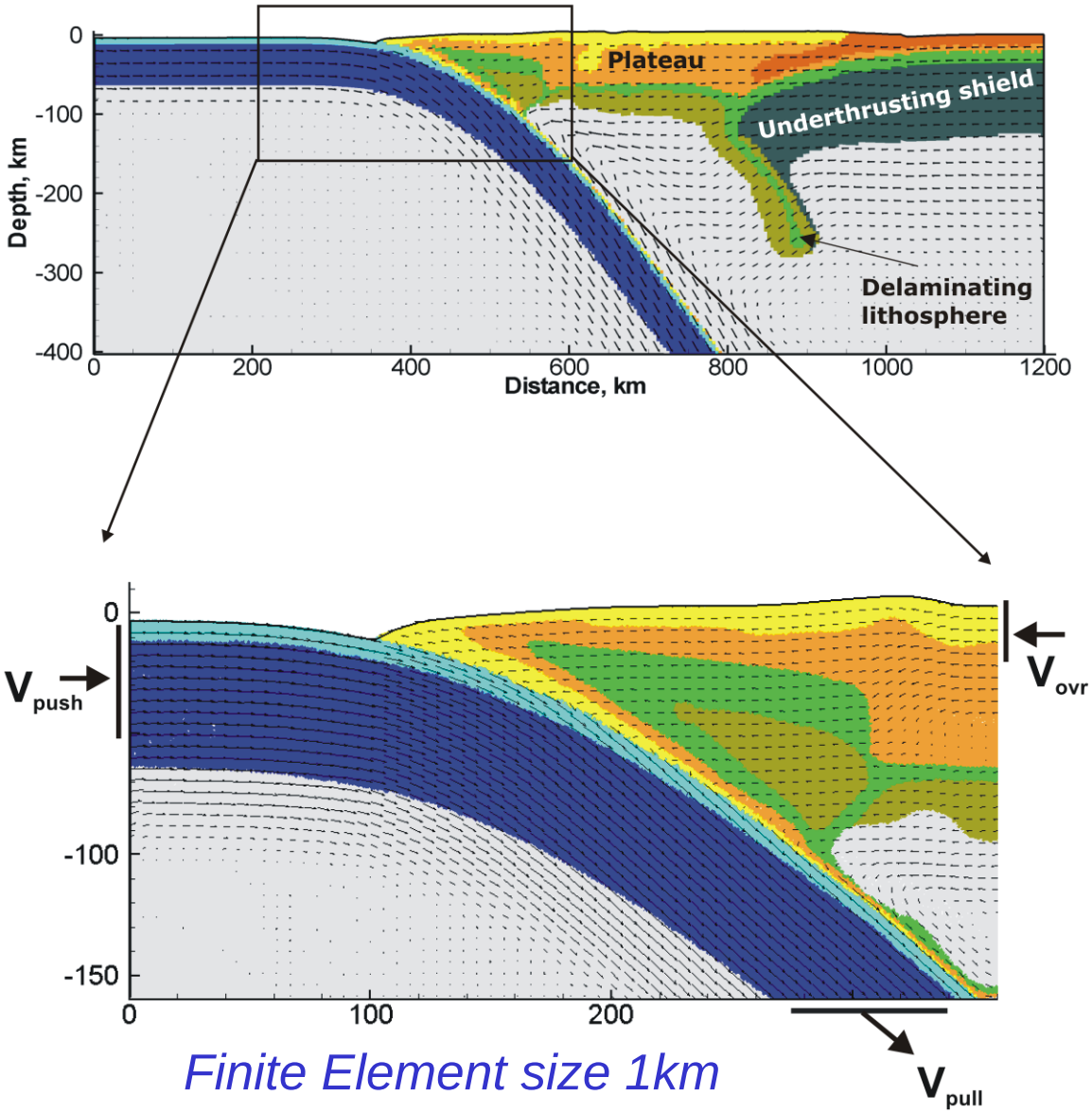
Lecture 7. Subduction processes in high resolution

Outline

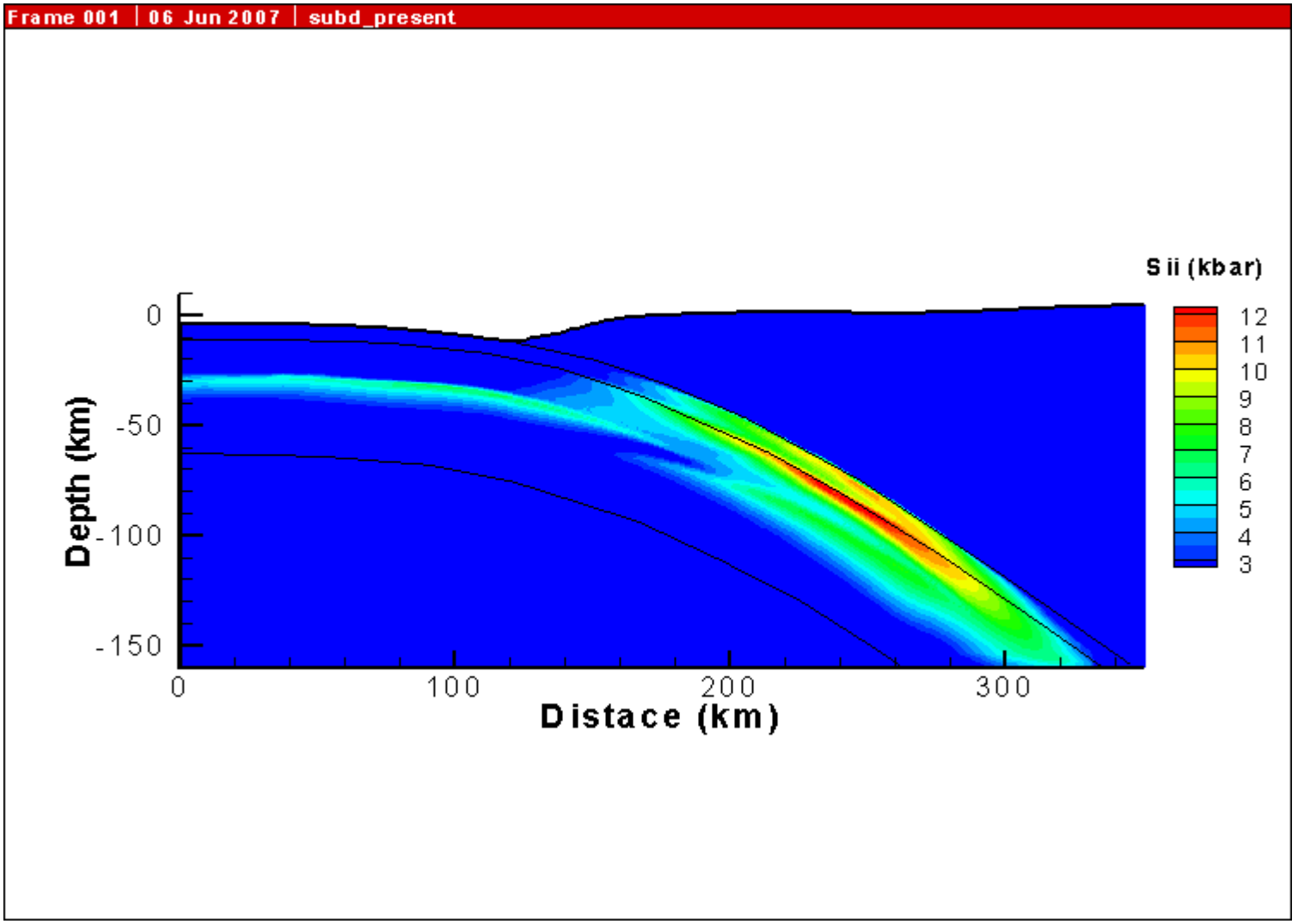
- Spatial “zoom-in” at subduction processes. Stress in the slab. Effect of gabbro-eclogite transformation and de-serpentinization.
- Effect of weakening of mantle wedge.
- Friction in subduction channel

Spatial “zoom-in”

