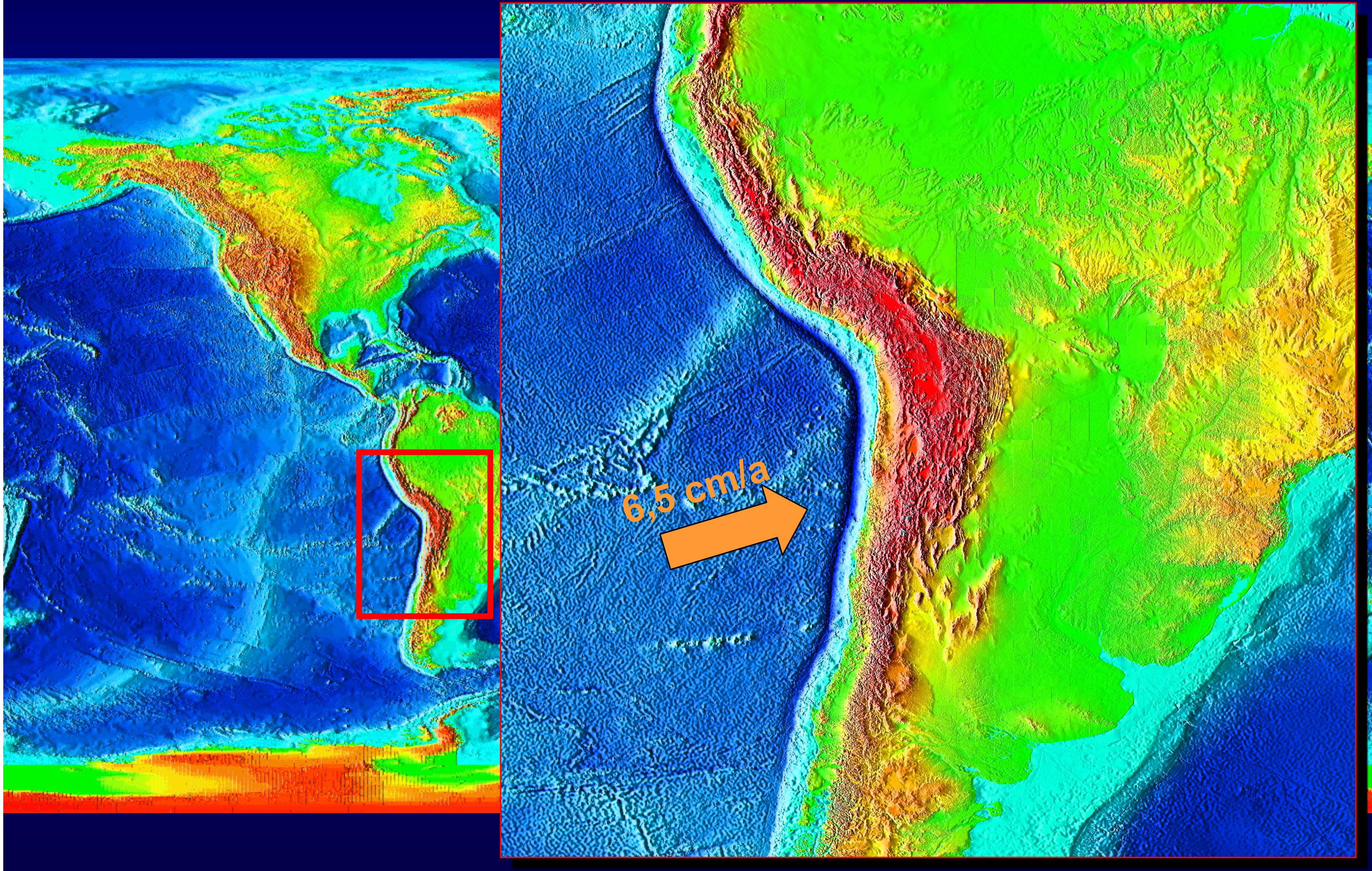
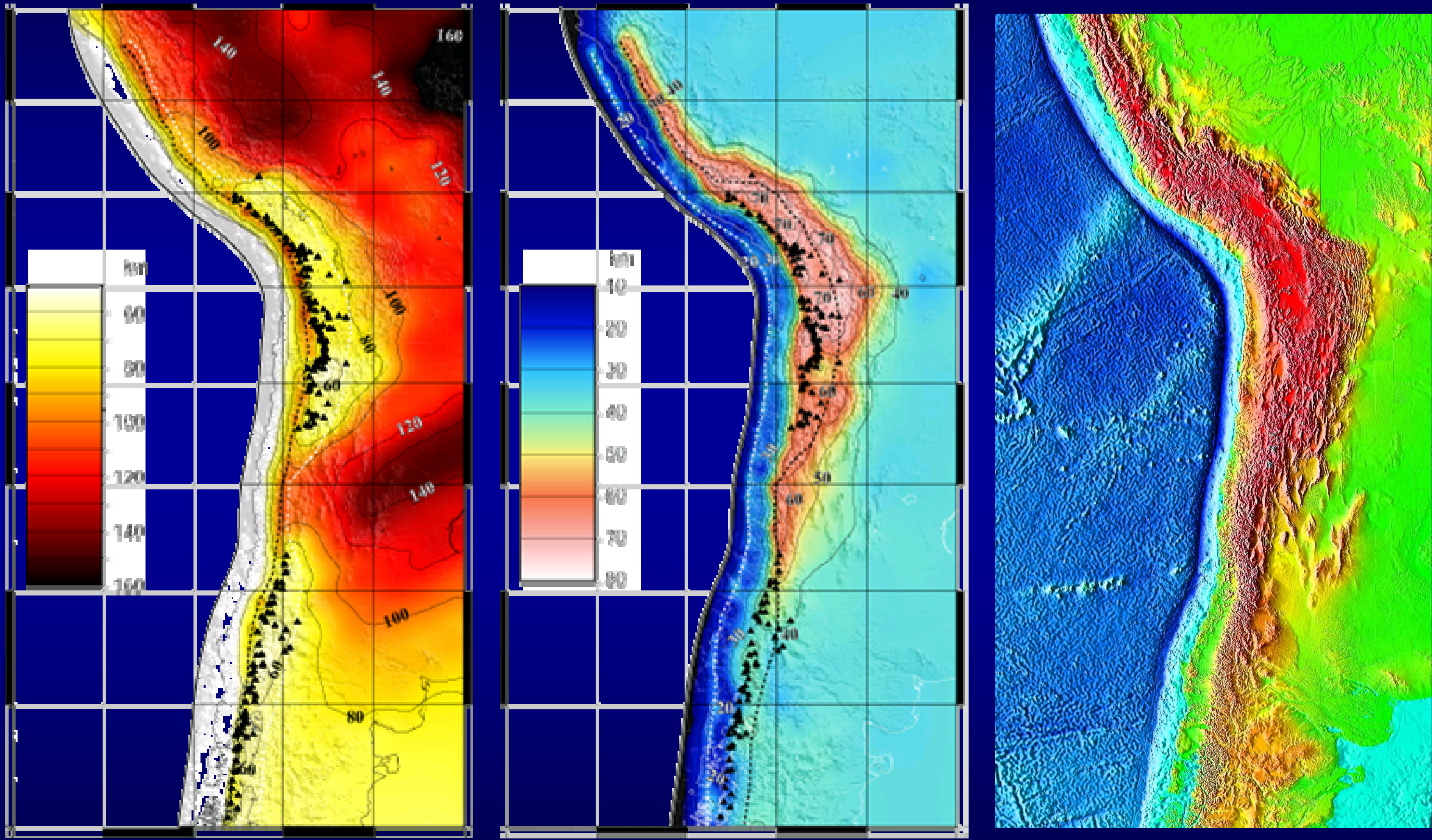
Mountain building at ocean-continent margins – the Andes case

by Onno Oncken, GFZ Potsdam



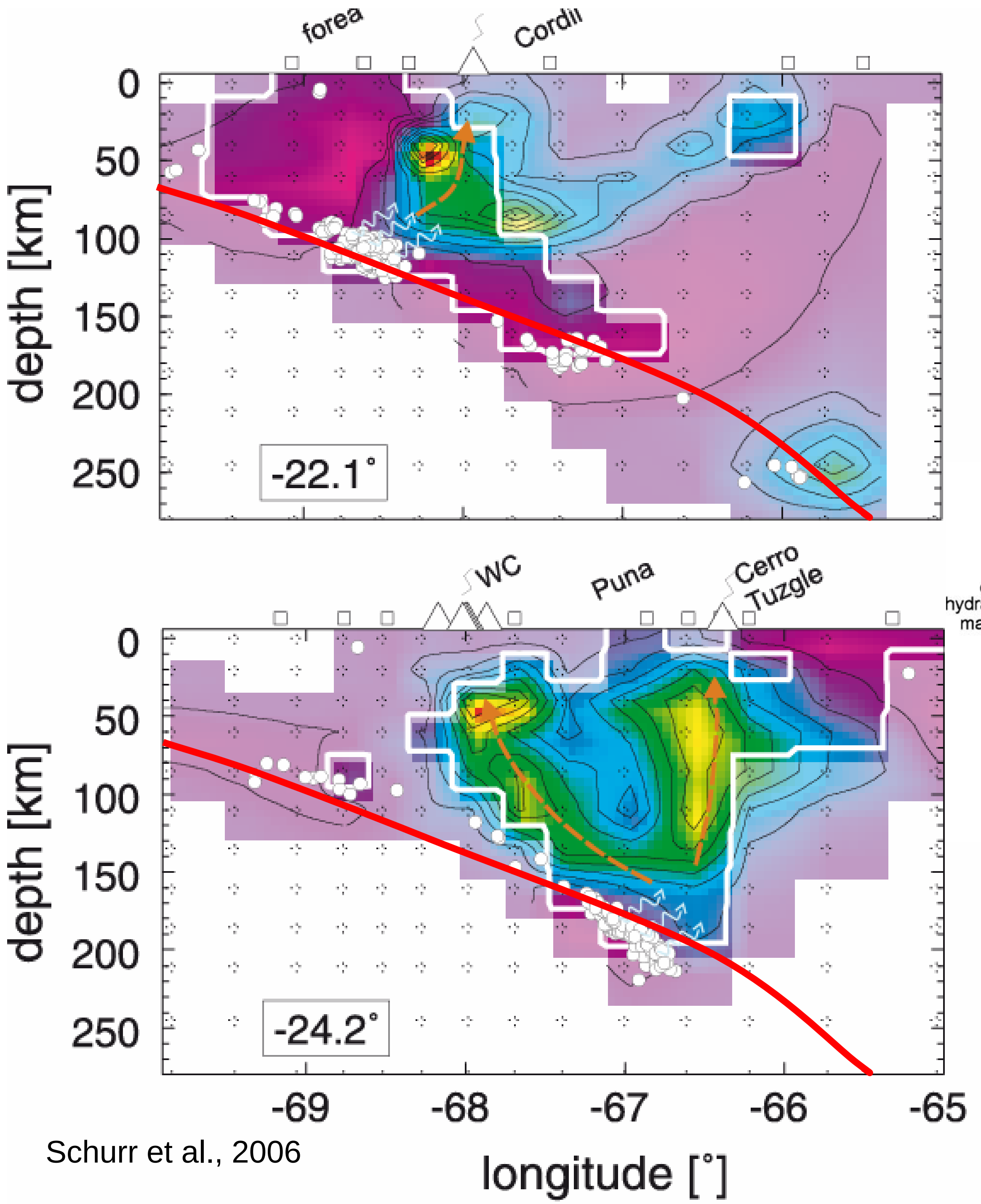
The Andes from below: mantle mass flux



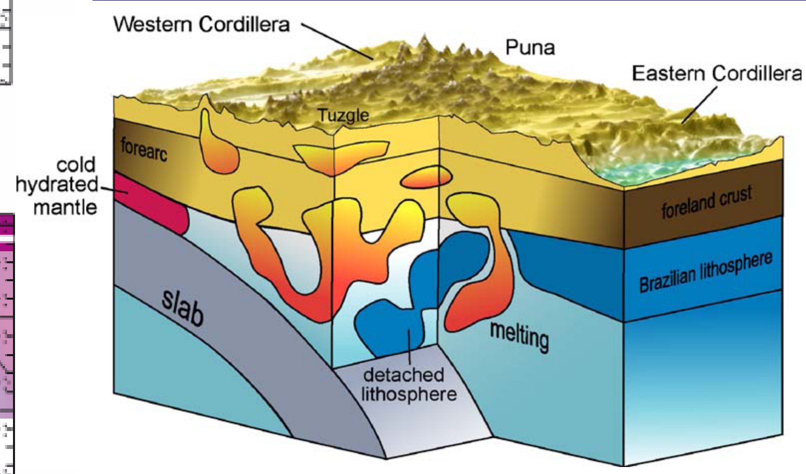
Lithosphere-Astenosphere Boundary | Continental Moho | Topography

