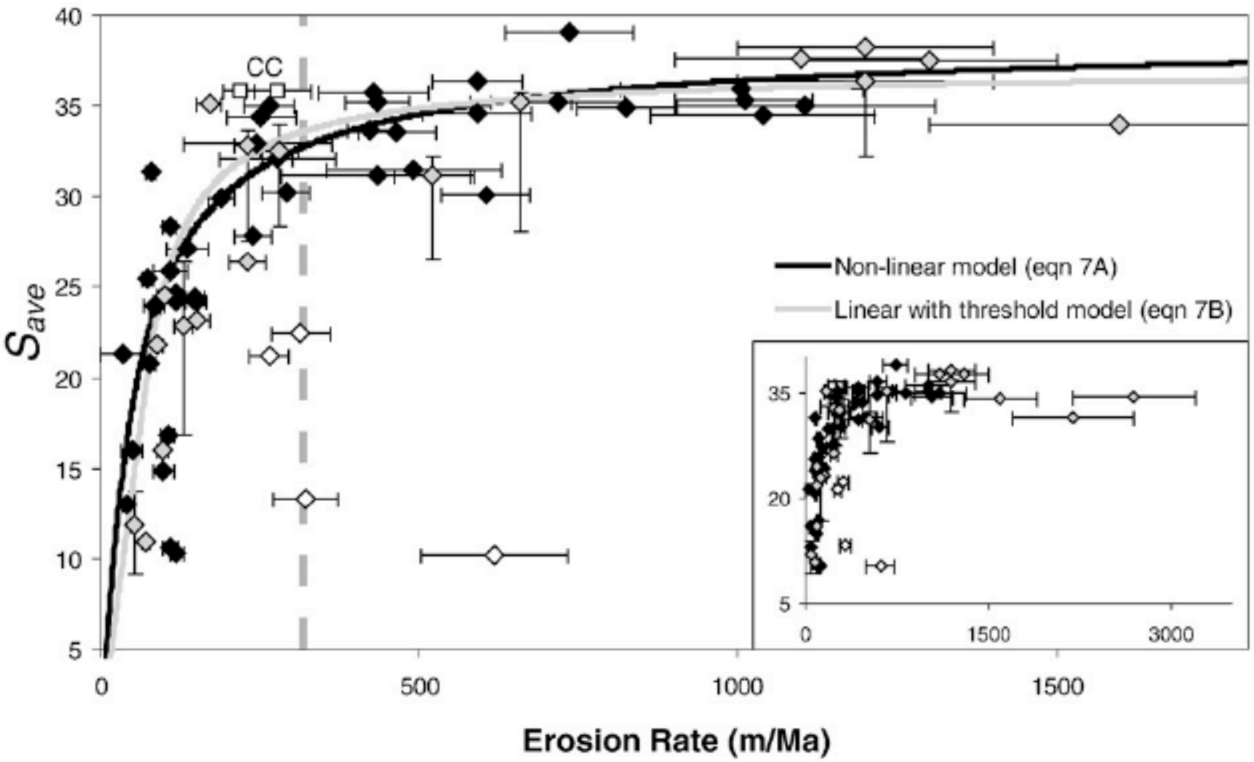


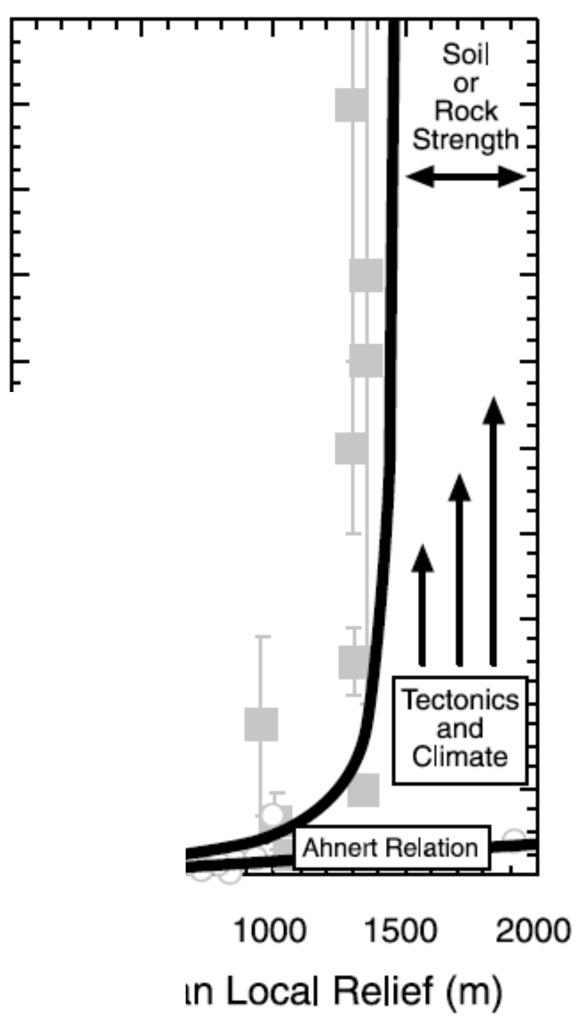
Gabet et al. 2008 Himalaya

Active tectonics and erosion

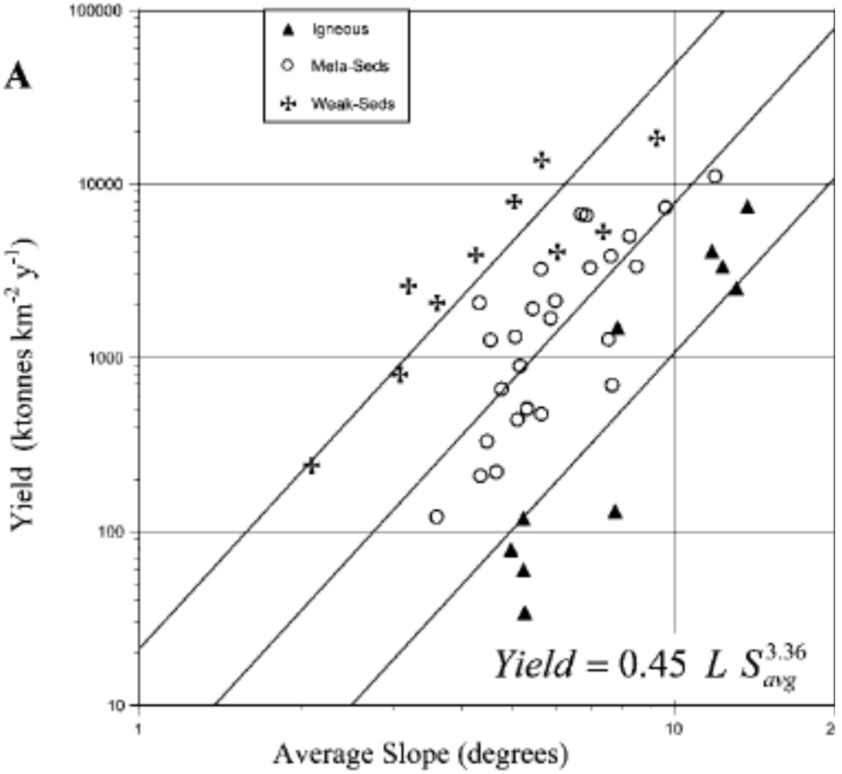
$$E = F(T)$$

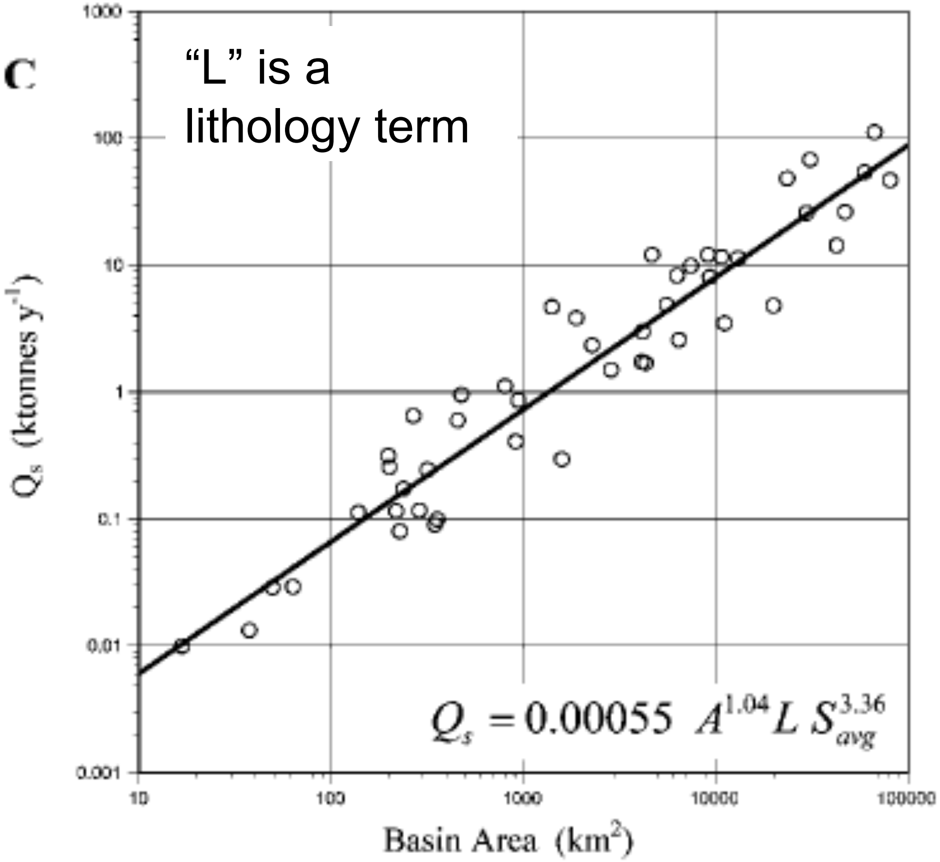
DiBase et al. 2010



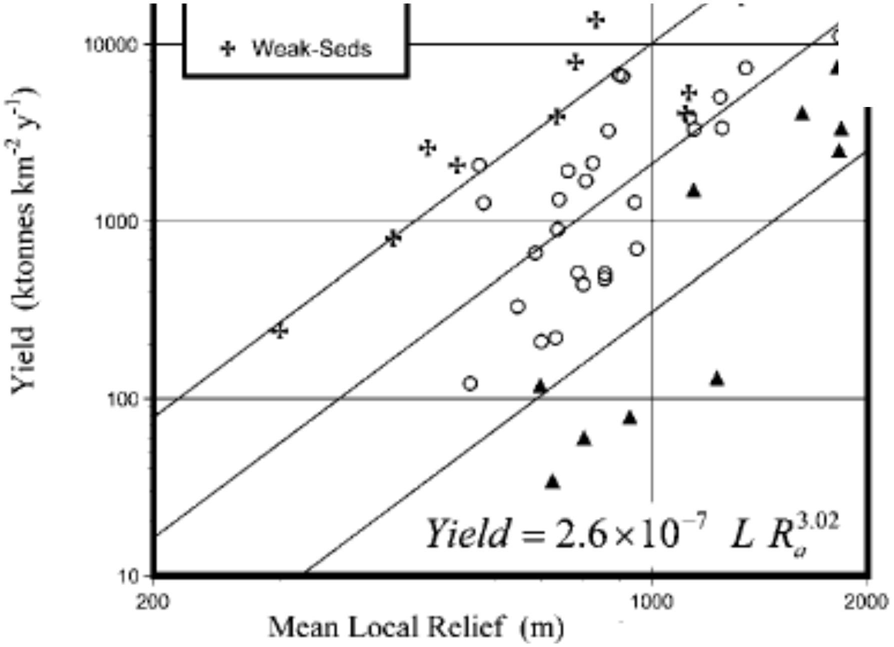


ontgomery and
randon, 2002





"L" is a lithology term