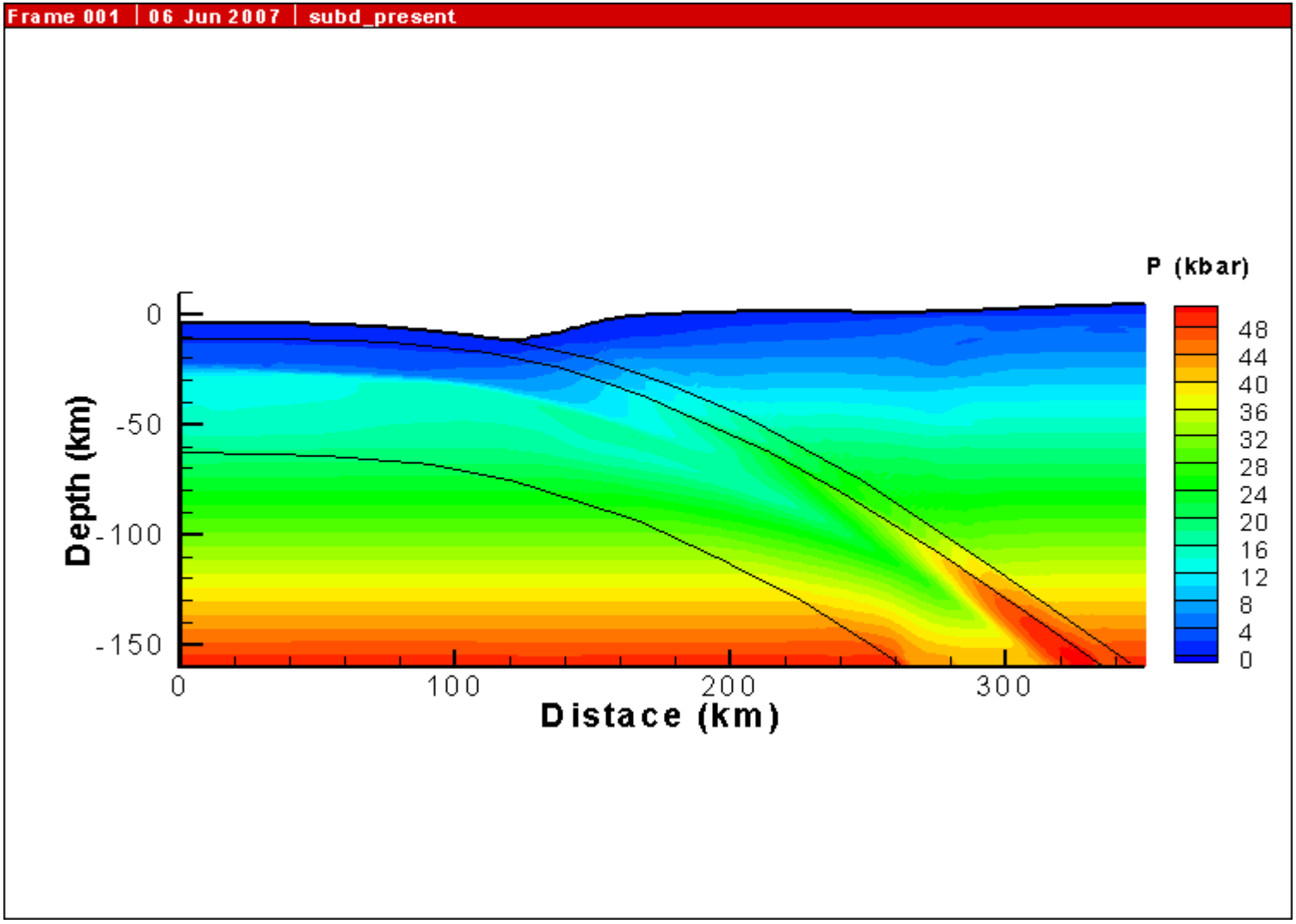


Finite Element size 1km

Stress without phase transformations

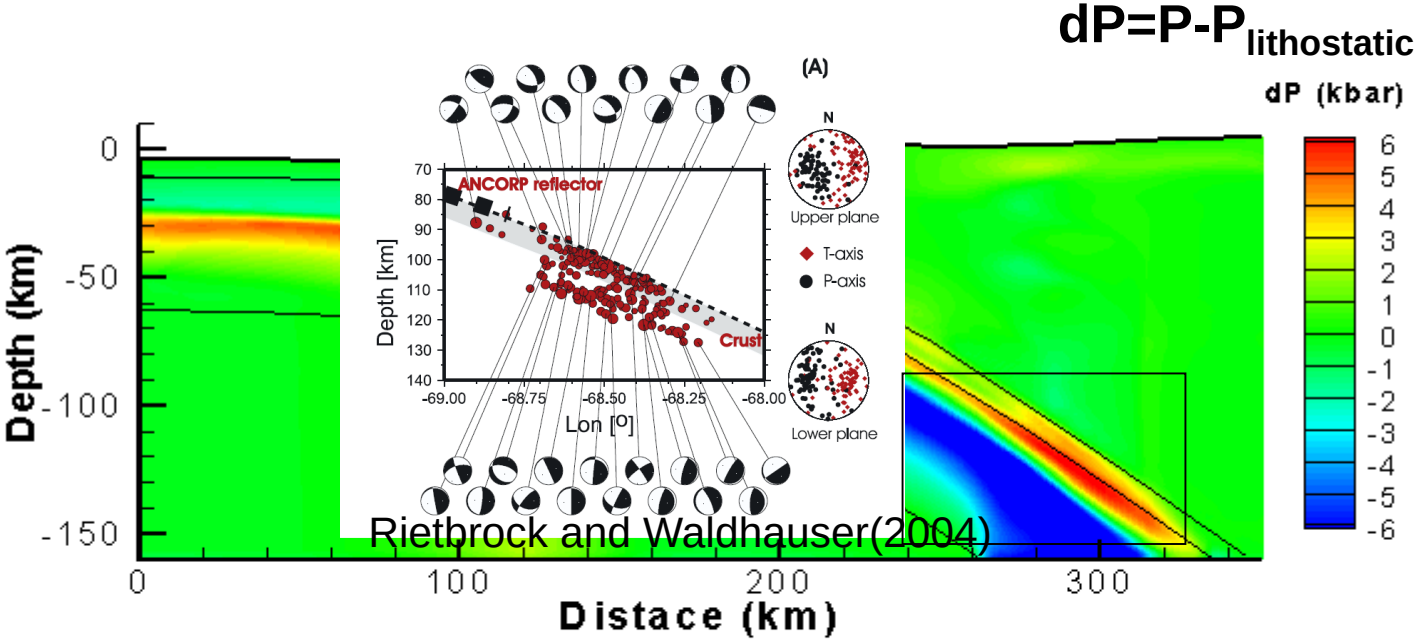


Pressure without phase transformations



Frame 001 | 06 Jun 2007 | subd_present

No phase transformations, no thermo-elasticity



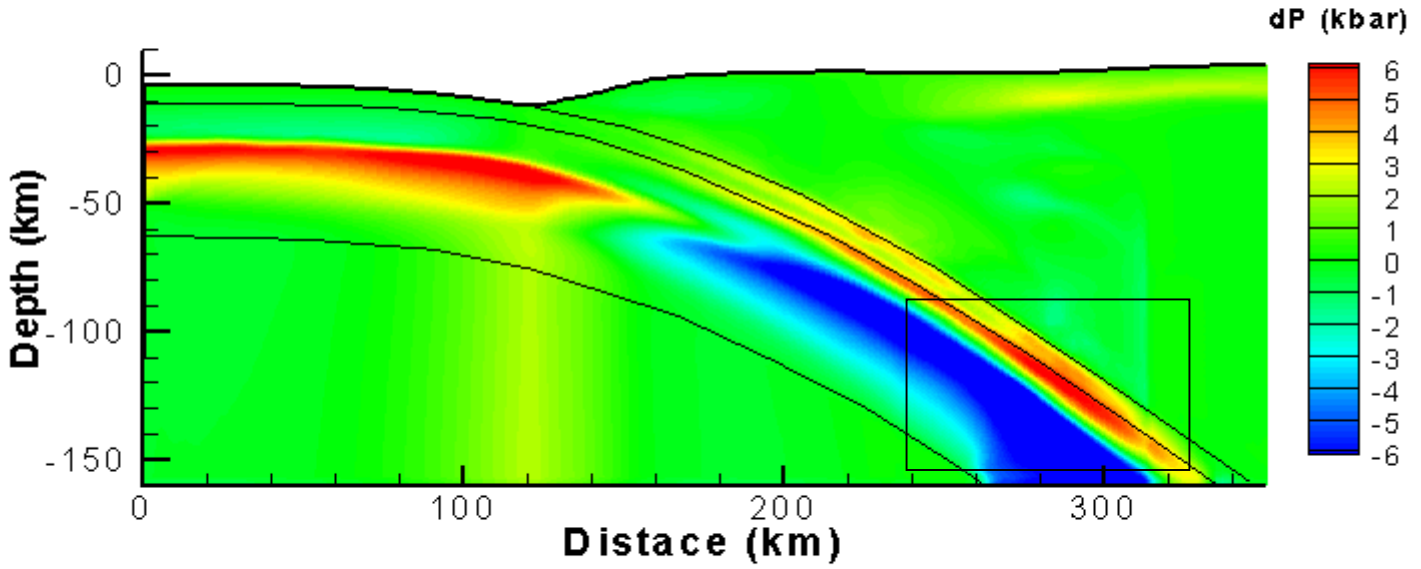
$$\frac{1}{K}\frac{DP}{Dt} - \alpha\frac{DT}{Dt} + \frac{\partial v_i}{\partial x_i} = 0$$

Mass conservation

Slab stress

Frame 001 | 06 Jun 2007 | subd_present

No phase transformations +thermoelasticity

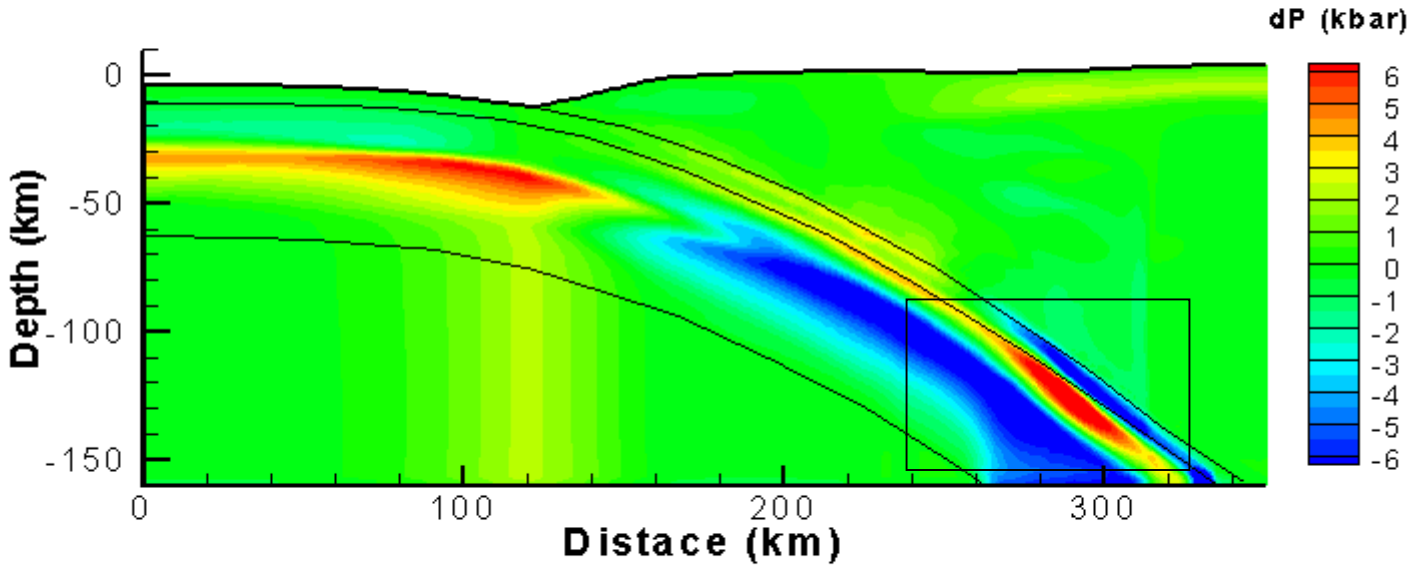


$$\frac{1}{K}\frac{DP}{Dt} - \alpha\frac{DT}{Dt} + \frac{\partial v_i}{\partial x_i} = 0$$