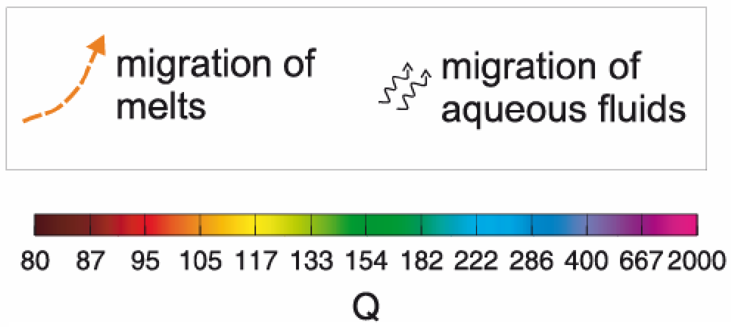
Tassara et al., 2006

Active delamination beneath Puna plateau

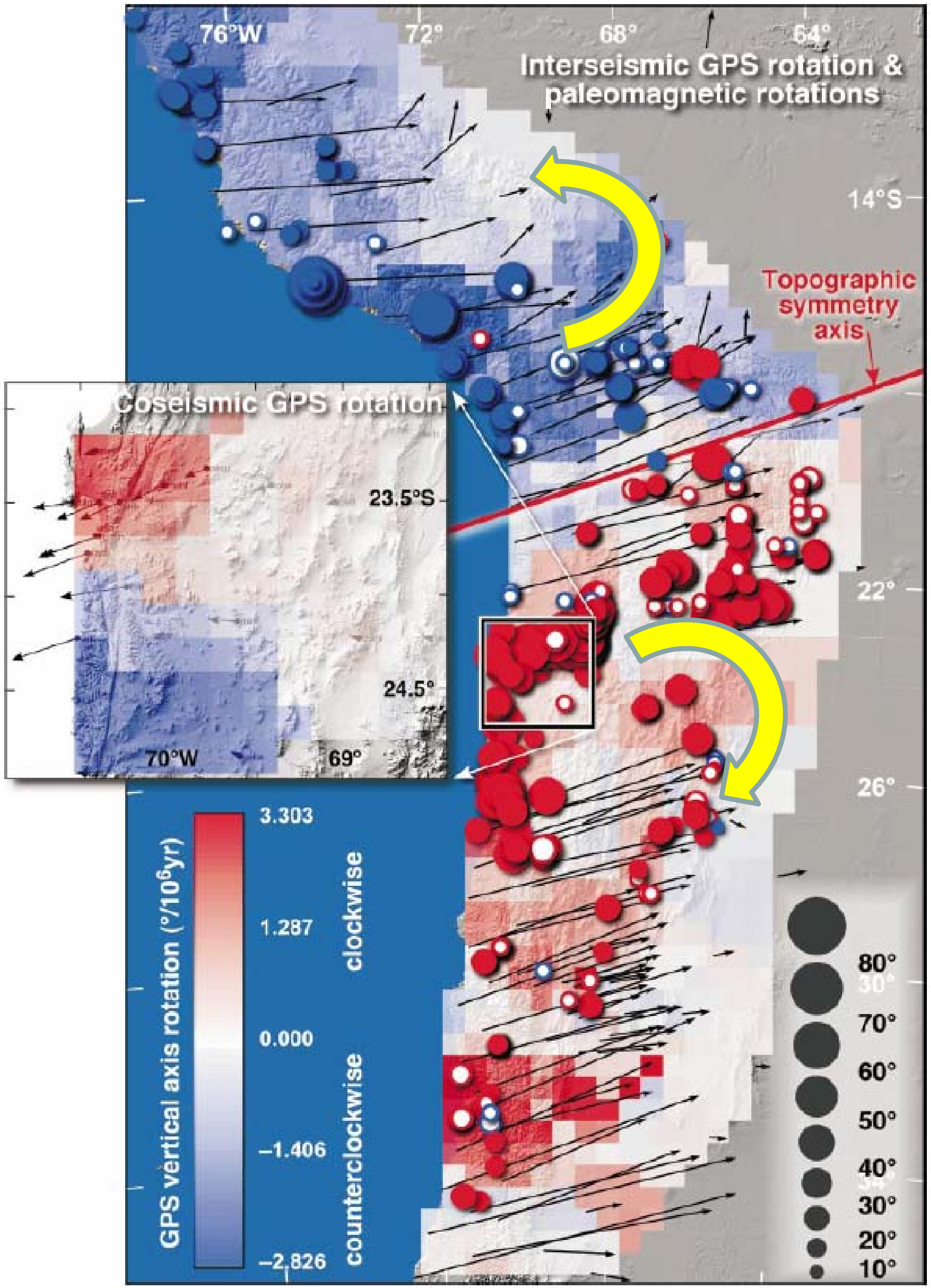


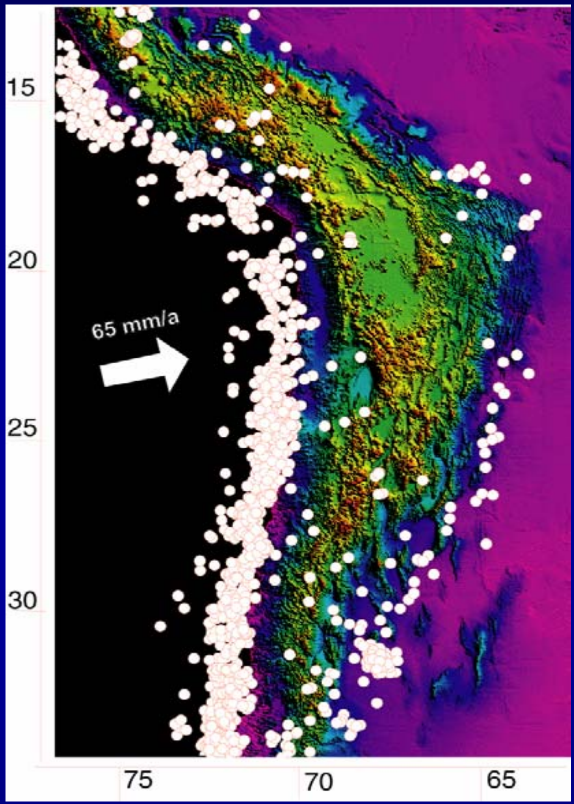
Schurr et al., 2006





Present day kinematics

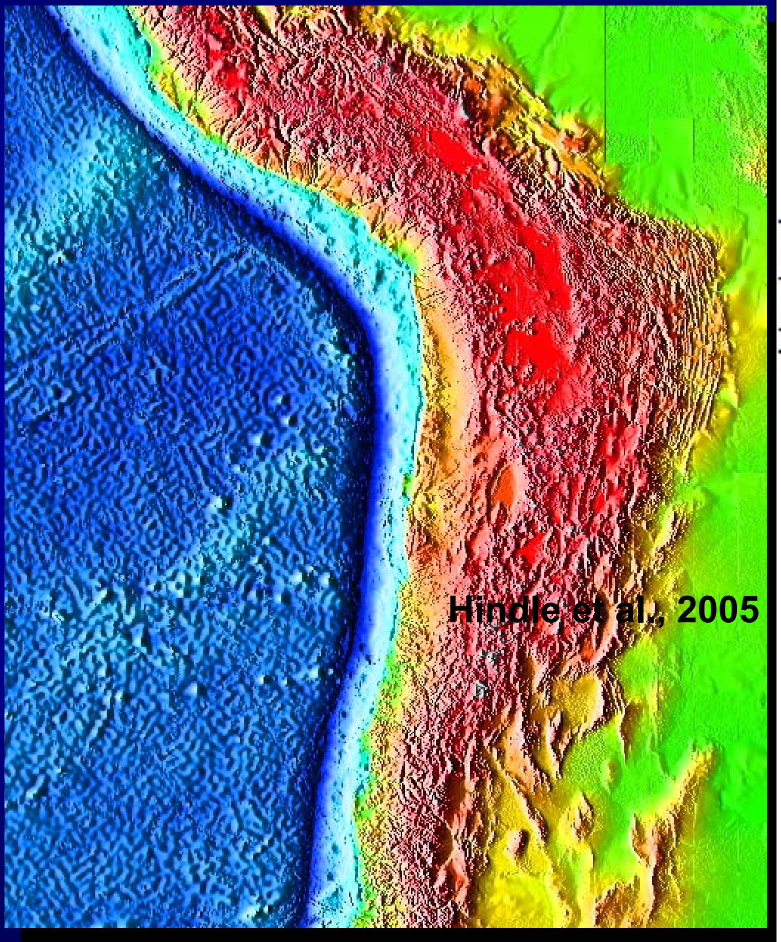


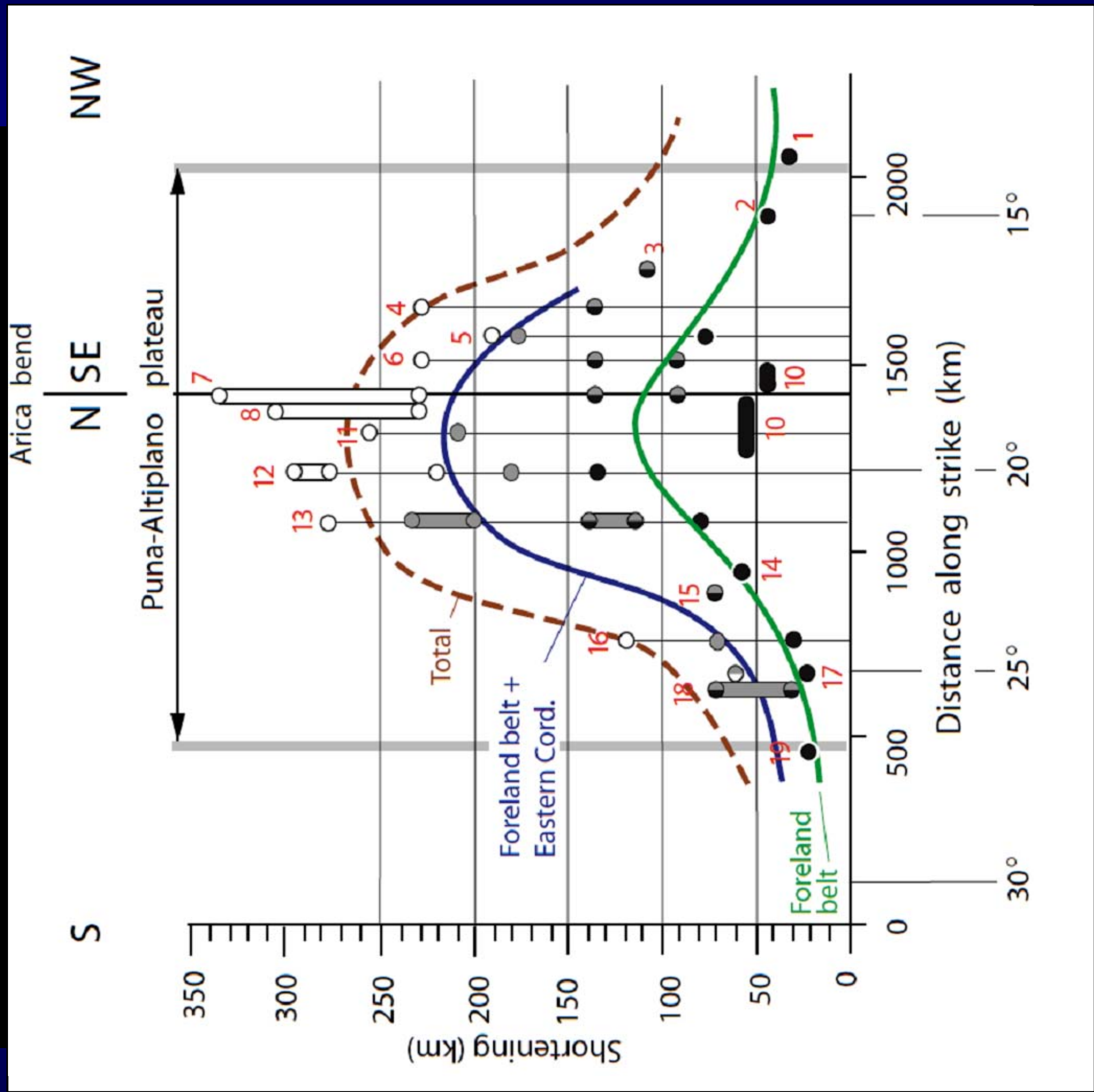


crustal seismicity < 50 km

Allmendinger et al., 2005

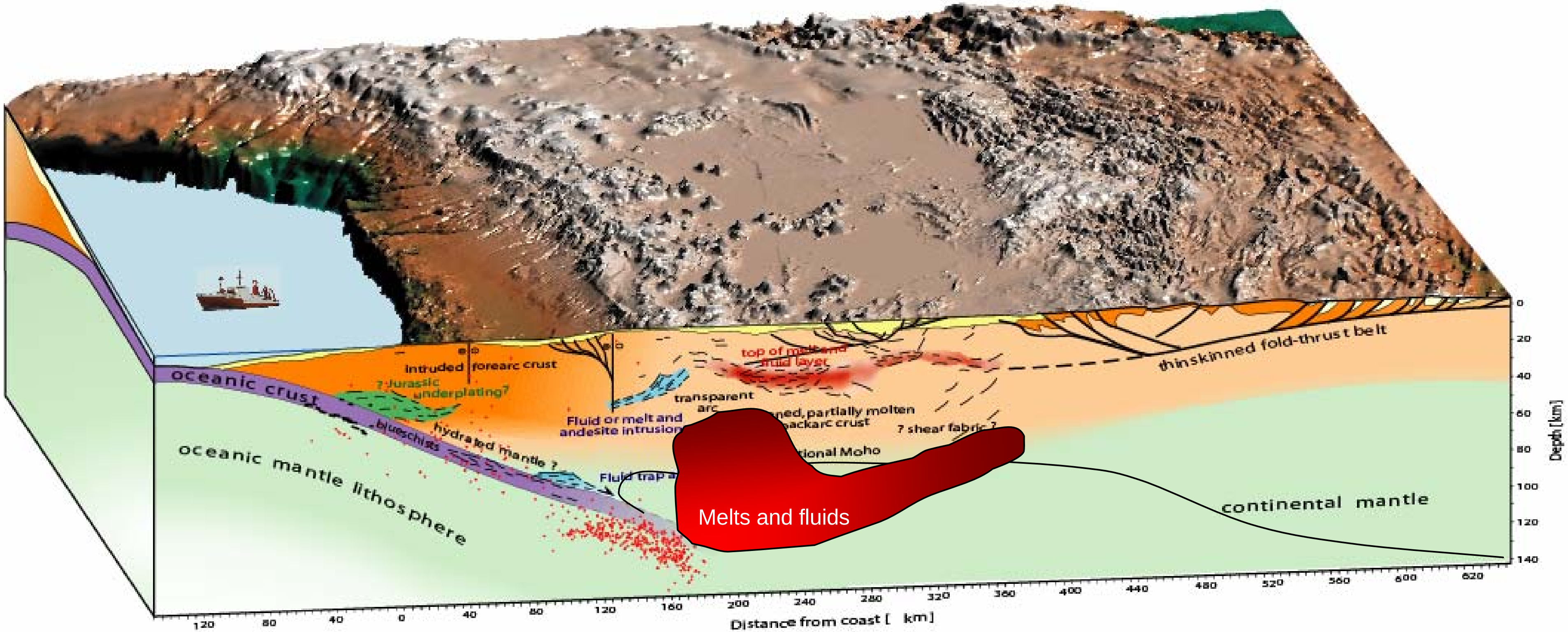
The central Andean shortening gradient





Kley et al. 1998; Oncken et al., 2006

Deformation



Magmatism

The paradox of weak subduction faults and convergent margin mountain building