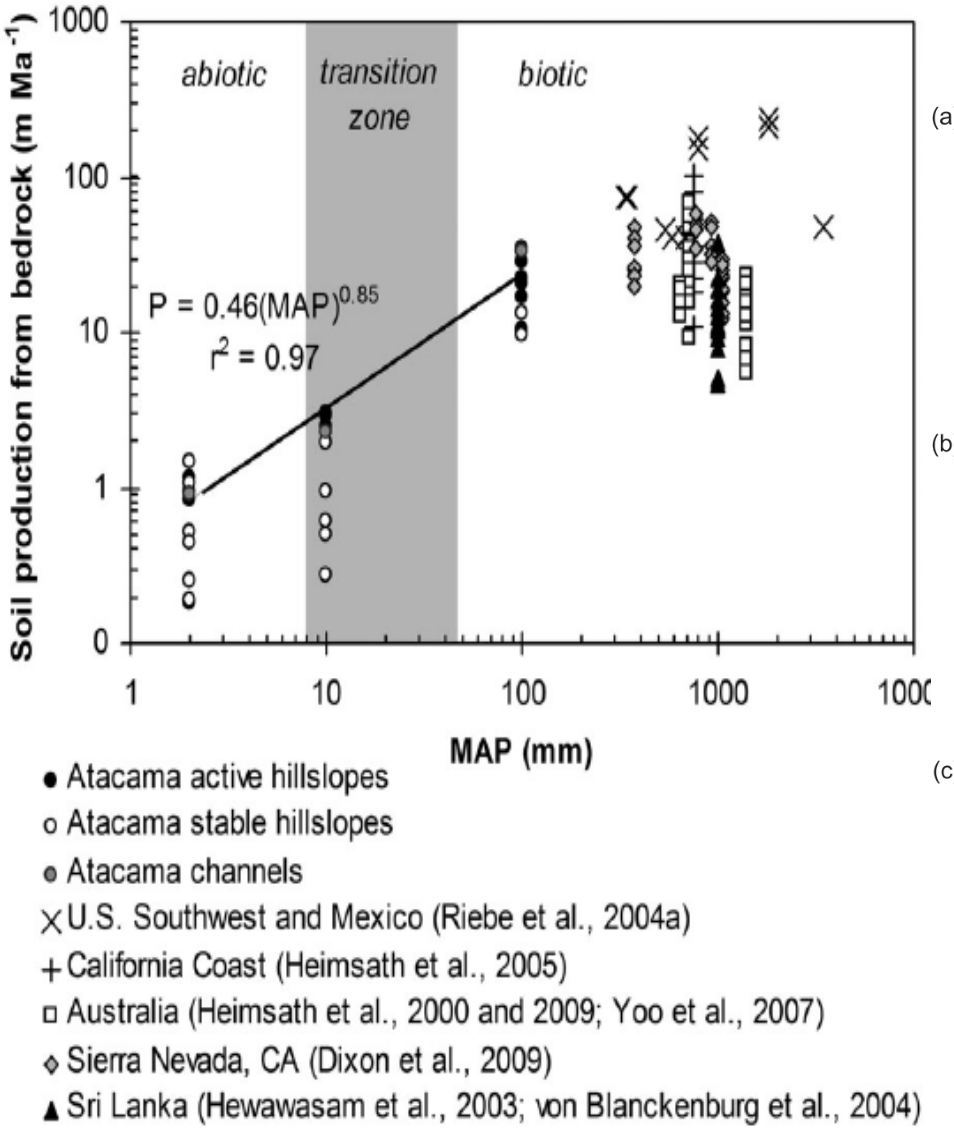


Aalto et al, J. Geol, 2006, erosion rates in Bolivian Andes based on suspended sediment data. Used to predict Andean Flux to Amazon basin

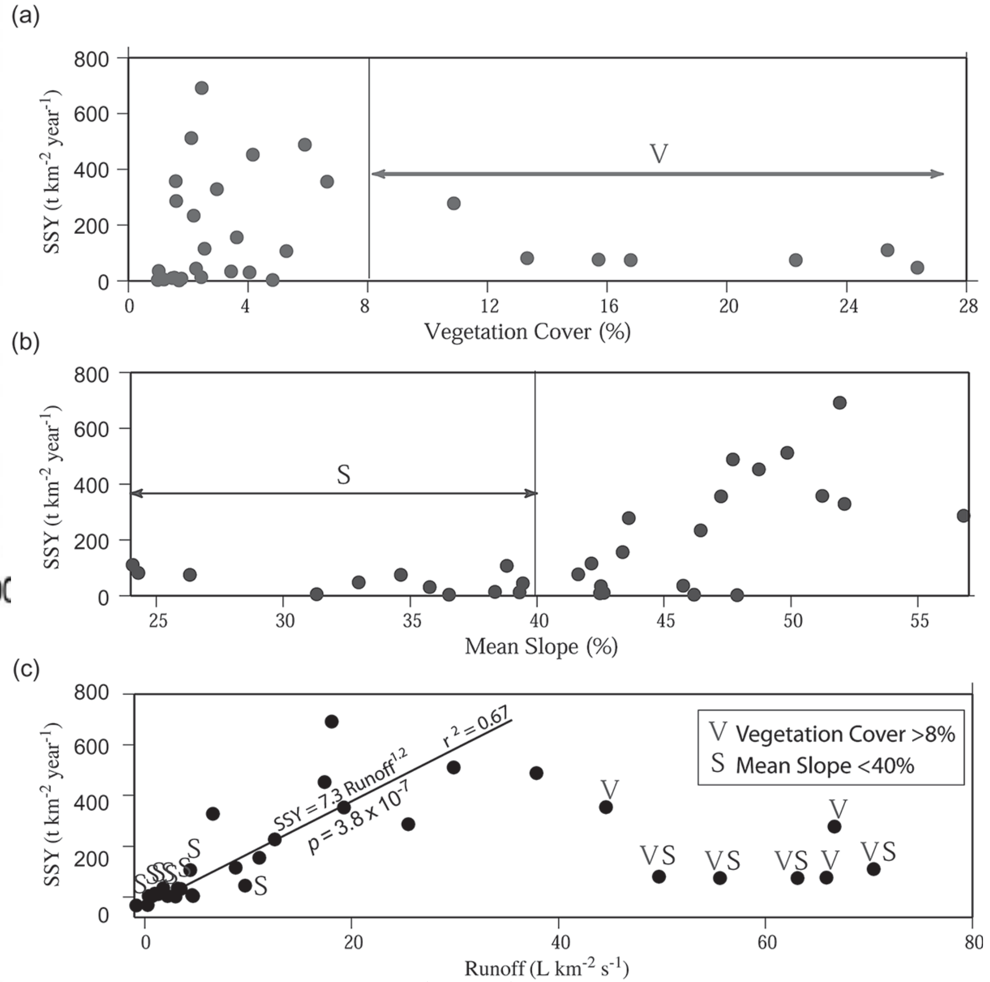
Yield (t/km^2-yr) or erosion is not a function of runoff (other than as runoff influences channel incision); Flux *does* scale with Area