Mass conservation

Frame 001 | 06 Jun 2007 | subd_present

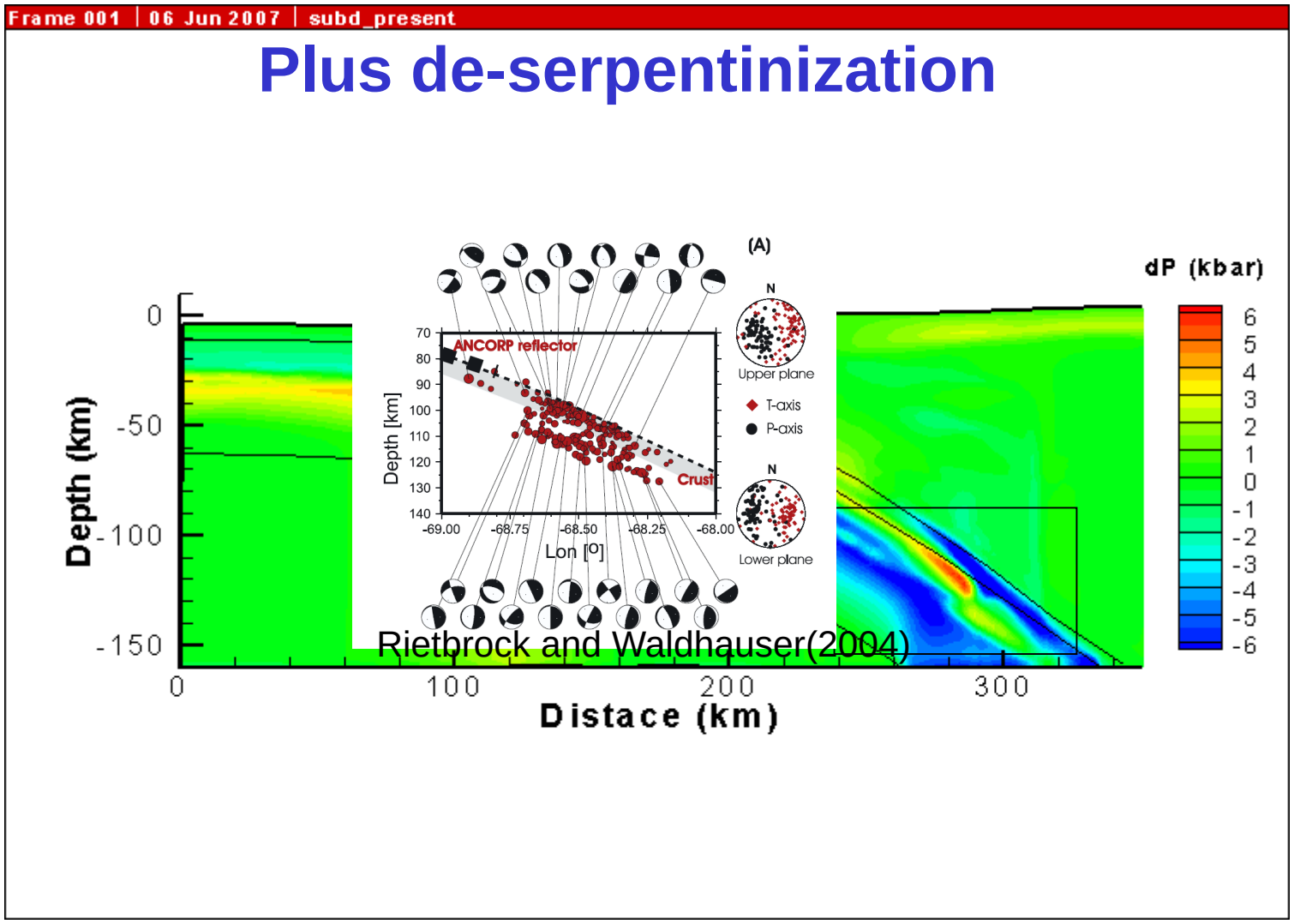
Plus gabbro-eclogite transformation



$$\frac{1}{K}\frac{DP}{Dt} - \alpha\frac{DT}{Dt} + \frac{\partial v_i}{\partial x_i} = \frac{D\zeta}{Dt}\frac{\Delta V}{V_0}$$

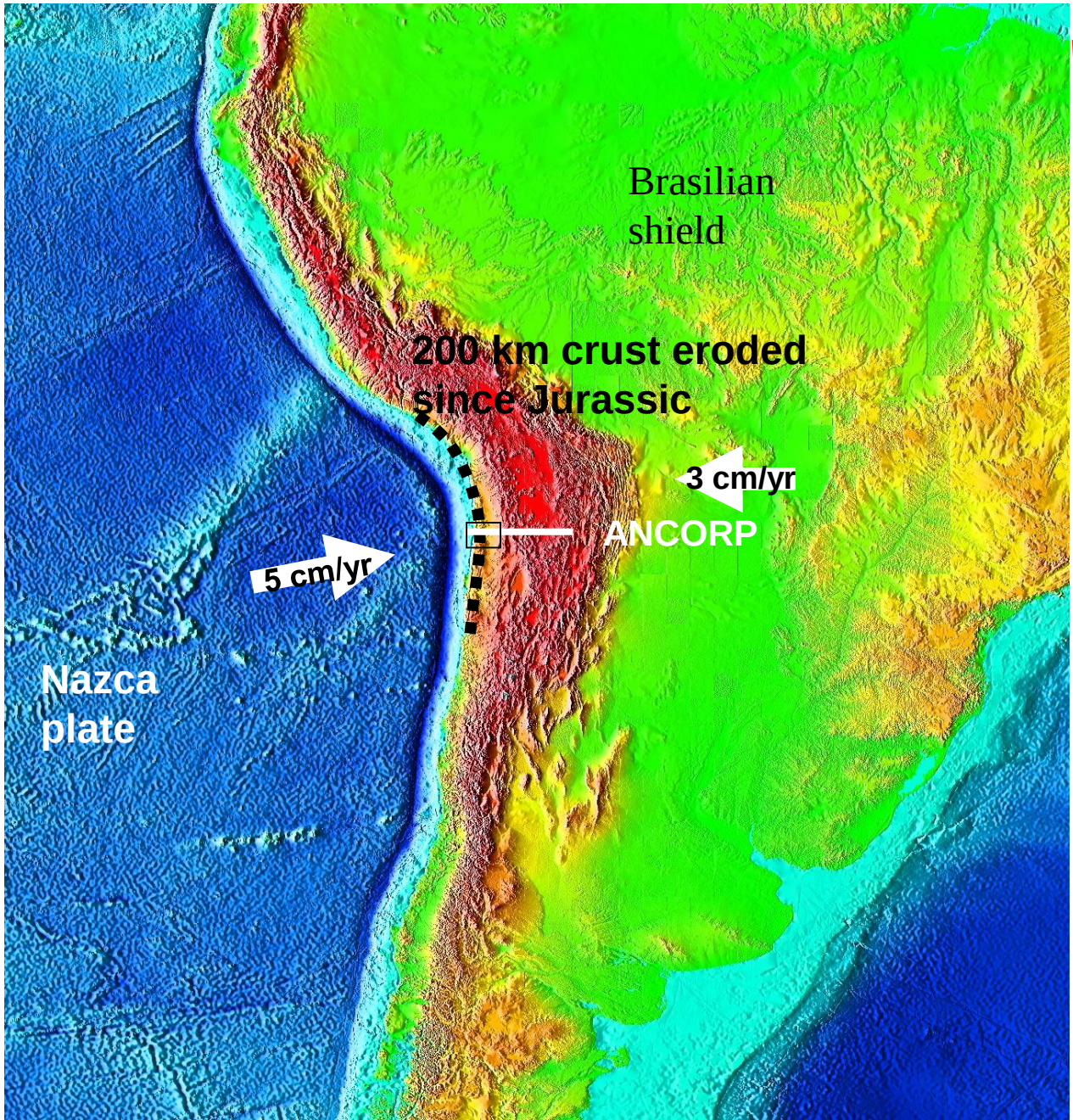
Mass conservation

Slab stress


Frame 001 | 06 Jun 2007 | subd_present
Plus de-serpentinization
(A)
N
Upper plane
T-axis
P-axis
N
Lower plane
ANCORP reflector
Crust
Depth [km]
Lon [°]
dP (kbar)
Depth (km)
Distace (km)
Rietbrock and Waldhauser(2004)

