Time-varying subduction and rollback velocities in slab stagnation and buckling

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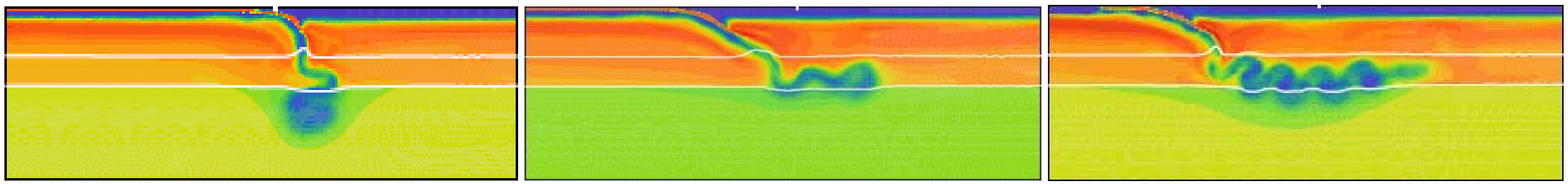
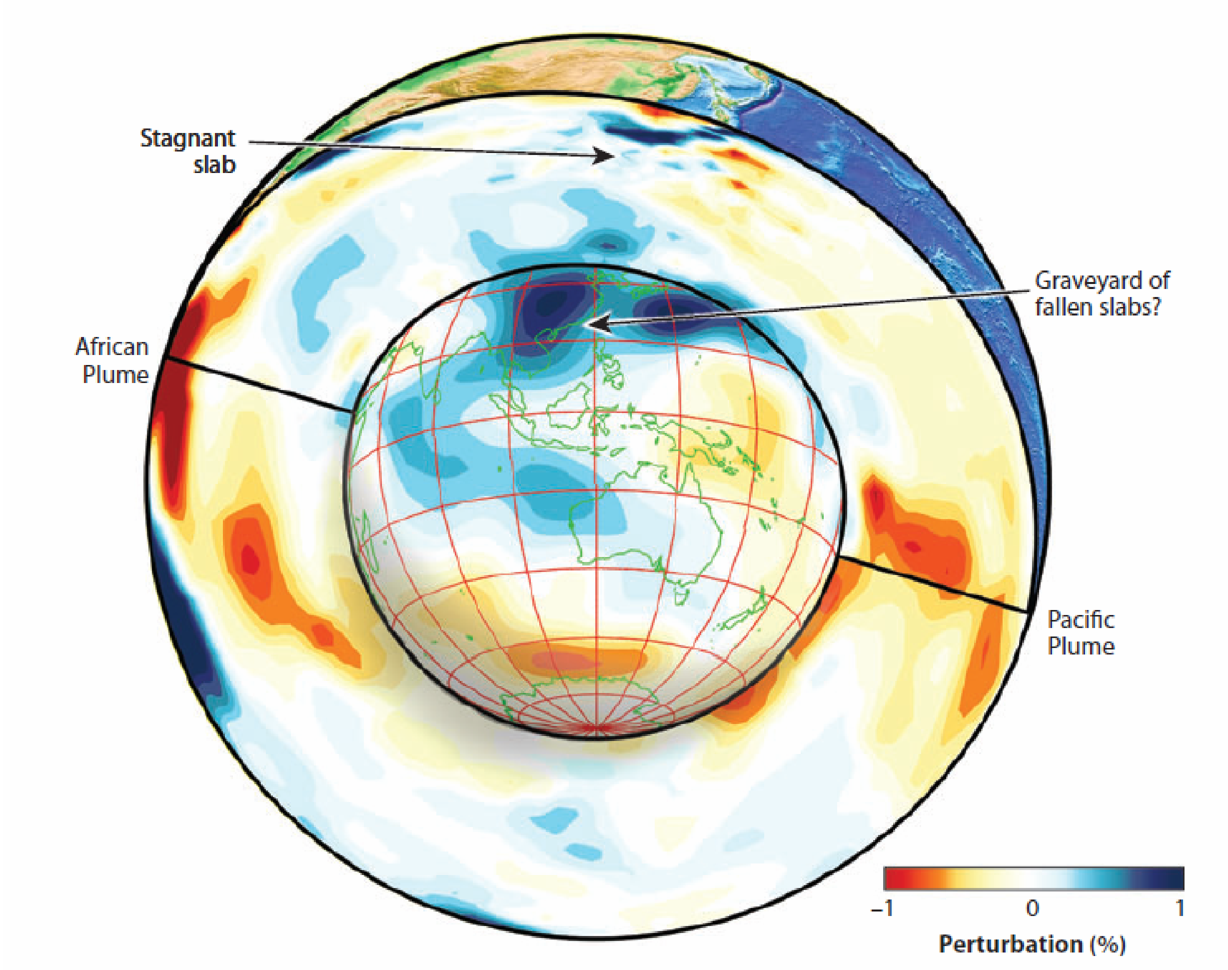
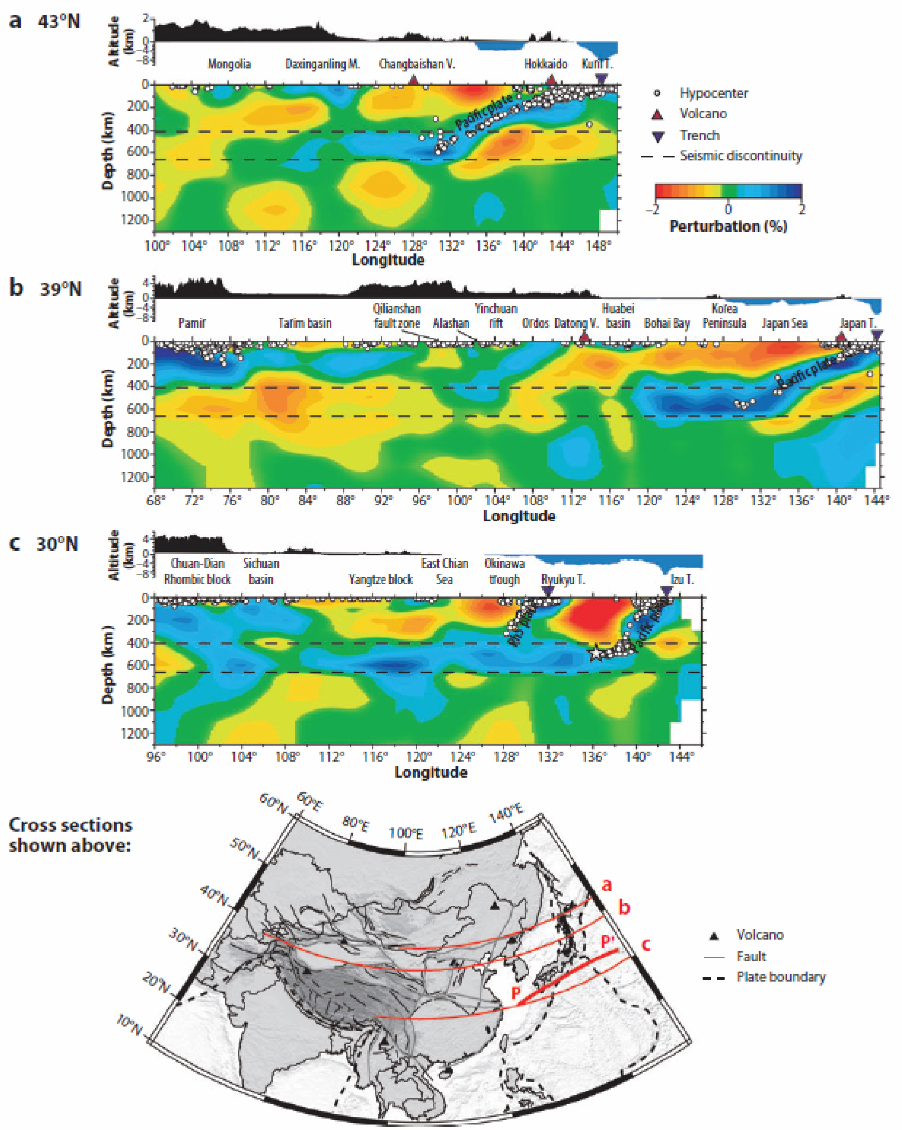