Active and Hyperarid

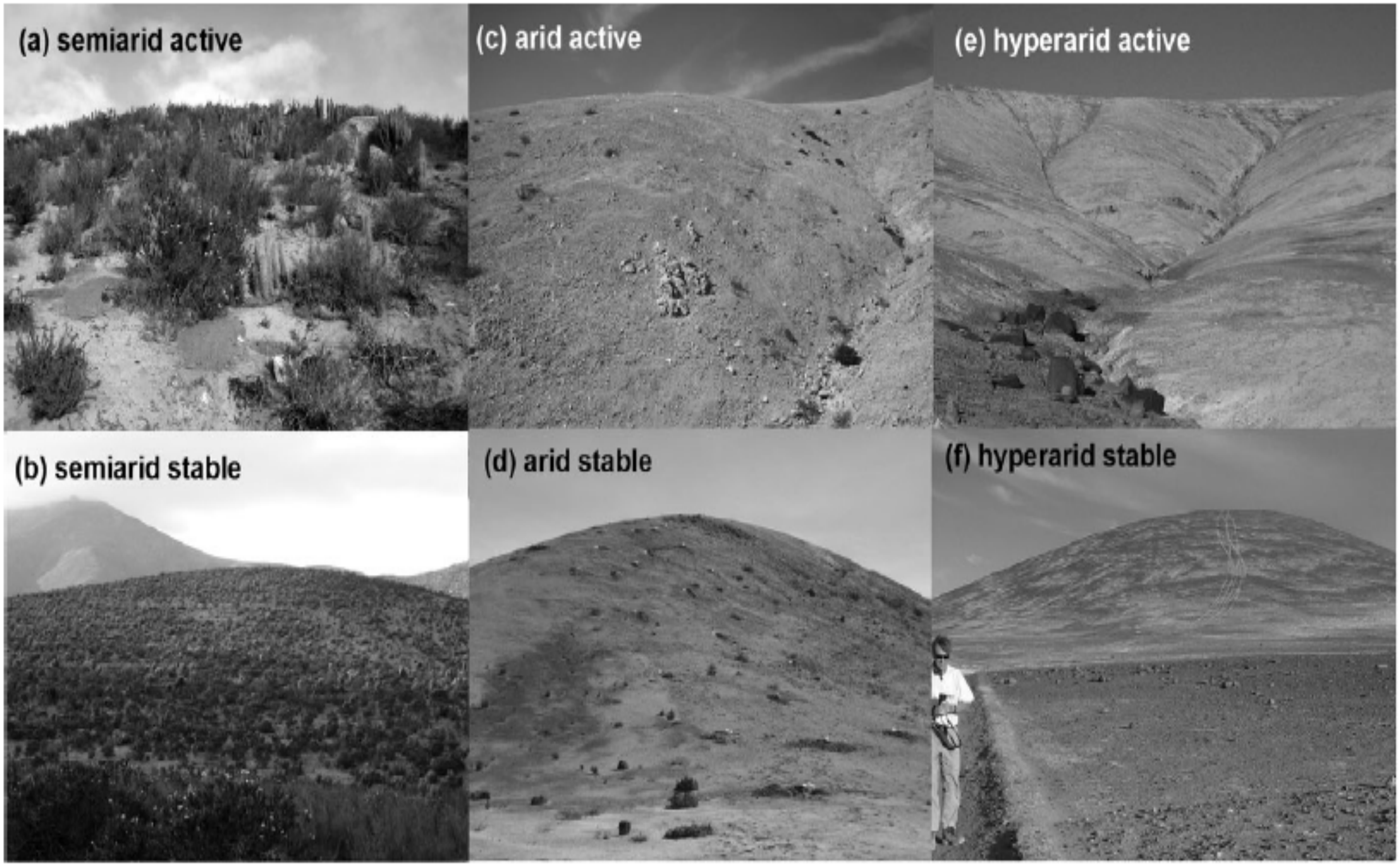
Owen et al. GSAB 2010



Pepin et al (2010) - Hydrological Sciences J`



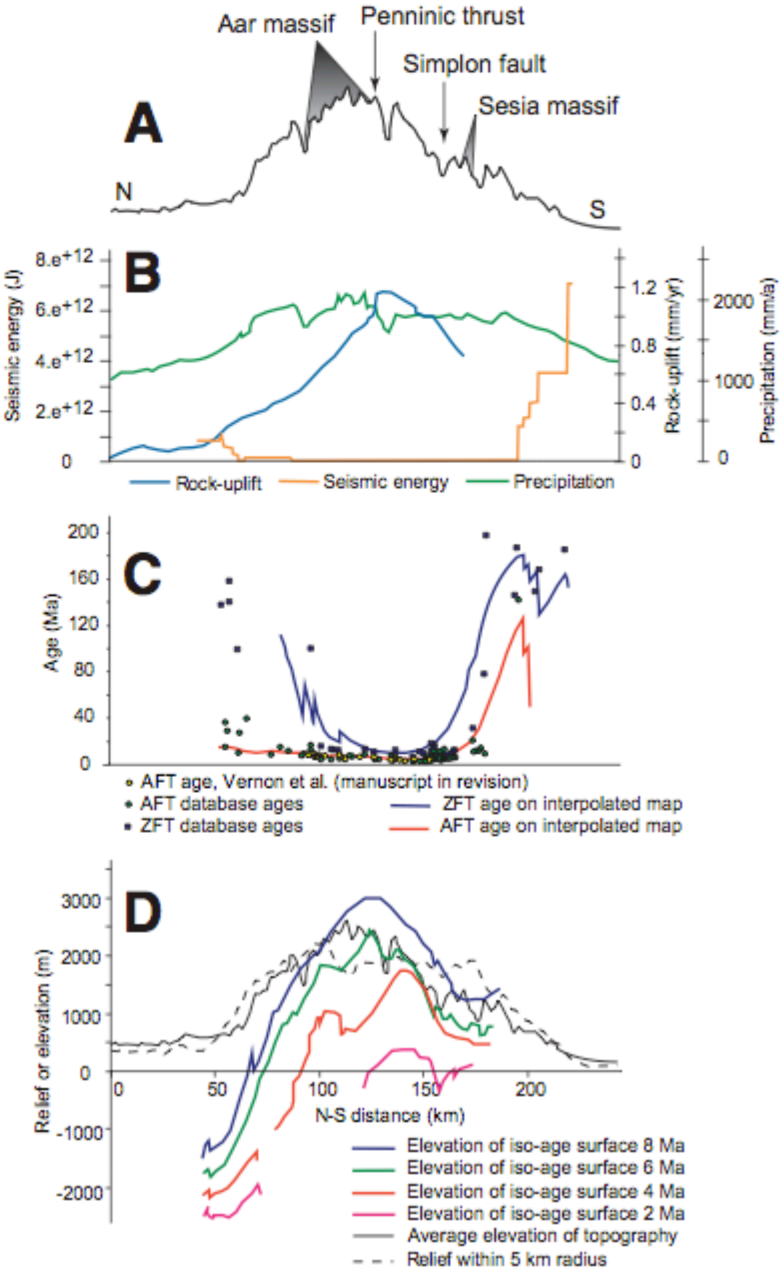
$$E = F(P)$$



With increasing rainfall, more runoff occurs, which cuts channels more rapidly and drives increased hillslope erosion. Salt covered hillslopes gives way to barren rocky surfaces and then to vegetated slopes.