Andean Orogeny

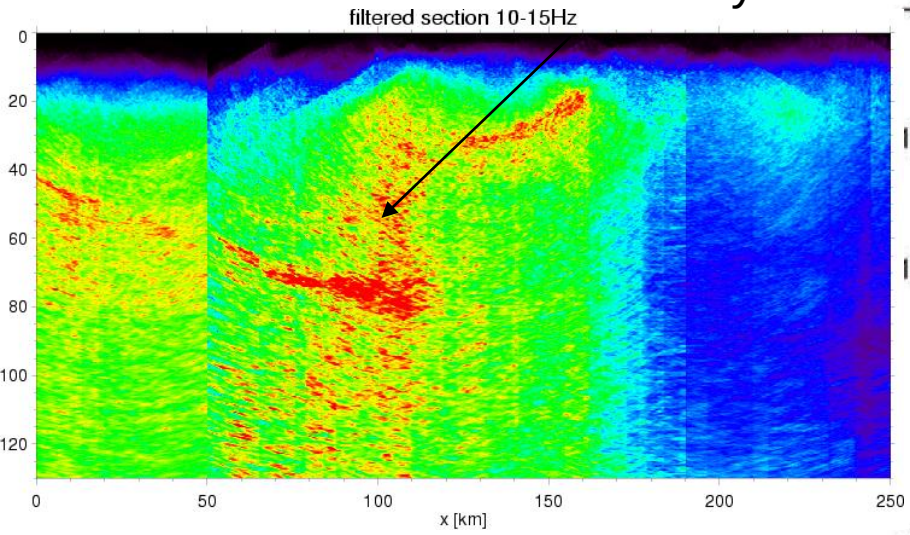
Wedge weakening



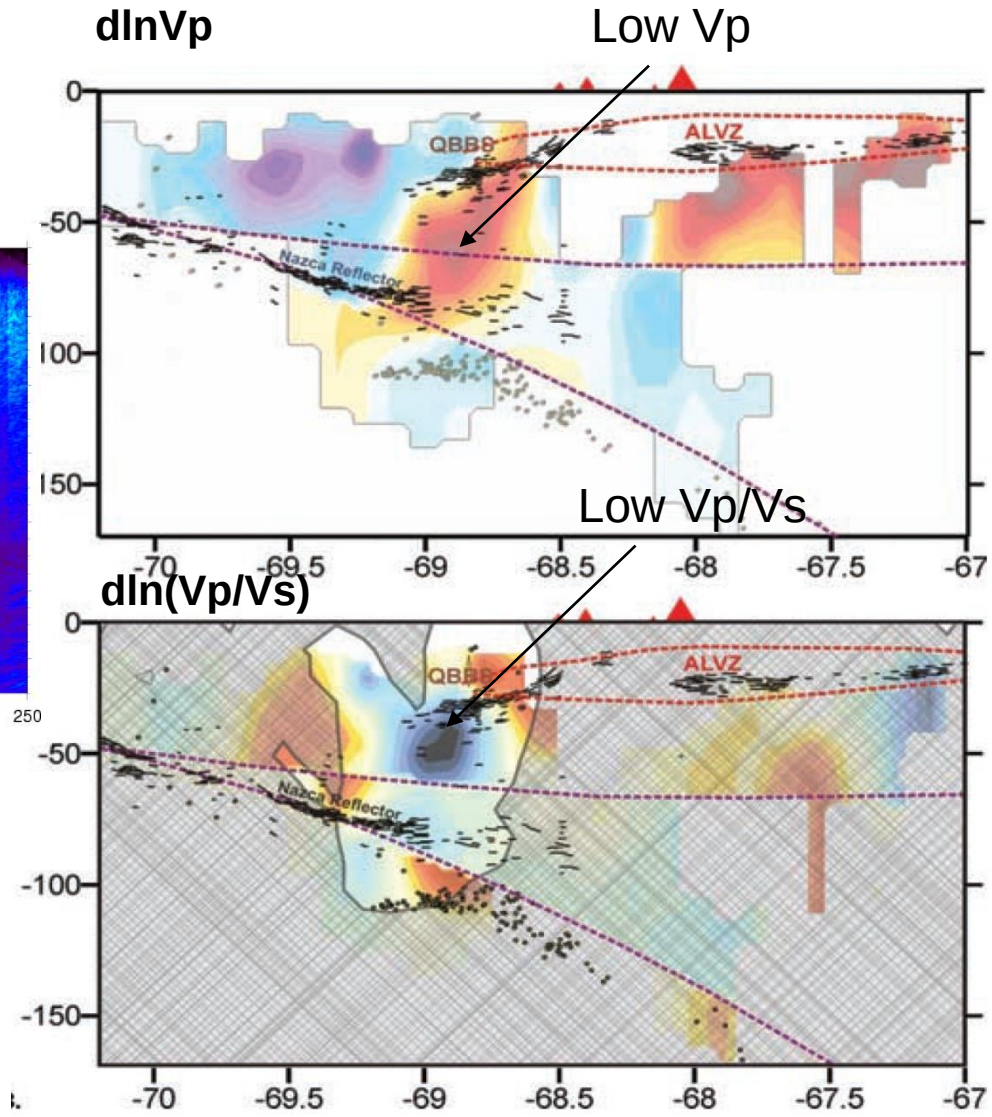
21°S

Wedge weakening

High reflectivity



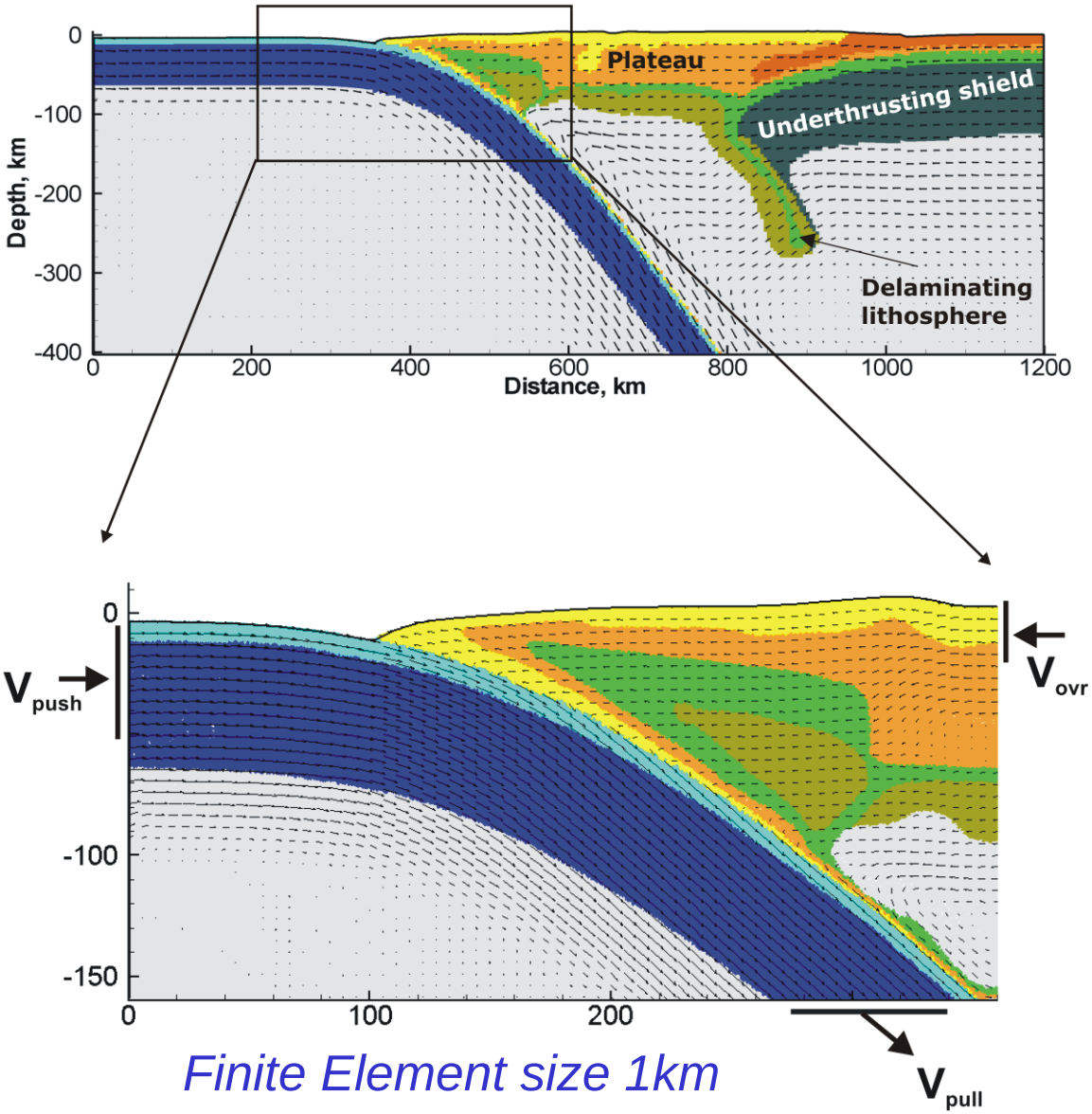
Yoon et al. (2007)



(Koulakov, Sobolev, Asch, 2006)

Spatial "zoom-in"

