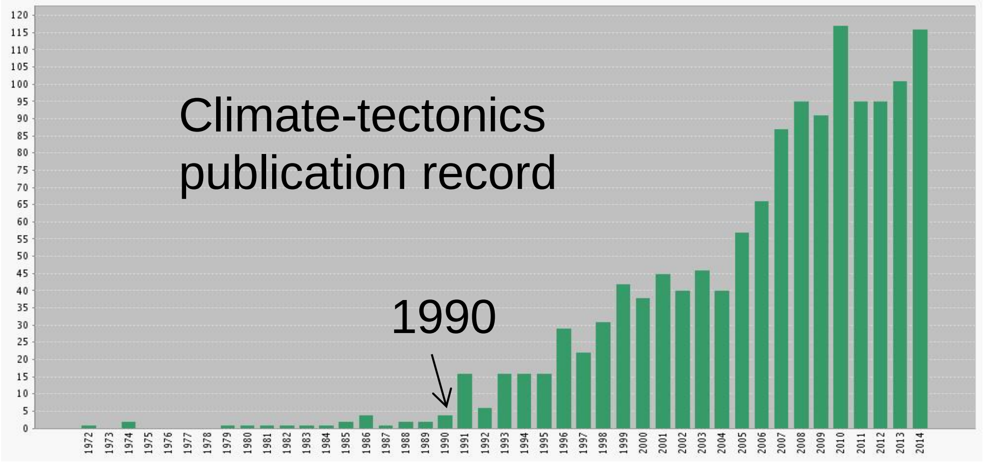
ESCI 555. **Seminar on interplays between mountain building, climate, and global carbon cycling**

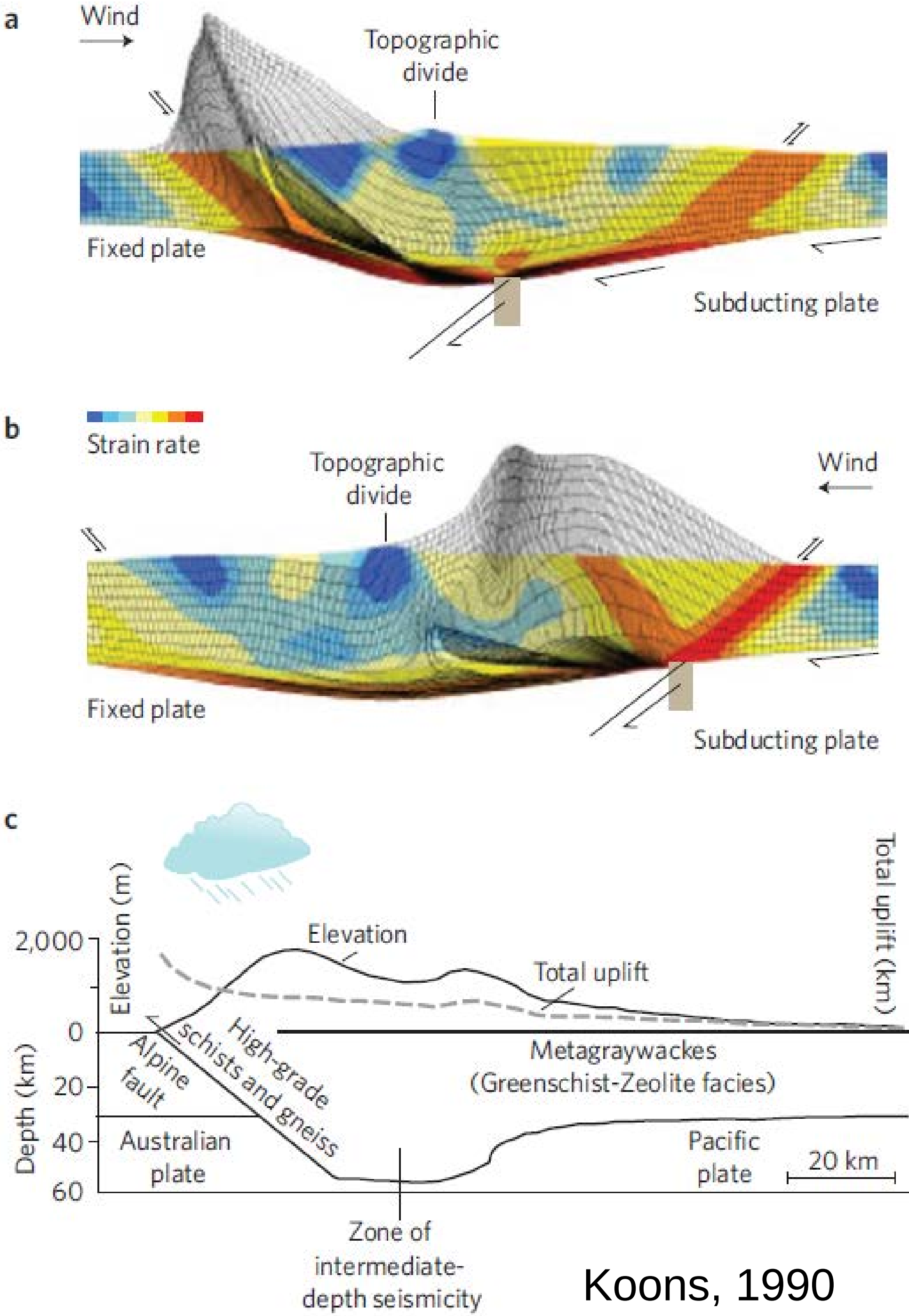
Kinematics of mountain building, mass fluxes, tectonics, erosion

Onno Oncken

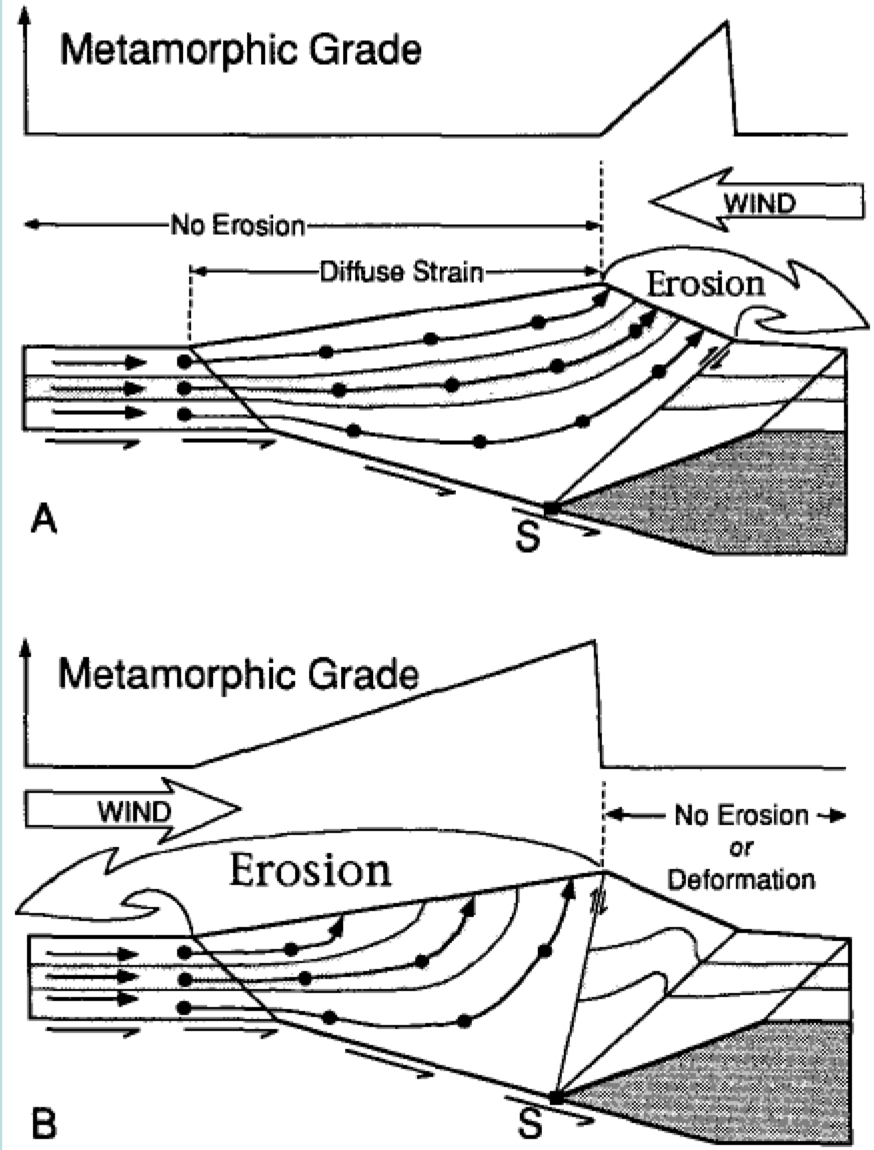
What role do mountains play in climate?
(Cin-Ty Lee; Jan. 2015)

What role does climate take in mountain building?

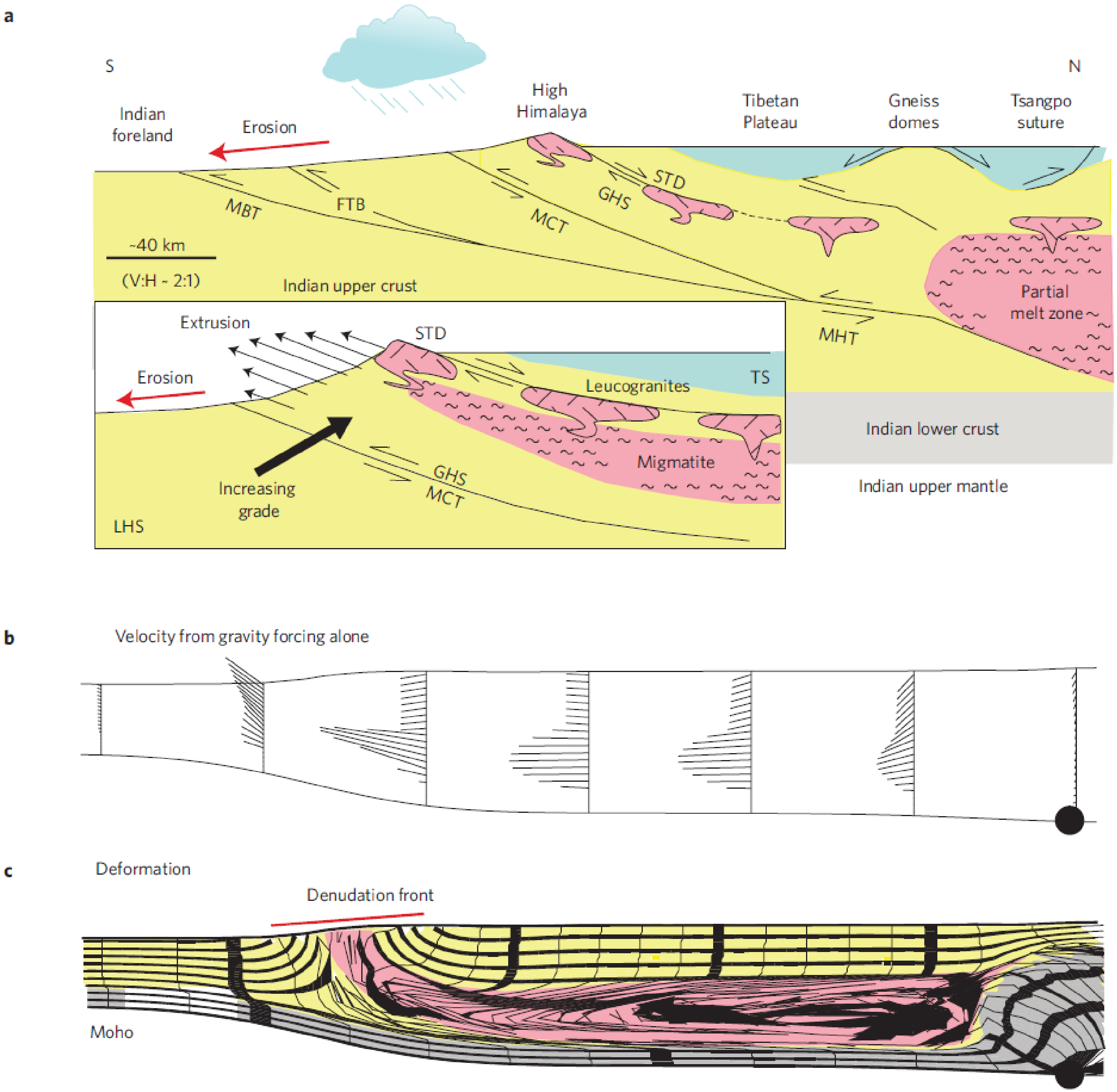




Koons, 1990



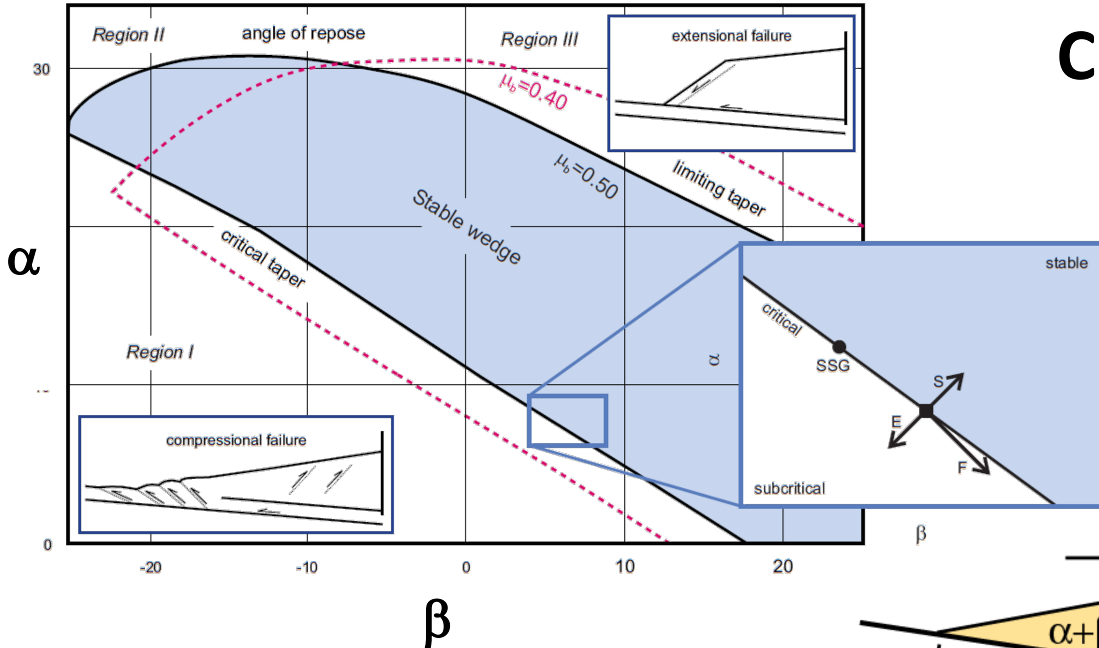
Willett, 1990

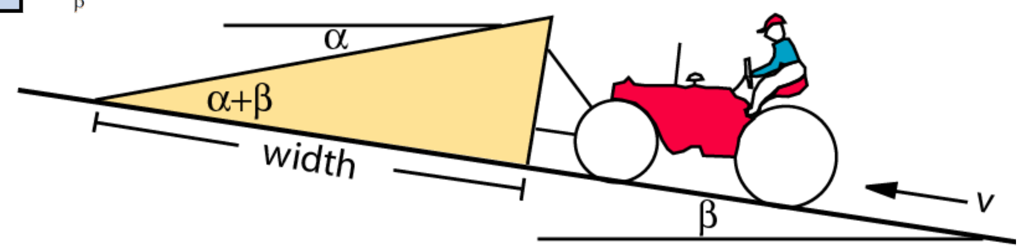


Channel flow and exhumation in Tibet and Himalayas driven by erosion

Beaumont et al., 2001

Critical wedge theory and kinematic predictions





Critical Taper Equation

(Davis et al., 1983):