Owen et al. GSAB (2010)

Inactive tectonics and erosion

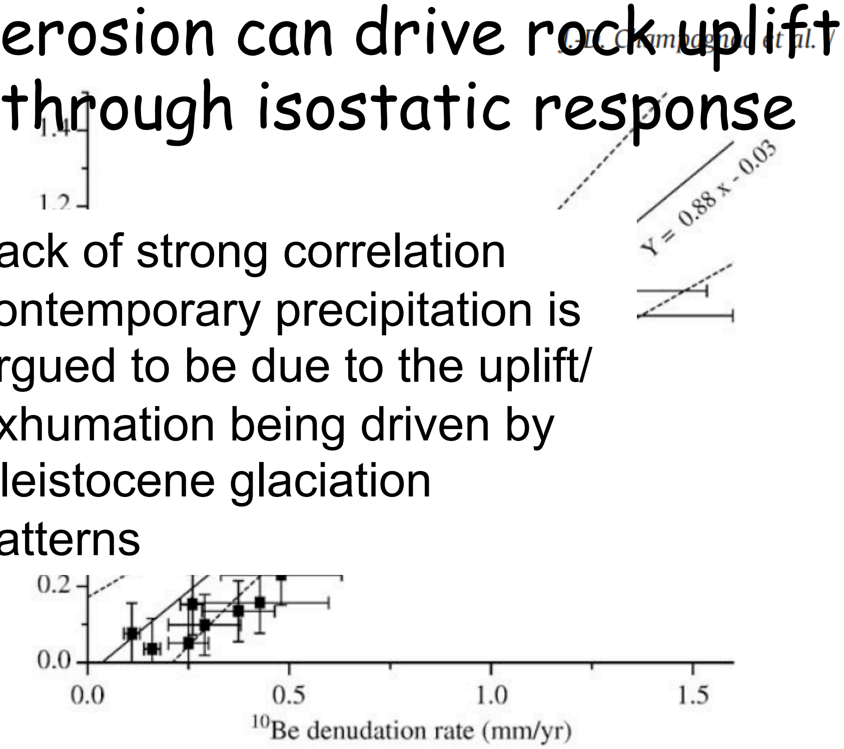


$$E \text{ € } \quad U$$

$$E = U = F(P)?$$

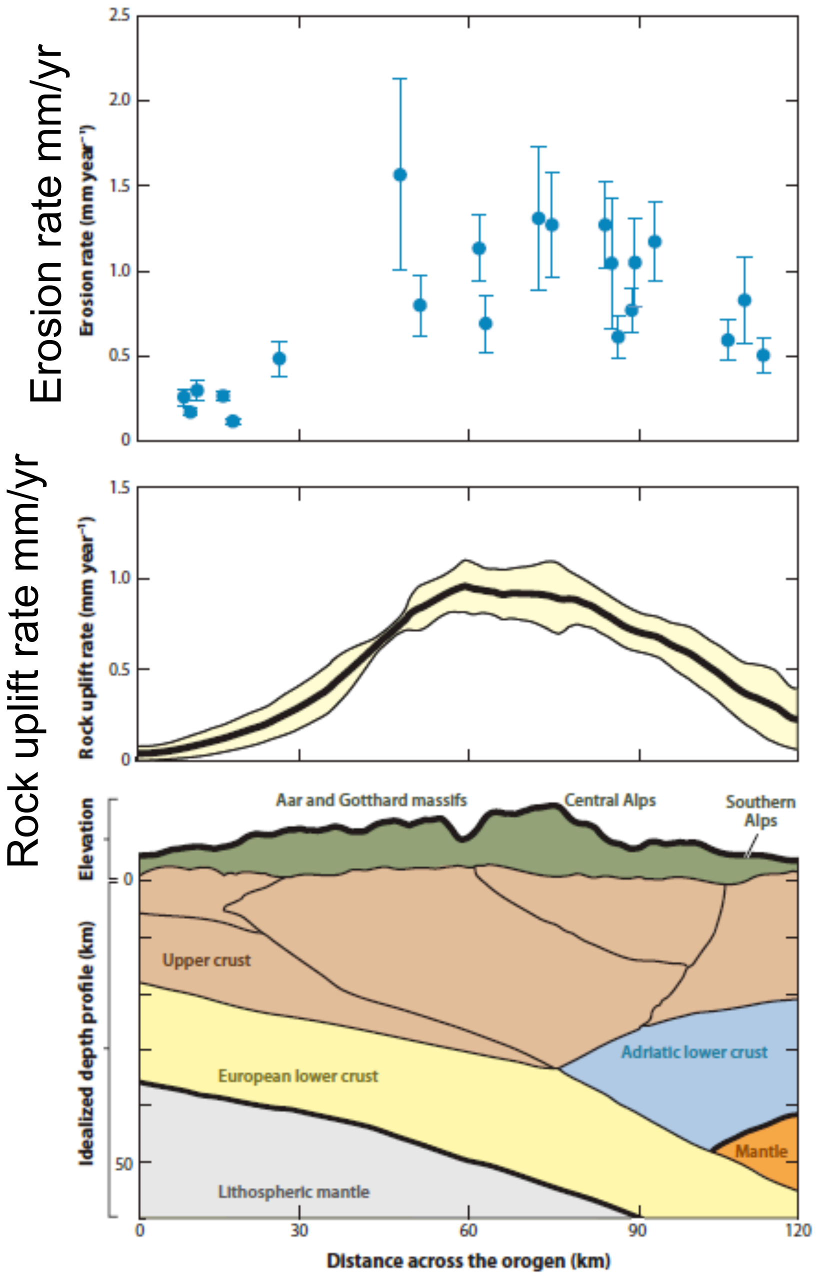
Where there is a mountain root, exhumation and thus erosion can drive rock uplift through isostatic response

Lack of strong correlation contemporary precipitation is argued to be due to the uplift/ exhumation being driven by Pleistocene glaciation patterns