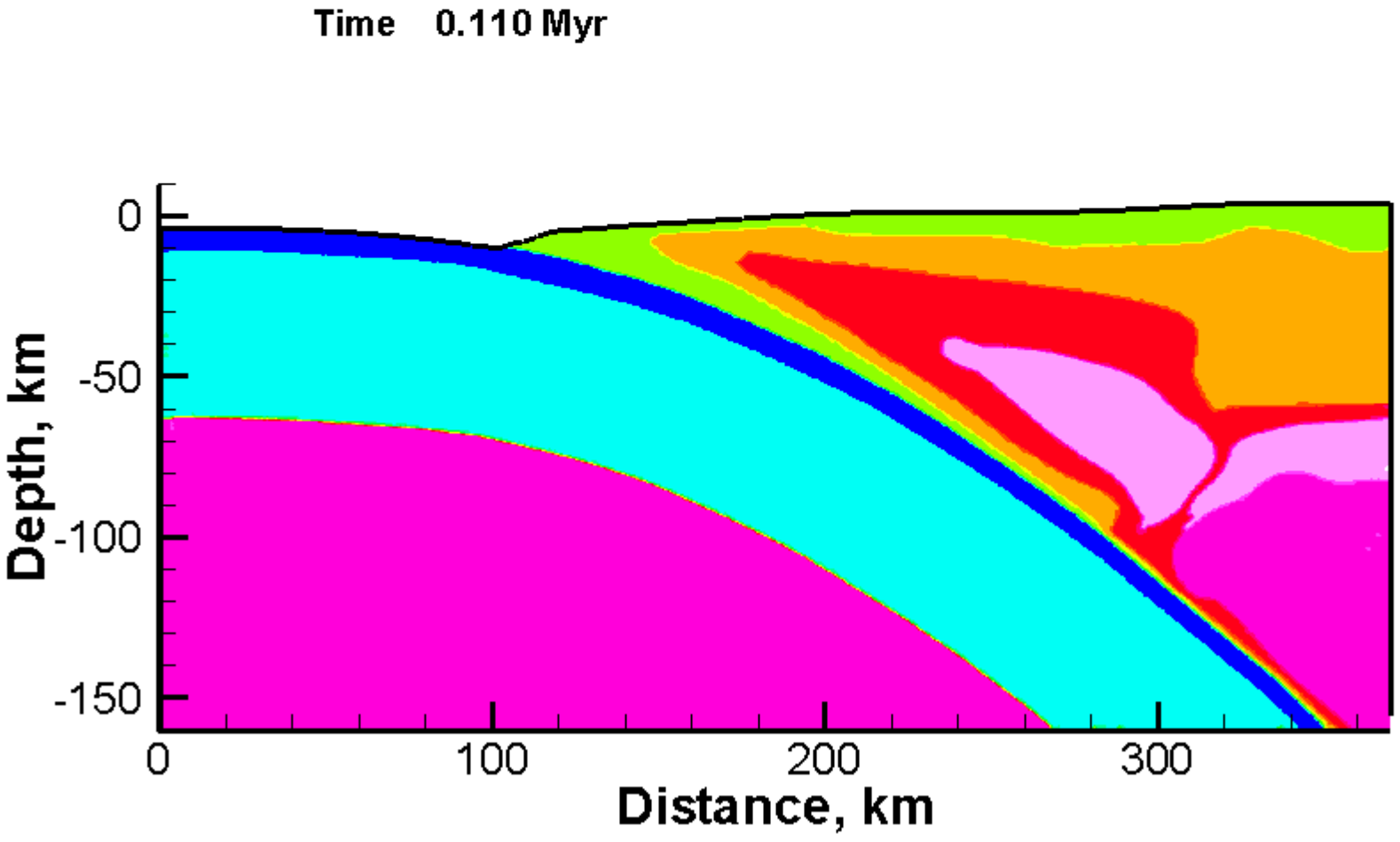
Wedge weakening



Finite Element size 1km

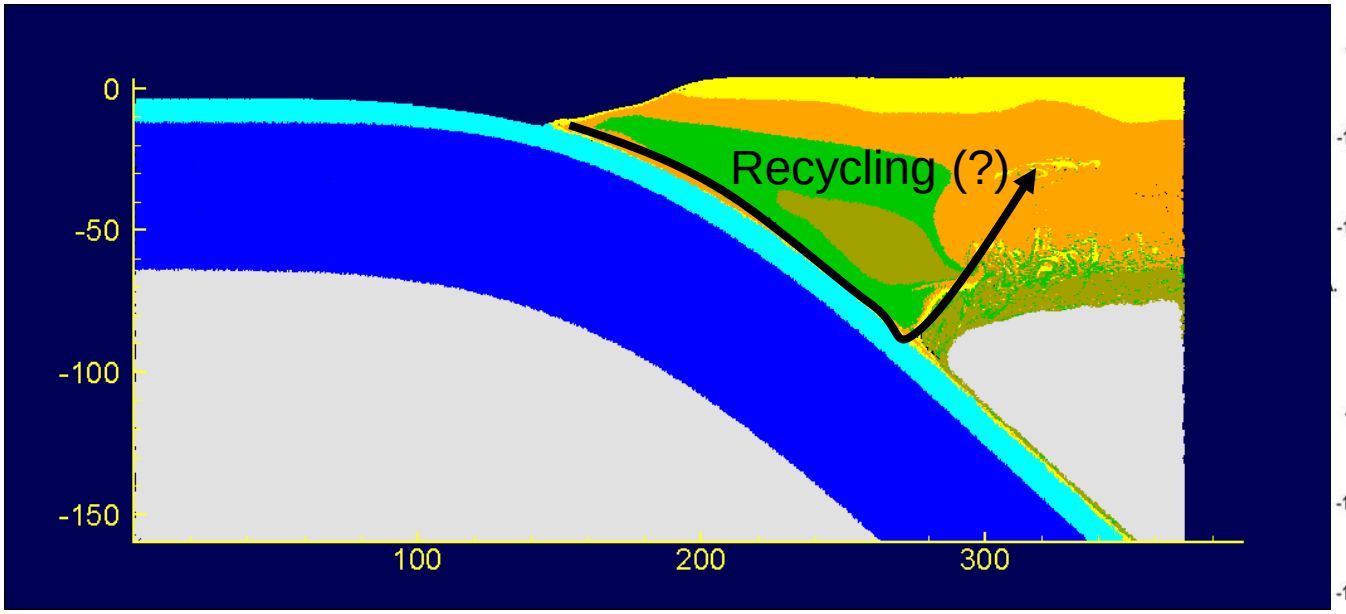
Wedge weakening

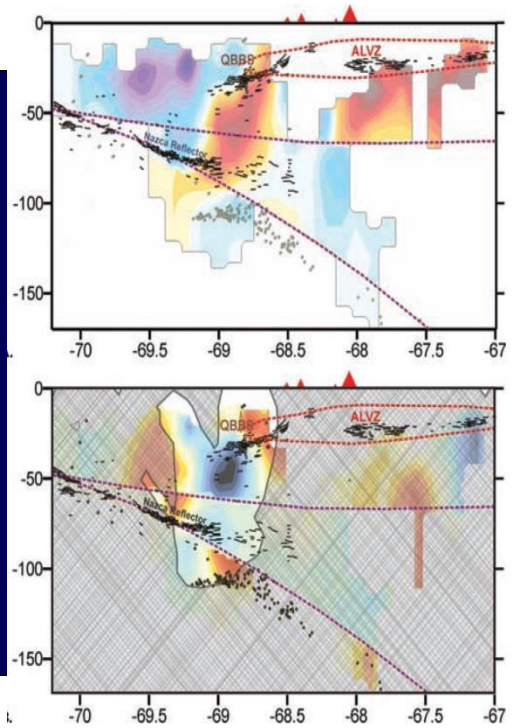
Mantle wedge weakening (1 km FE)



Wedge weakening

Mantle wedge evolution



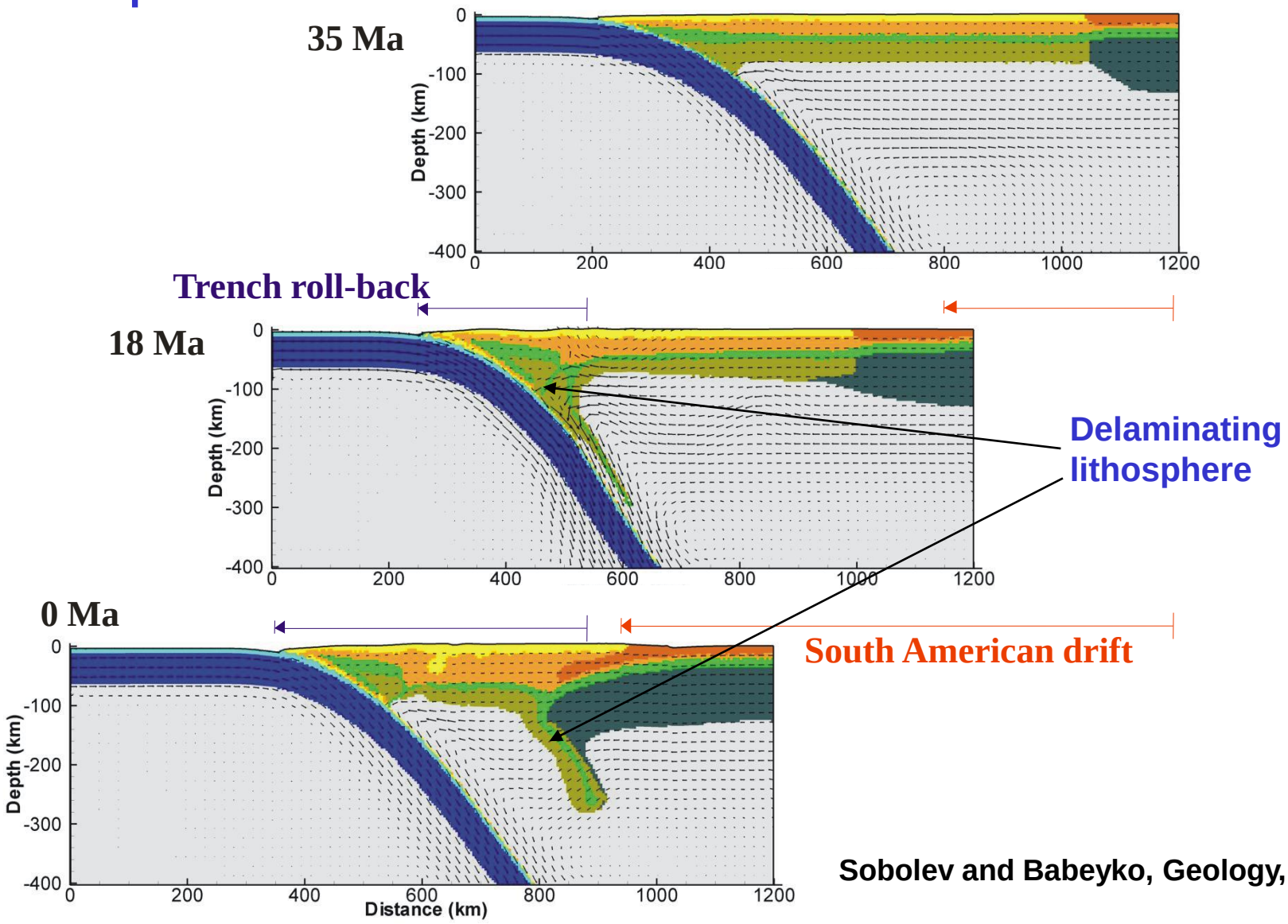


Conclusions

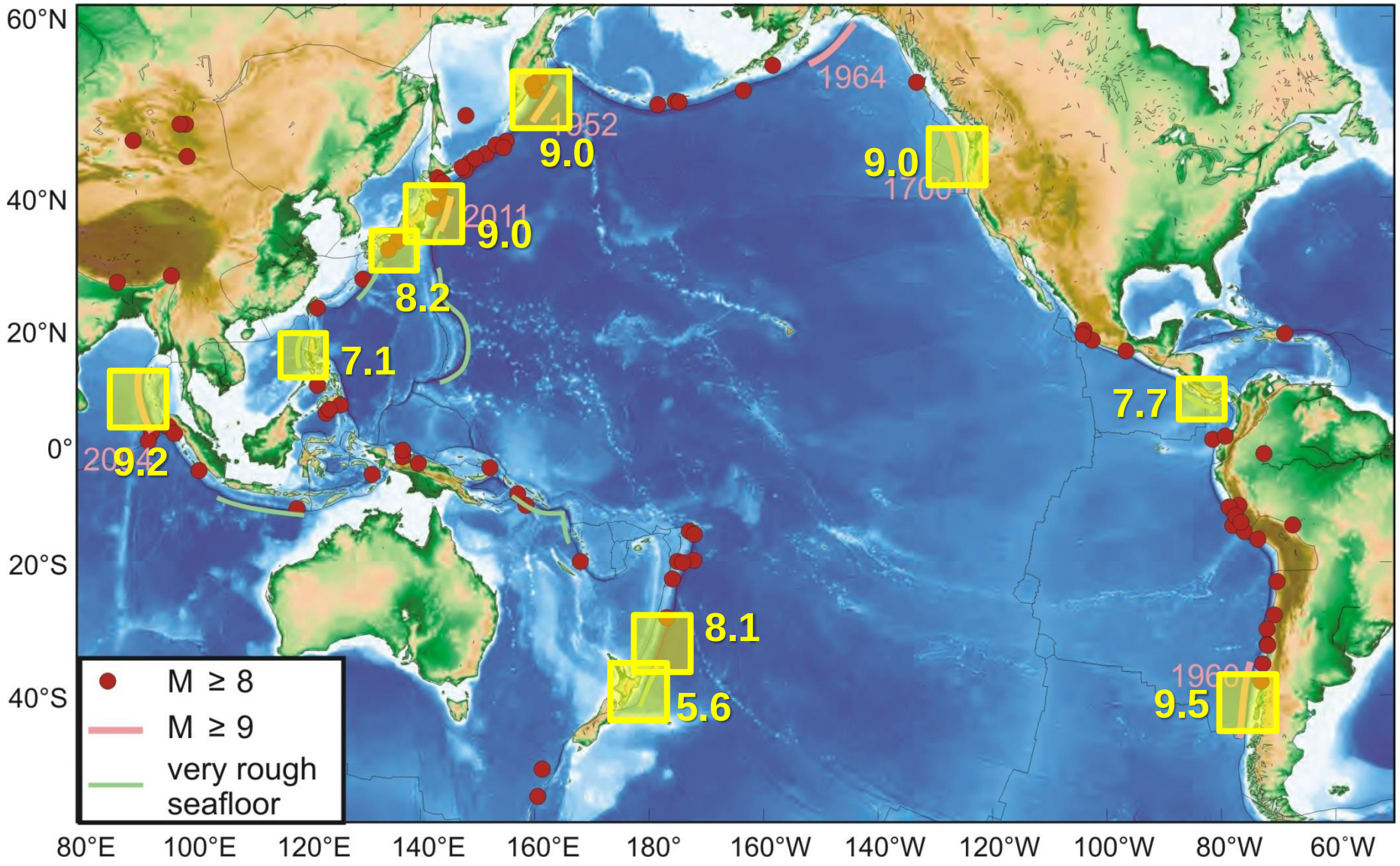
- Spatial “zoom-in” technique allows to increase model resolution and to consider effects not detectable in the low-resolution models.
- Modeled stresses in the slab without phase transformations are inconsistent with seismological observations in central Andes, but introduction of gabro-eclogite transformation in the crust and deserpentinization in the uppermost mantle result in the right stresses
- Mantle wedge weakening may cause the recycling of the upper crust in the overriding plate