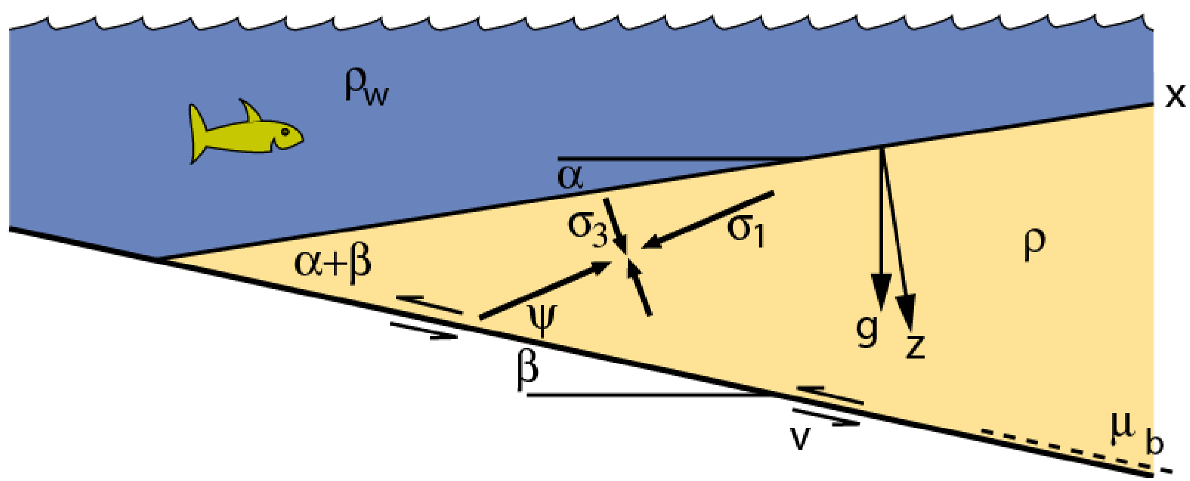
where $\mu_b = \tan \phi_b$

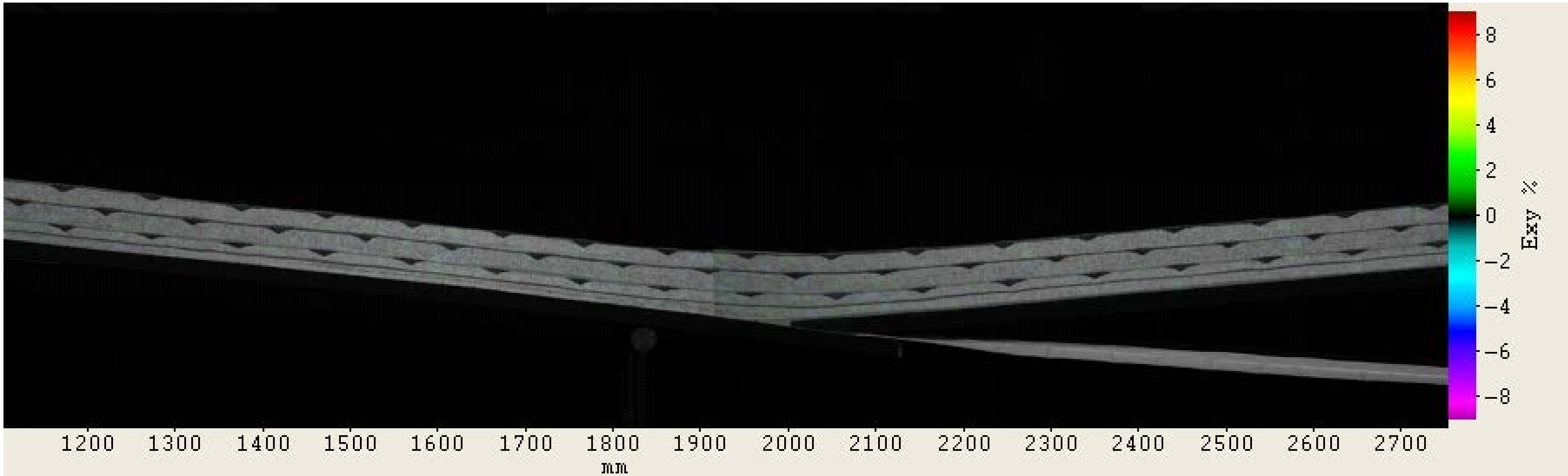
‚dry' case

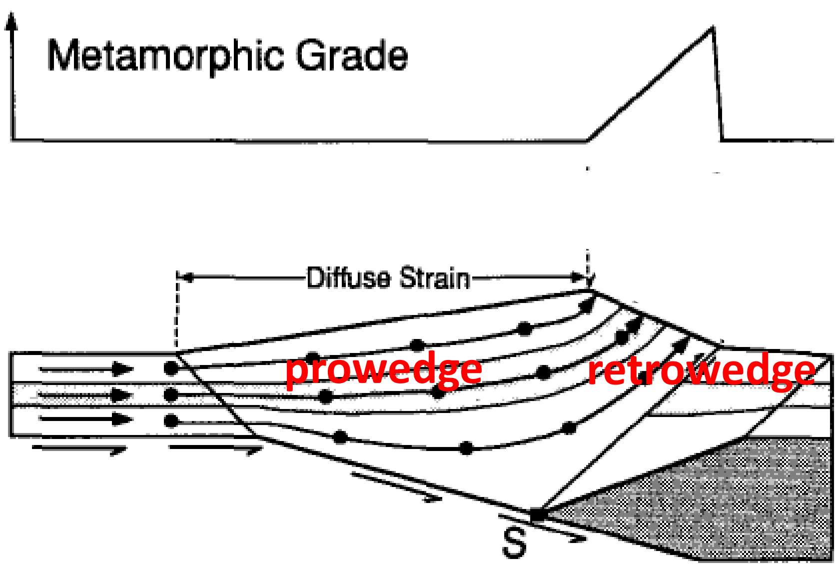
$$\alpha + \beta = \frac{\phi_b + \beta}{1 + K}$$

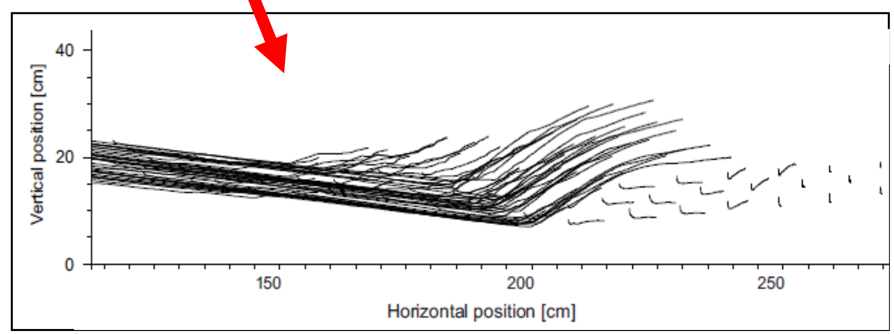
submarine case

$$\alpha + \beta = \frac{(1-\lambda_b)\phi_b + (1-\rho_w/\rho)\beta}{(1-\rho_w/\rho) + (1-\lambda_b)K}$$

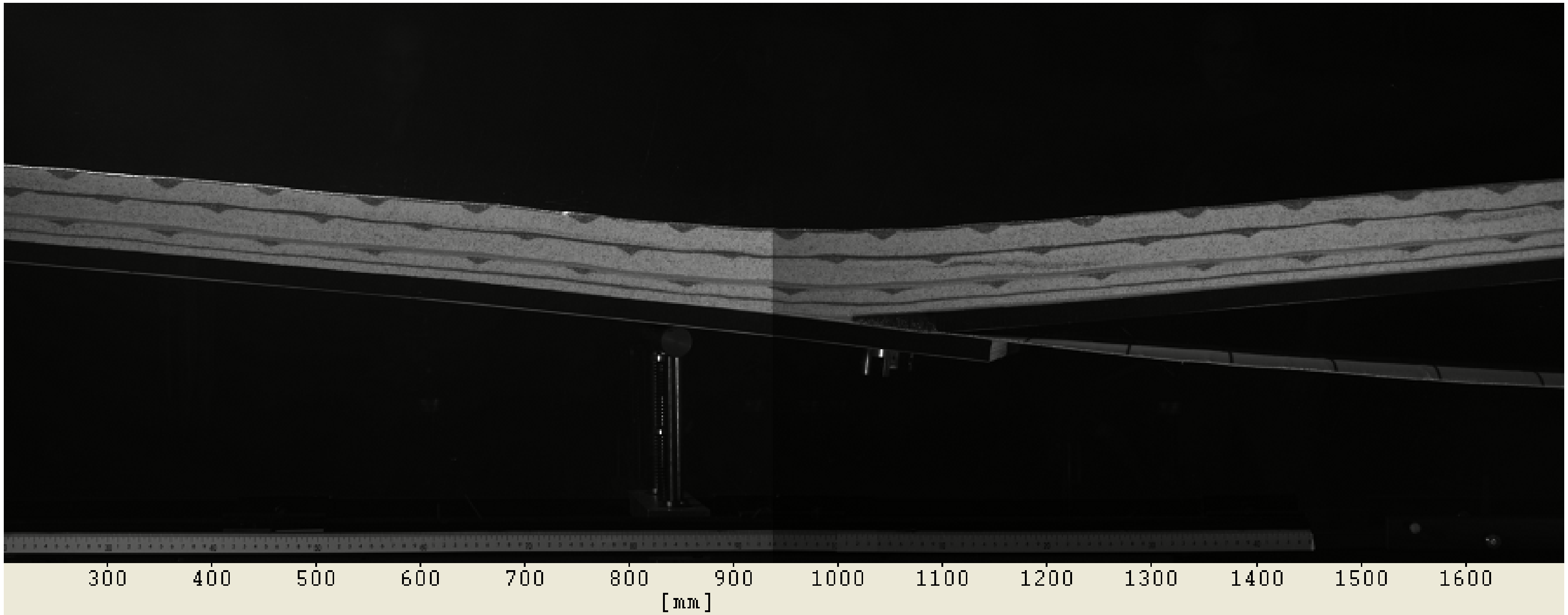




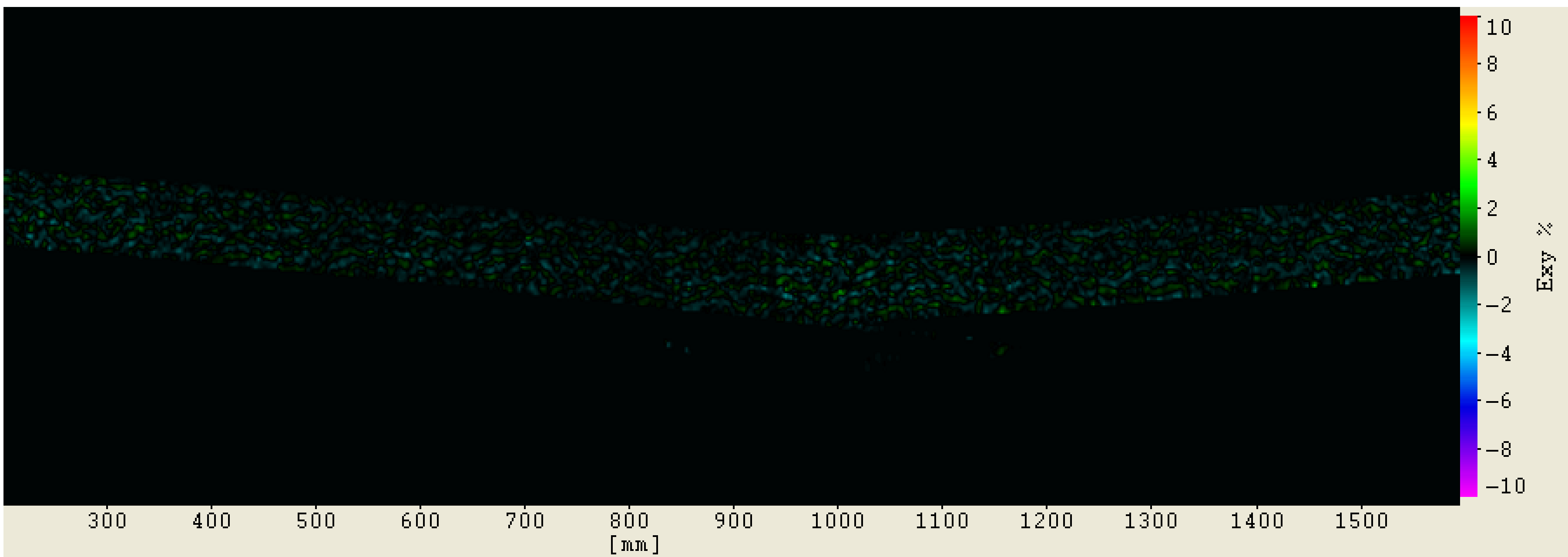




Hoth et al., 2006



300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
[mm]



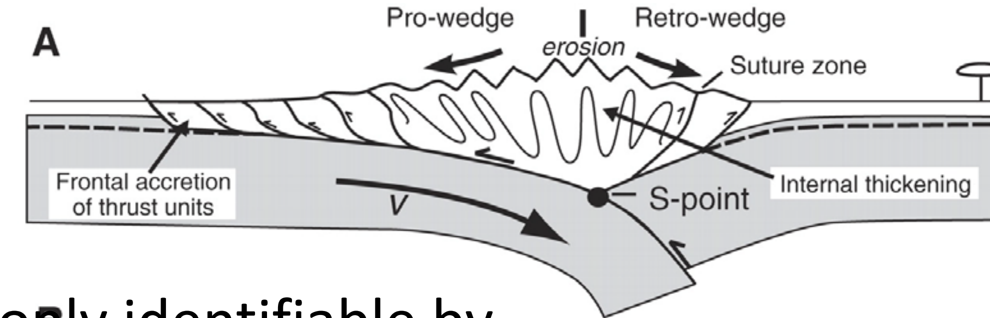
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
[mm]
10
8
6
4
2
0
-2
-4
-6
-8
-10
Exy %

In critical wedge systems undergoing erosion, deformation is

- **complex with complete lack of periodic cycles, and**
- **likely is spatially and temporally offset from erosion site.**

Yet, large-scale features (e.g. wedge taper) remain stable.

Hence, what should an appropriate research strategy look like that allows identifying climate as the trigger of tectonics?