Vernon et al. Geology 2009

Inactive tectonics and erosion



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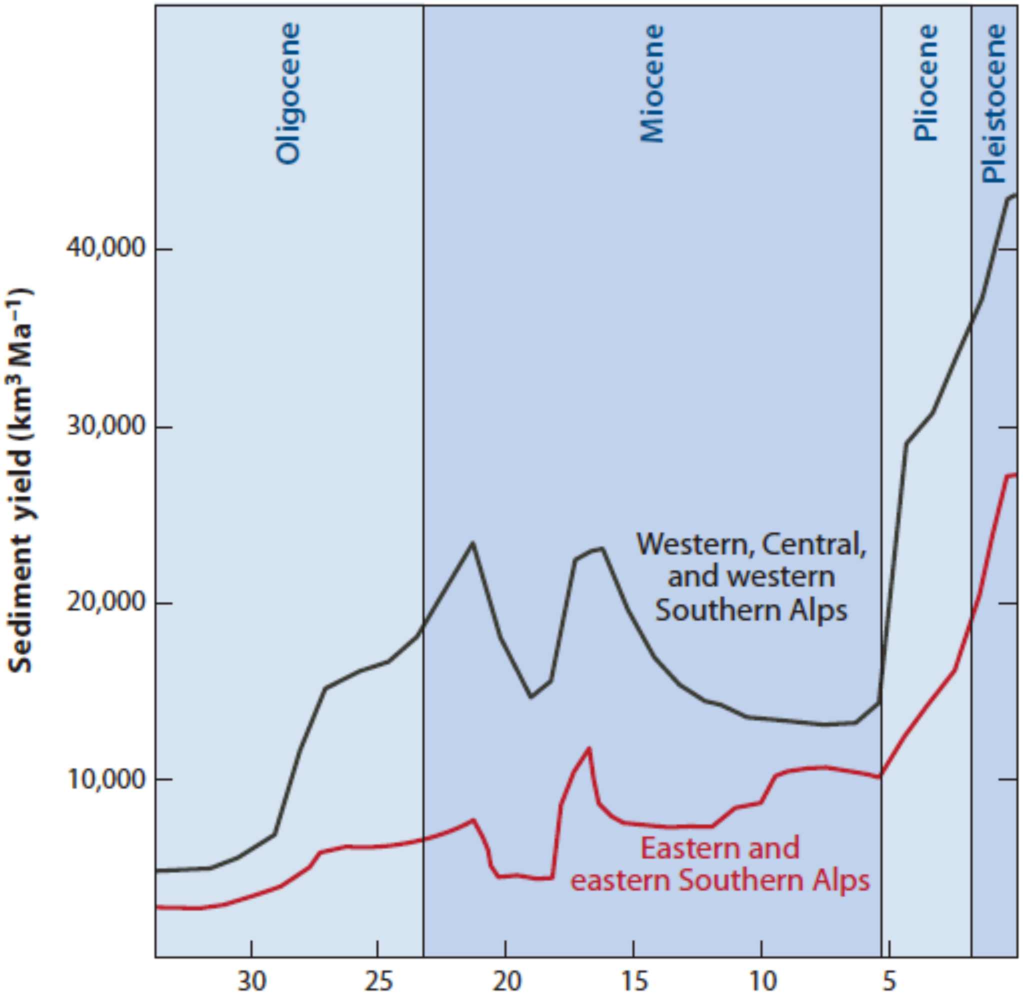
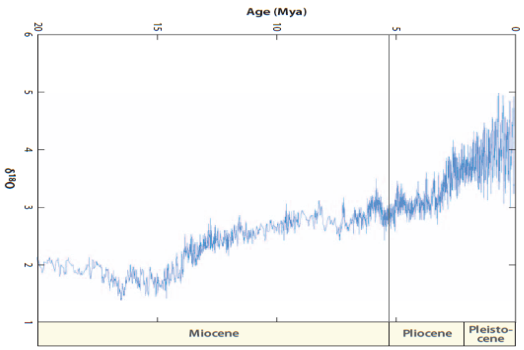
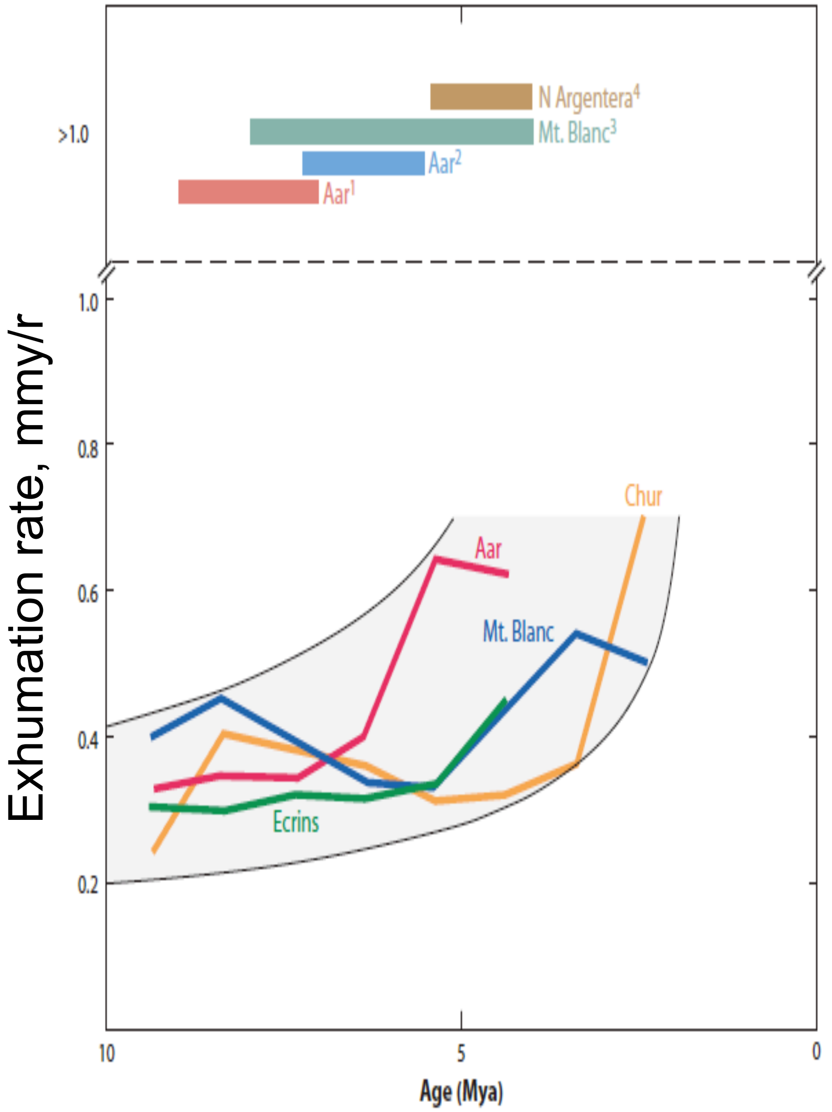
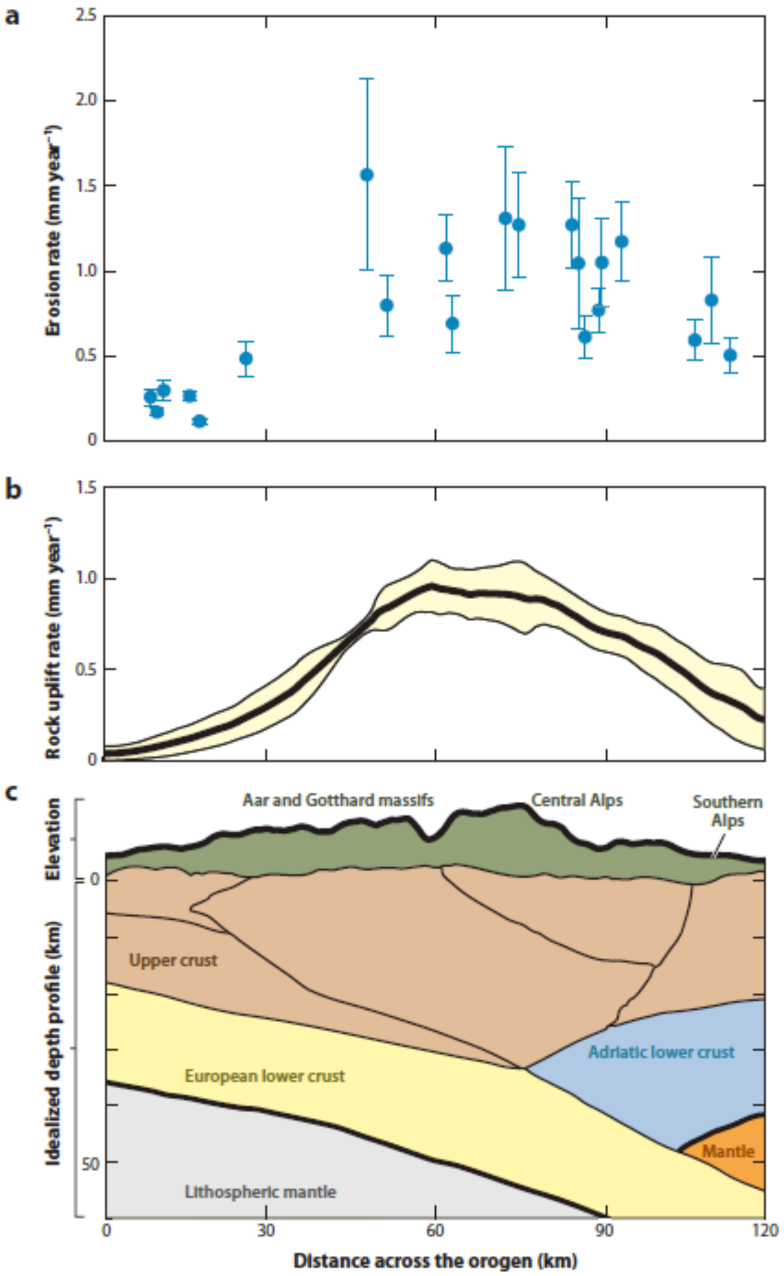
Willett, Annual Reviews, 2010


Oligocene
Miocene
Pliocene
Pleistocene
Sediment yield (km^3 Ma^{-1})
40,000
30,000
20,000
10,000
30
25
20
15
10
5
Western, Central, and western Southern Alps
Eastern and eastern Southern Alps


Age (Mya)
20
15
10
5
0
6
5
4
3
2
1
δ18O
Miocene
Pliocene
Pleistocene


N Argentera4
Mt. Blanc3
Aar2
Aar1
>1.0
1.0
0.8
0.6
0.4
0.2
Exhumation rate, mmy/r
Chur
Aar
Mt. Blanc
Ecrins
10
5
0
Age (Mya)

Inactive tectonics and erosion



$$E \text{ € } \quad U$$

$$E = U = F(P)?$$

Where there is a mountain root, exhumation and thus erosion can drive rock uplift through isostatic response