The central Andes model

Friction μ = 0.05



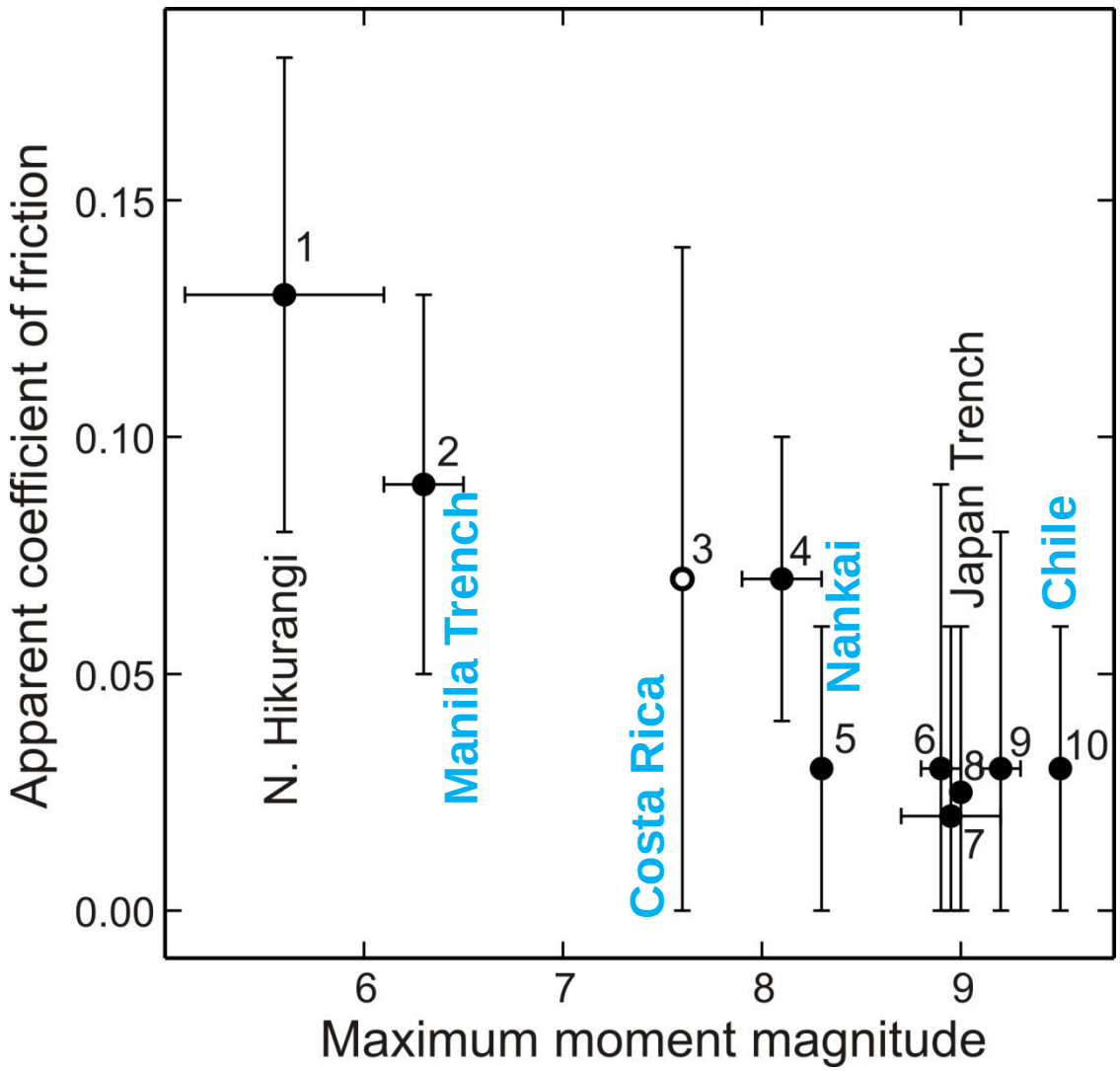
Sobolev and Babeyko, Geology, 2005



Subduction zones with adequate heat flow data to constrain frictional heating

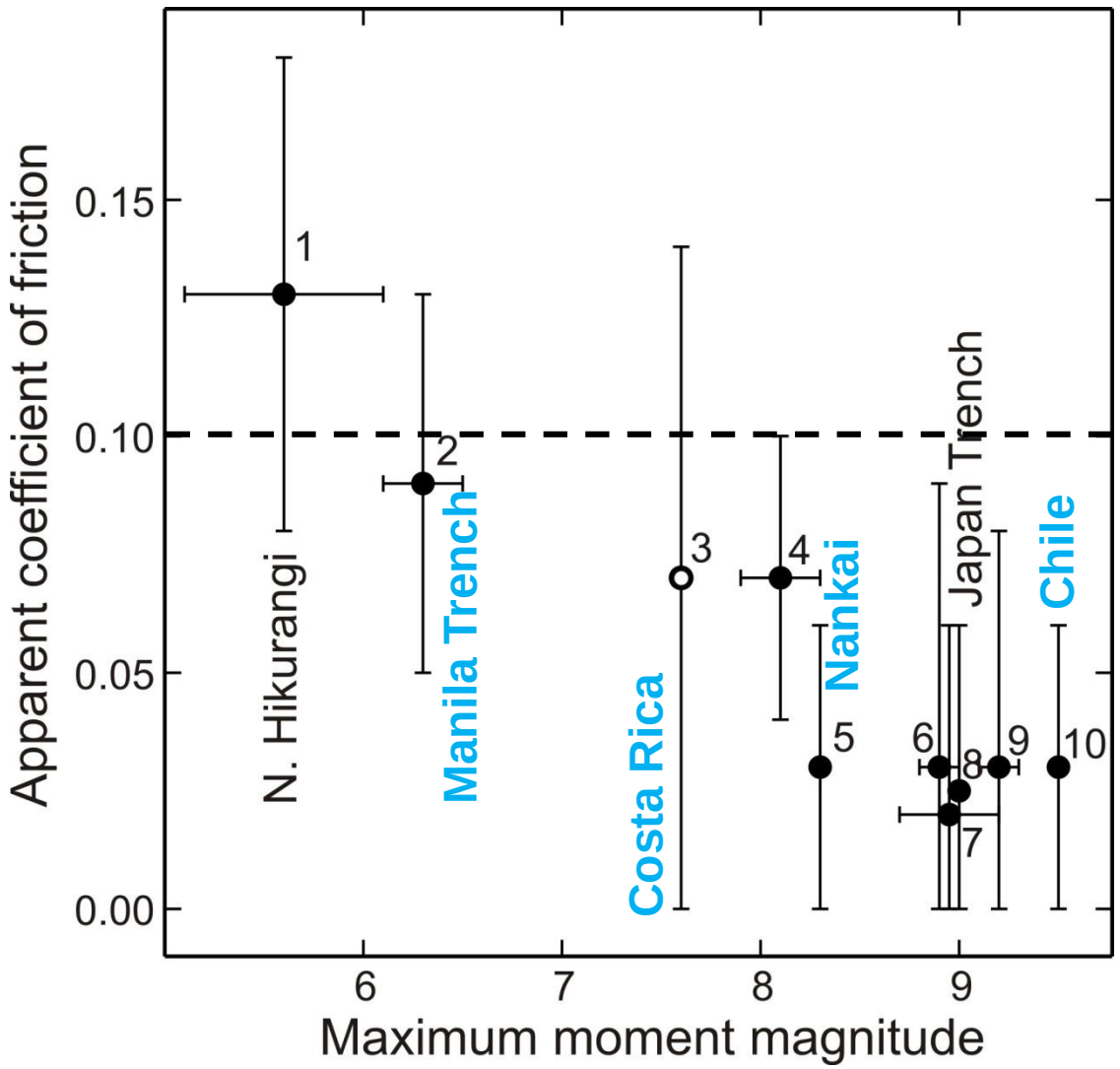
Gao and Wang, Science, 2014

creeping **seismogenic**



Gao and Wang, Science, 2014

creeping **seismogenic**

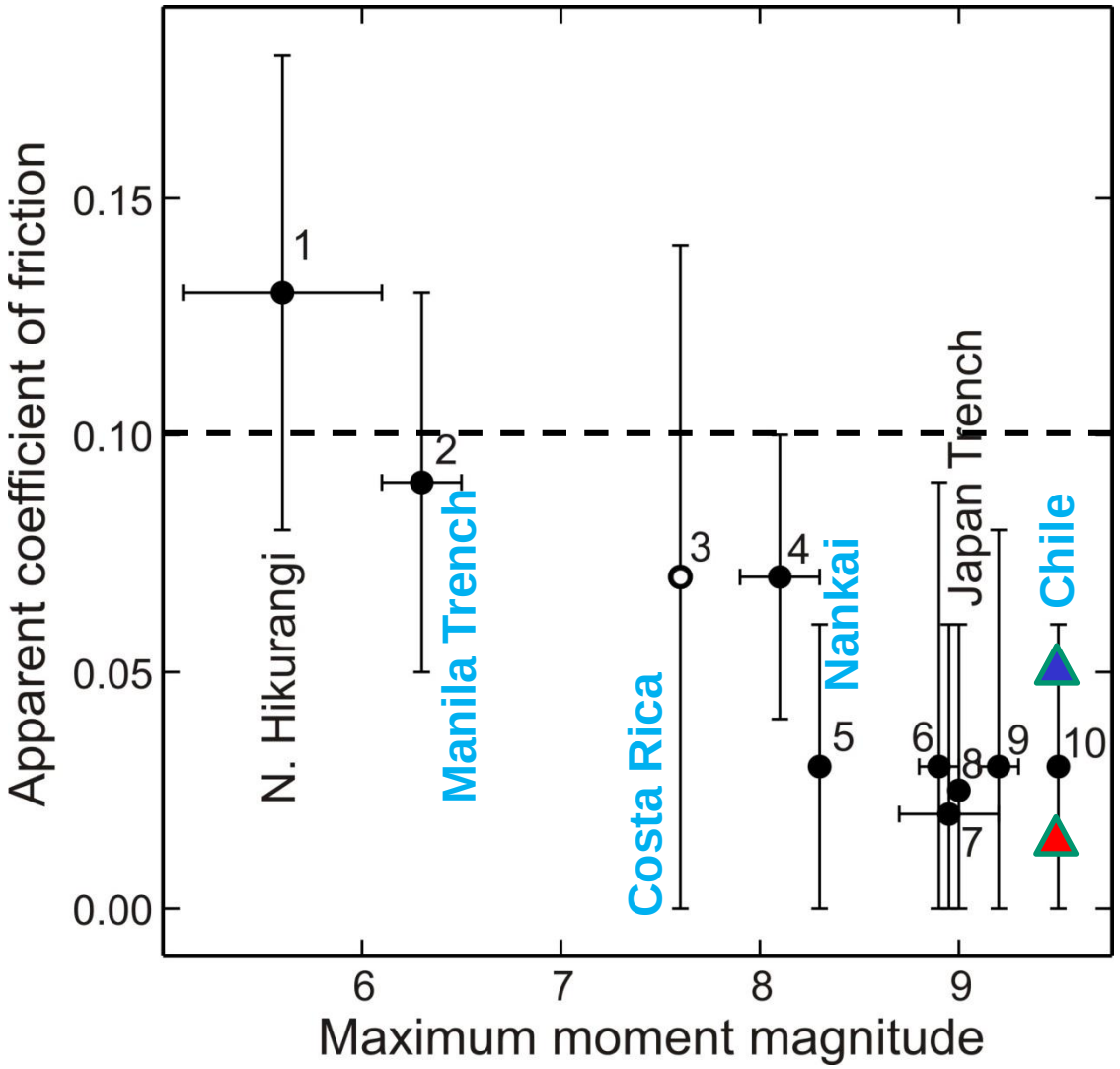


Max friction for subduction