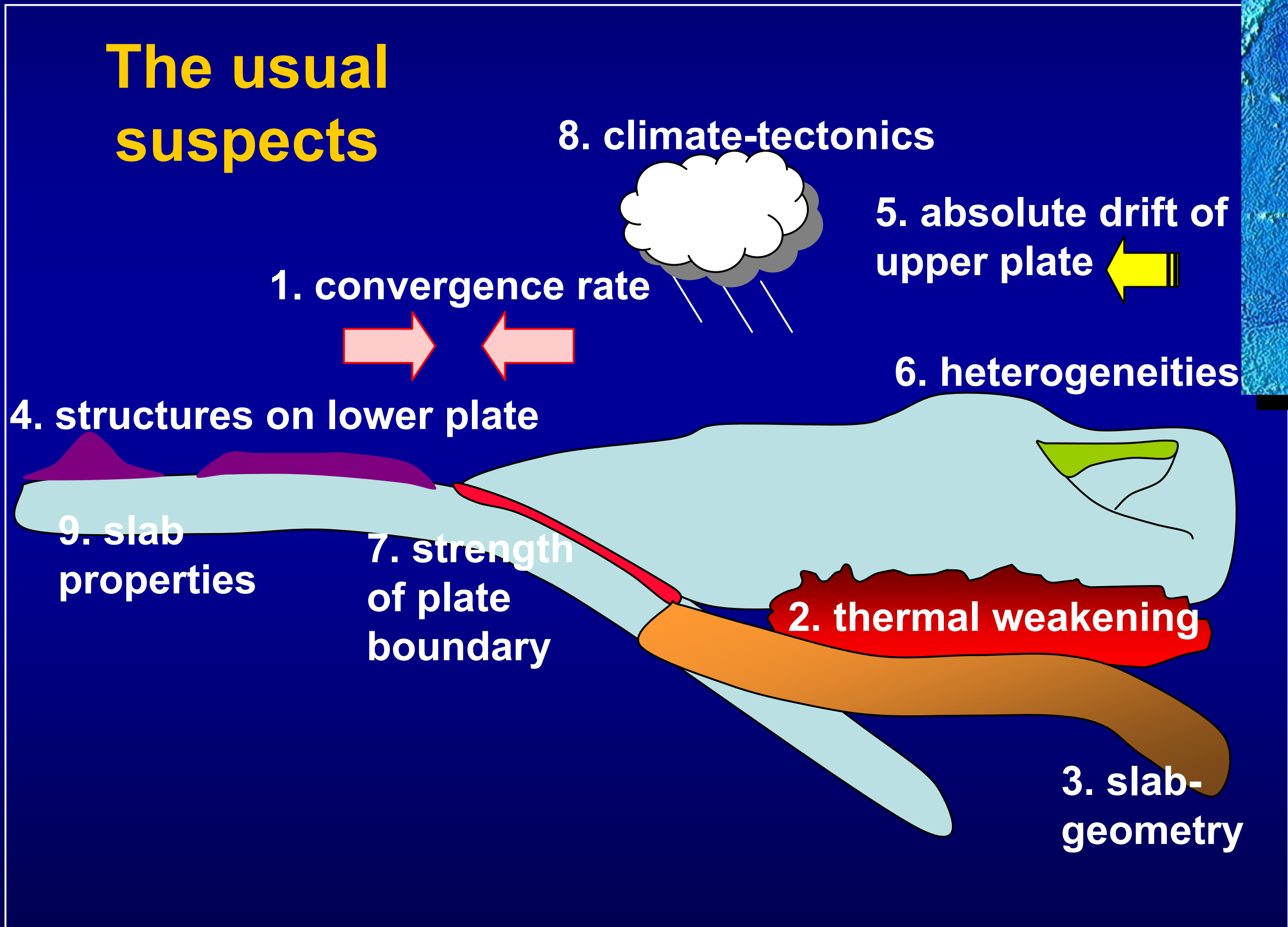
From coseismic stress drop estimates, inversion of geodetic data and taper, force balance estimates and from modelling typical mechanical properties of subduction faults are:

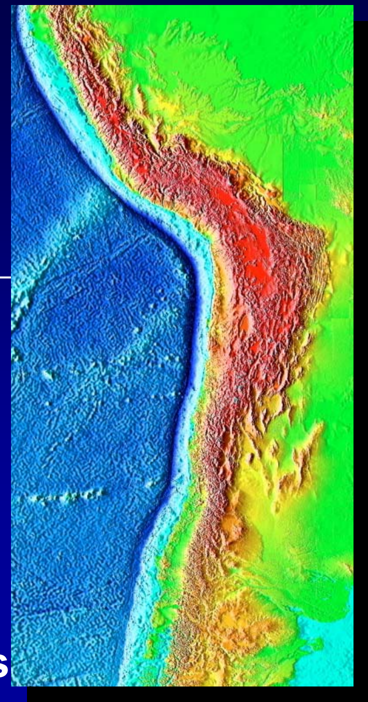
effective coefficient of friction	**< 0.1**
average stresses	**10-40 MPa**

… hence, well below strength observed in continental plates that are usually goverened by Byerlee‘s law in brittle crust

Who is in control ?

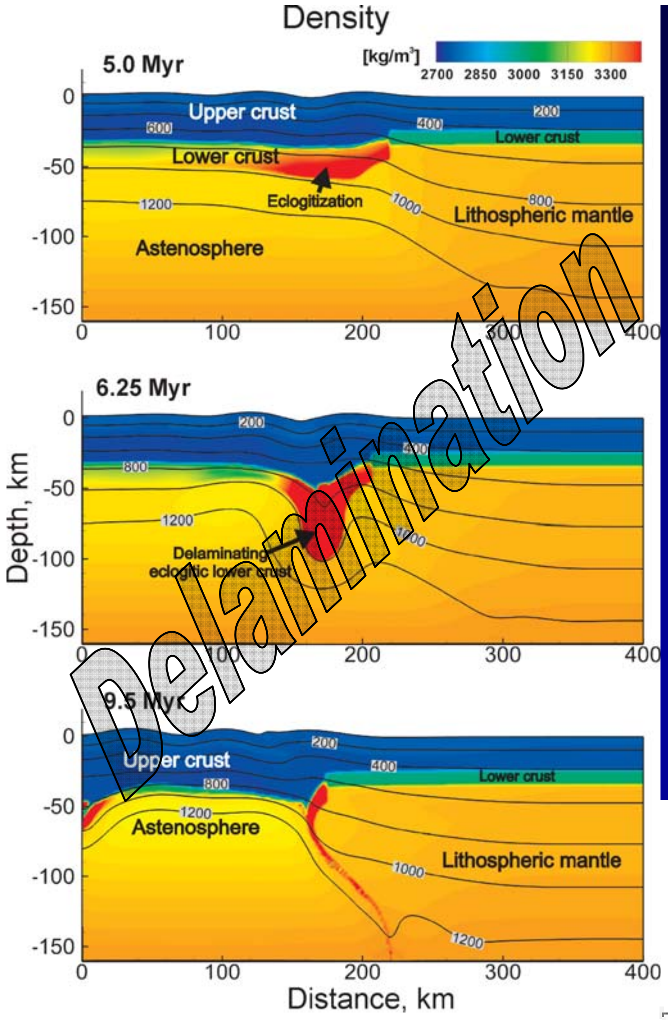
How to unravel mechanisms of orogeny in the Andes