SLAB STAGNATION

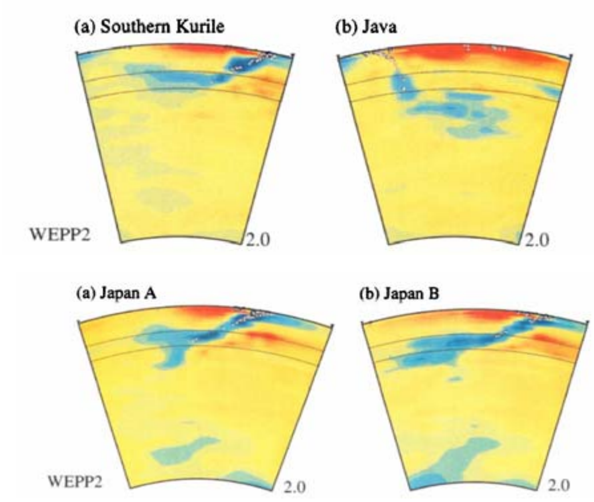


Fukao et al., 2009

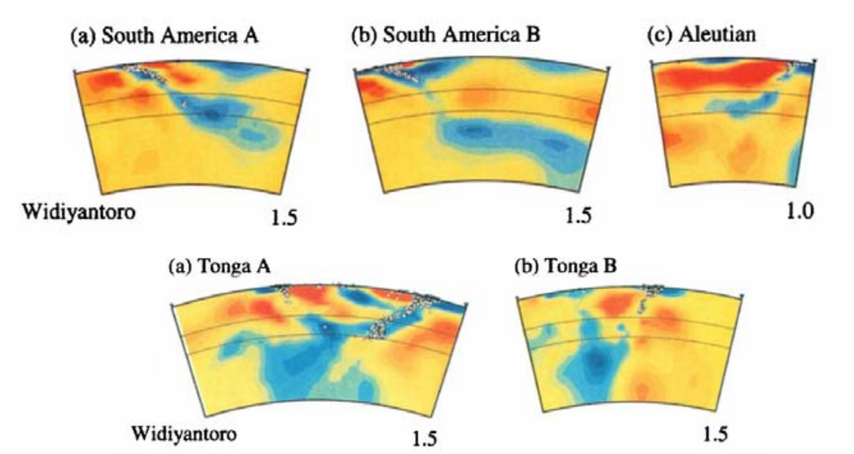
SLAB STAGNATION



Huang and Zhao, 2006



Obayashi et al., 1997



Widiyantoro, 1997

TRENCH ROLLBACK – ADVANCE

old slabs → cold and heavy → rollback

BUT: cold old slabs are stiff → good stress guide → advance
(Gerault et al., 2012)

Husson, 2012 → rollback is controlled primarily by mantle drag,
slab rheology plays only minor role