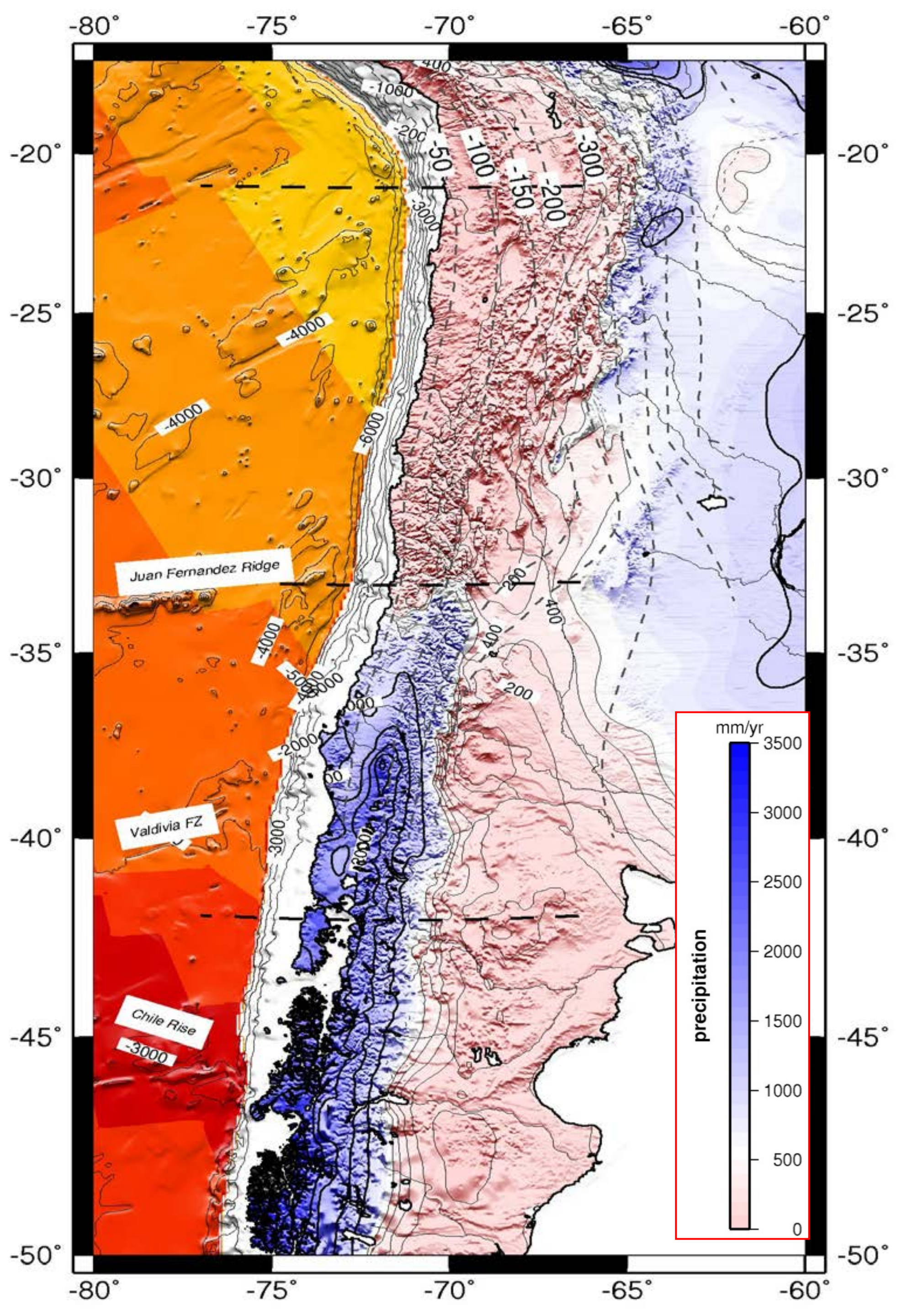
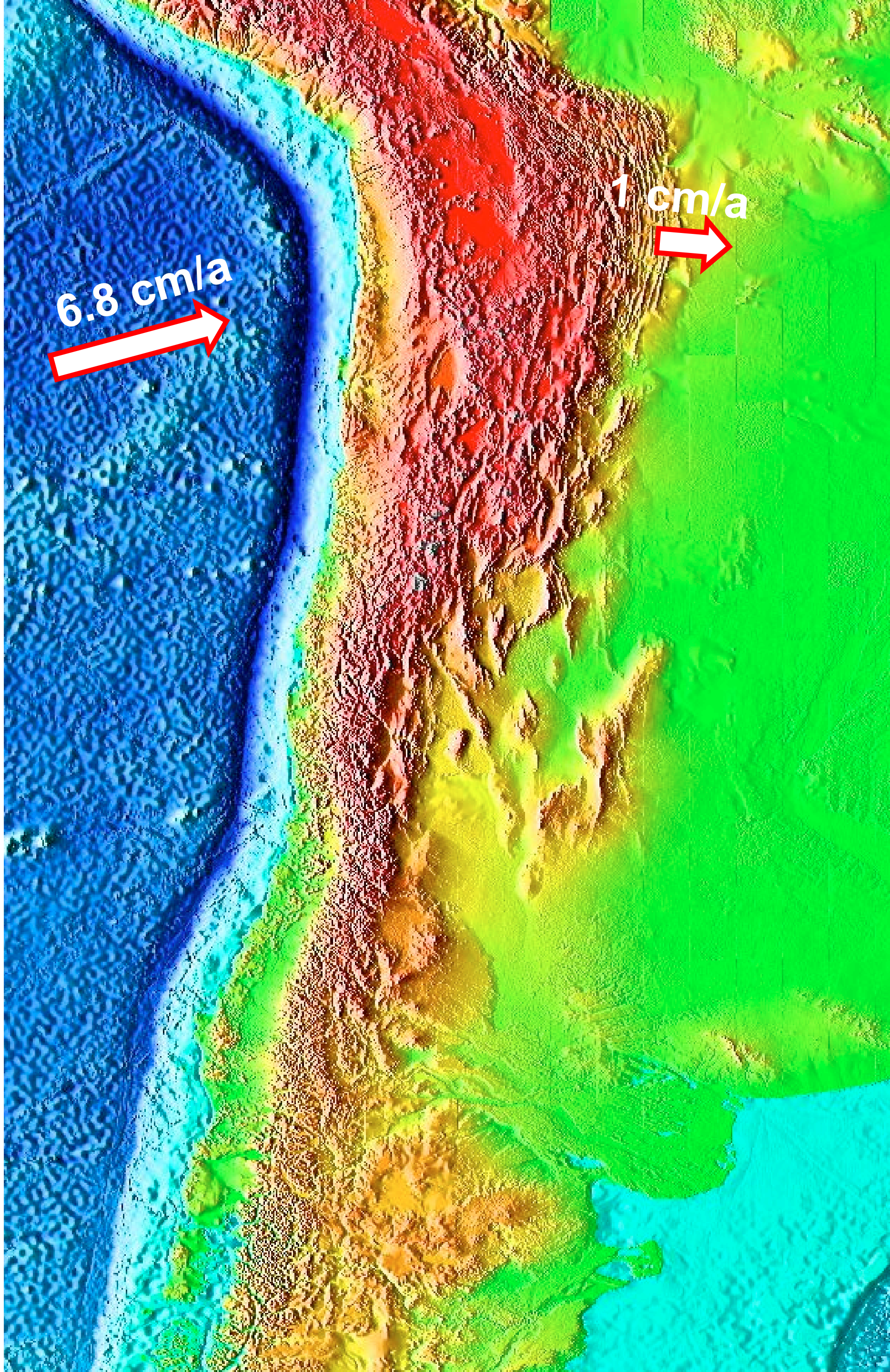
Climate effect on orogeny is only identifiable by combination of following observations

(at large(!), i.e. orogen scale):

1. Retreat of the deformation front into the orogen,
2. Concentration of strain within the interior,
3. Decrease in relief,
4. Increase in rock uplift rate,
5. Isostatic rebound of foreland (from erosional unloading of wedge),
6. Increase of sediment flux into surrounding basins.

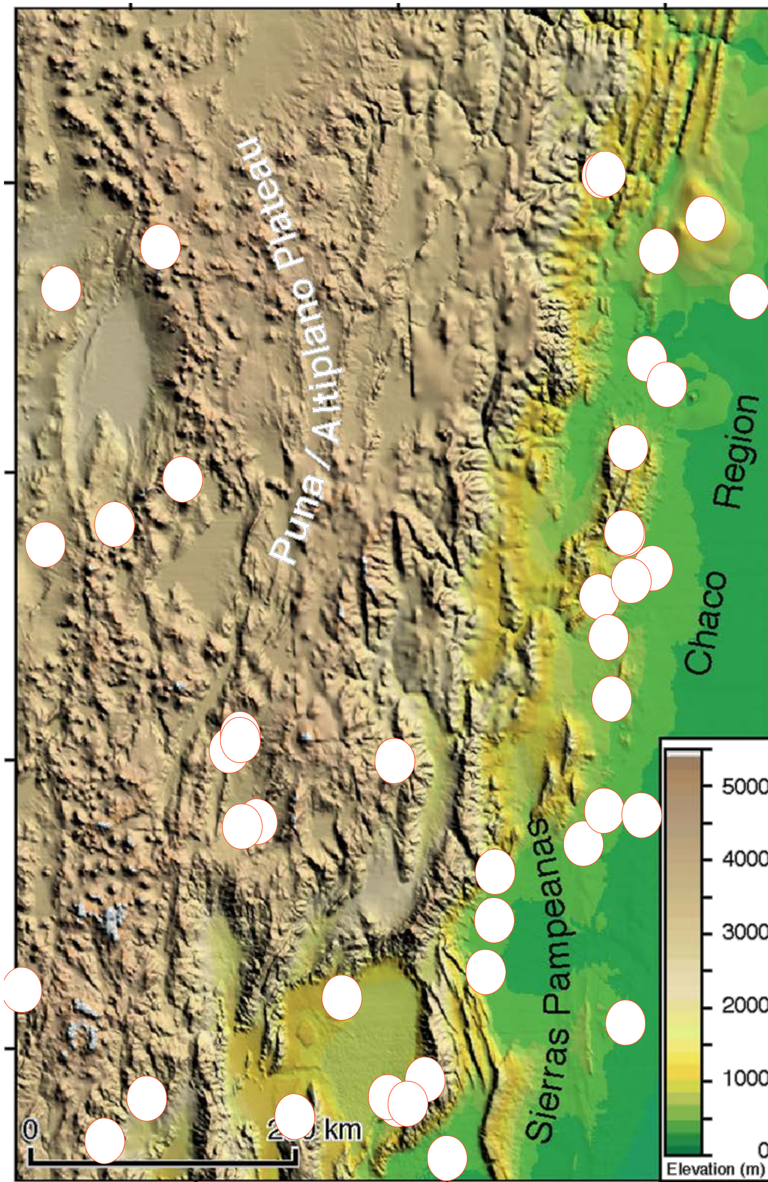
Whipple 2009

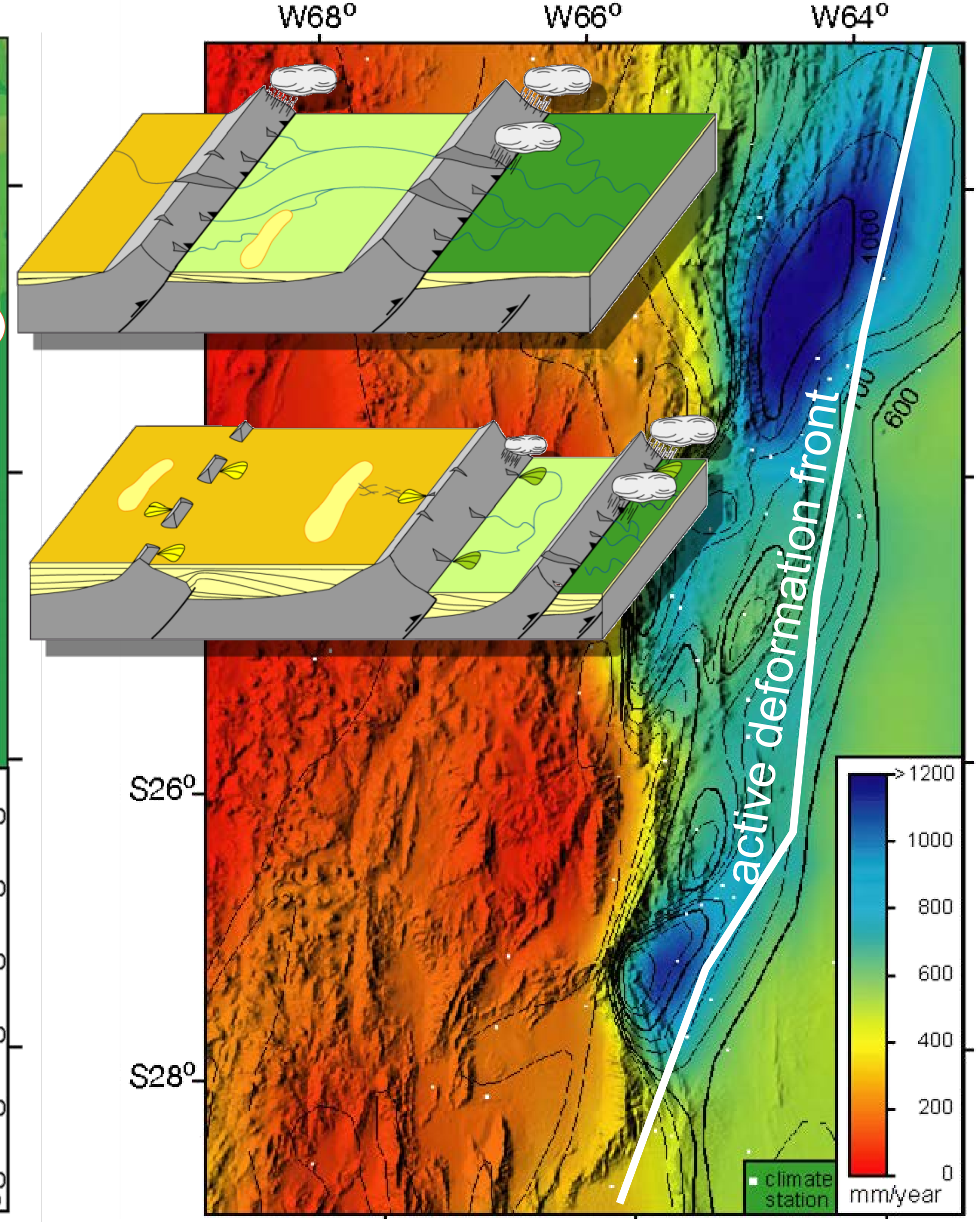
Beyond all, establish time series of above processes !!

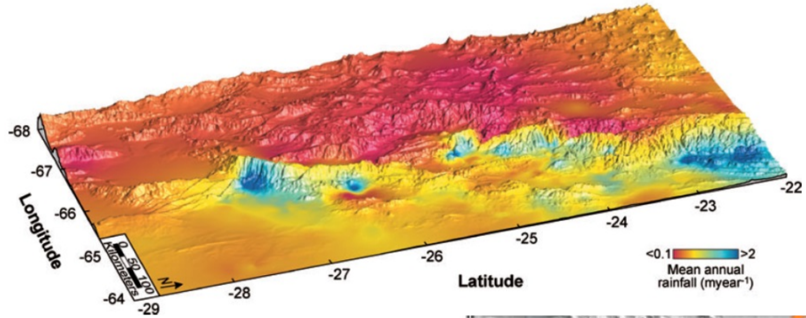

-80°
-75°
-70°
-65°
-60°
-20°
-25°
-30°
-35°
-40°
-45°
-50°
Juan Fernandez Ridge
Valdivia FZ
Chile Rise
-4000
-3000
-2000
3000
200
400
-100
-150
-200
-300
mm/yr
3500
3000
2500
2000
1500
1000
500
0
precipitation

6.8 cm/a
1 cm/a

Climate-Tectonics in backarc

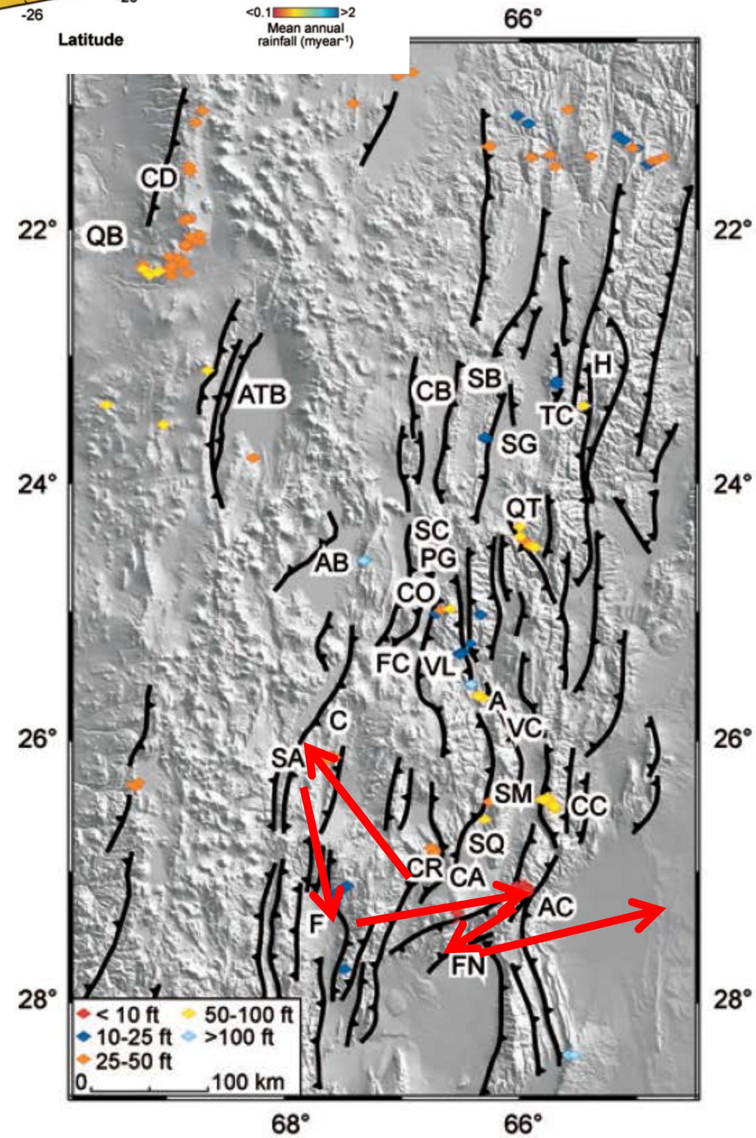
Haselton et al., 2002; Sobel et al., 2003; Hilley and Strecker, 2005