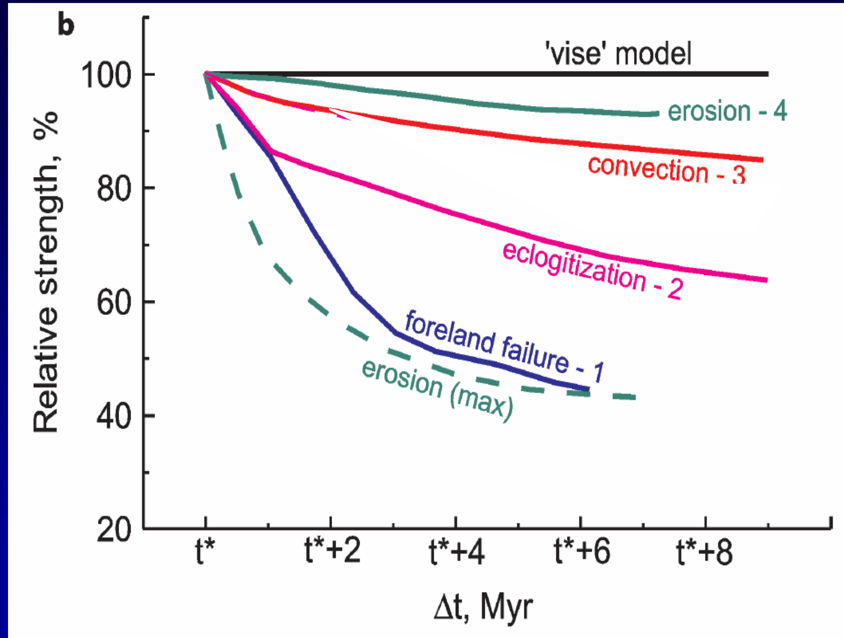


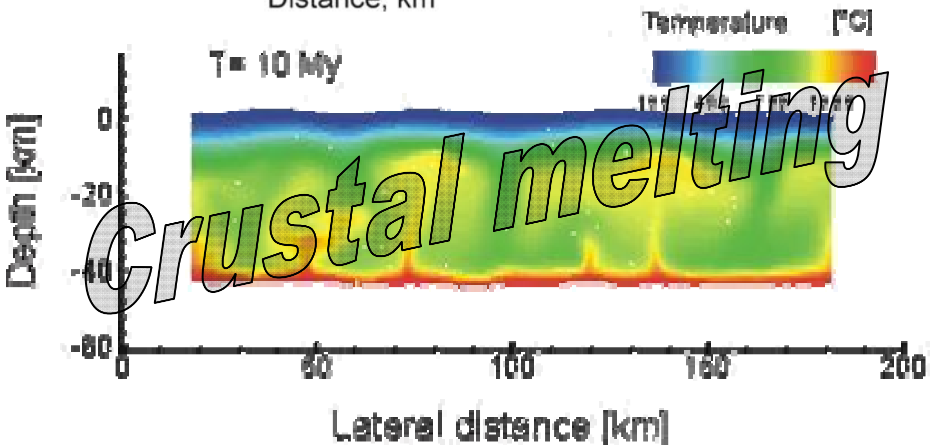


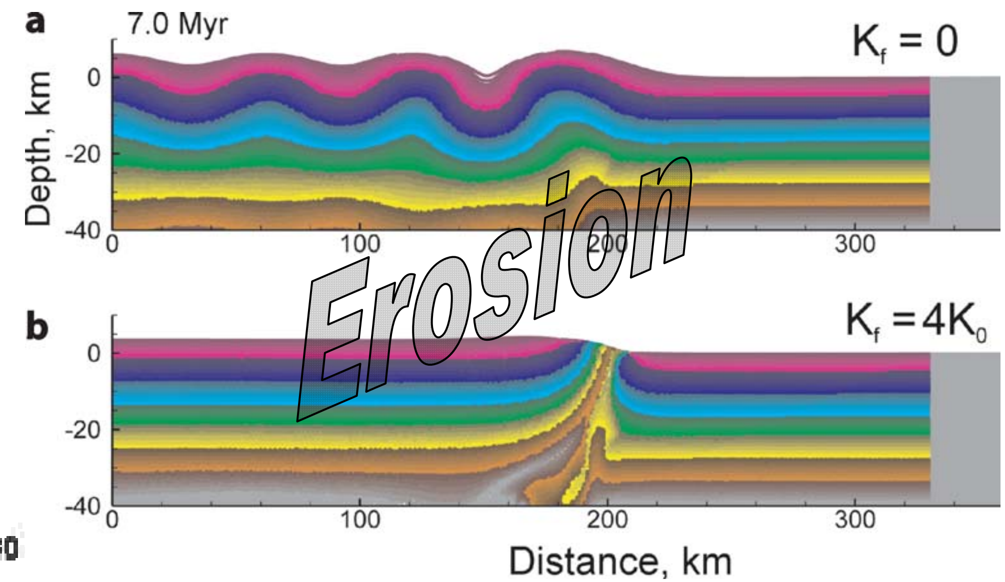
How to weaken a plate margin

Babeyko et al., 2002, 2006

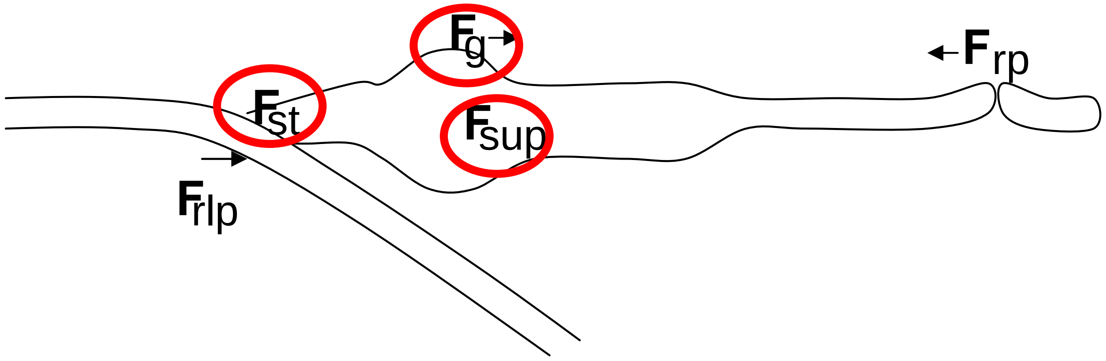




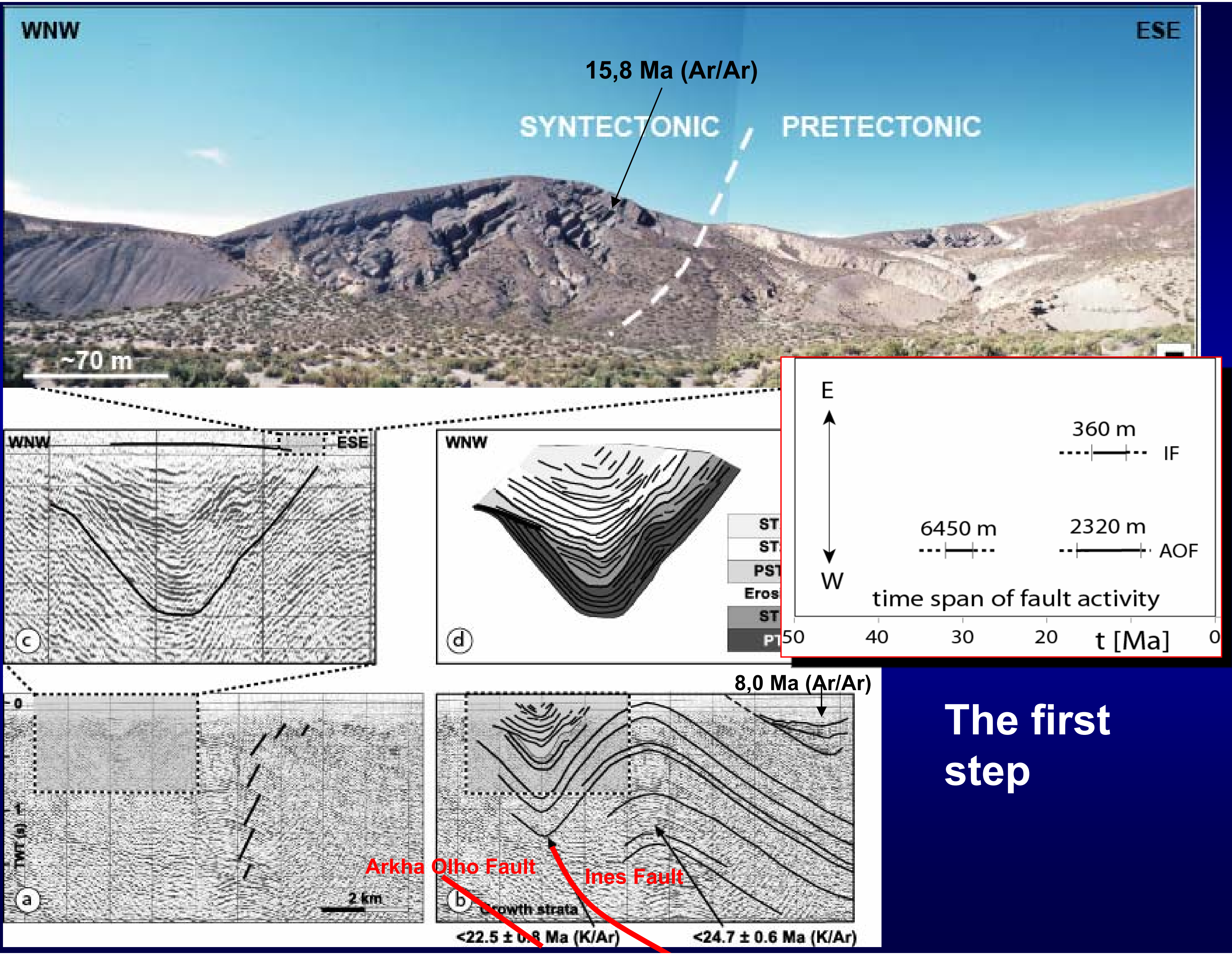




Convergent margin orogeny – a weakening or a forcing issue?