TRENCH VELOCITY

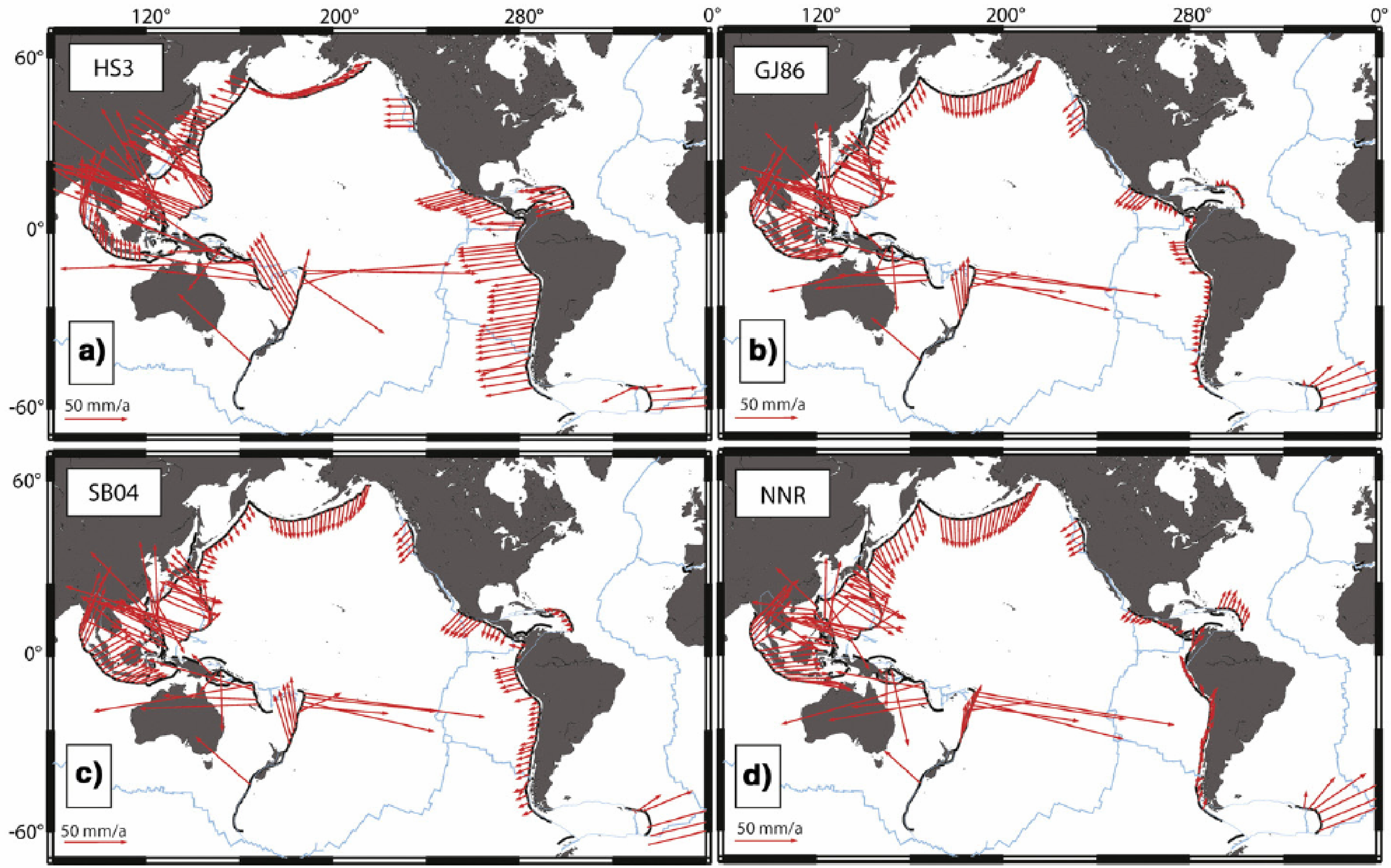


Fig. 3. Normal component of trench velocity $V_{t(n)}$ in four absolute reference frames: (a) hot spot reference frame of Gripp and Gordon (2002), which analyses the Pacific hot-spot track; (b) hot spot reference frame of Gordon and Jurdy (1986), which considers both the Indo-Atlantic and the Pacific hot-spot tracks; (c) hot spot reference frame of Steinberger et al. (2004), which investigates only the Indo-Pacific hot-spot tracks; (d) no-net-rotation reference frame (Gripp and Gordon, 2002). Reference velocity is indicated at the bottom-left of each panel.

Funiciello et al., 2008

NUMERICAL MODELING TRENCH ROLLBACK

Target: find the parameters of slabs (rheological parameters, age?) that may control the trench migration

Main focus: rheological description – effects of nonlinear rheology

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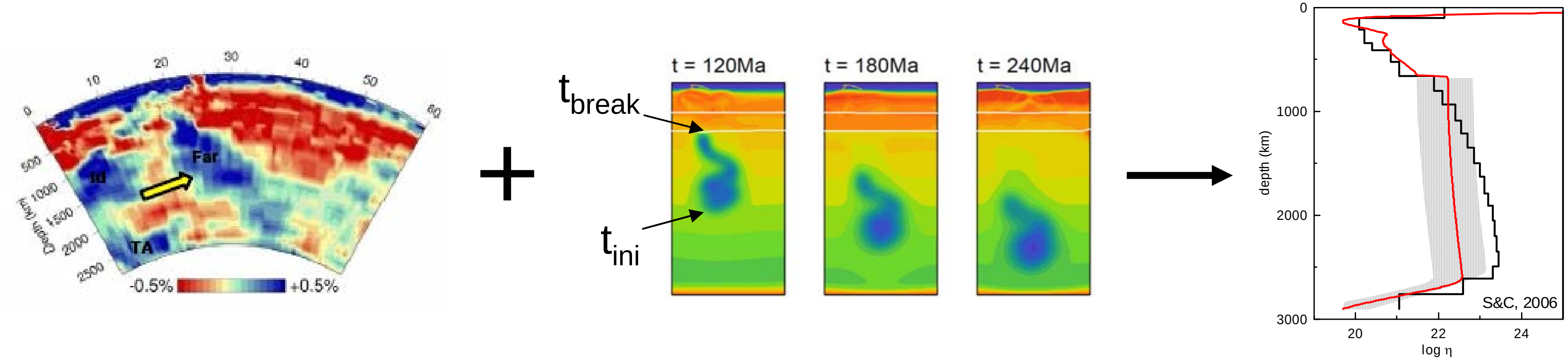
??? FREE PARAMETERS OF RHEOLOGICAL DESCRIPTION ???

Activation parameters, lower mantle viscosity jump

Estimate of the lower mantle viscosity based on sinking speed of detached slabs



MODEL: COMPOSITE RHEOLOGY

Diffusion creep

$$\dot{\varepsilon}_{diff} = A_{diff}\ \sigma\ \exp\left(-\frac{E_{diff} + pV_{diff}}{RT}\right)$$

Dislocation creep

$$\dot{\varepsilon}_{disl} = A_{disl}\ \sigma^{n} \exp\left(-\frac{E_{disl} + pV_{disl}}{RT}\right)$$