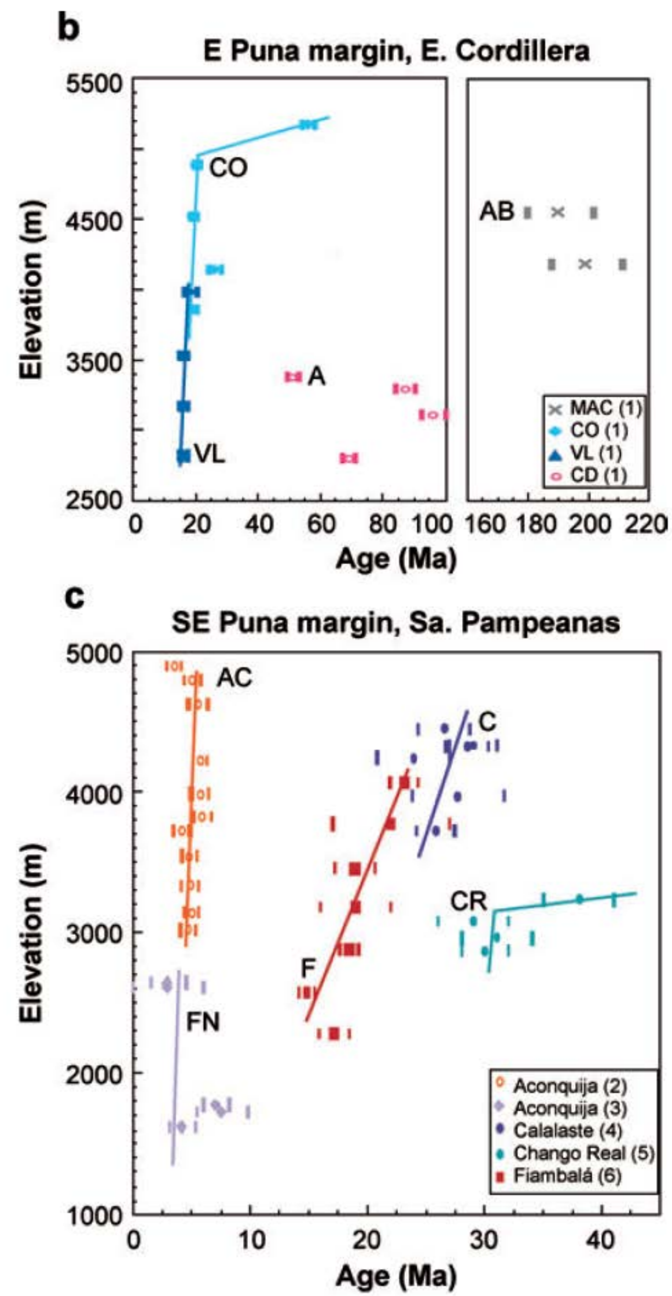






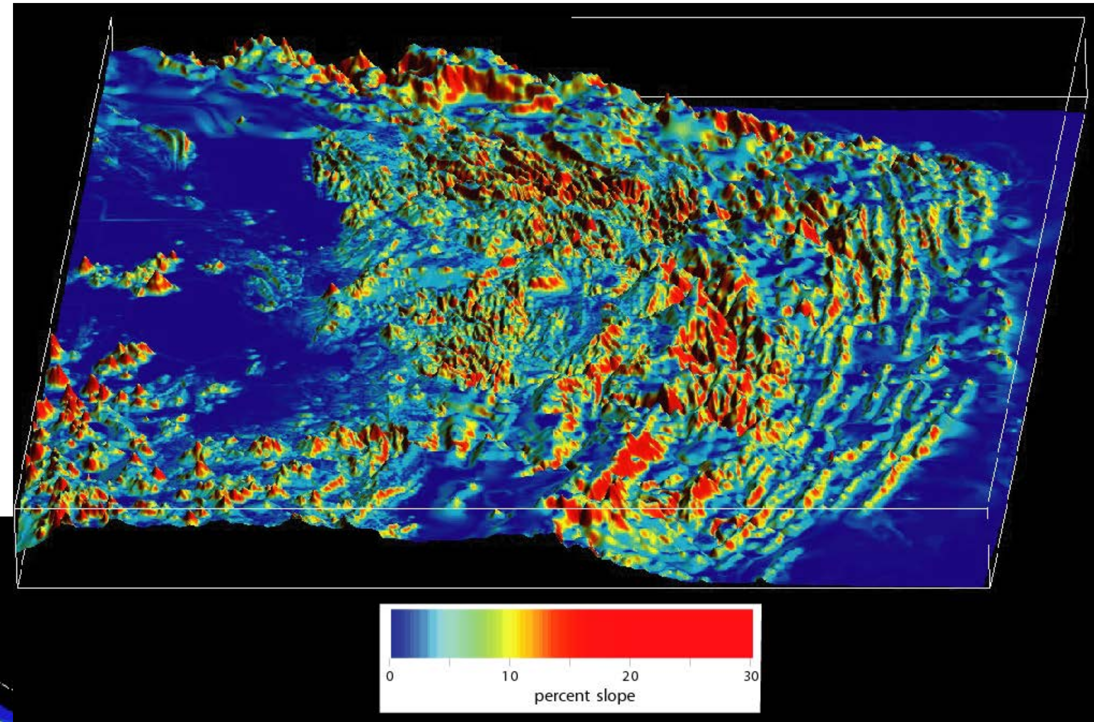
‚Tango‘-style faulting



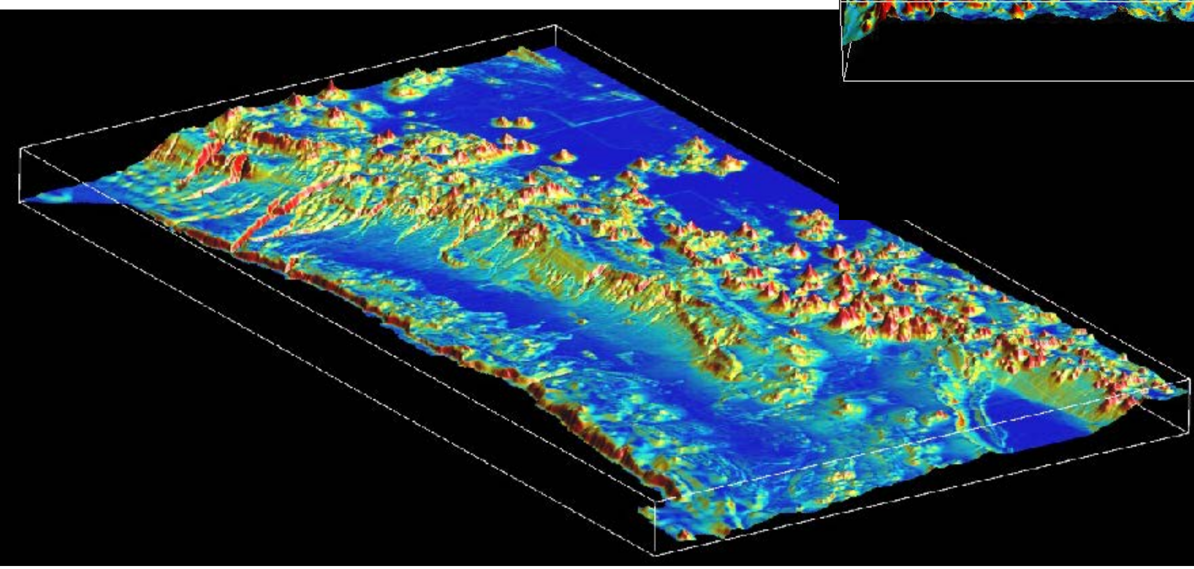


Strecker et al., 2007

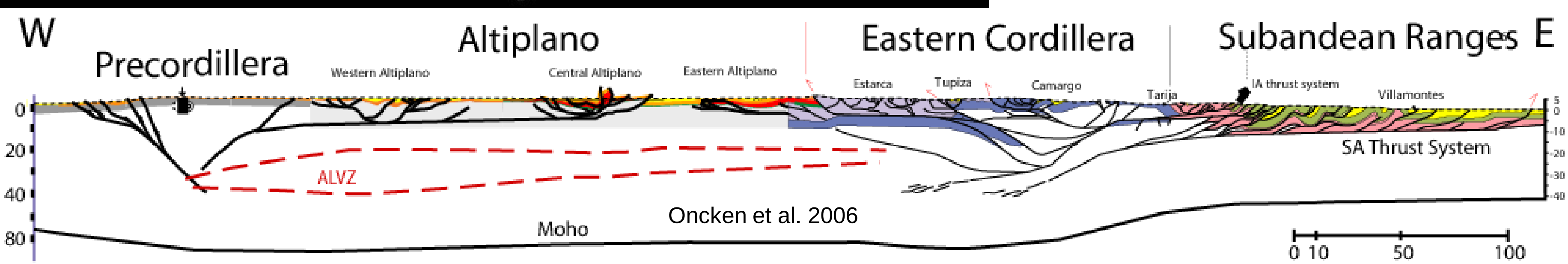
Topography, climate and deformation style