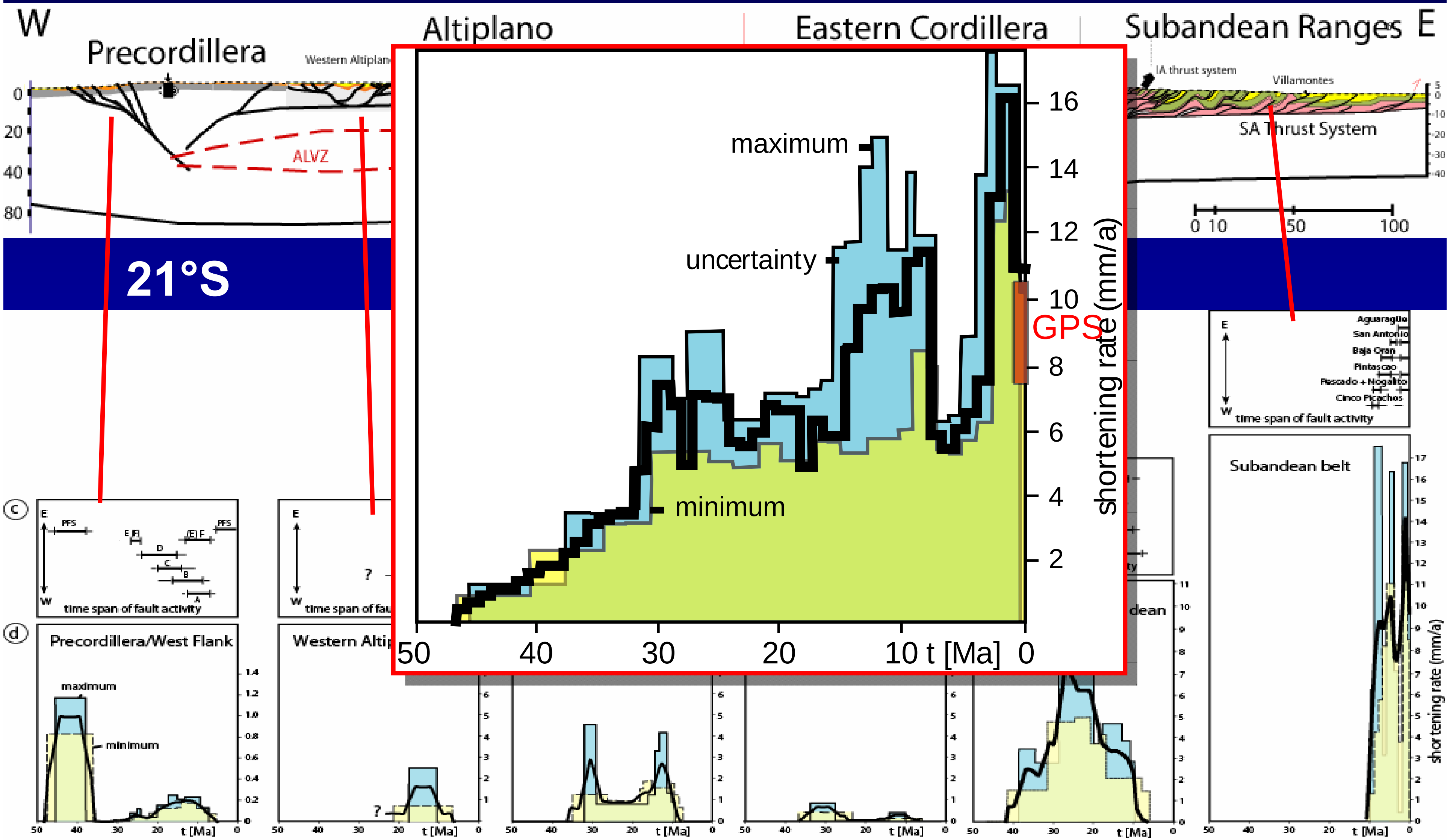


$$0 \approx F_{rp} + F_{rlp} + F_{st} + F_{sup} + F_g$$

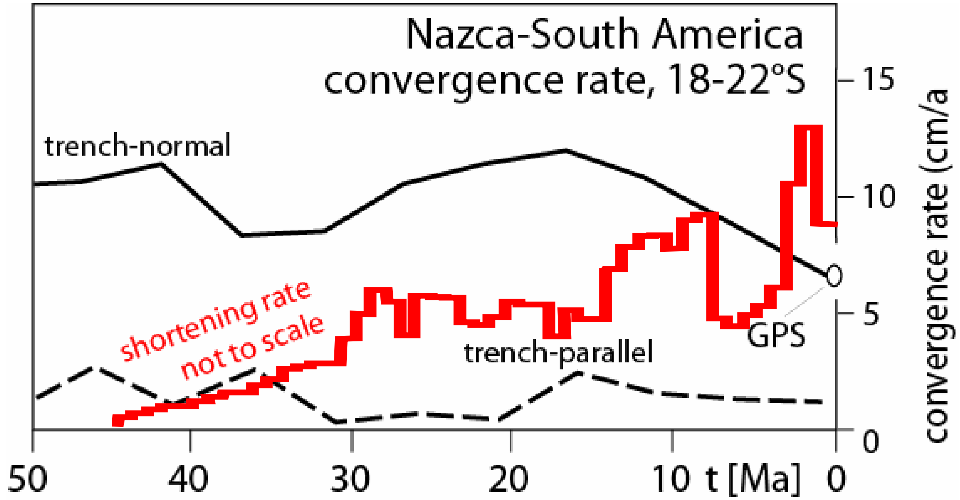


The first step

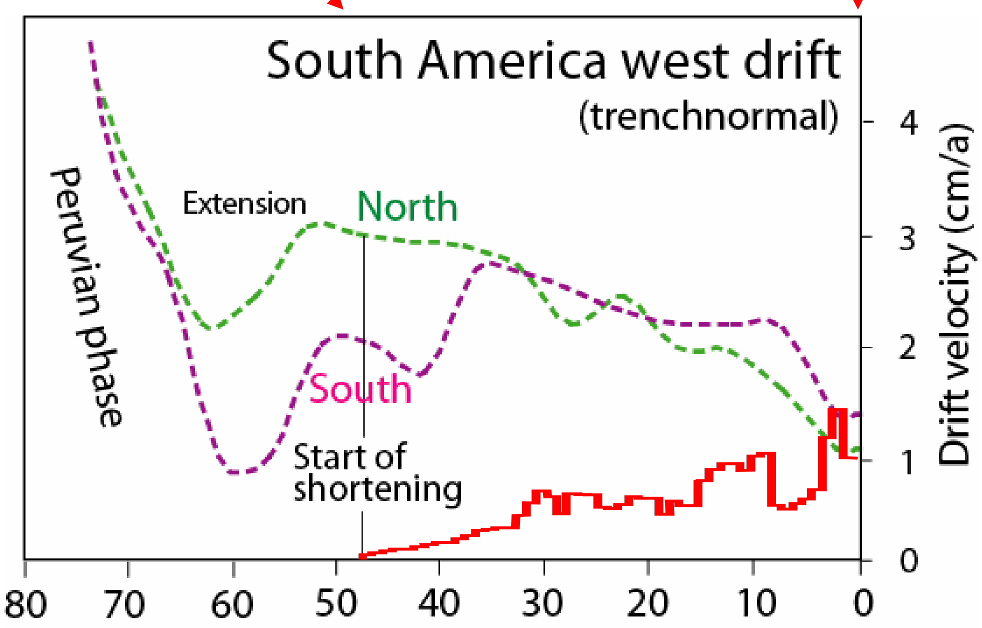
Orogen speedometry

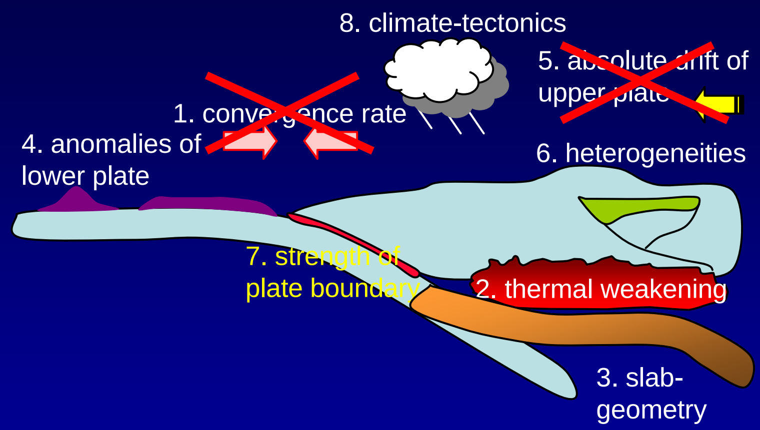


Elger, Oncken, Glodny, 2005; Oncken et al. 2006



Convergence velocity from
Sdrolias & Müller, 2006

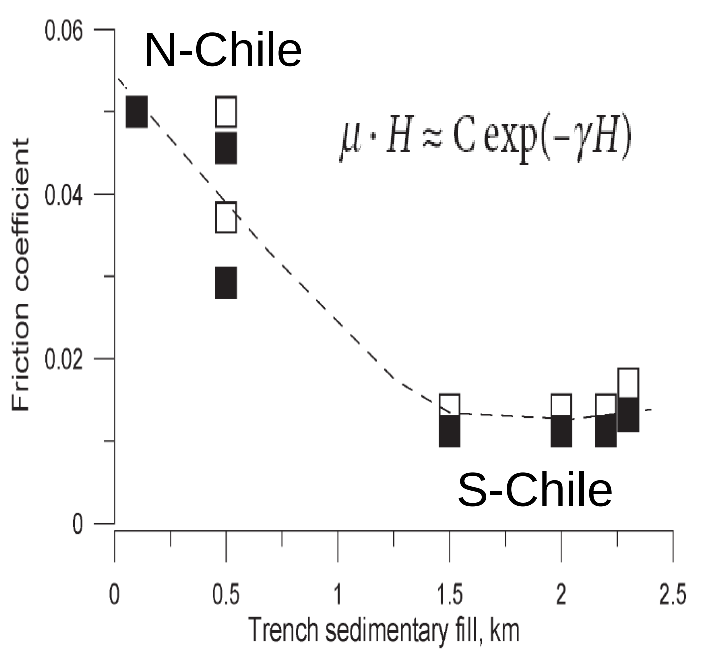




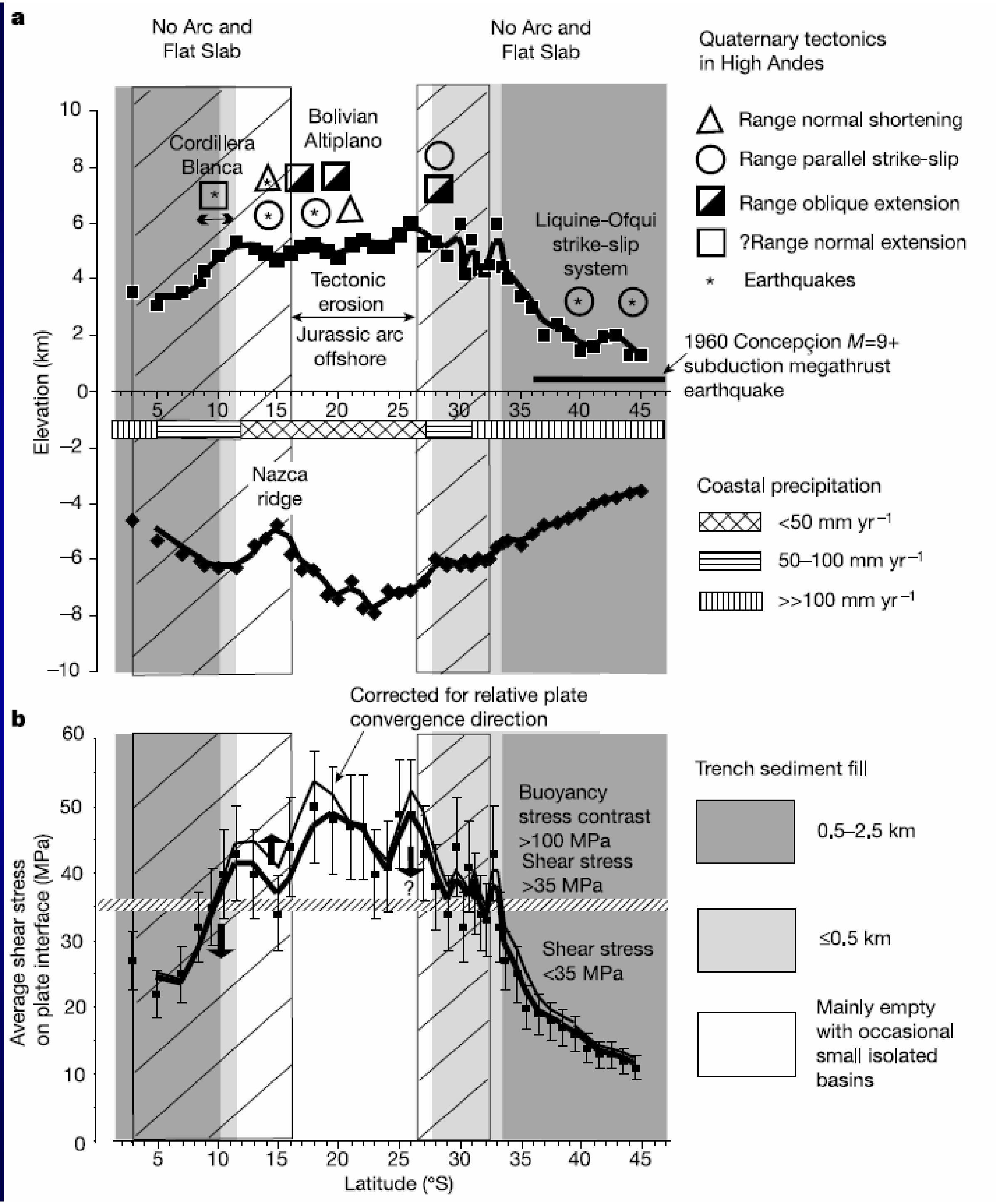
Exploring the role of plate kinematics

Oncken et al. 2006, in prep.

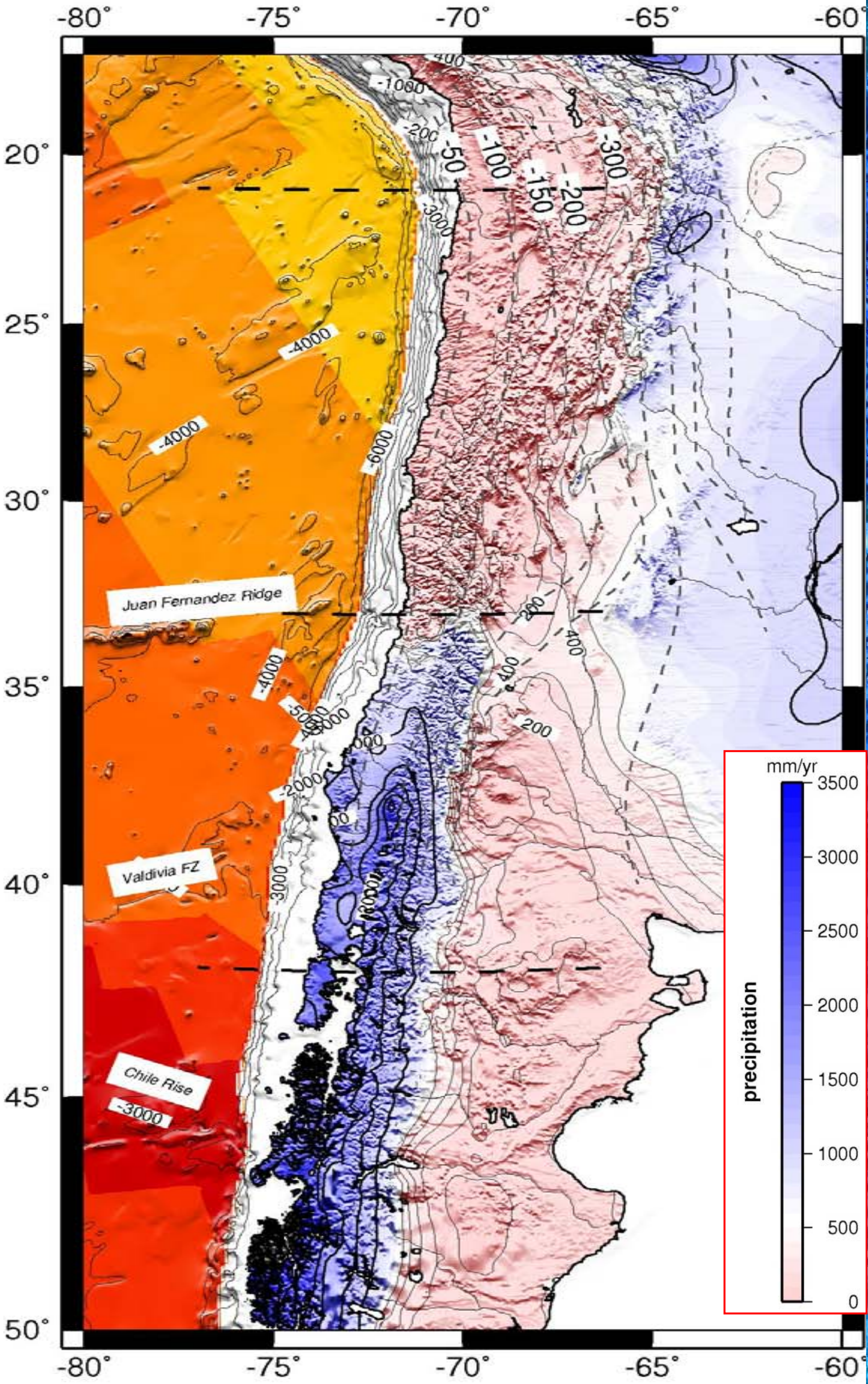
Present day plate interface strength of Andean margin