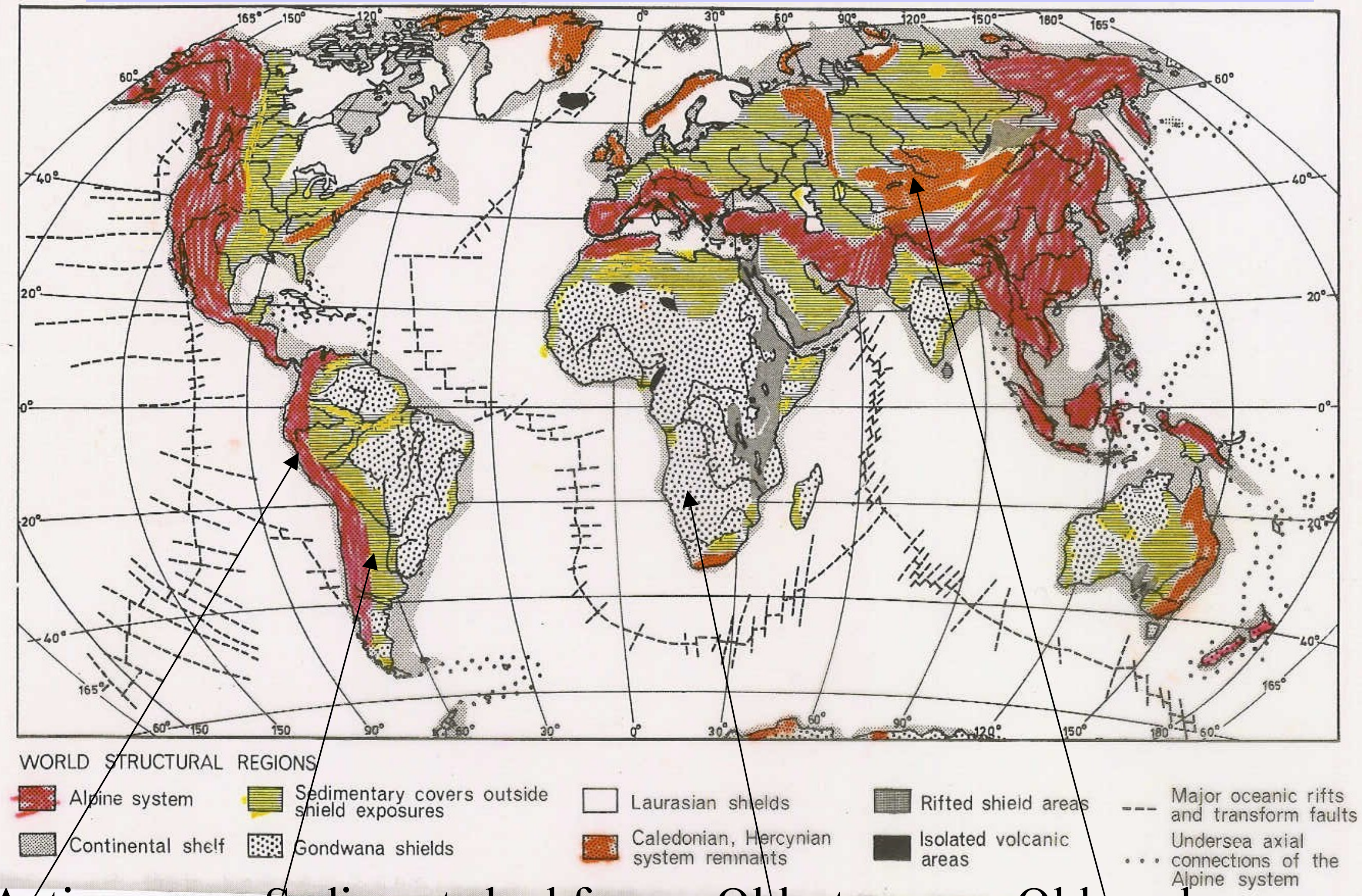
Lack of strong correlation with contemporary precipitation is argued to be due to: 1) the uplift/exhumation being driven by Pleistocene glaciation patterns, 2) longer time scale response of earlier increase in precipitation

Willett, Annual Reviews, 2010

“Inactive”

Tectonics sets the pace of landscape evolution

Geologic history (deep time) leads to legacy geology that strongly influences current landscapes

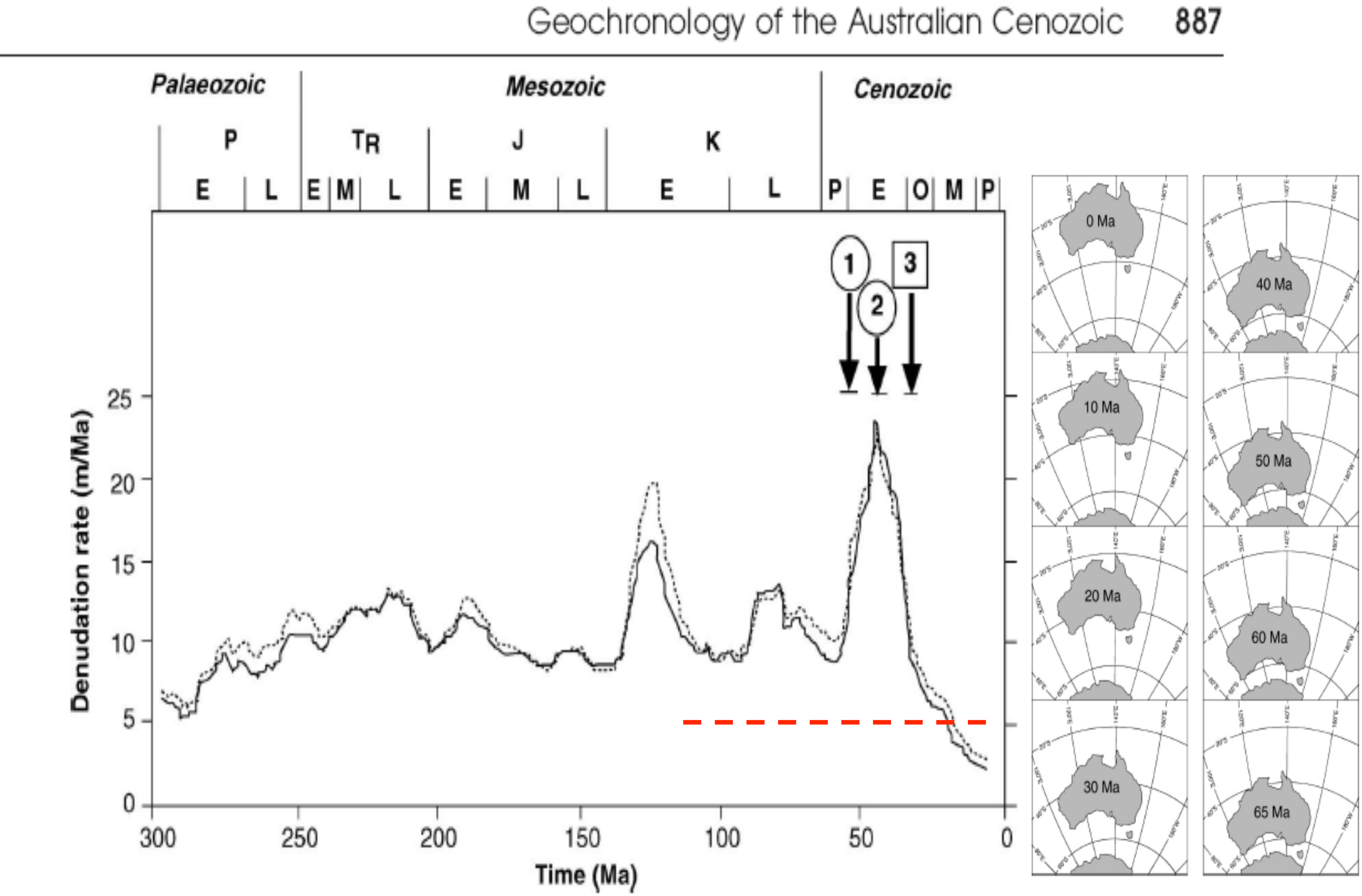


Active mountains

Sediment shed from active mountains

Oldest “basement”

Old, no longer active mountains



fission-track thermochronology Kohn et al. 2002 reported in Vasconcelos et a. 2008