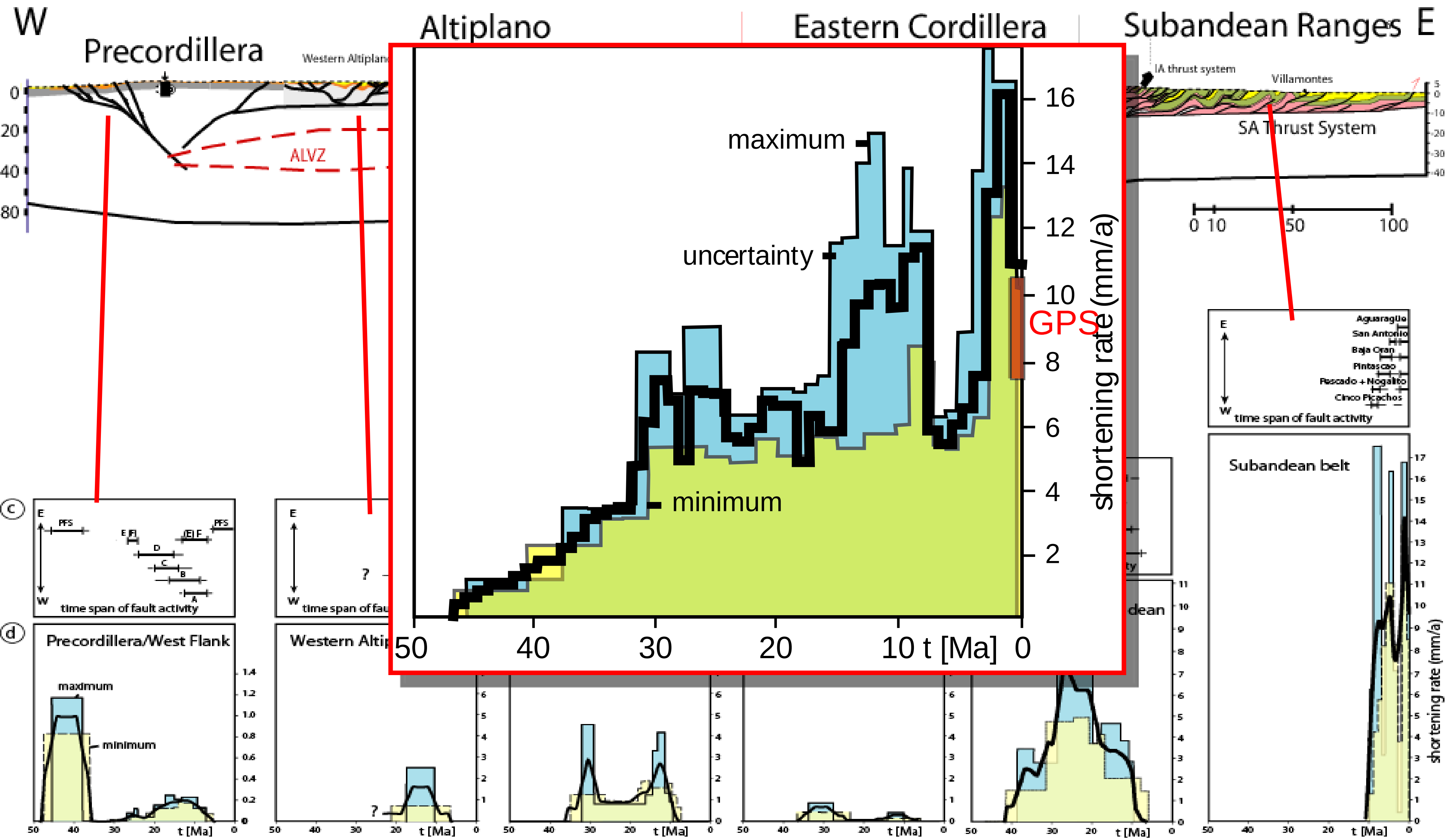
Arid west flank



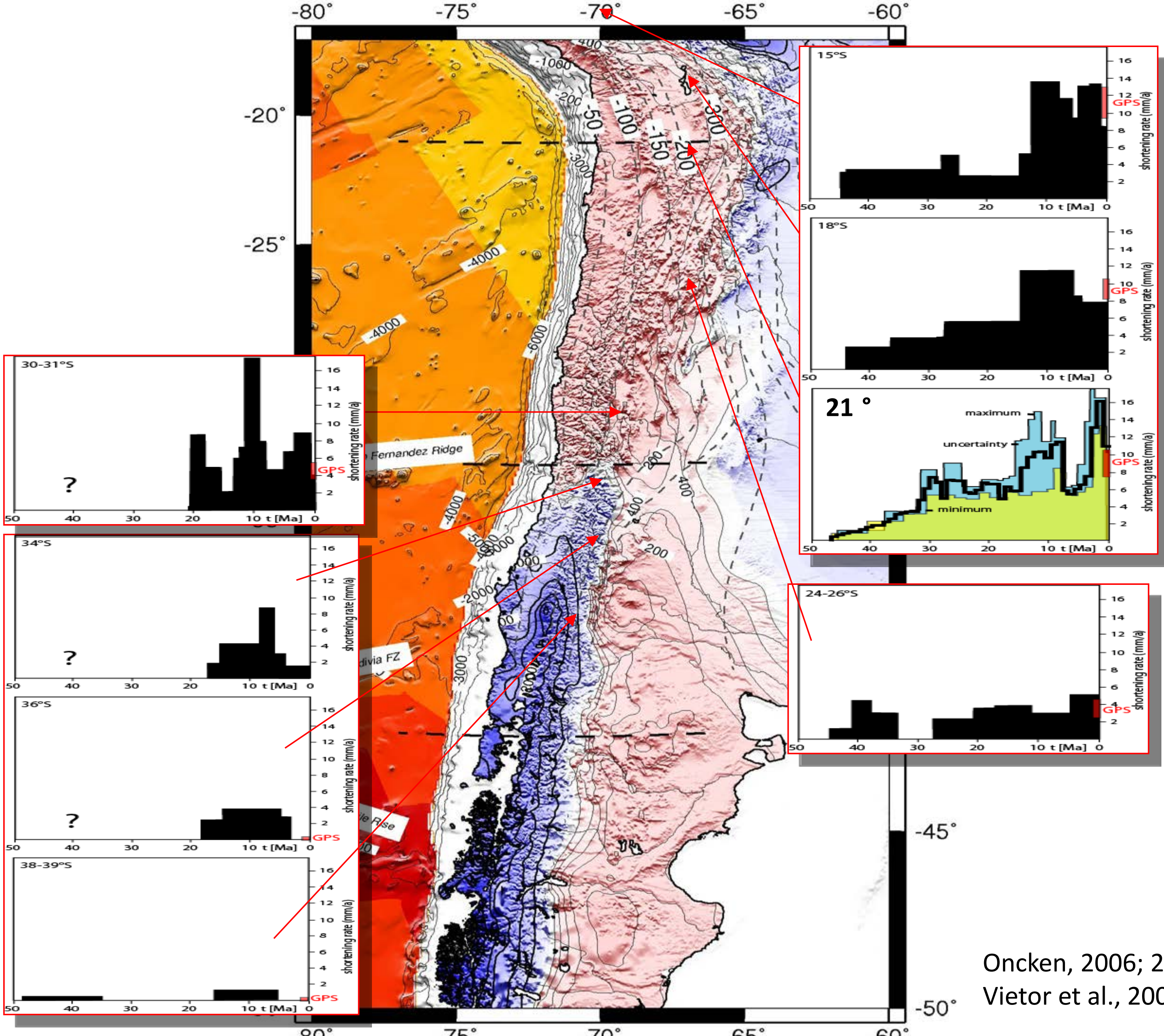
Humid east flank



Orogen speedometry



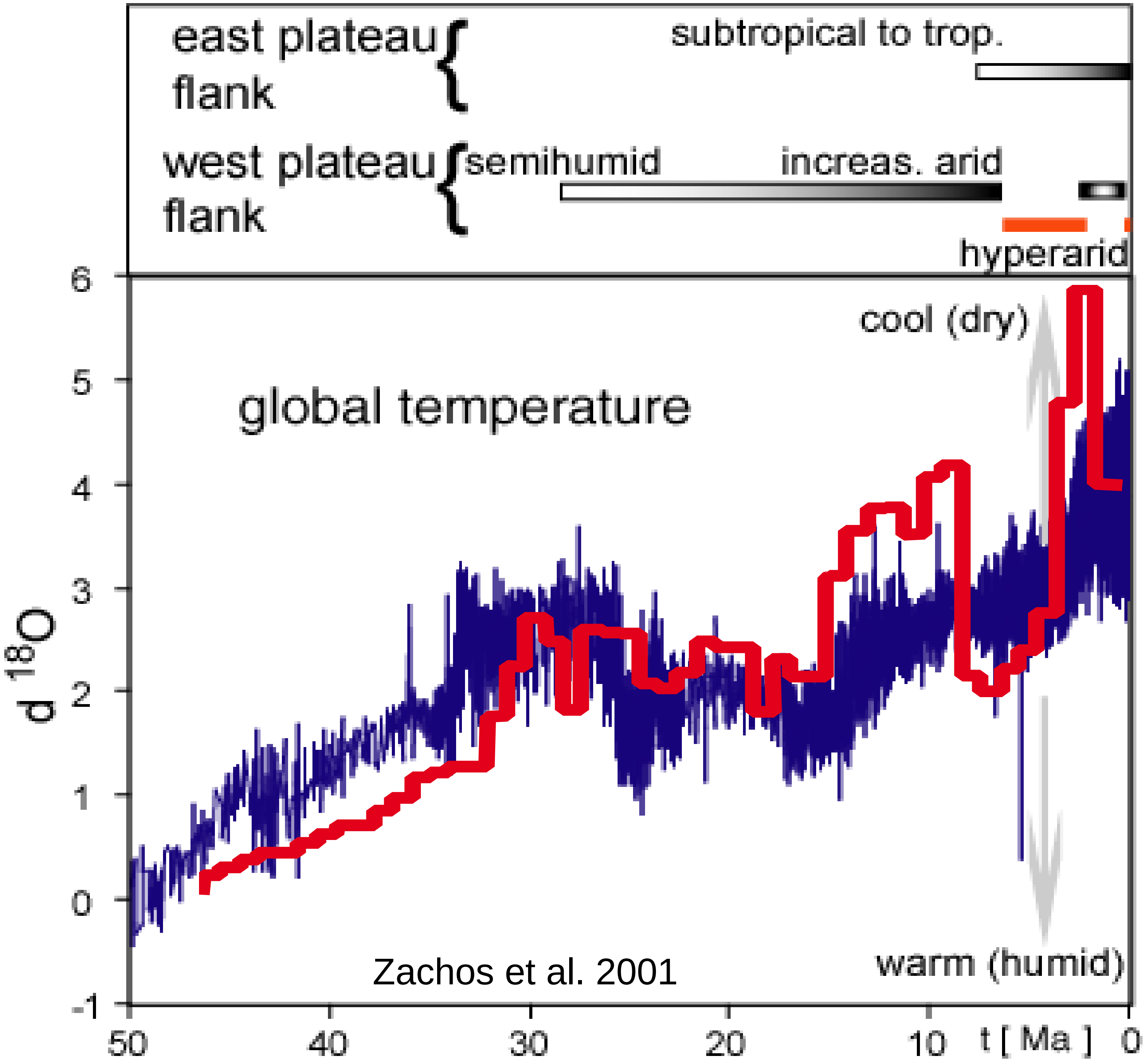
Oncken et al. 2006, 2012

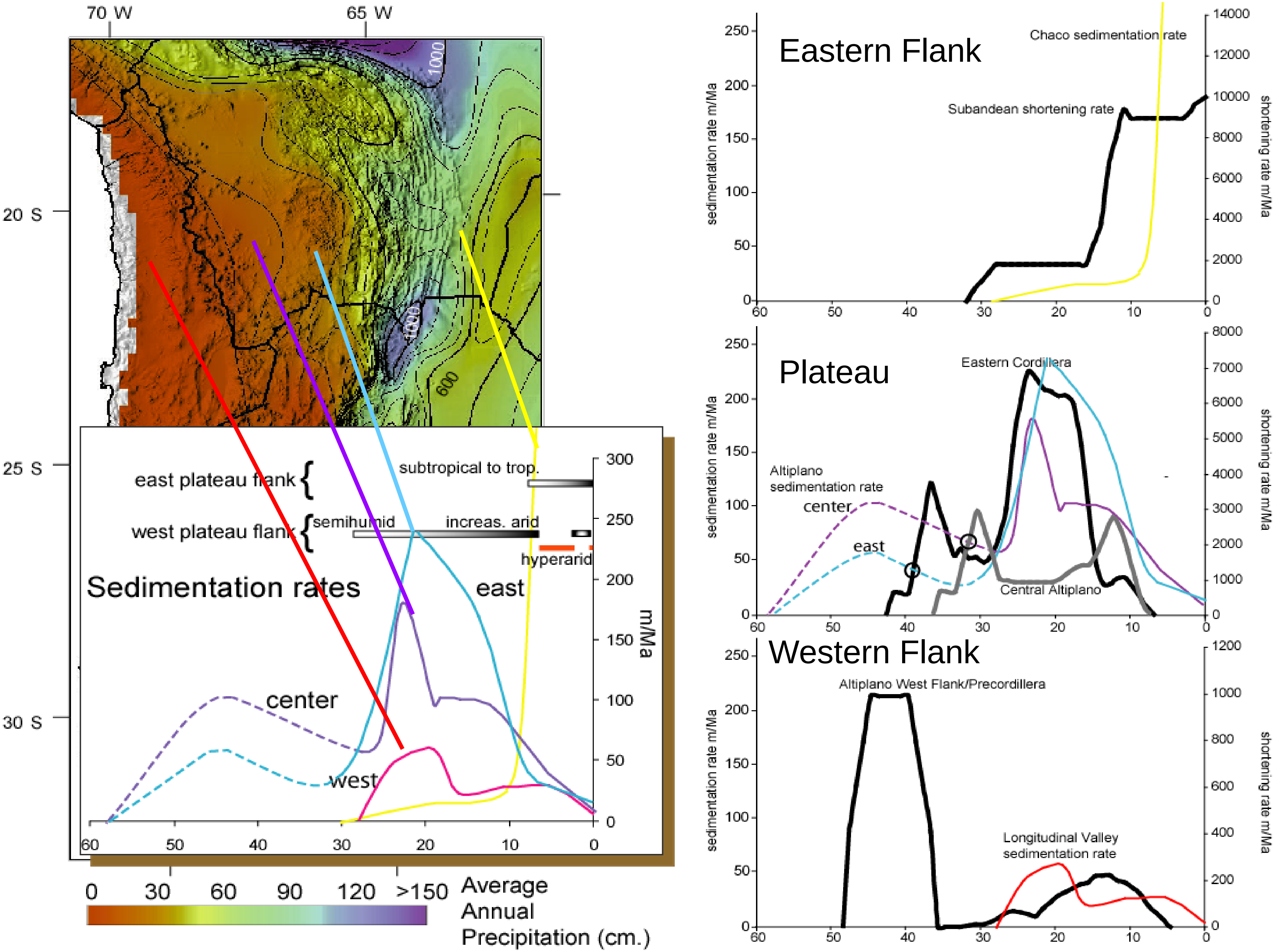


Oncken, 2006; 2012;
Vietor et al., 2006

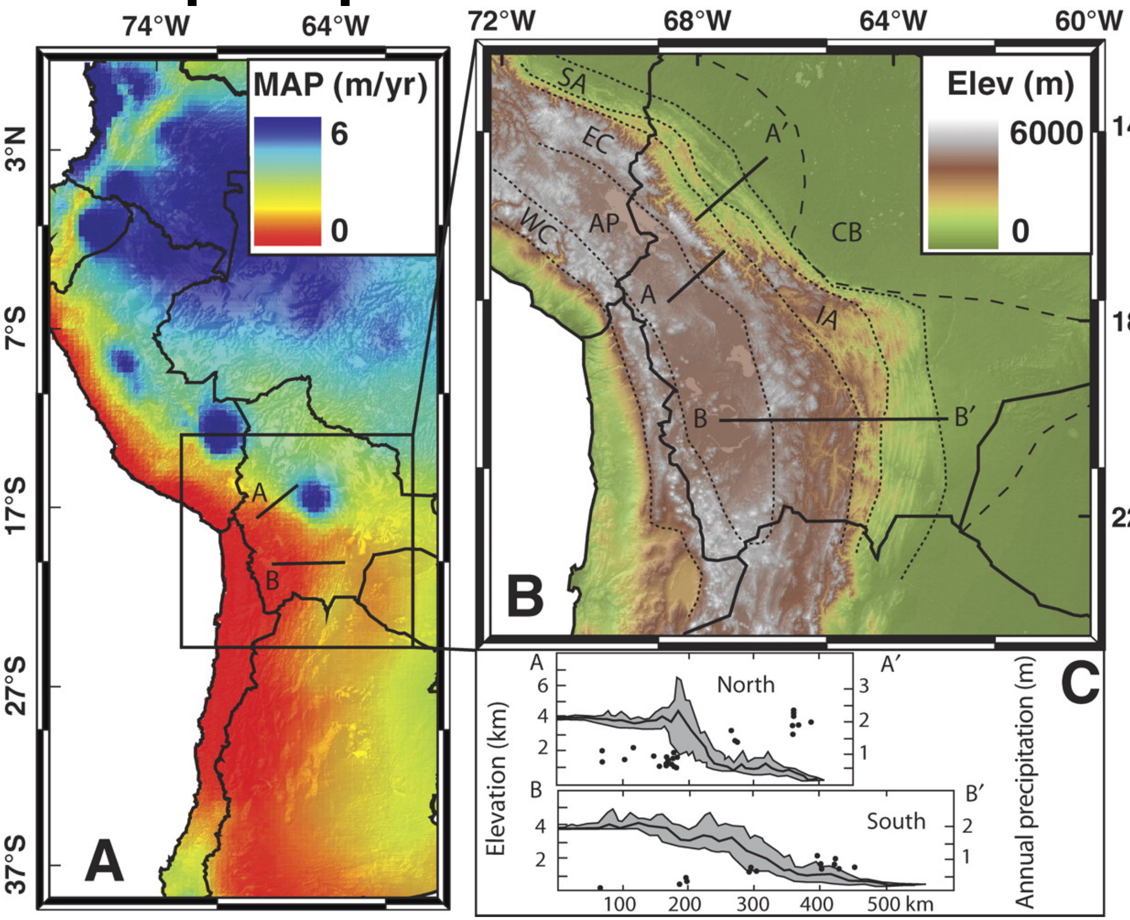
Central Andes climate evolution

… and shortening rate trend

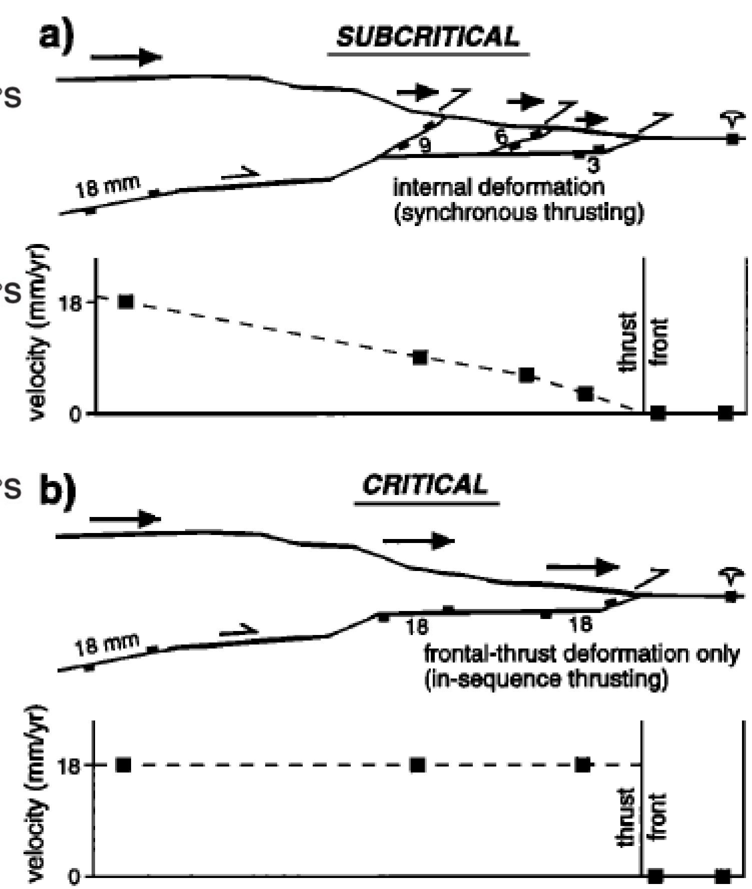



70 W
65 W
20 S
25 S
30 S
1000
600
east plateau flank
subtropical to trop.
west plateau flank
semihumid
increas. arid
hyperarid
Sedimentation rates
east
center
west
m/Ma
0
30
60
90
120
>150
Average Annual Precipitation (cm.)
Eastern Flank
Chaco sedimentation rate
Subandean shortening rate
sedimentation rate m/Ma
shortening rate m/Ma
Plateau
Eastern Cordillera
Altiplano sedimentation rate
center
east
Central Altiplano
Western Flank
Altiplano West Flank/Precordillera
Longitudinal Valley sedimentation rate

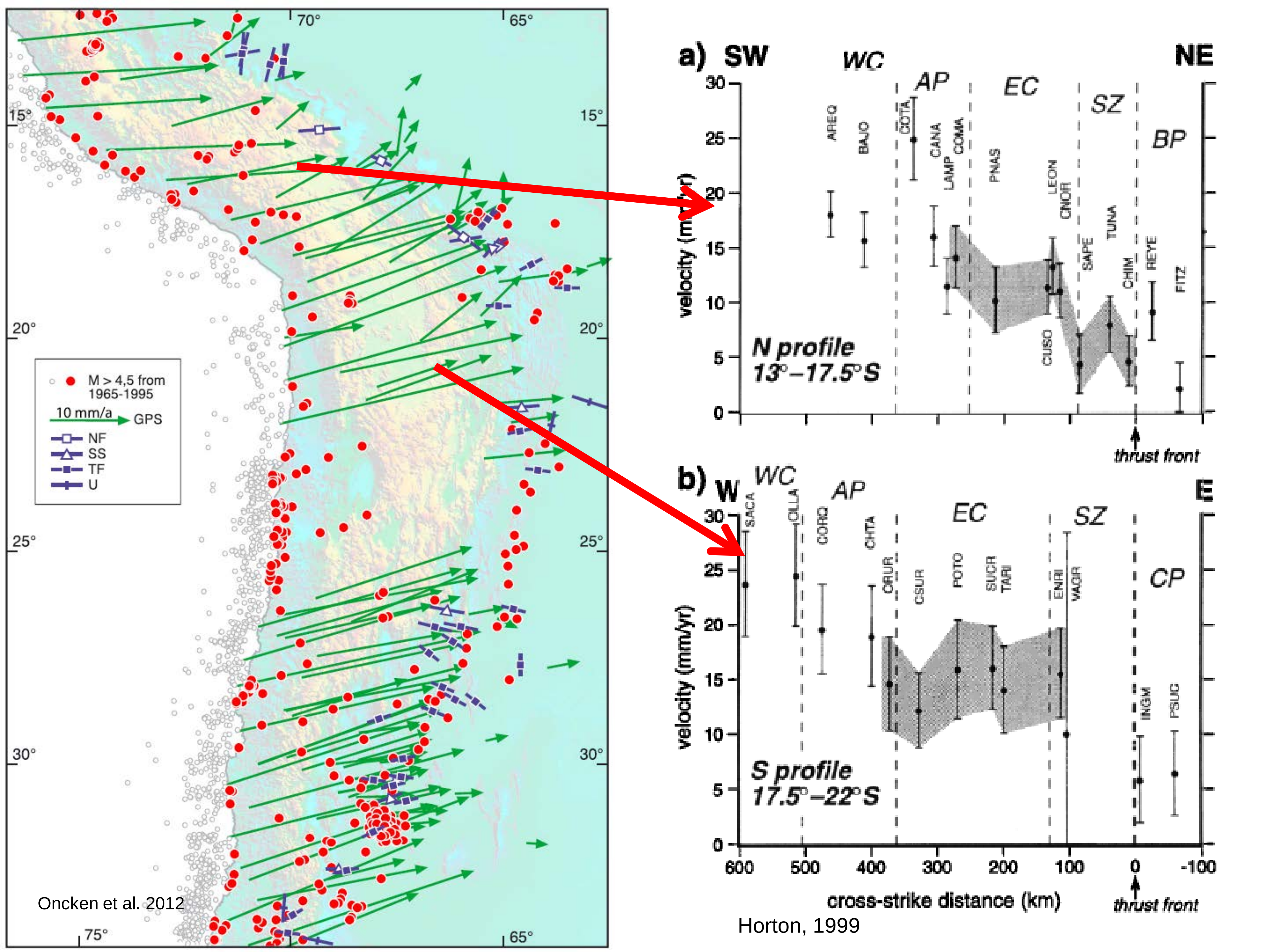
Central Andean taper and precipitation

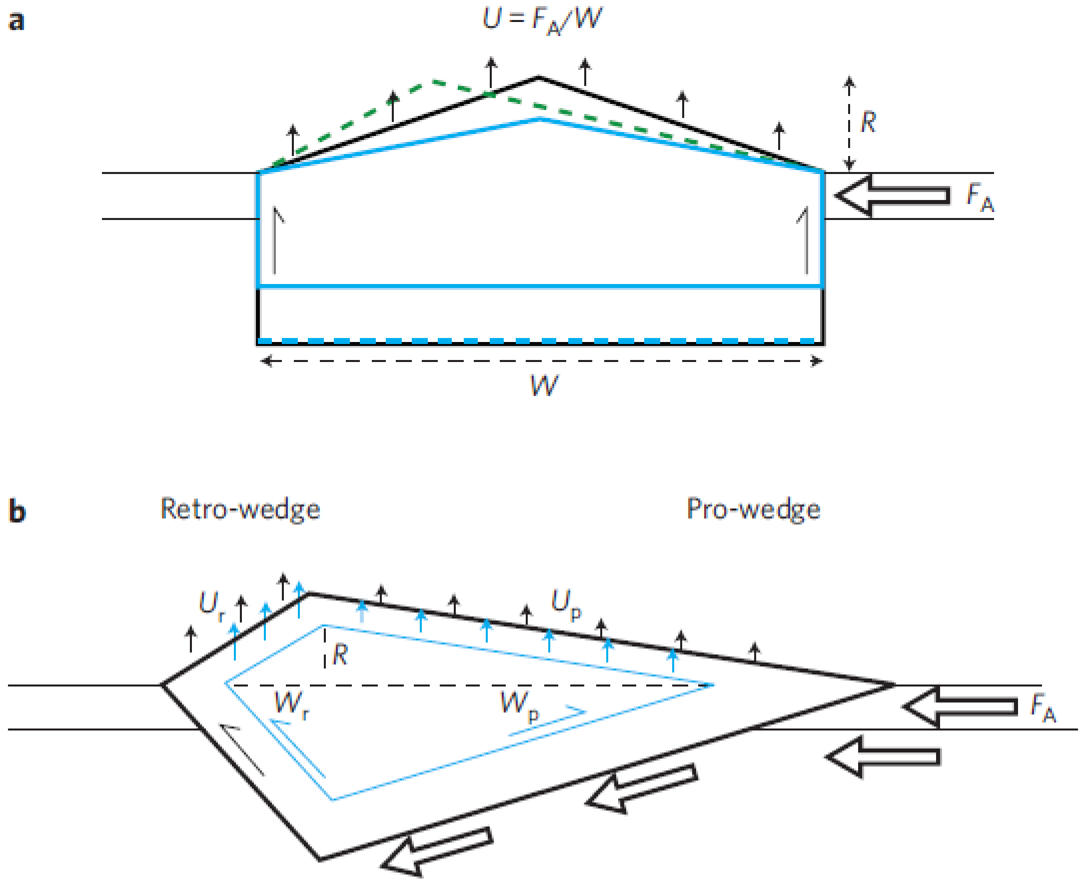


Shortening gradients and criticality (expected)