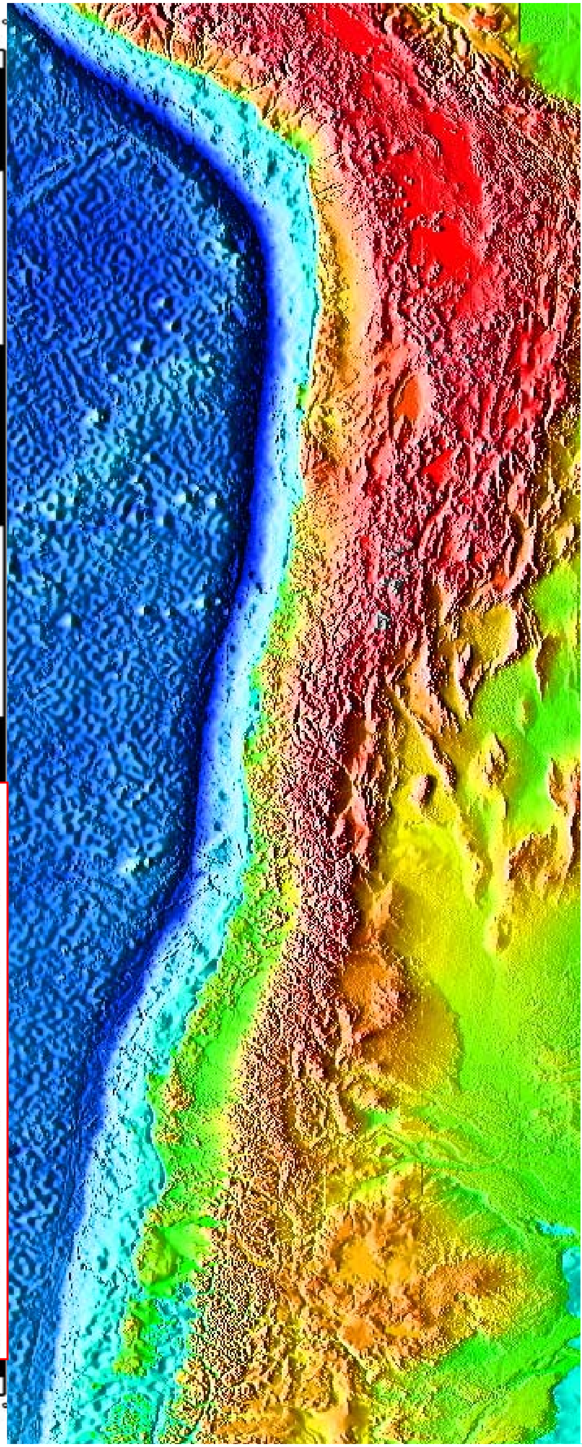
Sobolev et al., 2006

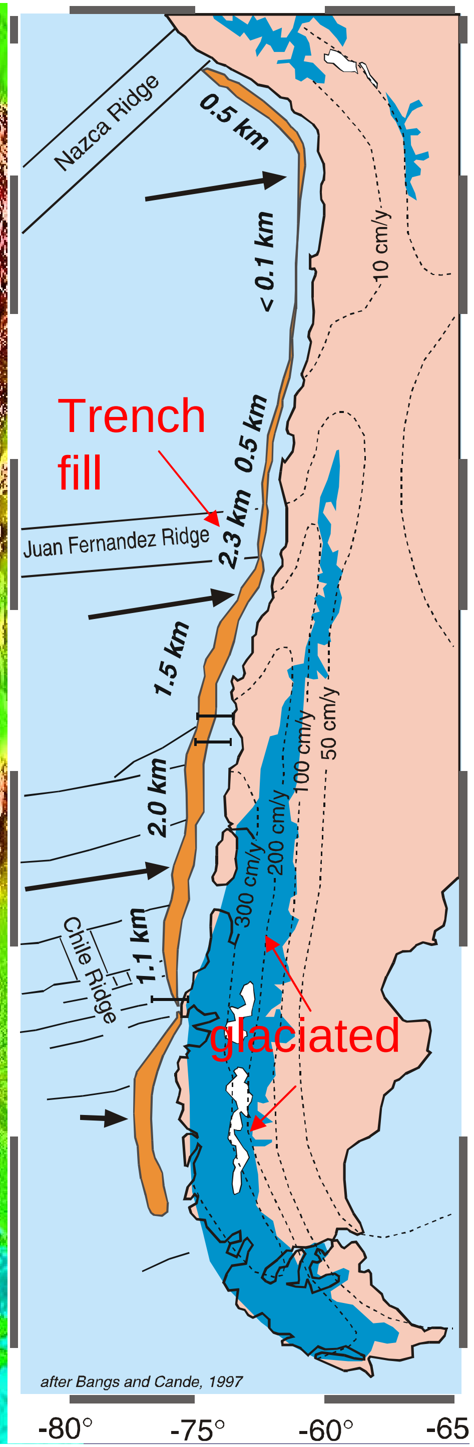


Lamb & Davis, 2003

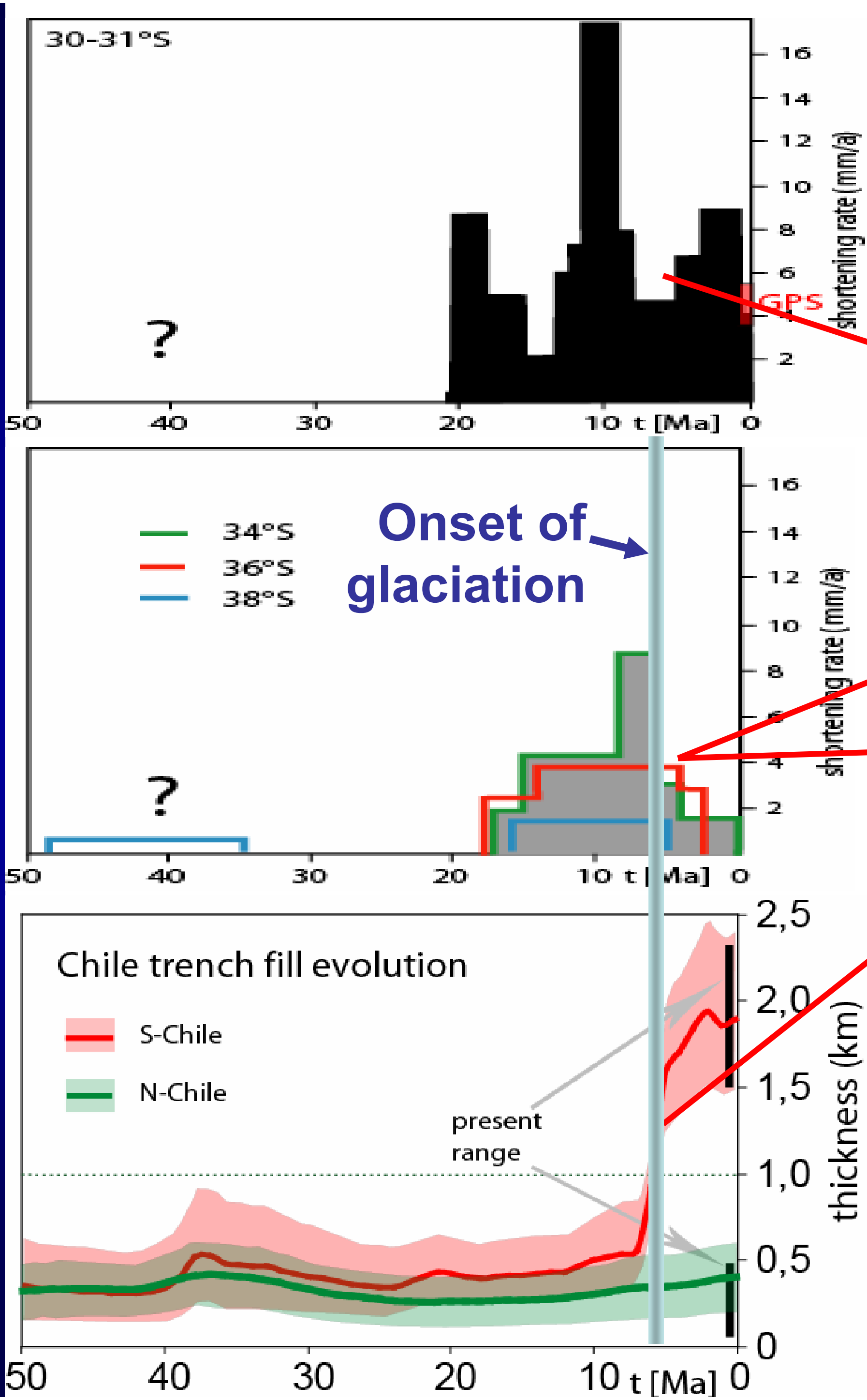


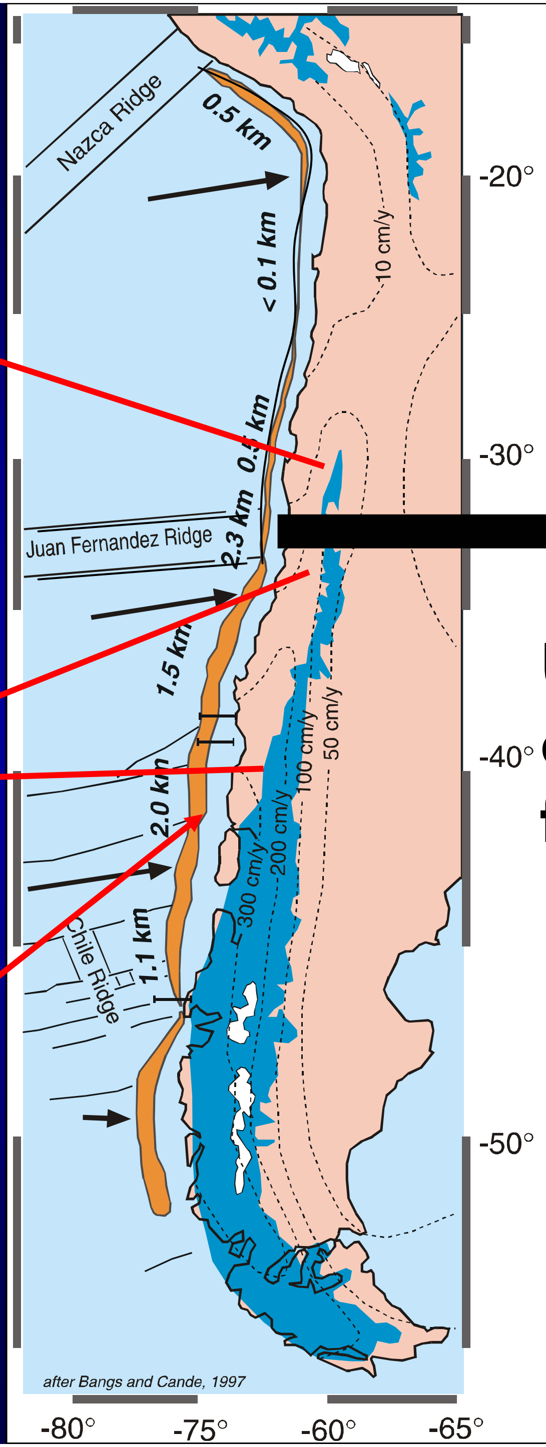
-80°
-75°
-70°
-65°
-60°
20°
25°
30°
35°
40°
45°
50°
Juan Fernandez Ridge
Valdivia FZ
Chile Rise
-4000
-3000
-1000
-100
-150
-200
-300
400
200
precipitation
mm/yr
3500
3000
2500
2000
1500
1000
500
0



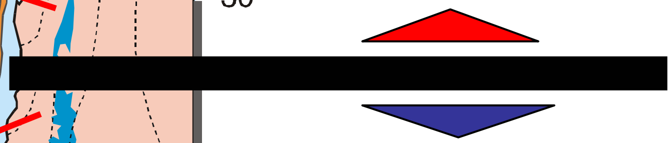


Nazca Ridge
0.5 km
< 0.1 km
10 cm/y
Trench fill
0.5 km
2.3 km
Juan Fernandez Ridge
1.5 km
100 cm/y
50 cm/y
2.0 km
200 cm/y
300 cm/y
1.1 km
Chile Ridge
glaciated
after Bangs and Cande, 1997
-80°
-75°
-60°
-65