Stress limiter

$$\dot{\varepsilon}_{sl} = C_L \left(\frac{\sigma}{\sigma_L}\right)^{n_L}$$

MODEL: RHEOLOGICAL PARAMETERS

Crust
Constant viscosity 10^{20} Pa s

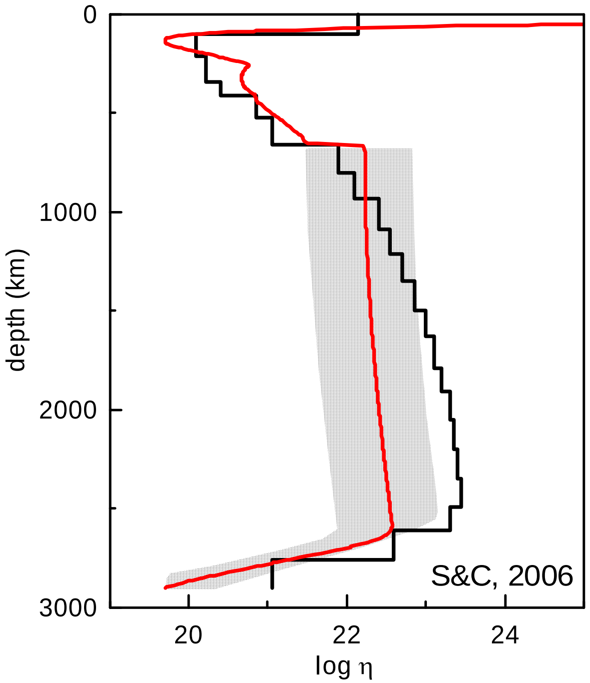
Upper mantle
Activation parameters according to Hirth and Kohlstedt (2003)
Yield stress 0.5 GPa

Lower mantle
Diffusion creep **A**-family $V_{diff} = 1.1 \times 10^{-6}$ m^3 mol^{-1}
B-family $V_{diff} = 2.2 \times 10^{-6}$ m^3 mol^{-1}

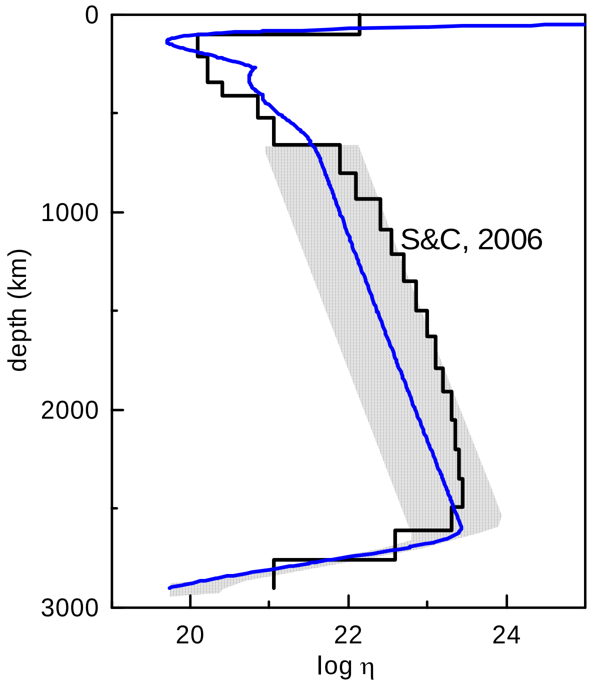
(PPV: $\eta_{PPV} = 10^{21}$ Pa s)