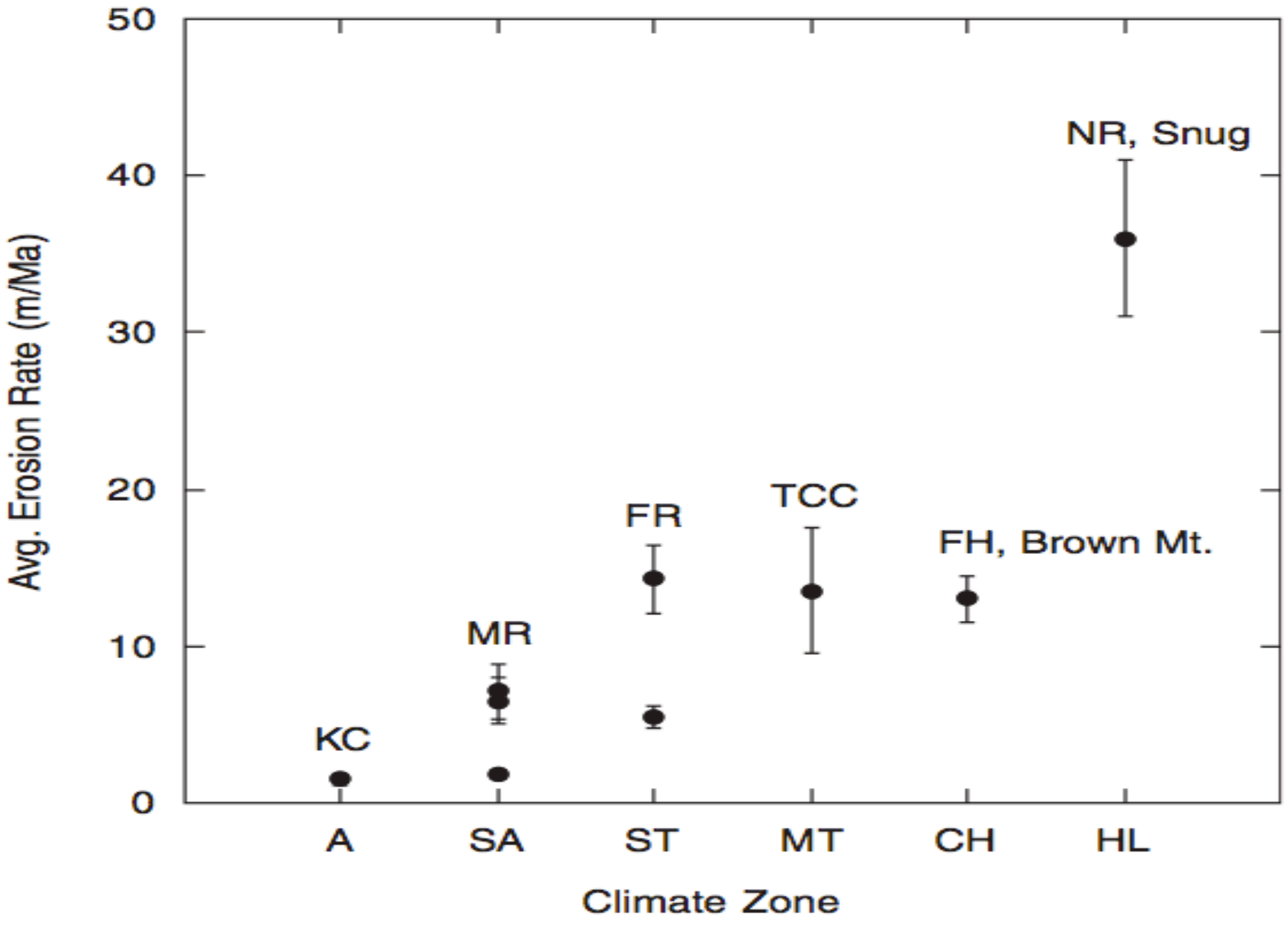
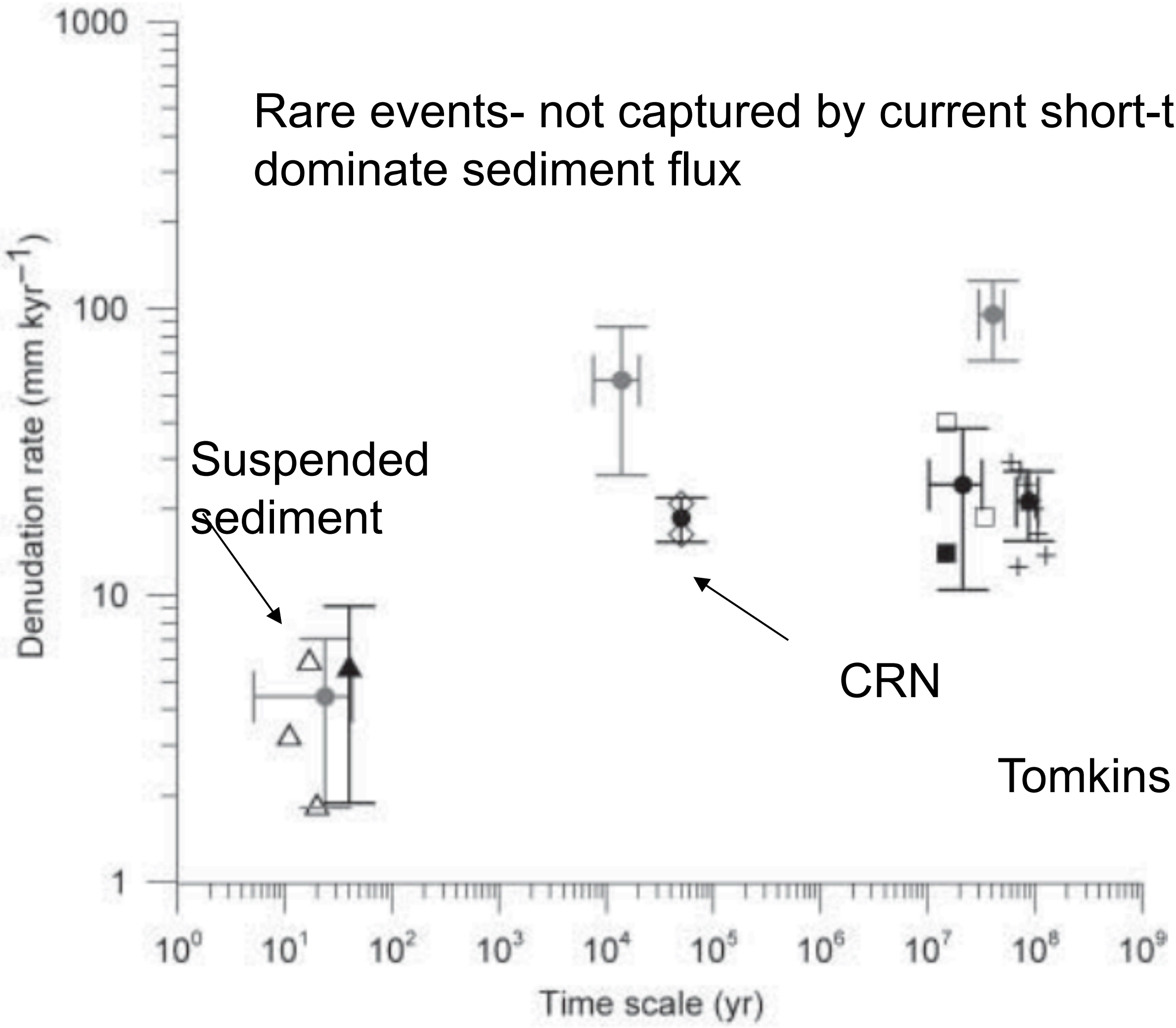


Fig. 11. Average erosion rate plotted against the climate zone characterizing each field site and labelled with the field site represented. A, arid (KC, Kings Canyon); SA, semi-arid (MR, MacDonnell Range); ST, semi-arid–temperate (FR, Flinders Range); MT, monsoonal tropic (TCC, Tin Camp Creek); CH, cool highland (FH, Frogs Hollow); HL, humid lowland (NR, Nunnock River).

Slow rates means a large response time to changes in forcing (climate and tectonics) and likely poor correlation between erosion, topography, and "climate".



Rare events- not captured by current short-term record may dominate sediment flux

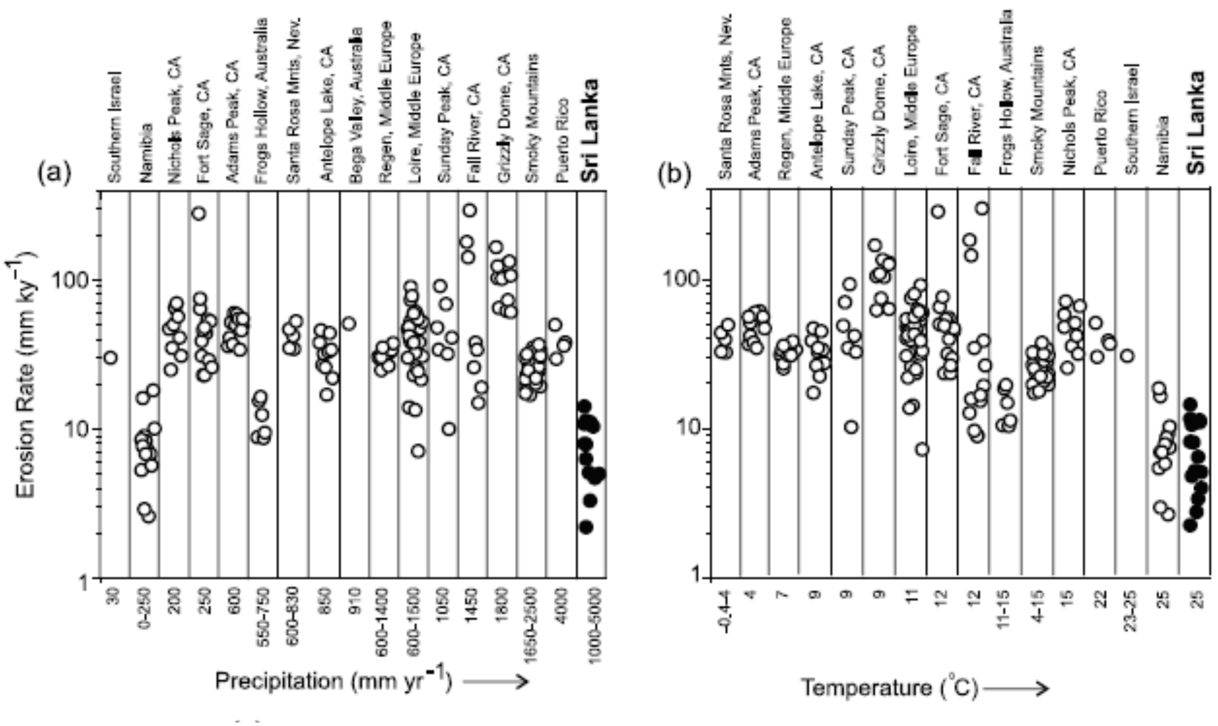
Suspended sediment

CRN

Tomkins et al. 2006 EPSL

Contemporary erosion rates have been found to be LOWER than millenial and million year time scale erosion– perhaps due to missing rare erosion events.