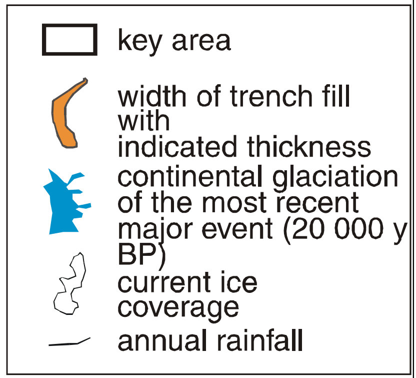


Continuous Neogene – recent upper plate contraction

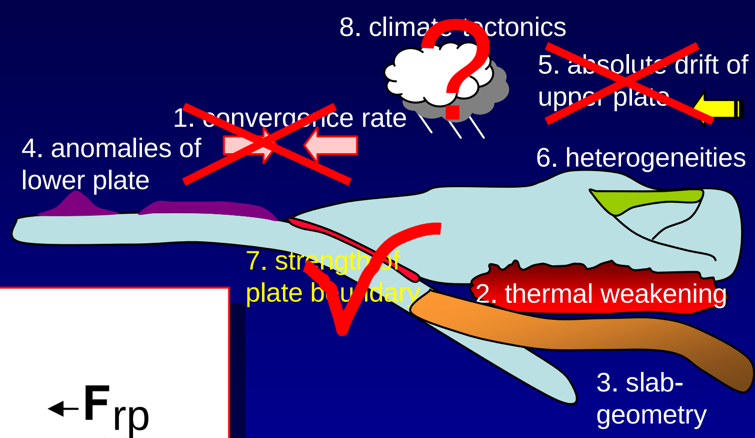


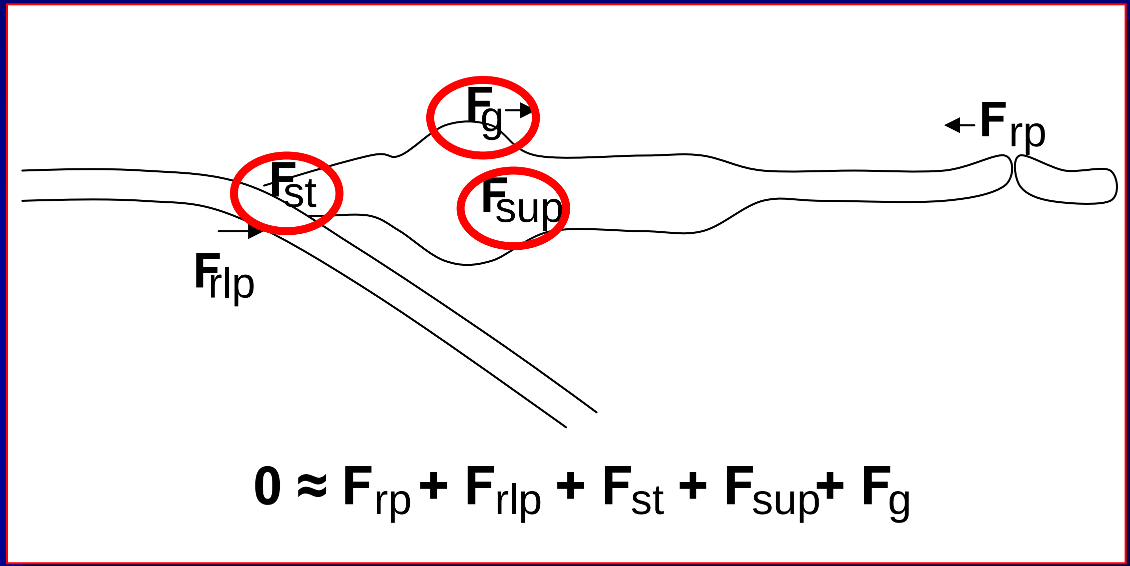
Upper plate contraction fades at 6 Mα

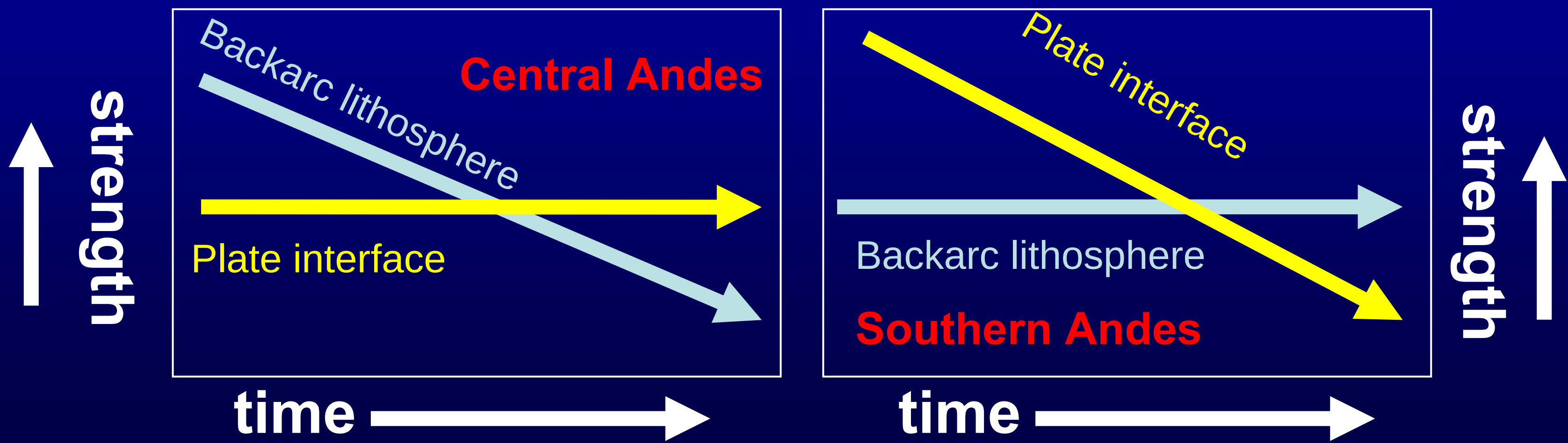
Modified from Vietor & Echtler, 2006



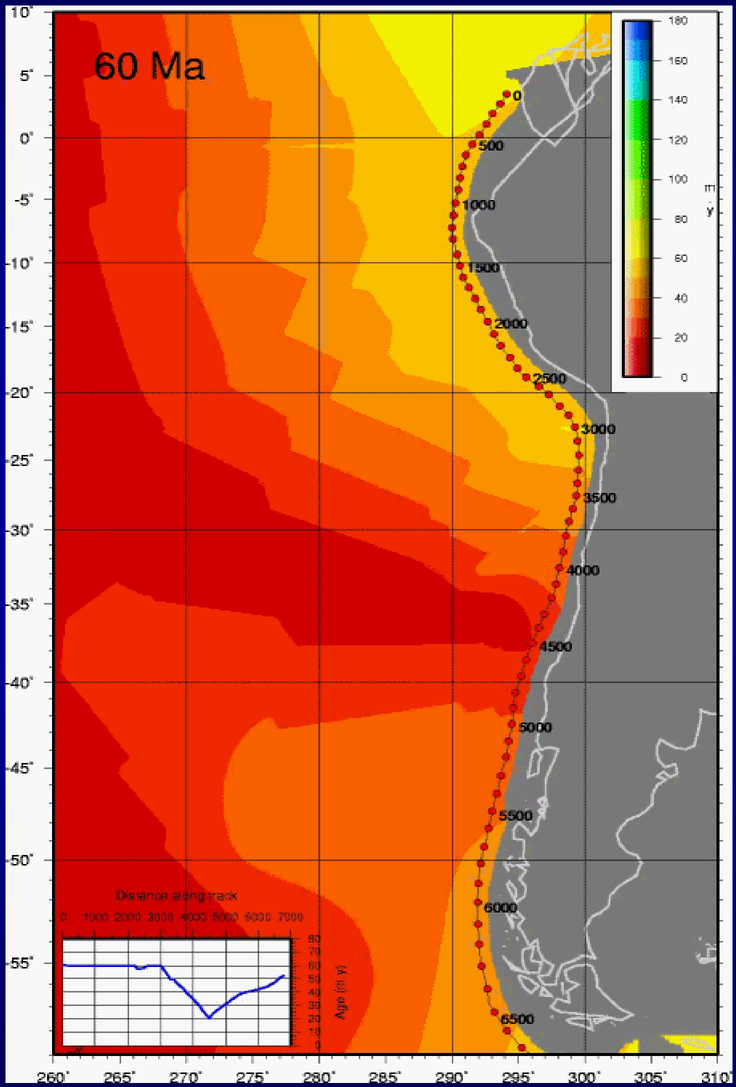
The plate interface strength issue?