MODEL: VISCOSITY INCREASE AT 660 km

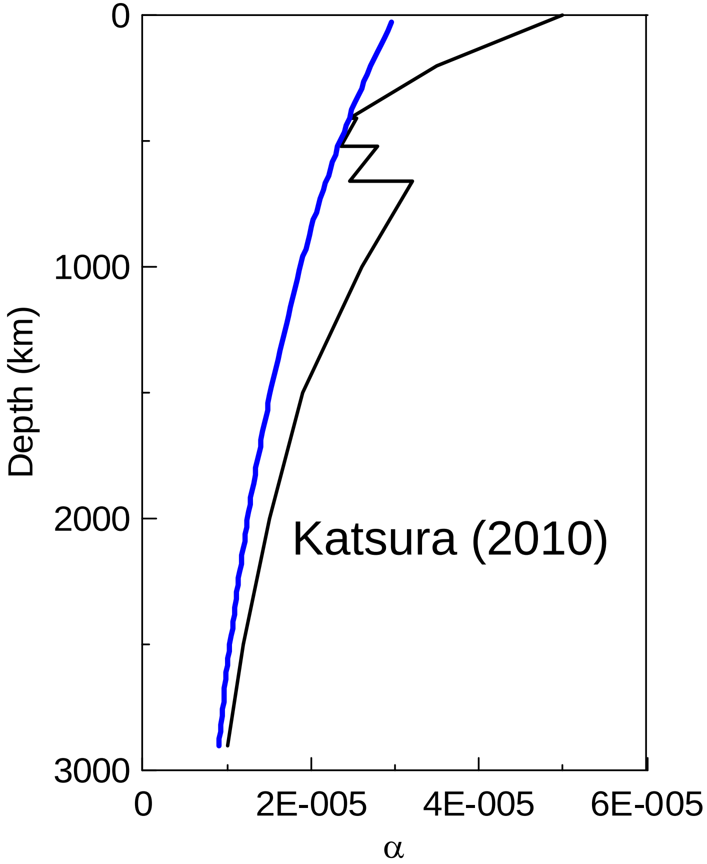
A-family



B-family



MODEL: THERMAL EXPANSIVITY



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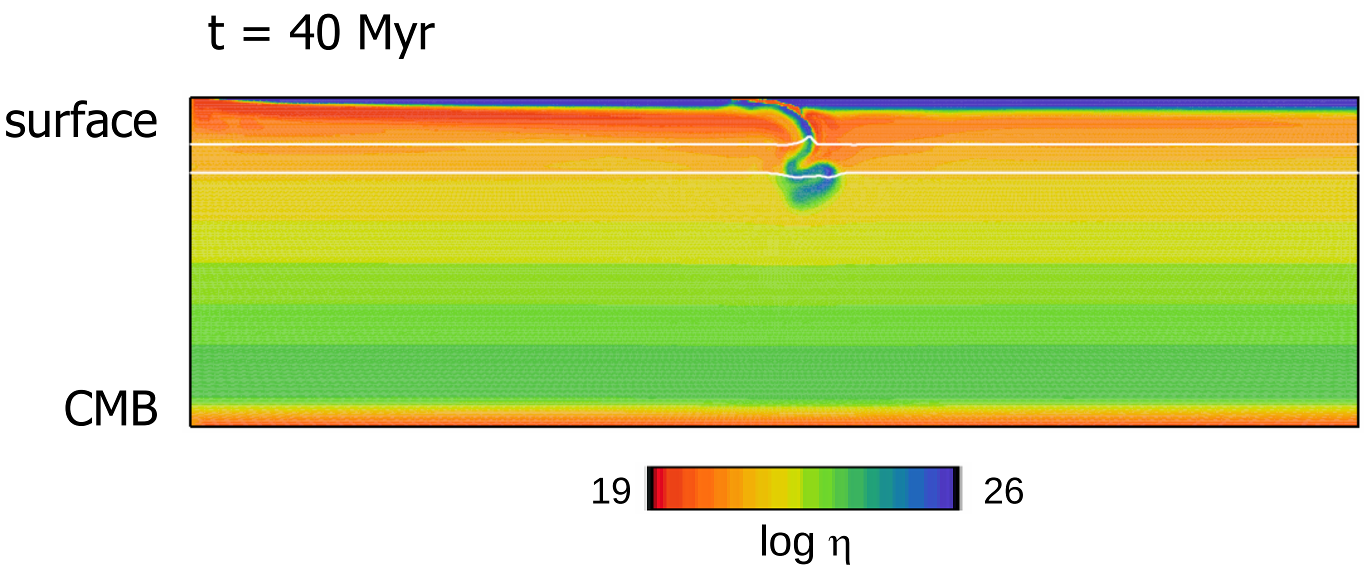
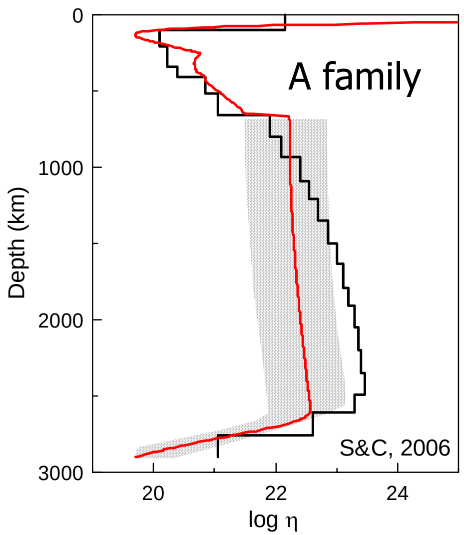
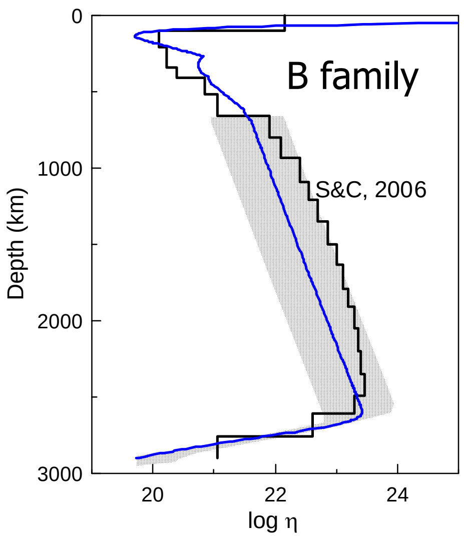
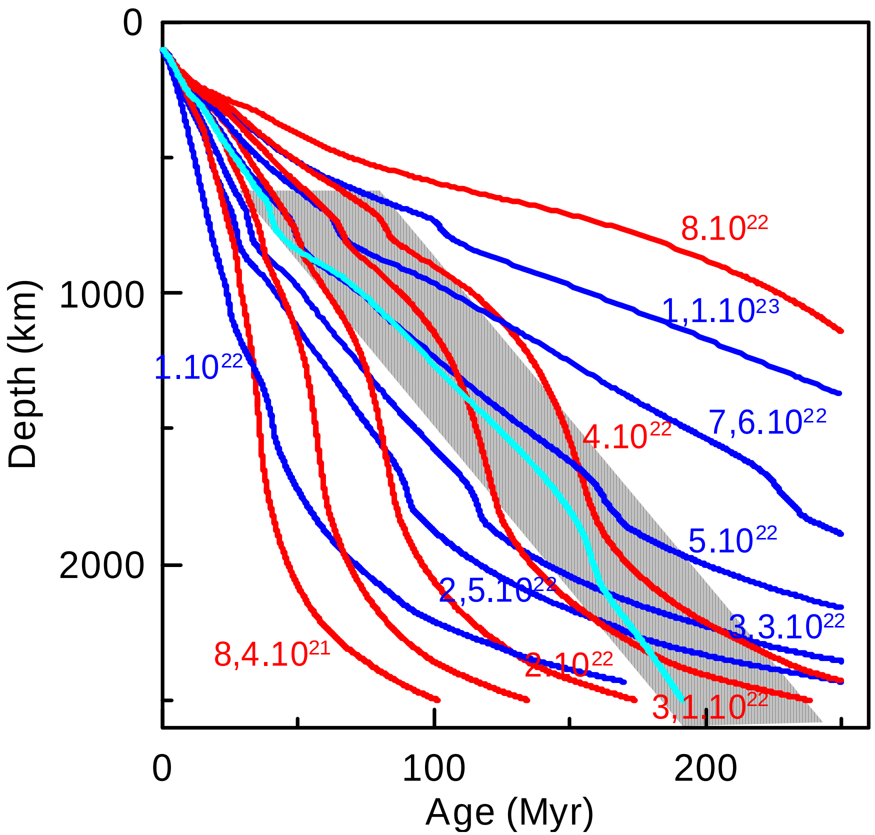


RESULTS:

AGE vs. DEPTH

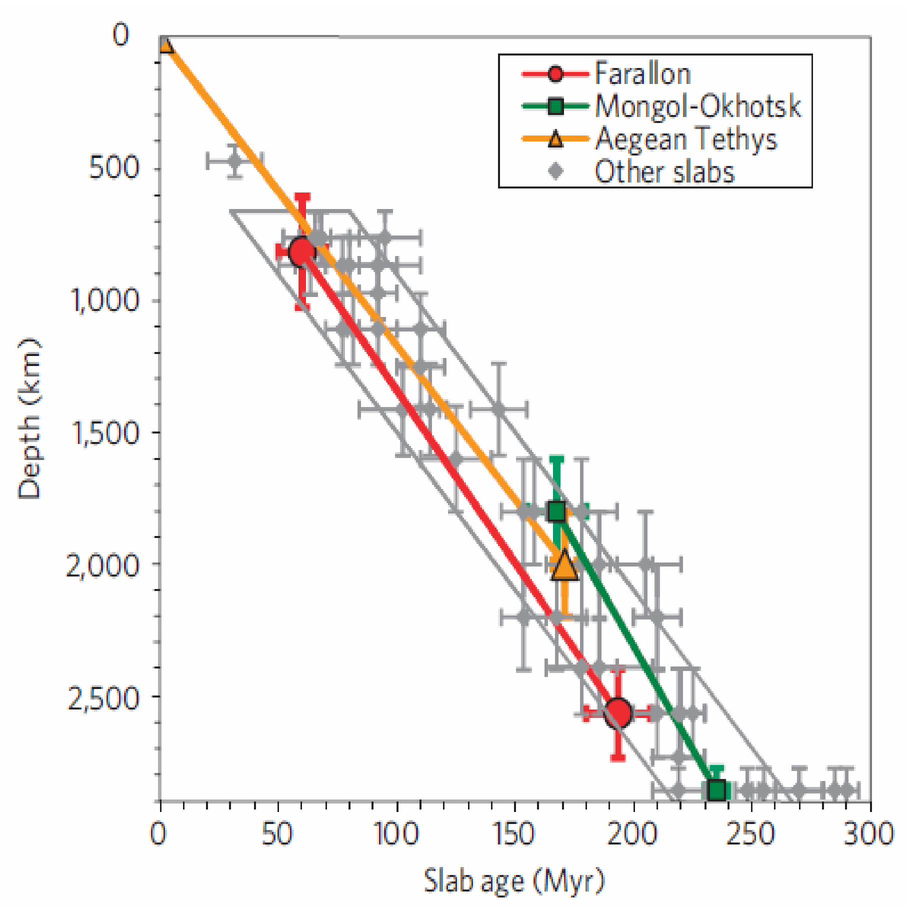




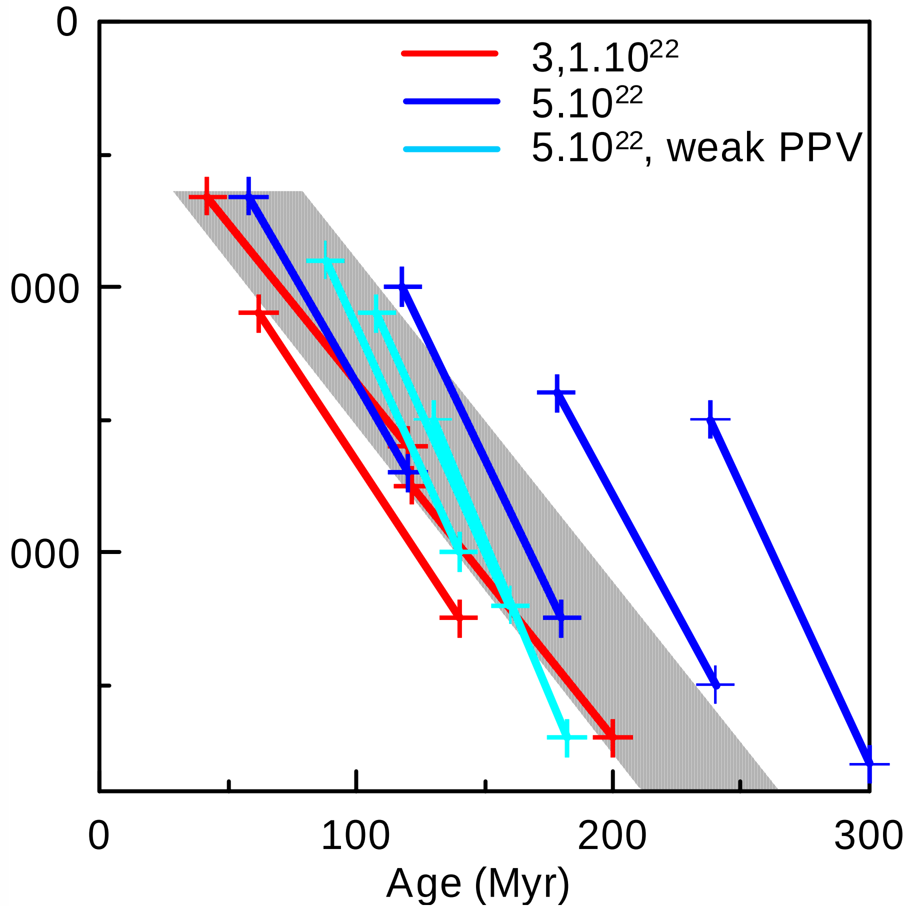


Čížková et al., PEPI 2012

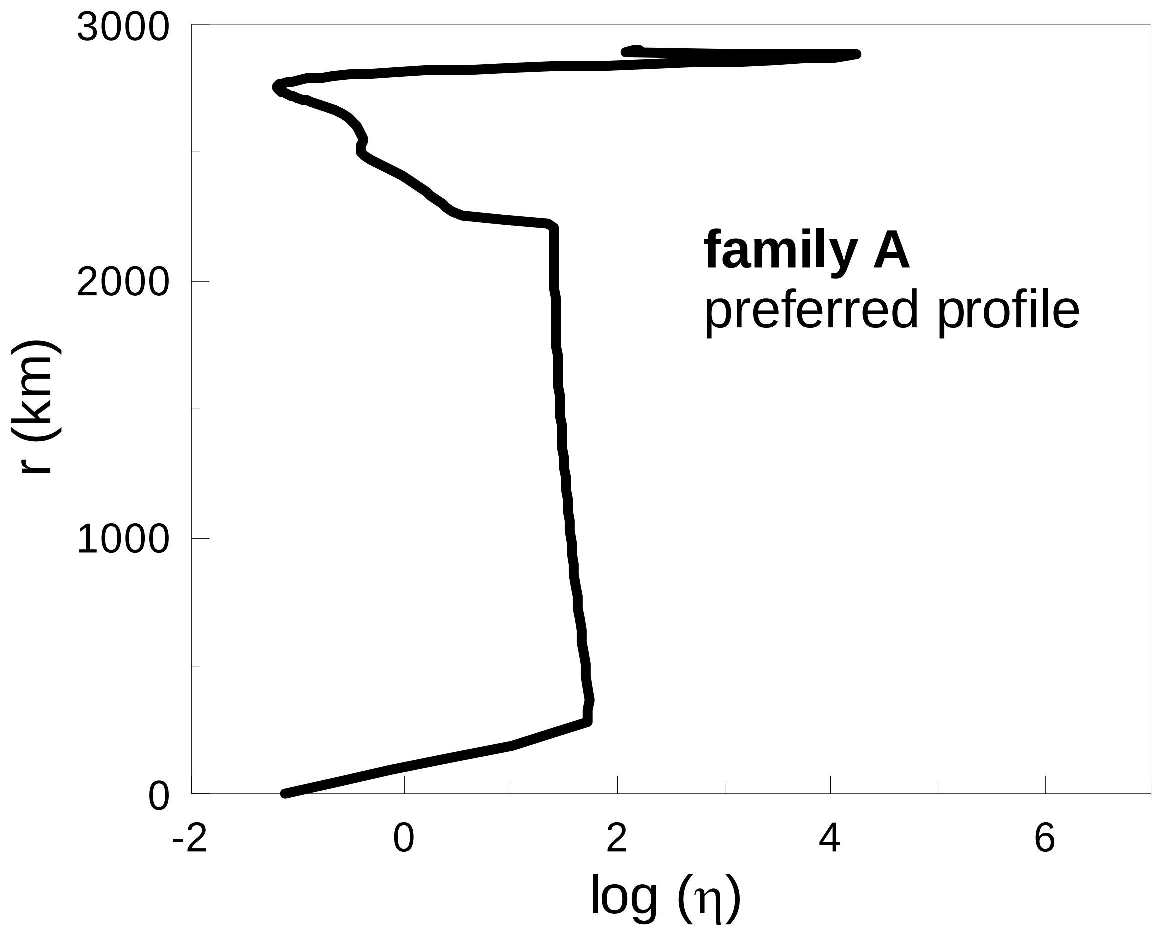
RESULTS: BOTTOM AND TOP OF SLAB REMNANTS