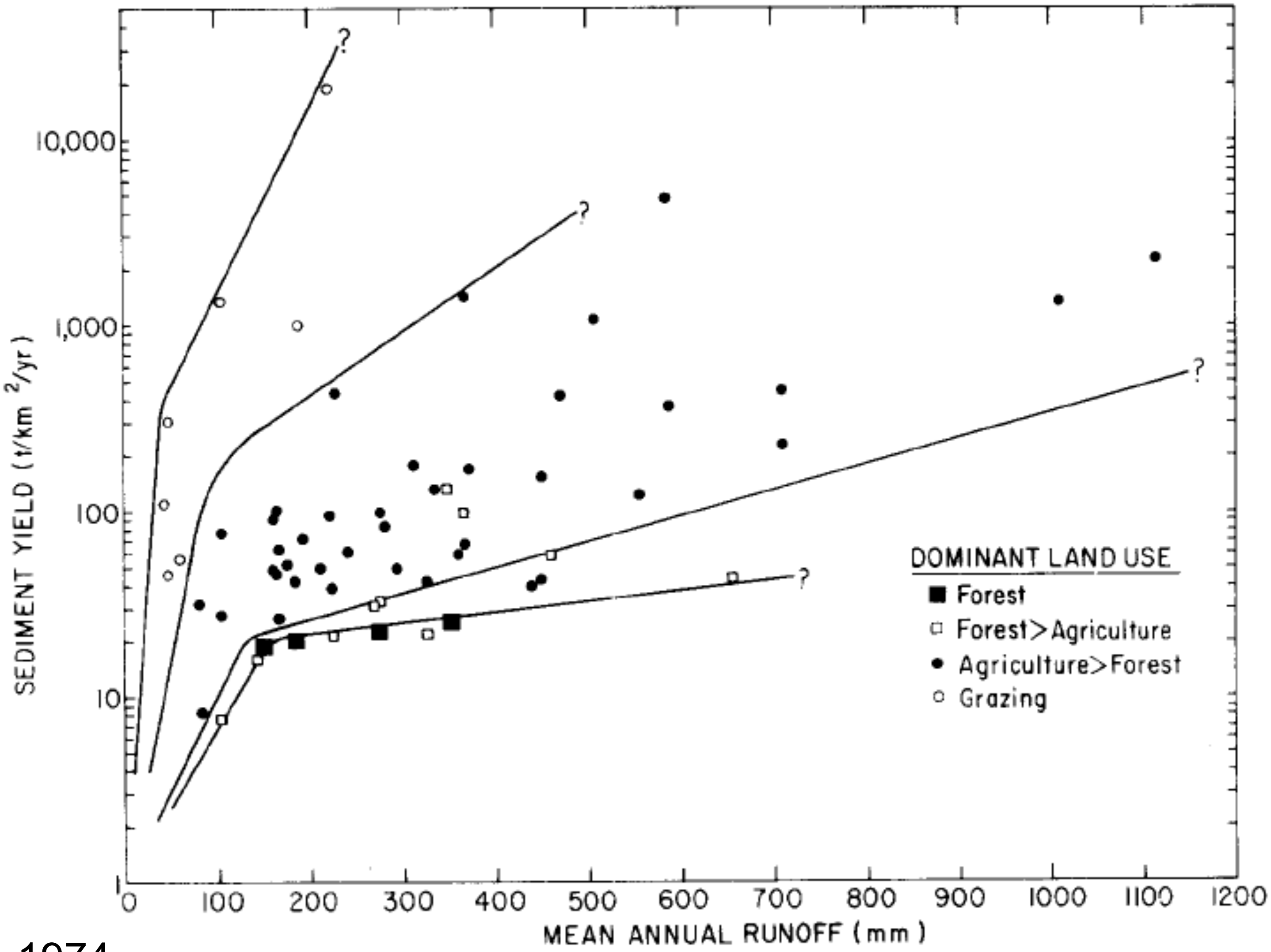
VON BLANCKENBURG ET AL.: WEATHERING AND EROSION IN SRI LANKA



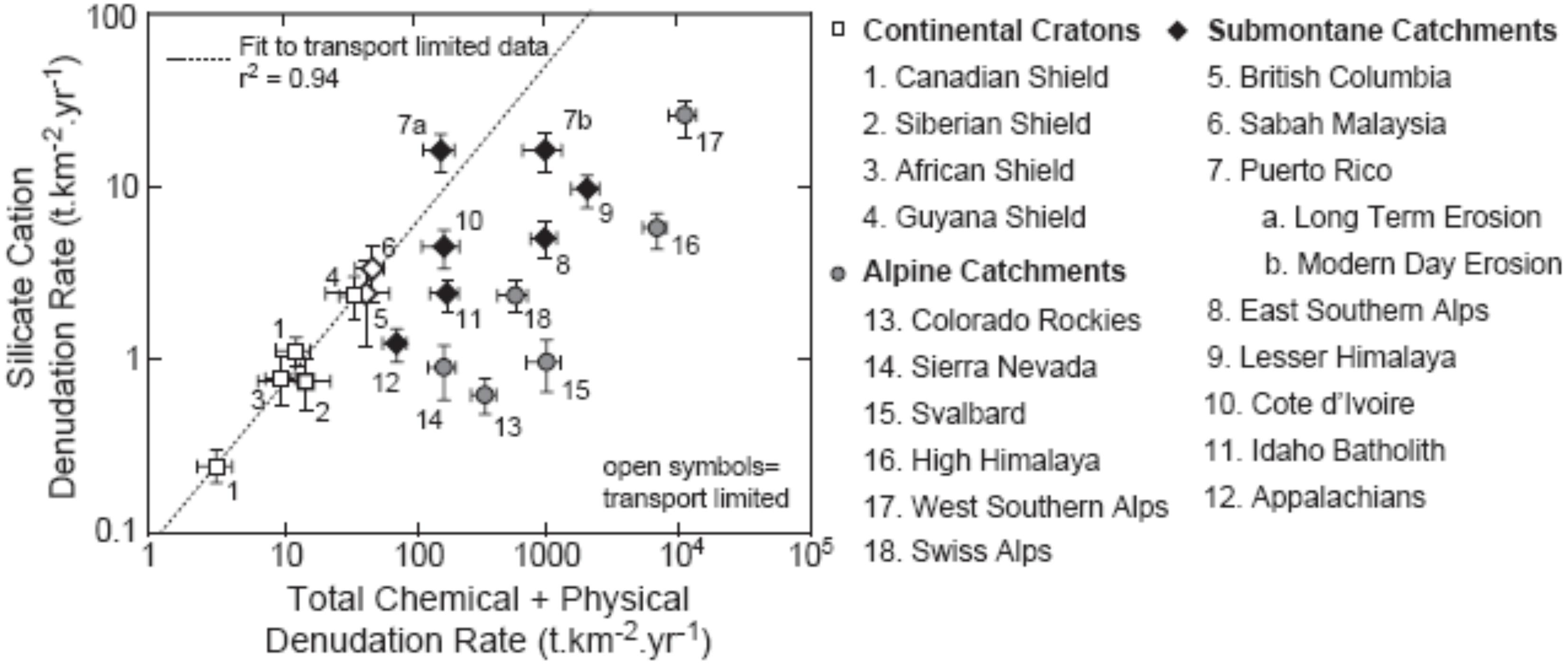
Wet, warm modestly steep Sri Lanka has low erosion rates because of the lack of tectonic activity, which would induce channel incision. Instead a deep, relatively stable weathering profile mantles the landscape.

While a useful summary, such comparisons need to be placed in a tectonic framework

Crystalline rocks only


SEDIMENT YIELD (t/km ²/yr)
10,000
1,000
100
10
1
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
MEAN ANNUAL RUNOFF (mm)
?
?
?
?
DOMINANT LAND USE
■ Forest
□ Forest>Agriculture
● Agriculture>Forest
○ Grazing

Dunne 1974



West et al. 2005

Final Comments

1) Cosmogenic radionuclides and low temperature thermochronology provide estimates of sediment supply to rivers. But these measures tell us very little about the *size* of sediment being supplied
2) Direct measurement of sediment transport in rivers are influenced by short period of observation and transient conditions due to Holocene climate change and landuse effects.
3) Sediment supply (erosion from upland hillslopes) over the longer time scale is driven by tectonics and climate, and controlled by topography and lithology (ignoring landuse effects).
4) Efforts to find correlation between erosion and tectonics, topography, climate and lithology have had mixed-success.
5) The drivers and controls are not well defined.

6) All such studies need to be placed in a tectonic and climate history framework

7) Active orogenic belts, E ~U , but $E \neq F(P)$. Local “aneurysm” may occur.

8) Hyperarid to semiarid, E = F(P).

9) Erosion generally correlates non-linearly with various measures of slope and relief.

10) Tectonically inactive areas show long-time scale erosional response to changes in climate

11) Erosion varies over about 6 orders of magnitude. Passive margin, cratonic areas typically eroding 1-10 m/my and collision tectonic areas typically eroding at 1000- 5000 m/my