Horton, 1999; McQuarrie et al. 2008


70°
65°
15°
20°
25°
30°
75°
M > 4,5 from 1965-1995
10 mm/a
GPS
NF
SS
TF
U
Oncken et al. 2012
a) SW
NE
WC
AP
EC
SZ
BP
N profile 13°–17.5°S
velocity (mm/yr)
AREQ
BAJO
COTA
CANA
LAMP
COMA
PNAS
LEON
CNOR
CUSO
SAPE
TUNA
CHIM
REYE
FITZ
thrust front
b) W
E
WC
AP
EC
SZ
CP
S profile 17.5°–22°S
SACA
CILLA
CORQ
CHTA
ORUR
CSUR
POTO
SUCR
TARI
ENRI
VAGR
INGM
PSUC
cross-strike distance (km)
thrust front
Horton, 1999



Whipple, 2009

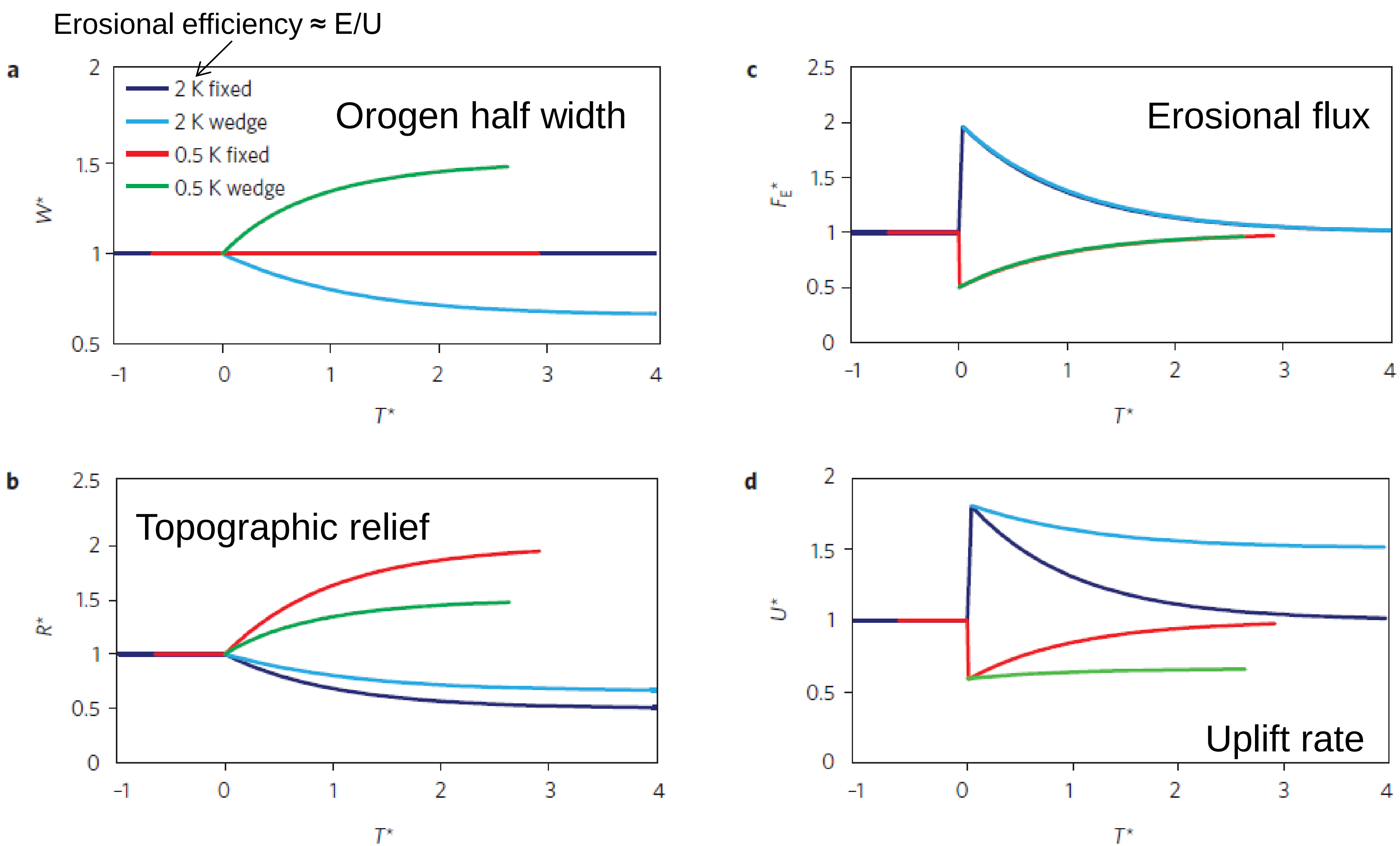
Flux ratio: F_E / F_A

Andes north of bend: 0.5

South of bend: 0.2

Central Alps prowedge: >1

The lag-time problem



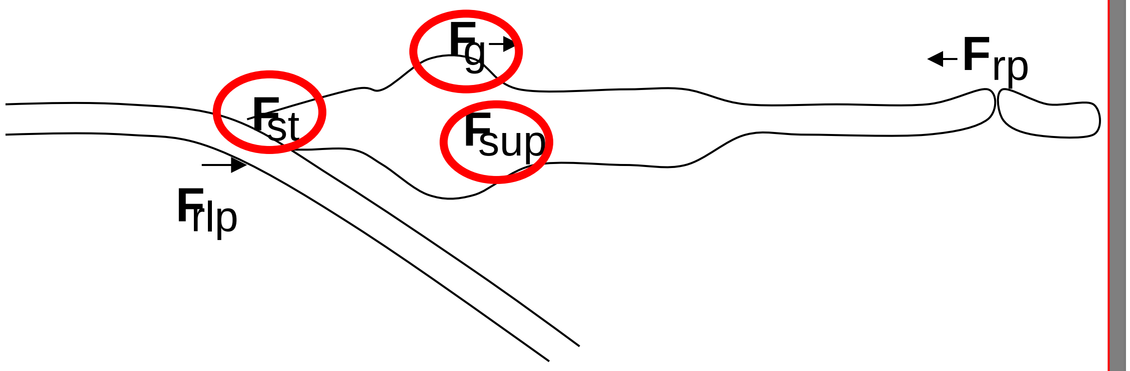
To rule out an isostasy-only response, search for response times of 2-10 Ma.

Whipple, 2009

More questions

- Is mass flux ratio linearly related to a tectonic response or are there thresholds?
- How can we overcome the elusive nature of the climate impact on tectonics in the observations?
- …

Mountain building and climate – weakening versus forcing?



$$0 \approx F_{rp} + F_{rlp} + F_{st} + F_{sup} + F_g$$

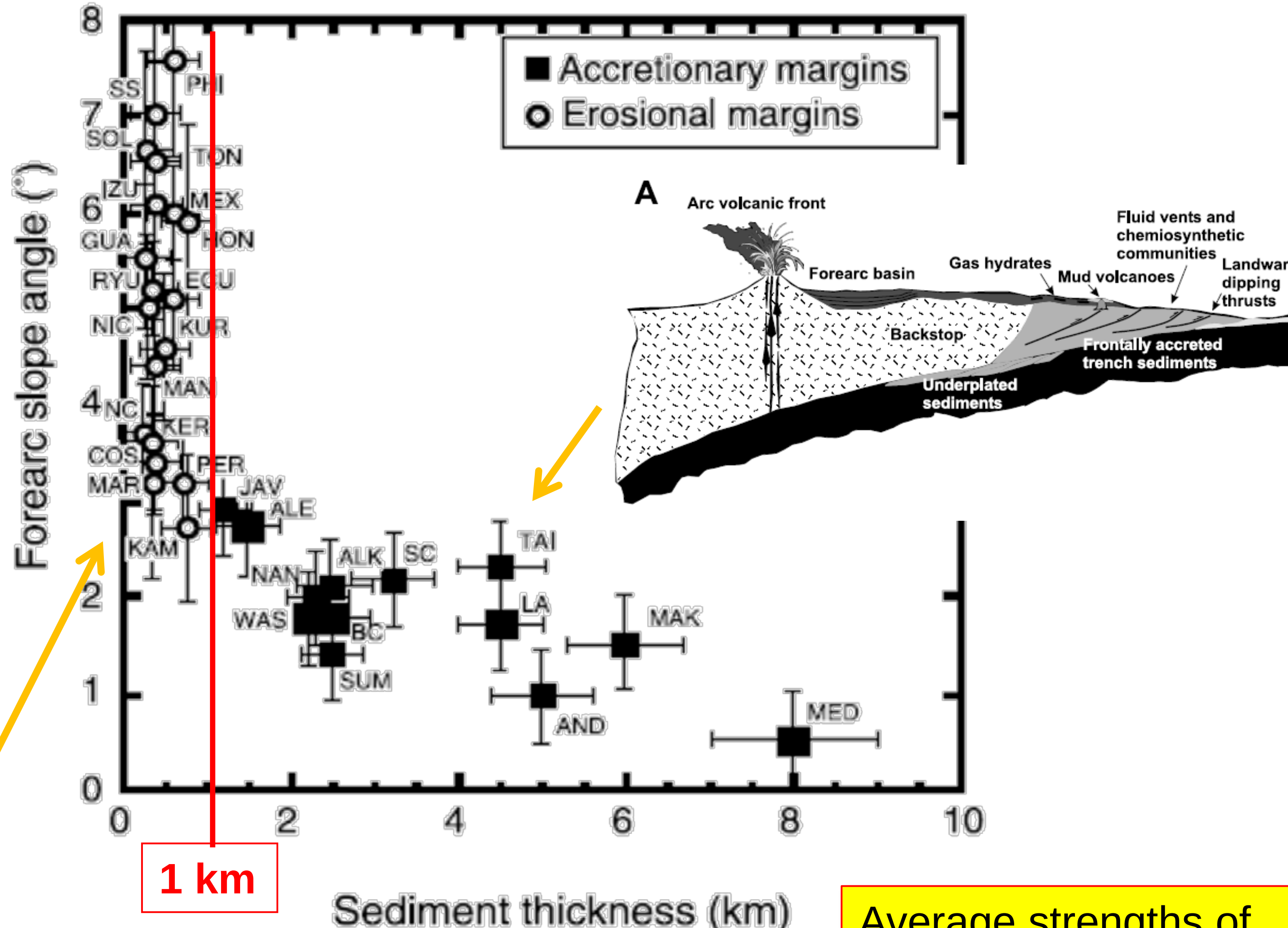
ridge push

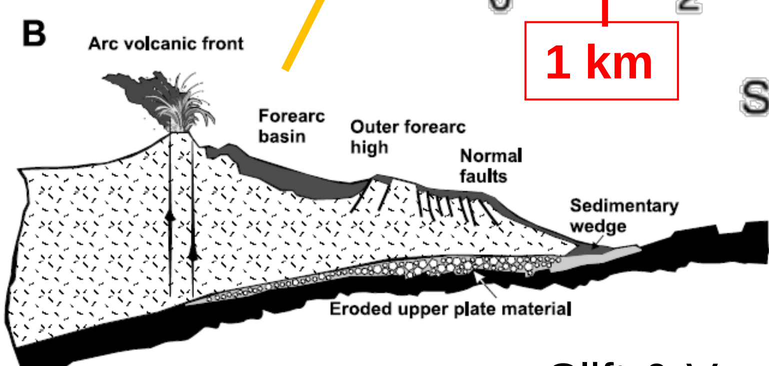
resistance of lower plate

shear traction

strength of upper plate

gravitational forces

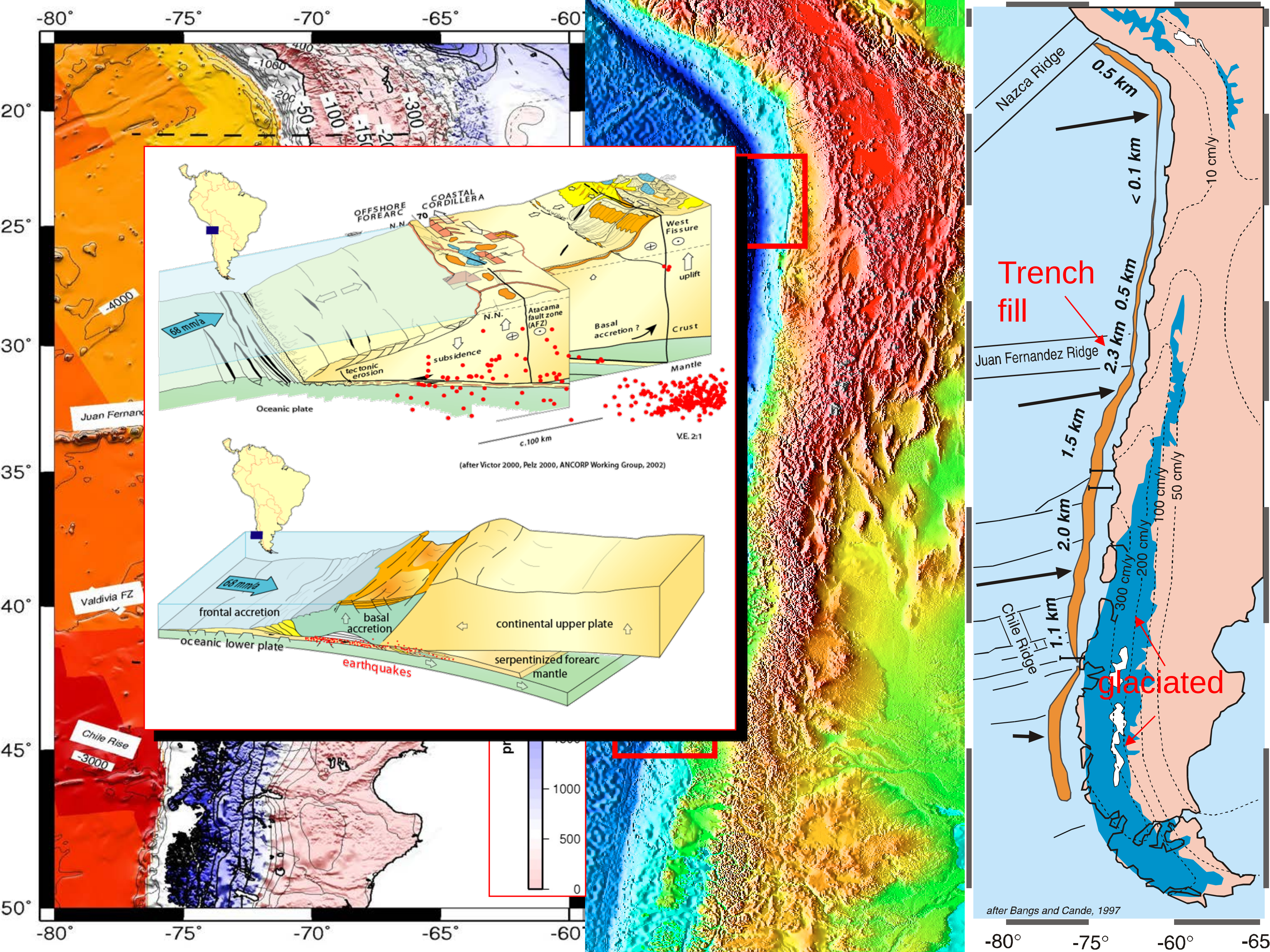




Clift & Vannucchi, 2004

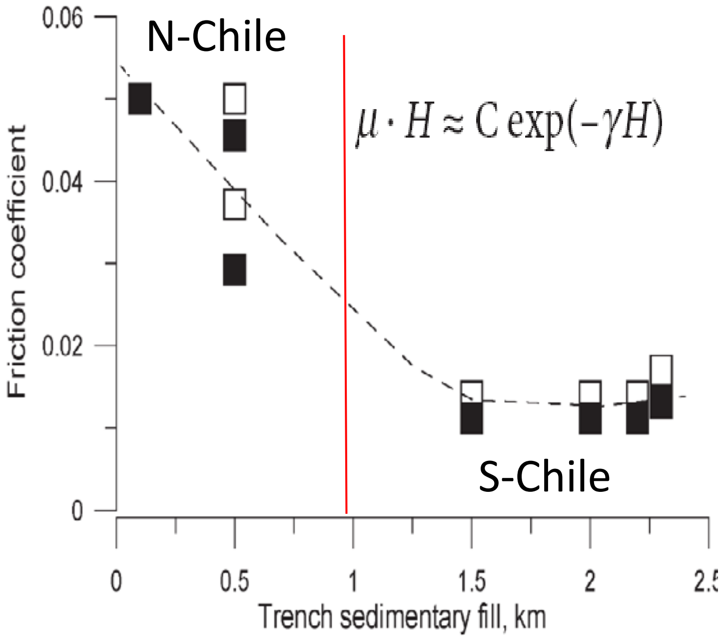
Average strengths of convergent plate interfaces:

7-15 MPa (40 MPa)

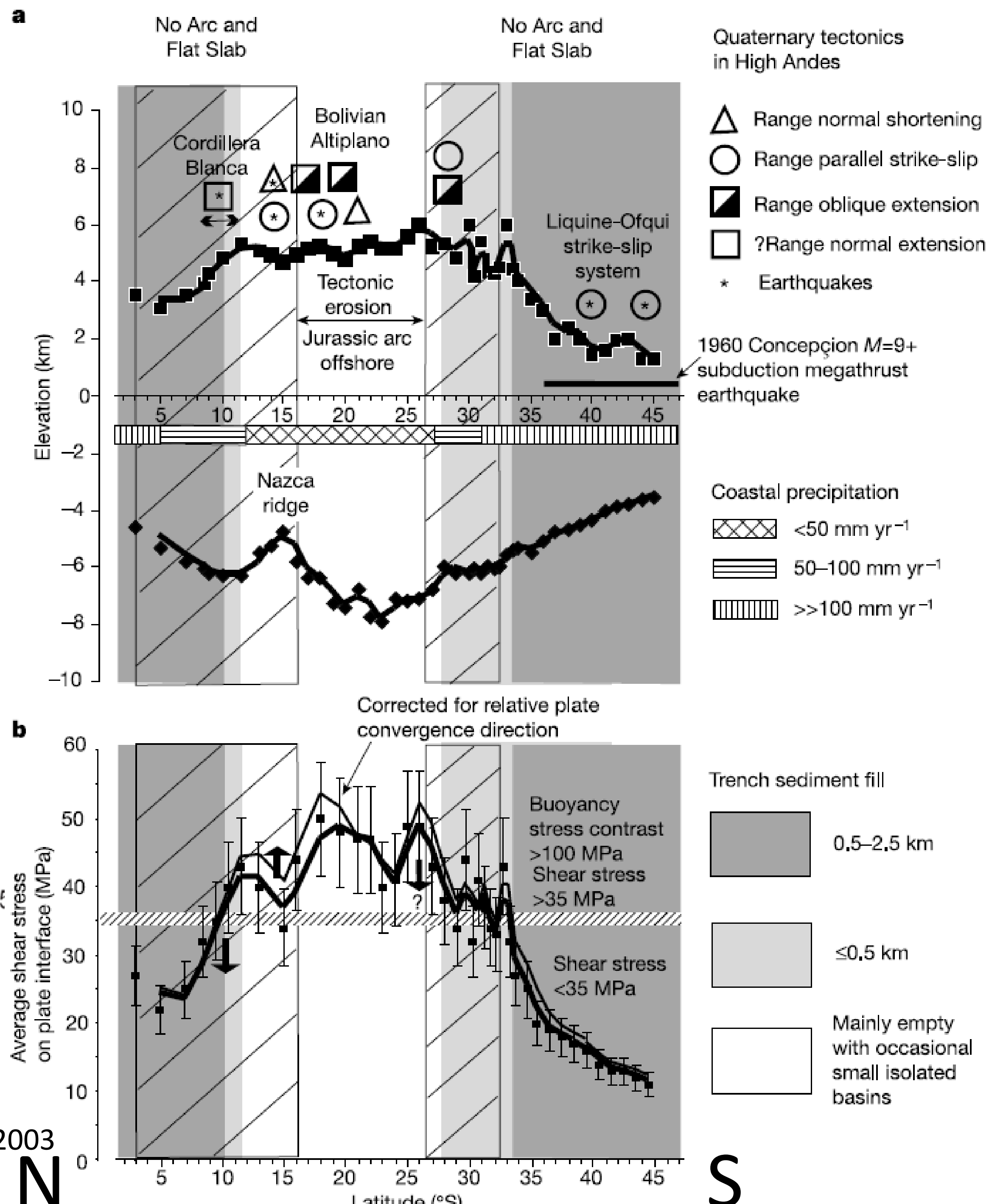


-80° -75° -70° -65° -60°
20° 25° 30° 35° 40° 45° 50°
Juan Fernandez
Valdivia FZ
Chile Rise
-4000
-3000
1000
500
0
OFFSHORE FOREARC
COASTAL CORDILLERA
N.N.
West Fissure
uplift
68 mm/a
subsidence
tectonic erosion
Atacama fault zone (AFZ)
Basal accretion ?
Crust
Mantle
Oceanic plate
c.100 km
V.E. 2:1
(after Victor 2000, Pelz 2000, ANCORP Working Group, 2002)
frontal accretion
basal accretion
continental upper plate
oceanic lower plate
earthquakes
serpentinized forearc mantle
Nazca Ridge
0.5 km
< 0.1 km
10 cm/y
Trench fill
0.5 km
2.3 km
Juan Fernandez Ridge
1.5 km
2.0 km
50 cm/y
100 cm/y
200 cm/y
300 cm/y
Chile Ridge
1.1 km
glaciated
after Bangs and Cande, 1997
-80° -75° -60° -65

Present day plate interface strength of Andean margin

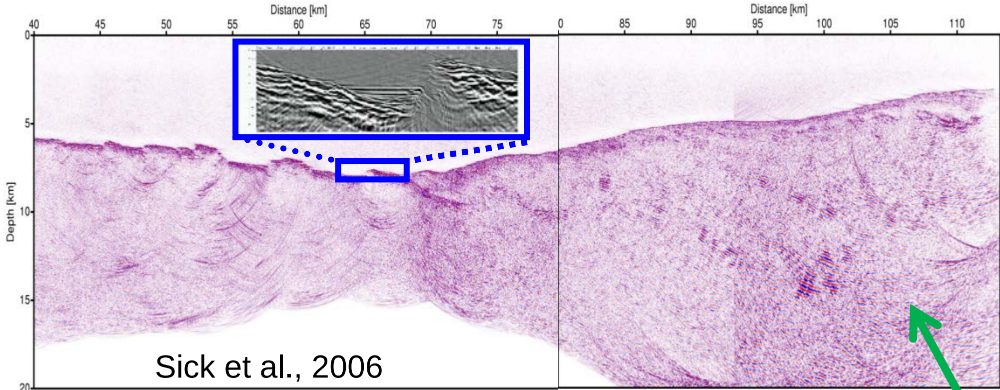


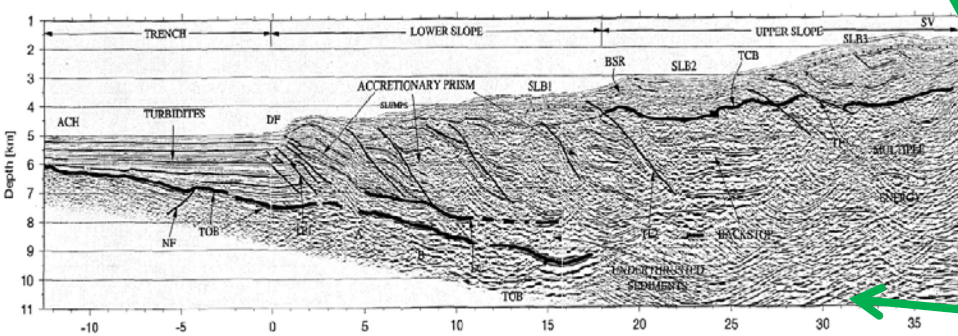
Sobolev & Babeyko, 2005



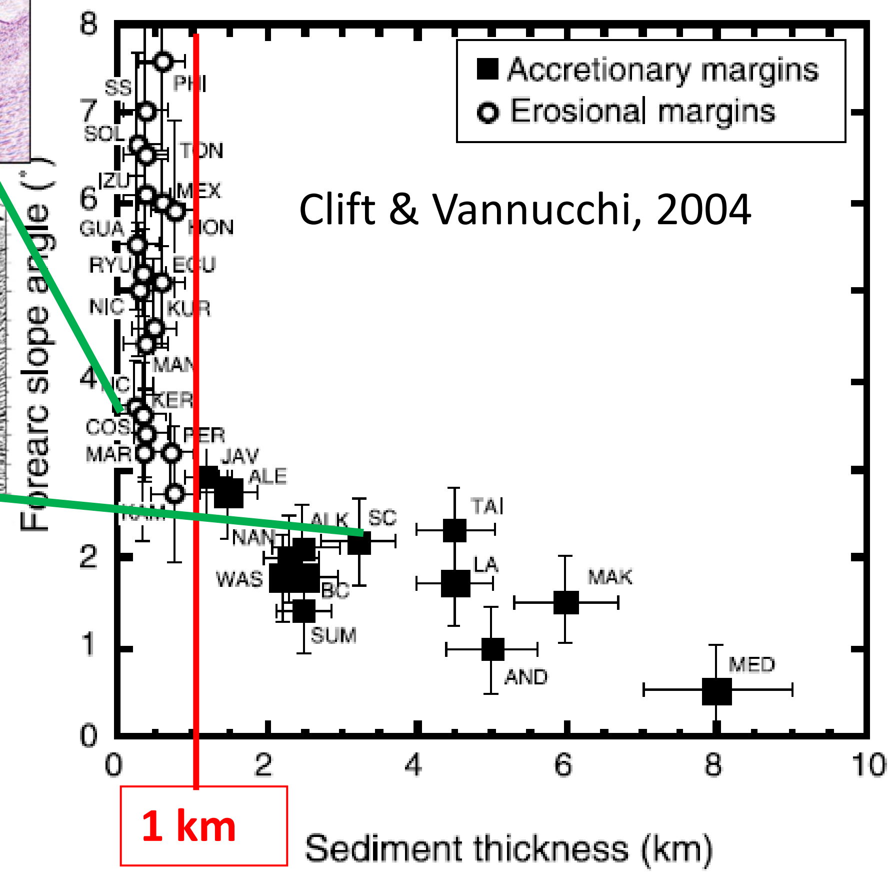
Lamb 2003

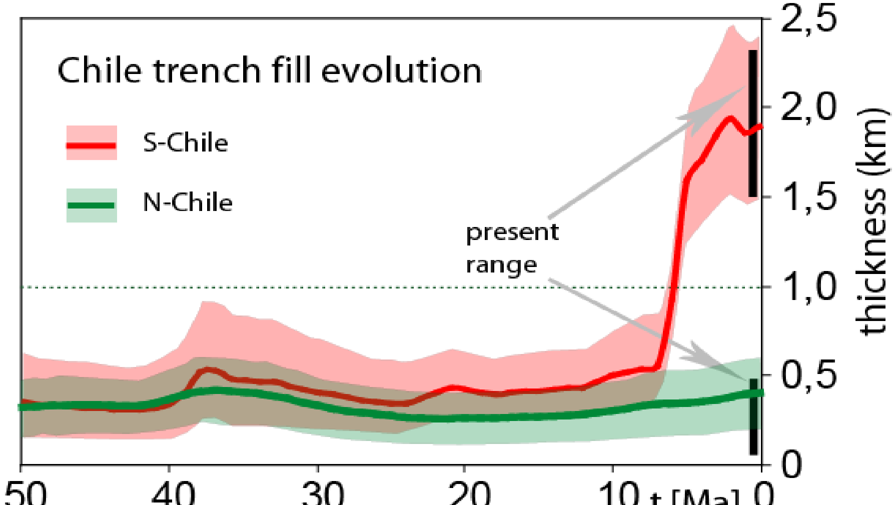
Controls on subduction erosion: the trench





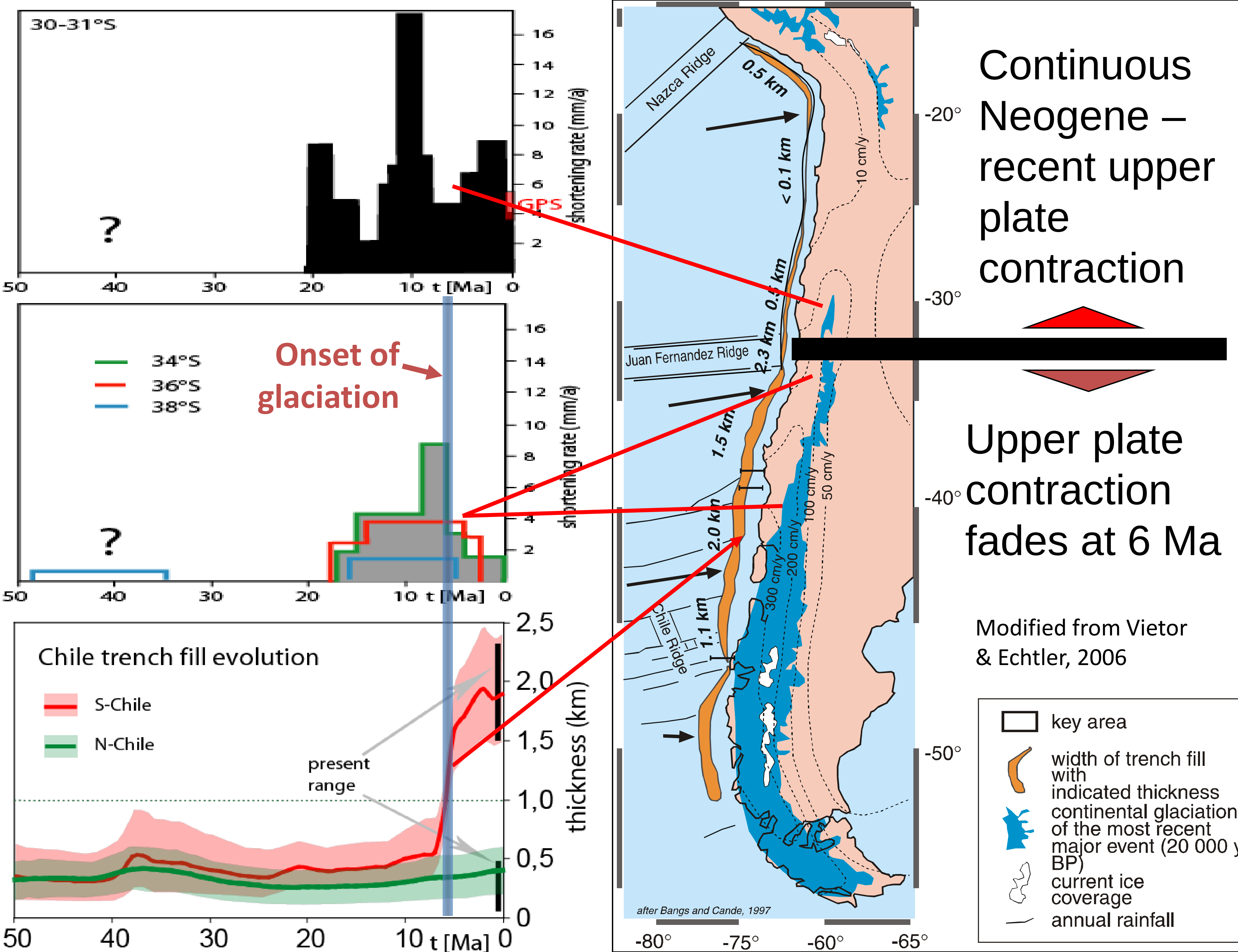
Bangs and Cande, 1997





$$T_{ts} = \left(\frac{(\dot{V}_{vf} + A\dot{V}_{er})(1 - CD)}{(1 - 0.01\phi)} + \dot{V}_{ps} + \dot{V}_{mw} - \dot{V}_{fs}\right)\frac{1}{\dot{P}C}$$