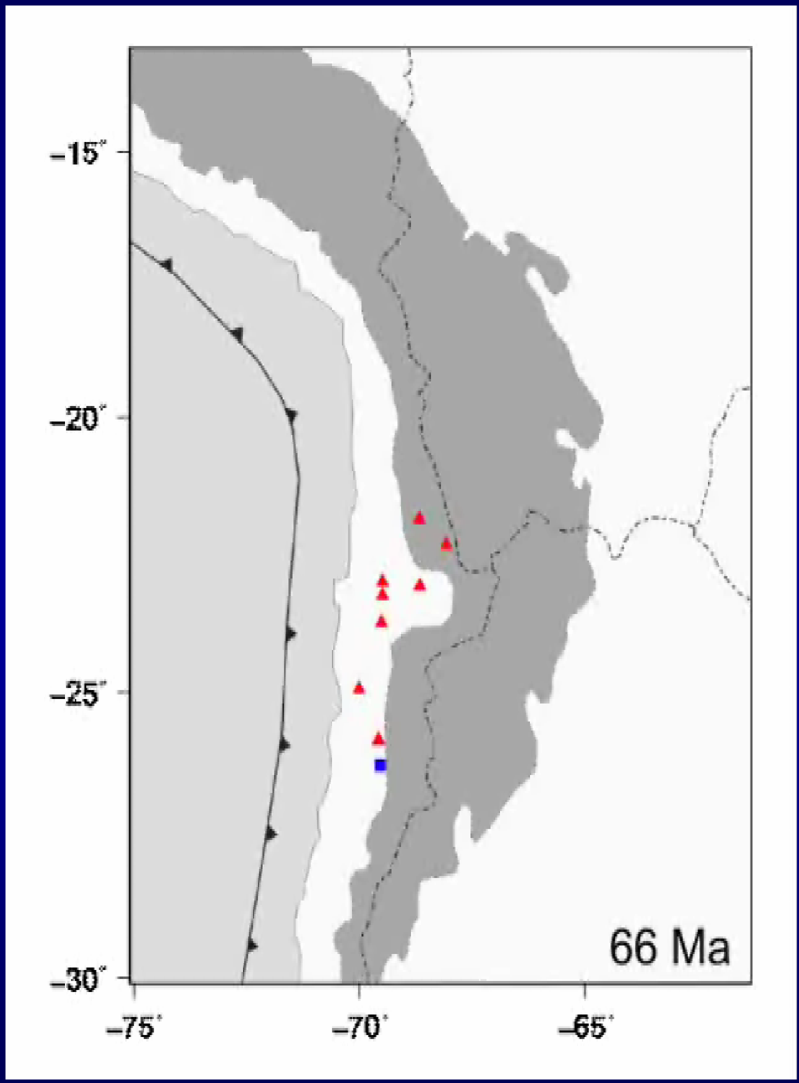




Subducting ridges and magmatism



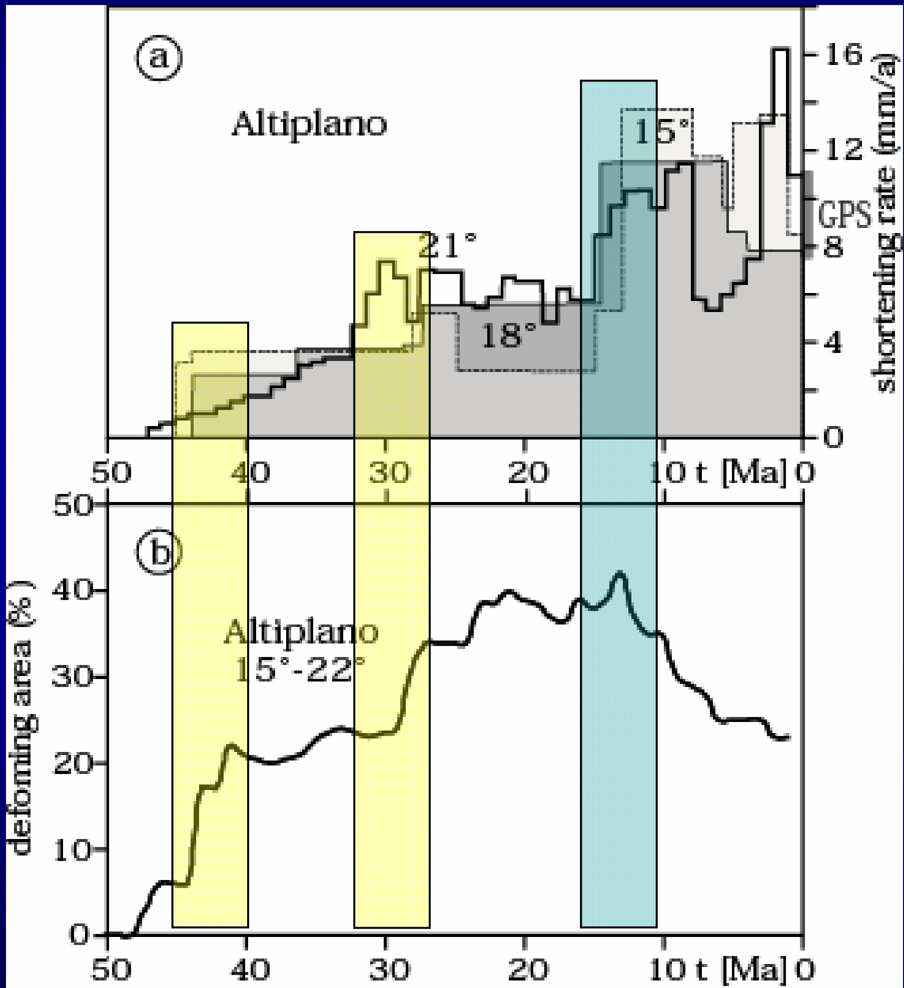
Courtesy of
Sdrolias & Müller, 2006

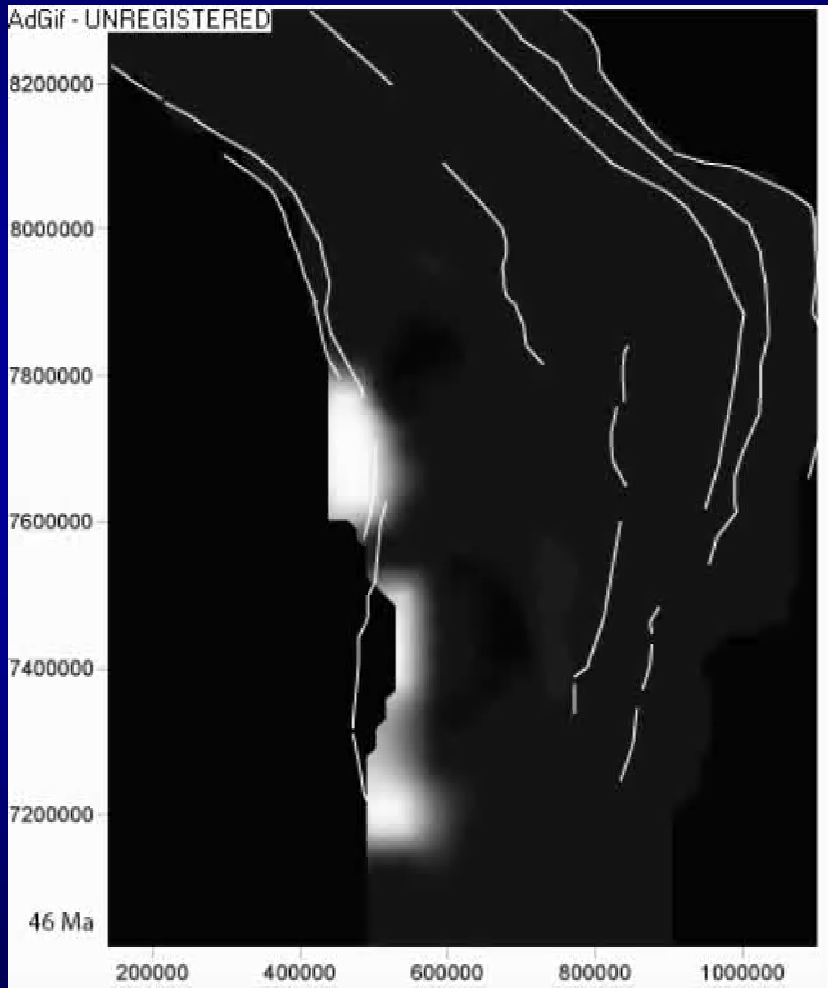


Trumbull et al., 2006

▲ Andesites
■ Ignimbrites

Evolution of spatial distribution of deformation accumulation

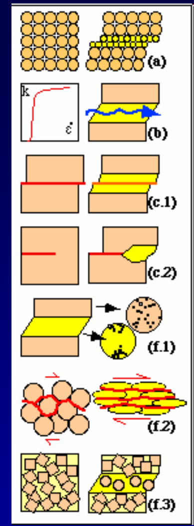




Oncken et al., in prep.

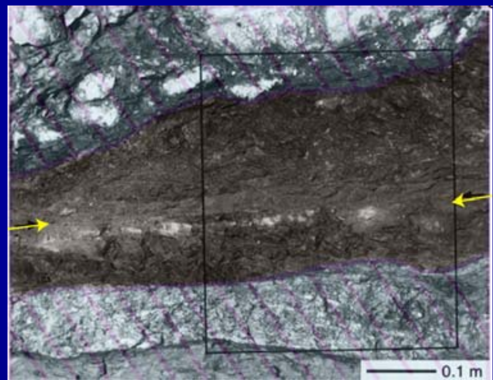
➔ **complete delocalization – localization cycle**

Strain weakening

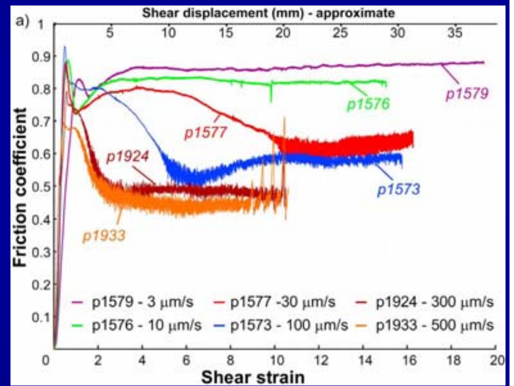


the microscale geometric weak., reaction soft., lattice strain recovery mech., shear heating, grain size reduct.

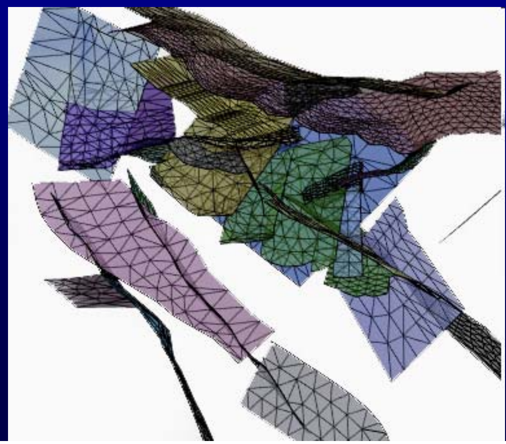
the fault scale



rate and state dependend weakening in gouge

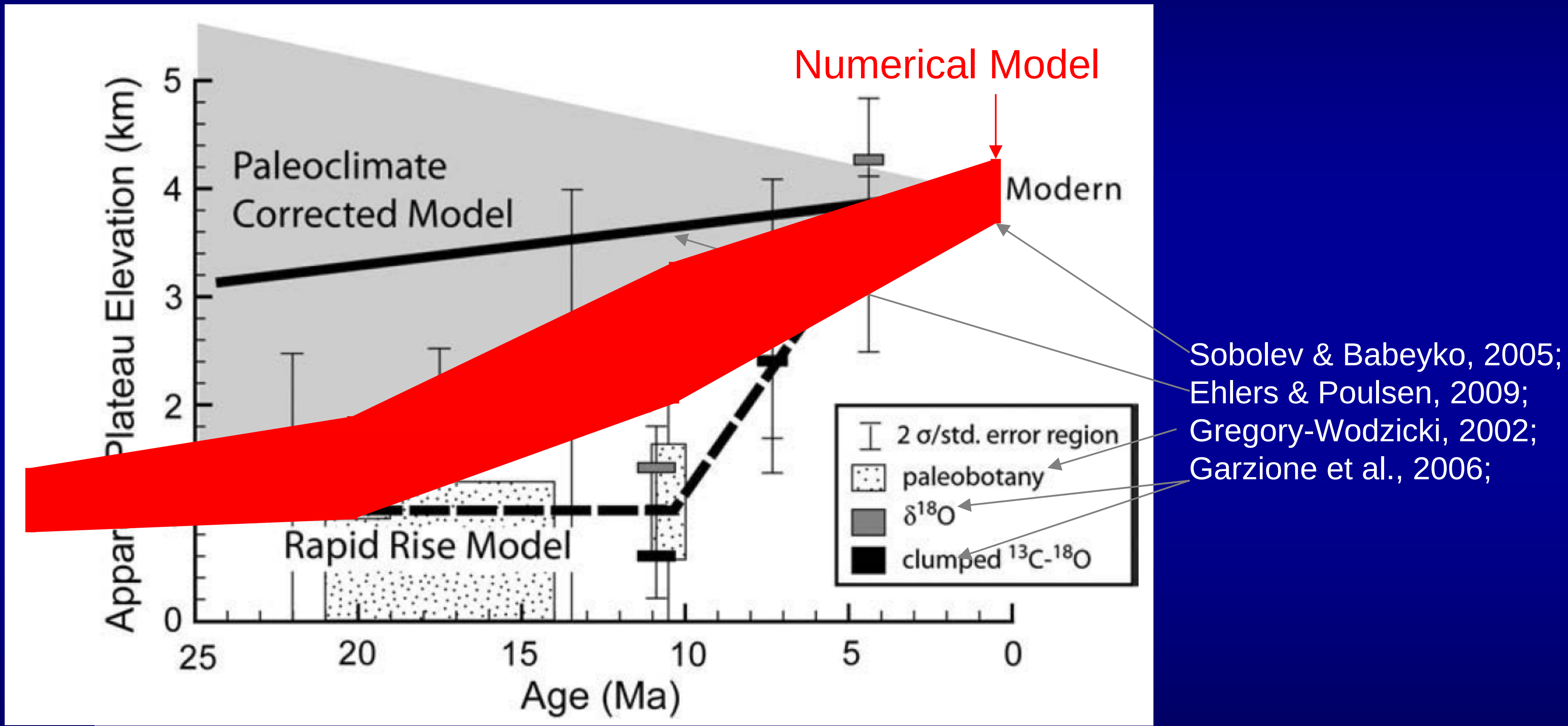


the lithosphere scale

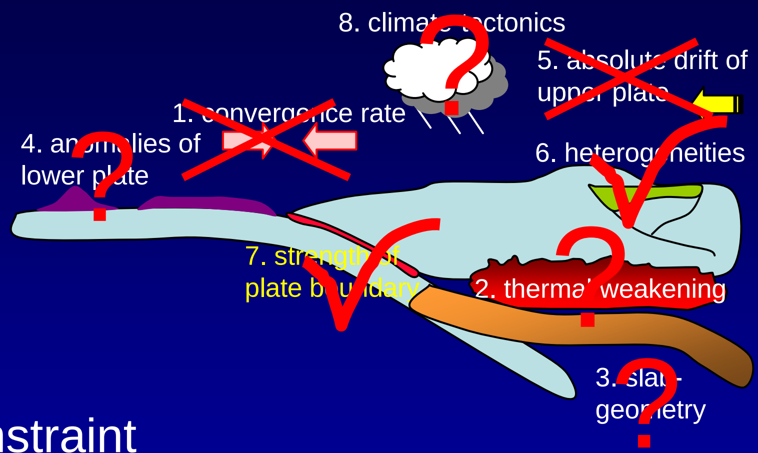


3D – network of weak faults satisfies strain compatibility and controls lithosphere strength

The rise of the Andes :
increasing their gravitational potential



Conclusions I



1. There is no relevant forcing from

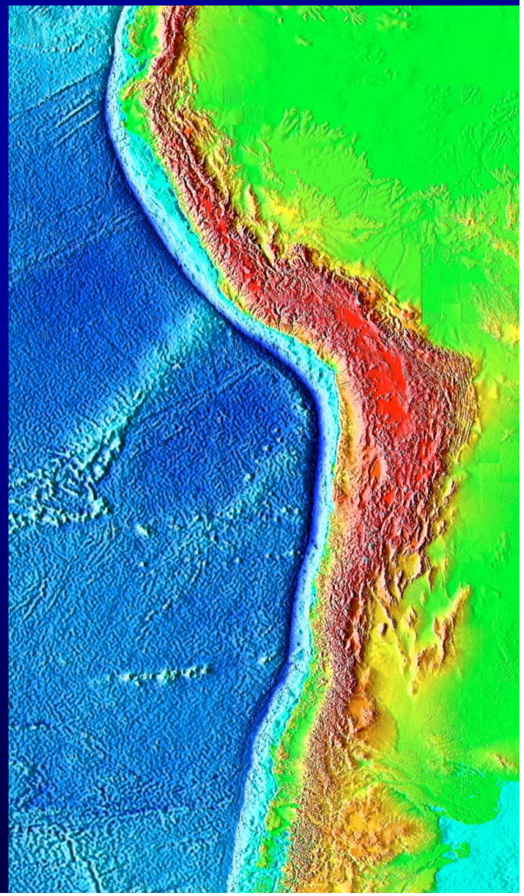
   variations in plate kinematics
   plate age and viscous coupling

   … convergence only provides background constraint

2. SA leading edge exhibts delicate force balance perturbed mainly by:

   - oceanic ridges/volcanic chains (forearc impact)
   - thermal weakening (mantle delamination?) (backarc impact)
   - climate change and sediment flux to trench (south)

3. Above mechanisms, which reflect external forcing mechanisms, are insufficient to explain Andean evolution and structural variability



Conclusions II

1. Styles of convergent margin orogeny hinge on evolution of strain-related strength of the upper plate leading edge ...

… latter not usually considered in modelling

2. External forcing overestimated with respect to internal, strain-related, lithosphere-scale failure observed in Central Andes, but not in the south

3. Multiple feedbacks prevents identification of key drivers (because of generally non-linear properties, unknown players, incomplete deep time series, etc.)

> correlation must not be mistaken for cause!
No chickens and eggs!?

> validation of model predictions in nature is a challenge for past processes