Van der Meer et al. (2010)



Čížková et al., PEPI 2012

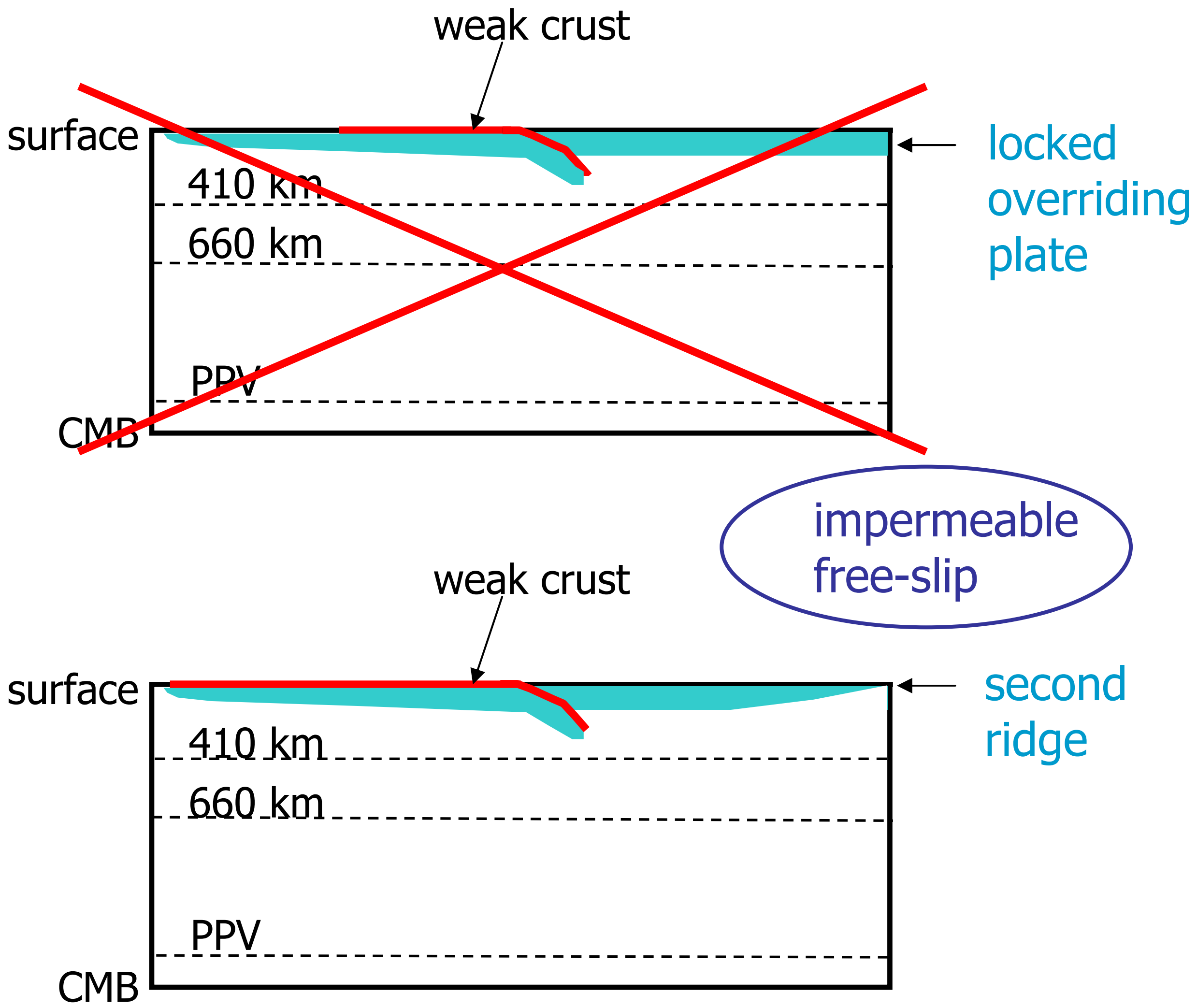


3000
2000
1000
0
r (km)
-2
0
2
4
6
log (η)
family A
preferred profile