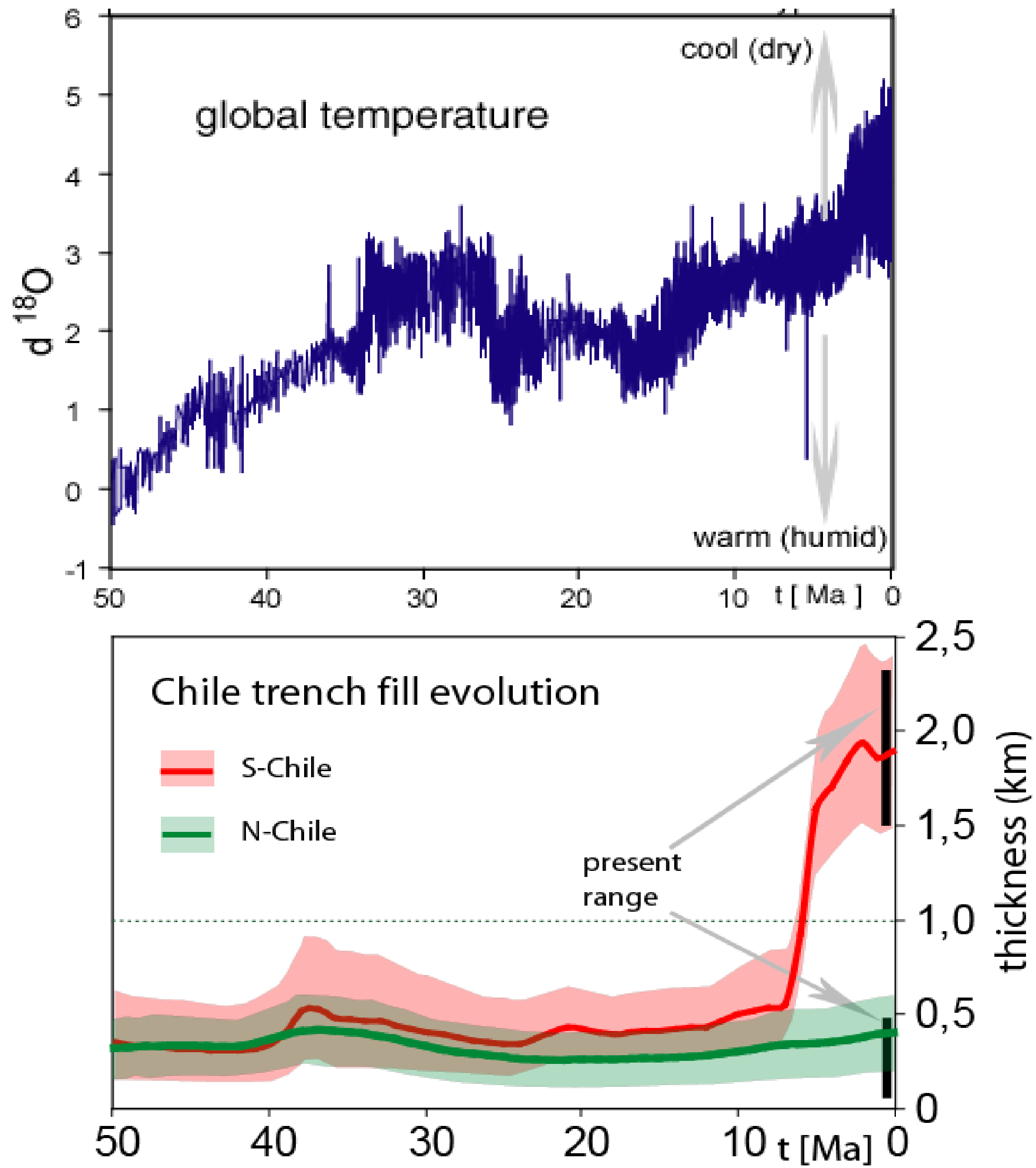
Oncken et al., 2006



Continuous Neogene – recent upper plate contraction

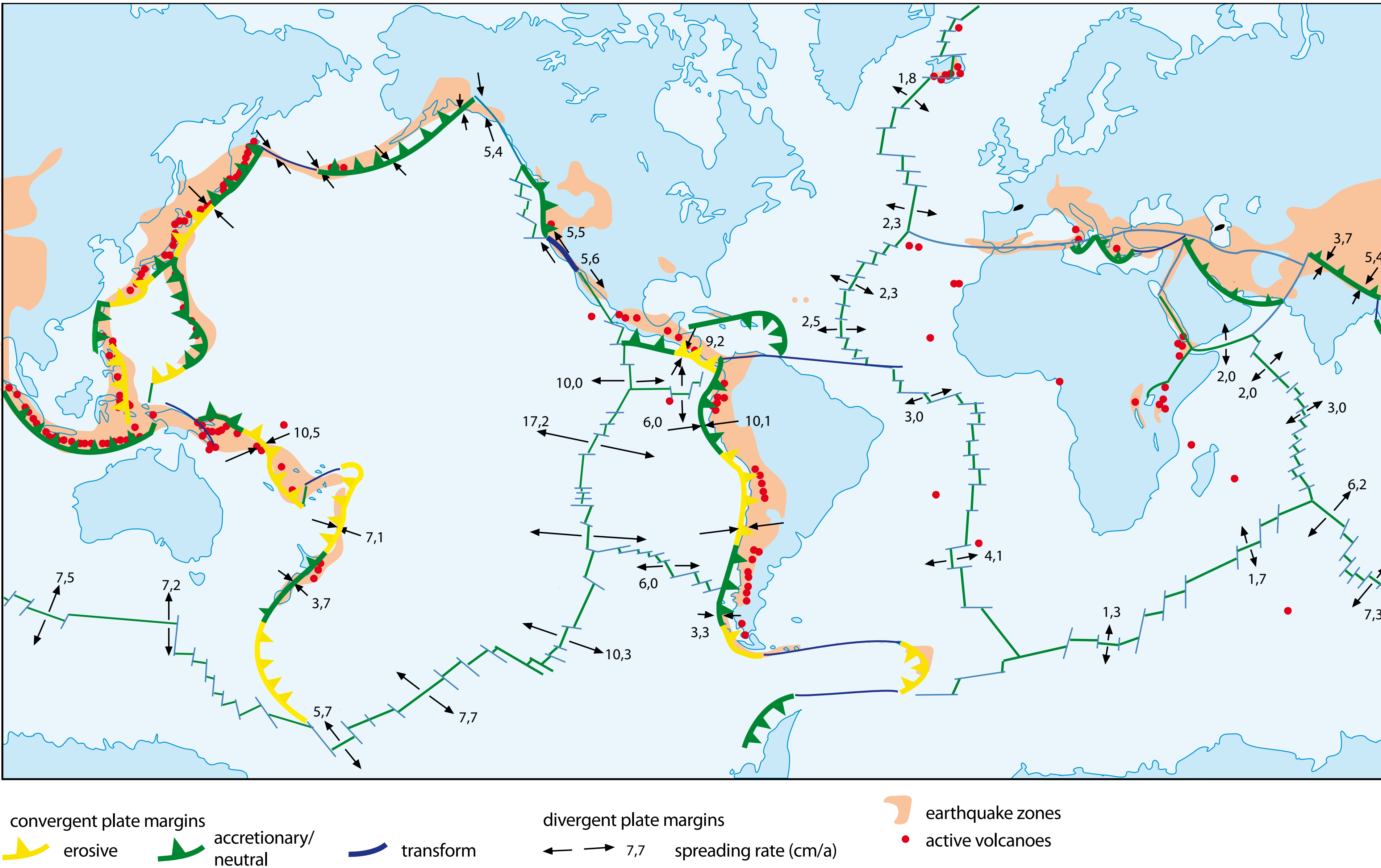
Upper plate contraction fades at 6 Ma

Modified from Vietor & Echtler, 2006

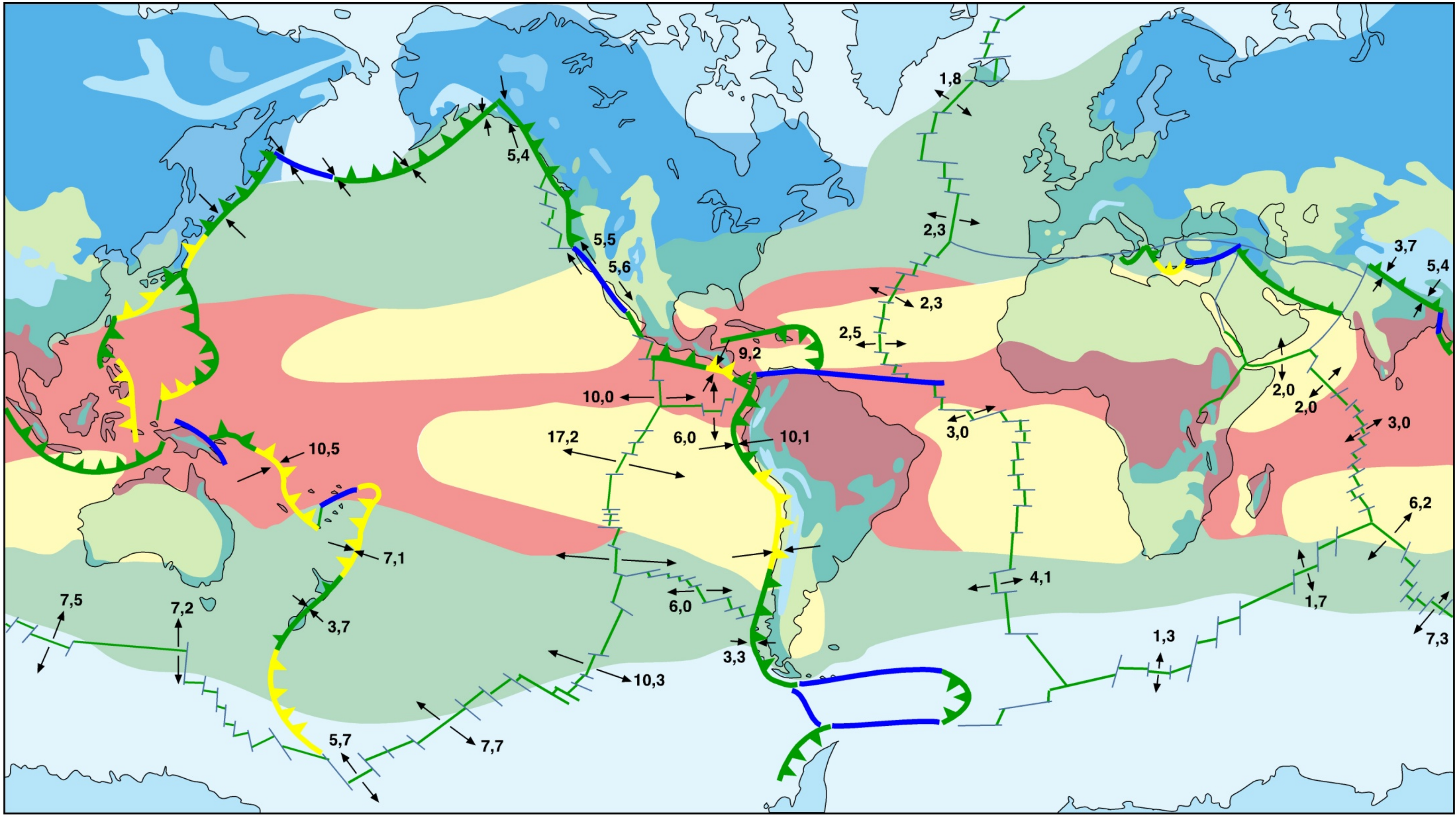


Does it require a climate threshold to trigger the sediment-flux-climate coupling?

Present global mass flux pattern



Present global mass flux pattern and climate zones



convergent plate margins

erosive

accretionary/ neutral

transform

divergent plate margins

7,7 spreading rate (cm/a)

Tropical

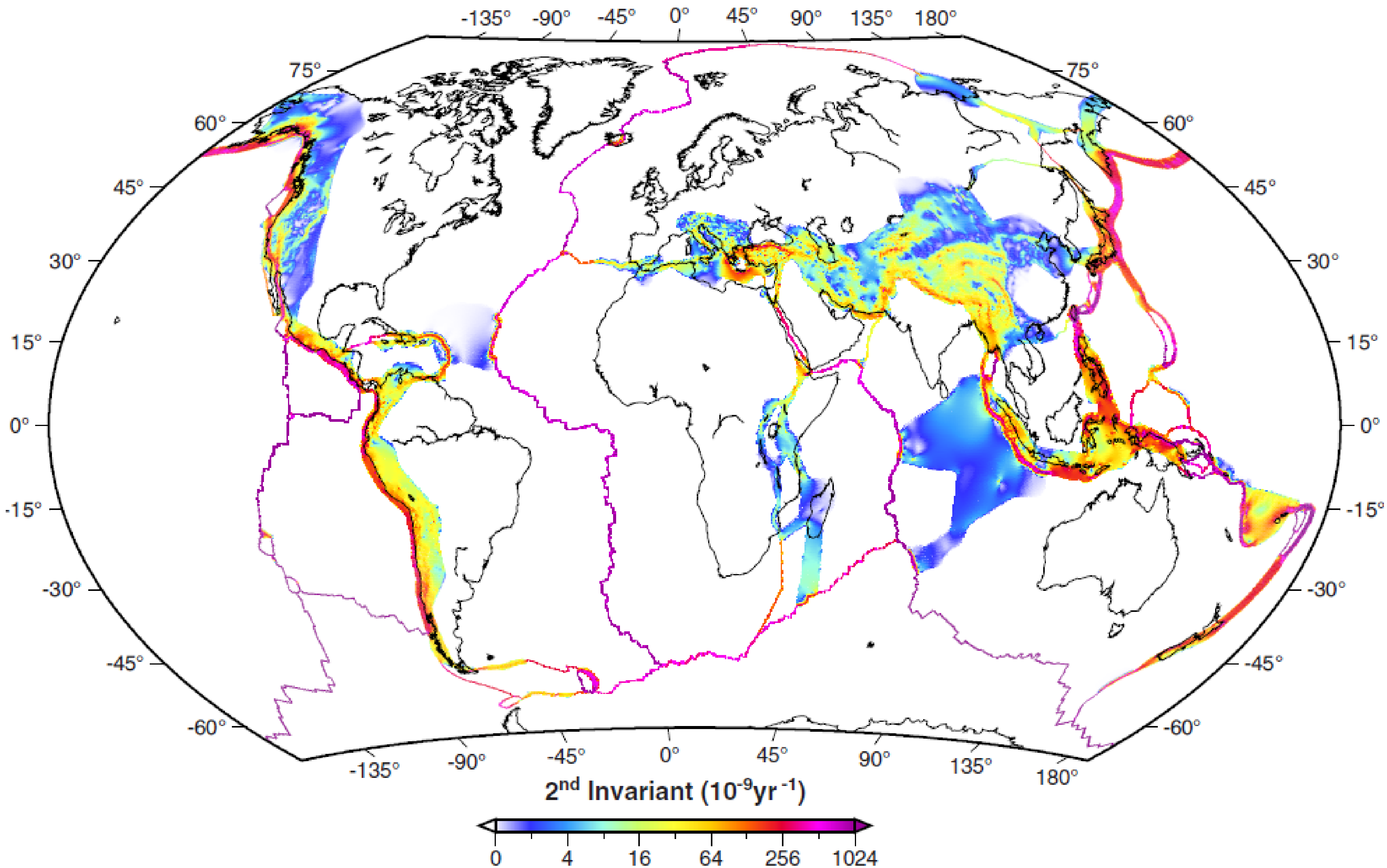
Arid

Warm-temperate

Cool-temperate

Polar/boreal

Global strain rates



Kreemer et al., 2014

Final questions

1. Clarify role of erodable topography in terms of erosion regime, relief, etc!

2. Do global strain rates correlate with sediment in trench and climate zones?

3. Plate interface strength appears to scale with sediment thickness, which itself is a function of climate + topography. What is the exact function?

4. How has mass flux evolved in pre-glacial climate environment and how did a ‚pre-glacial‘ world look like in terms of trench fill, orography, and climate? Would the feedback system in the past have to led to different interactions and results?