Sobolev et al, 2006

Gao and Wang, Science, 2014

creeping **seismogenic**



Max friction for subduction

Sobolev et al, 2006

Northern Chile

Sobolev and Babeyko, 2005

Southern Chile

Gao and Wang, Science, 2014

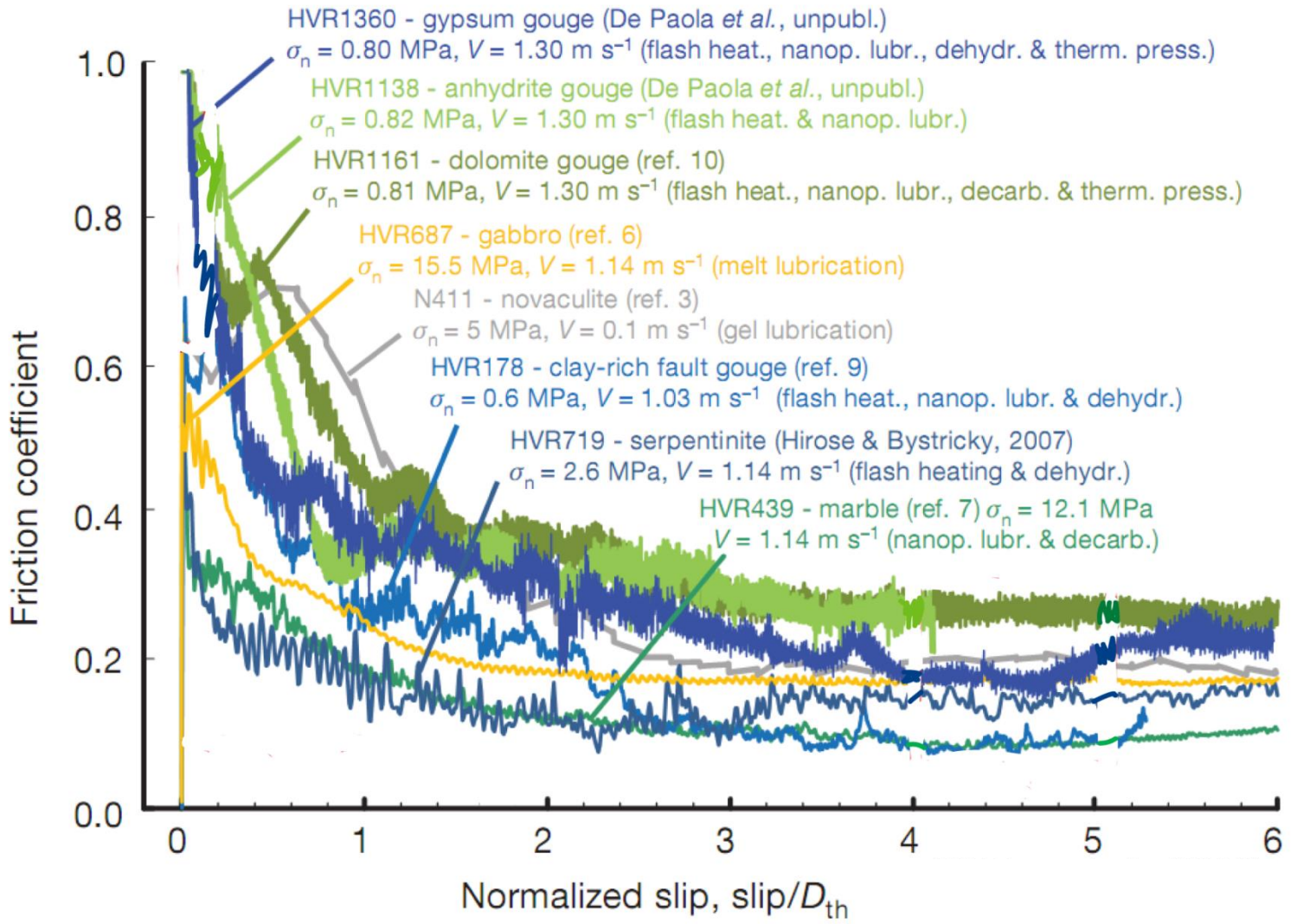
Conclusion

Estimates of low friction in subduction decoupling zones from geodynamic models is fully consistent with robust estimates of friction based on heat flow data

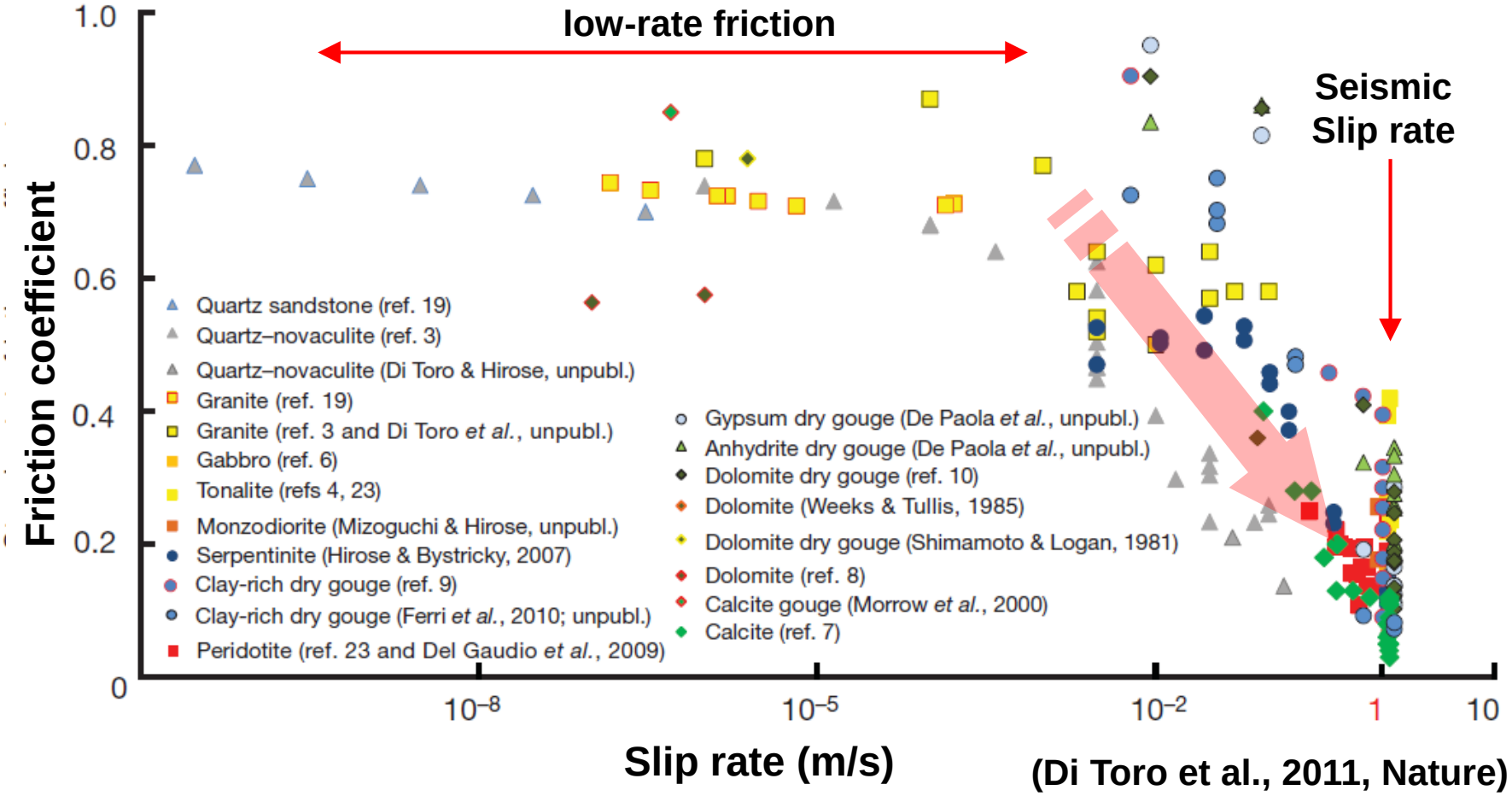
Question

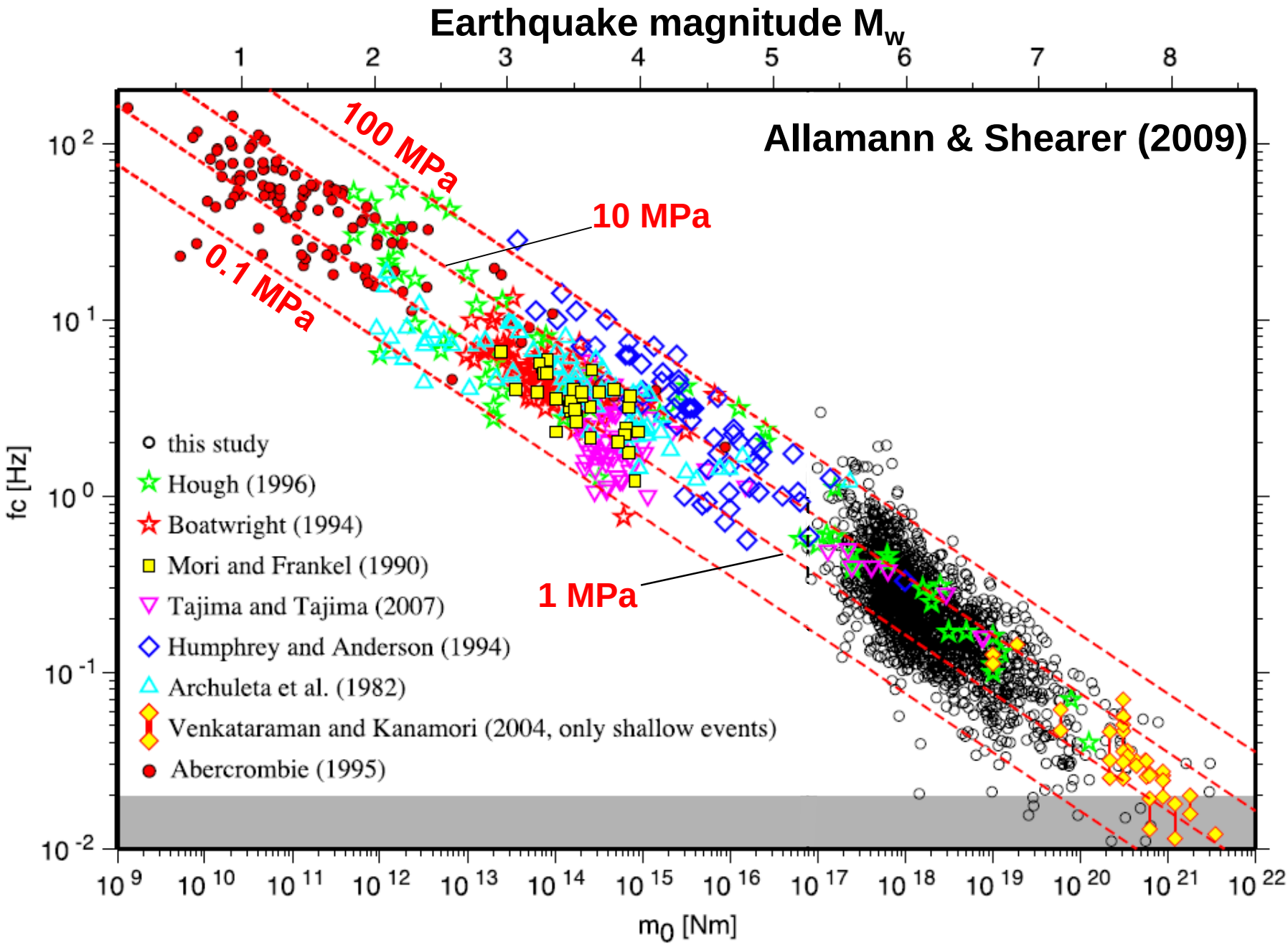
Is that low friction static (effect of high pressure porous fluid) or dynamic (result of dynamic weakening)?

Experimental results on dynamic weakening

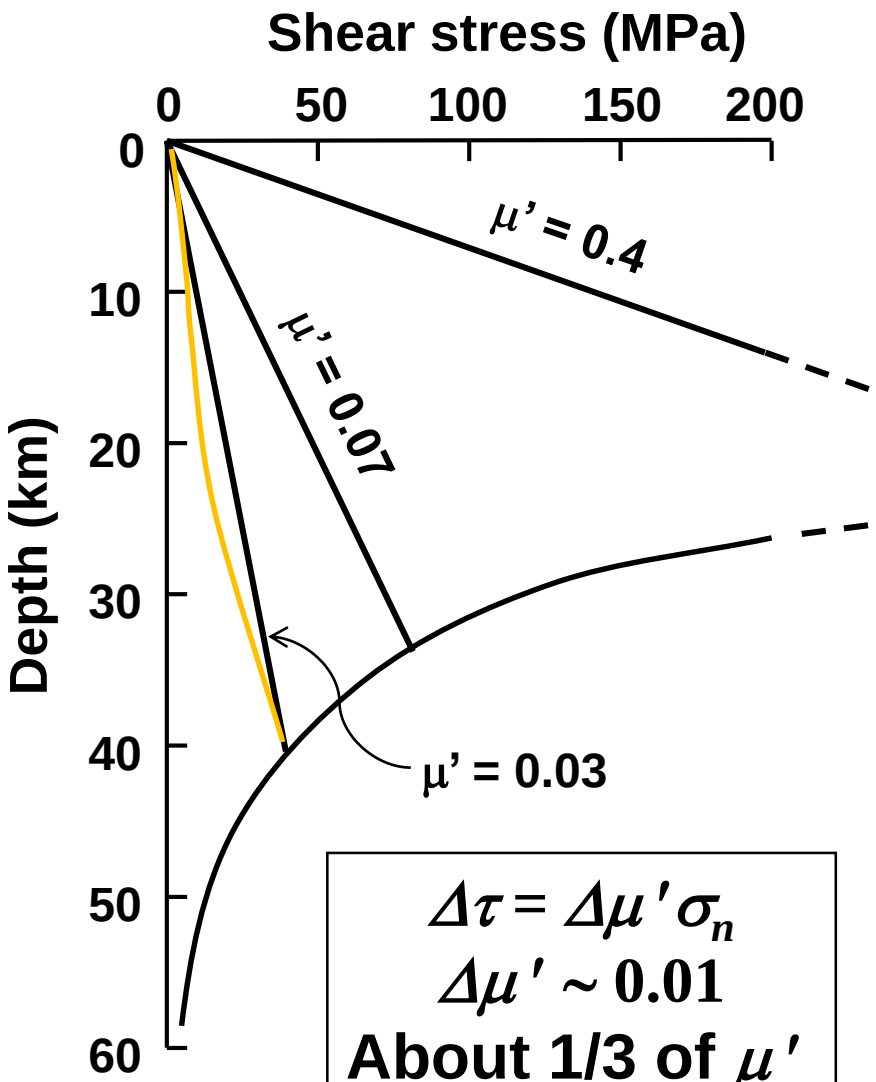


(Di Toro et al., 2011, Nature)


low-rate friction
Seismic
Slip rate
Friction coefficient
1.0
0.8
0.6
0.4
0.2
0
Quartz sandstone (ref. 19)
Quartz–novaculite (ref. 3)
Quartz–novaculite (Di Toro & Hirose, unpubl.)
Granite (ref. 19)
Granite (ref. 3 and Di Toro et al., unpubl.)
Gabbro (ref. 6)
Tonalite (refs 4, 23)
Monzodiorite (Mizoguchi & Hirose, unpubl.)
Serpentinite (Hirose & Bystricky, 2007)
Clay-rich dry gouge (ref. 9)
Clay-rich dry gouge (Ferri et al., 2010; unpubl.)
Peridotite (ref. 23 and Del Gaudio et al., 2009)
Gypsum dry gouge (De Paola et al., unpubl.)
Anhydrite dry gouge (De Paola et al., unpubl.)
Dolomite dry gouge (ref. 10)
Dolomite (Weeks & Tullis, 1985)
Dolomite dry gouge (Shimamoto & Logan, 1981)
Dolomite (ref. 8)
Calcite gouge (Morrow et al., 2000)
Calcite (ref. 7)
10−8
10−5
10−2
1
10
Slip rate (m/s)
(Di Toro et al., 2011, Nature)



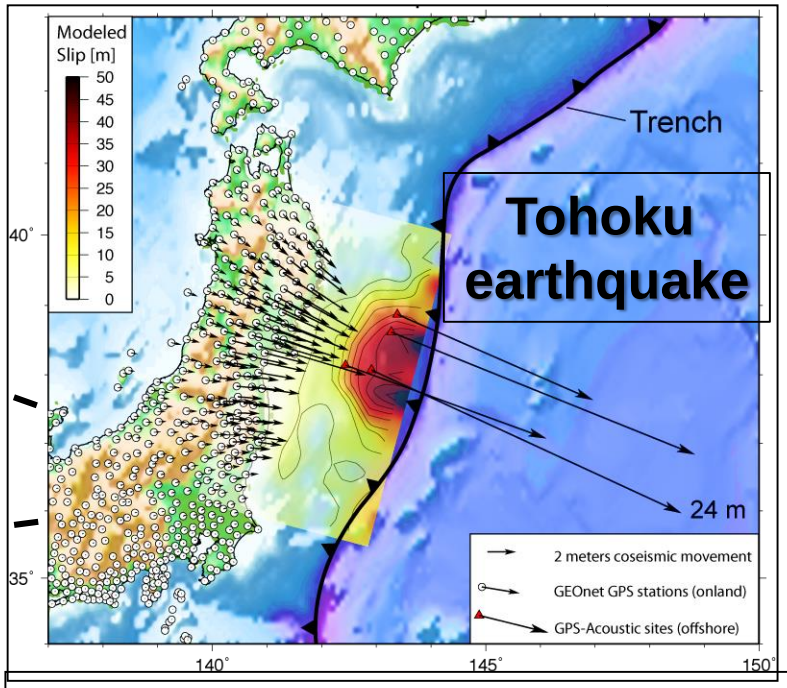
Gao and Wang, Science, 2014



$$\Delta\tau = \Delta\mu'\sigma_n$$

$$\Delta\mu' \sim 0.01$$

About 1/3 of μ'



Stress drop estimates:

Simons et al. (2011): 2-10 MPa

Koketsu et al. (2011): 4.8 MPa

Lee et al. (2011): 7 MPa

Kumagai et al. (2012): Locally up to 40 MPa

From GEOMOD 2014 presentation of K. Wang

Question

Is that low friction static (effect of high pressure porous fluid) or dynamic (result of dynamic weakening)?

Answer

Dynamic friction change in large earthquake is less than 0.01. It means that low friction in subduction channel has static reasons, e.g. high pressure fluid