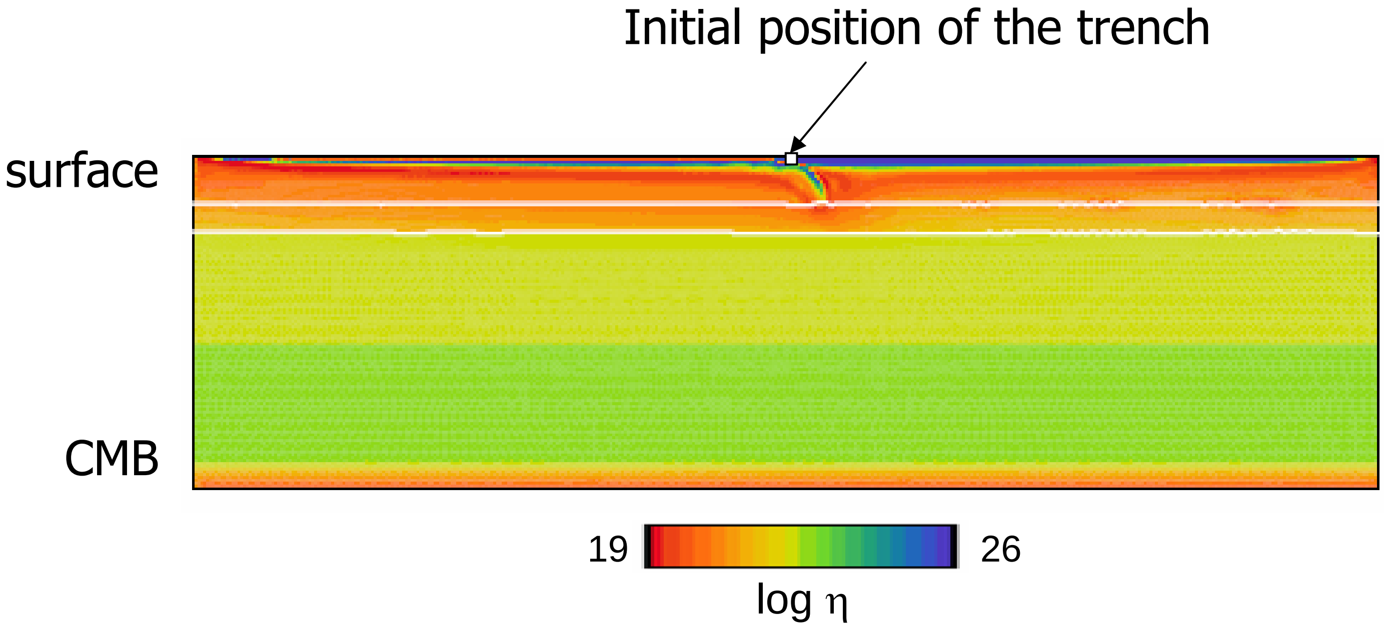
MODEL SETUP – ROLLBACK AND SLAB STAGNATION STUDY

Sinking slabs

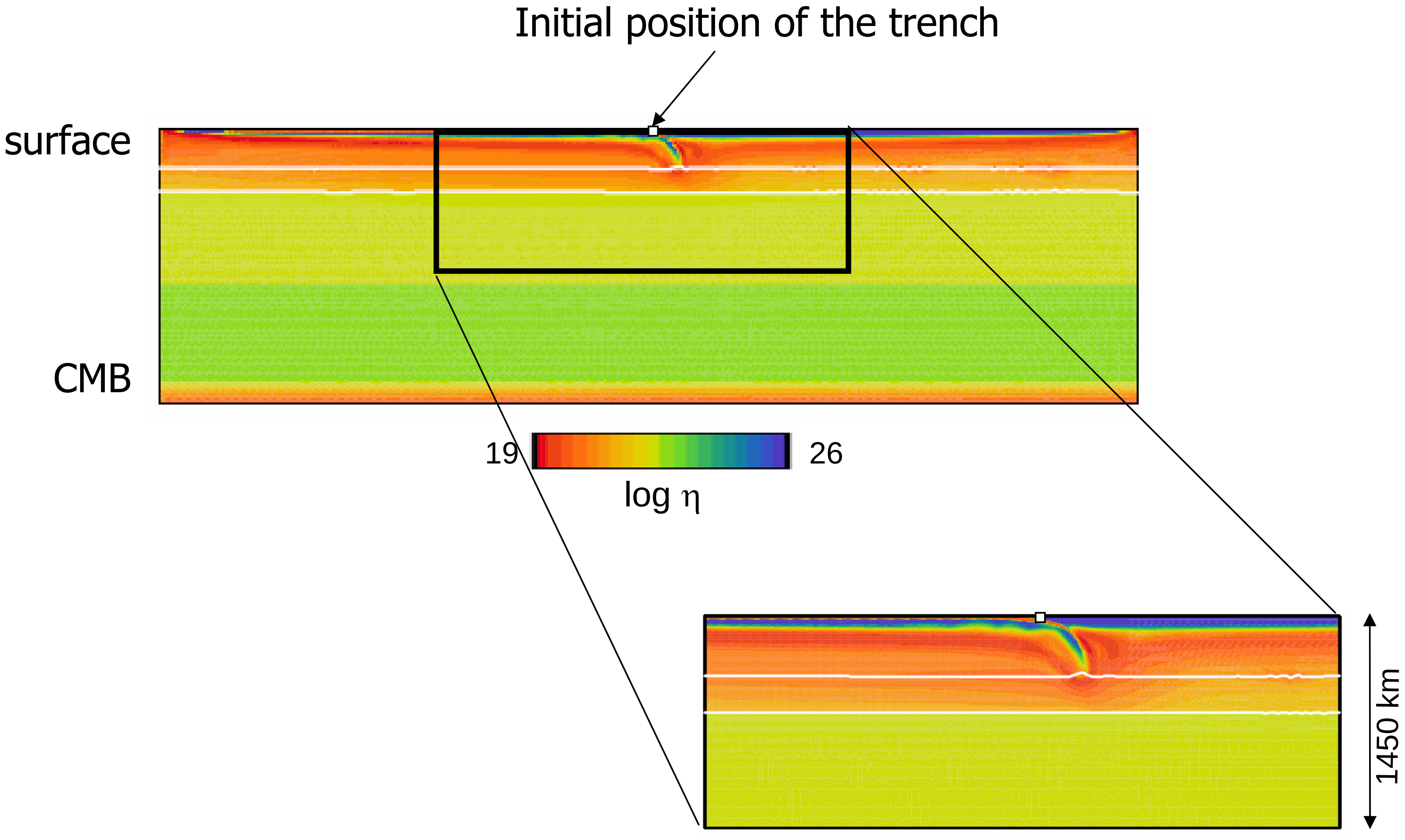
Rollback and stagnation



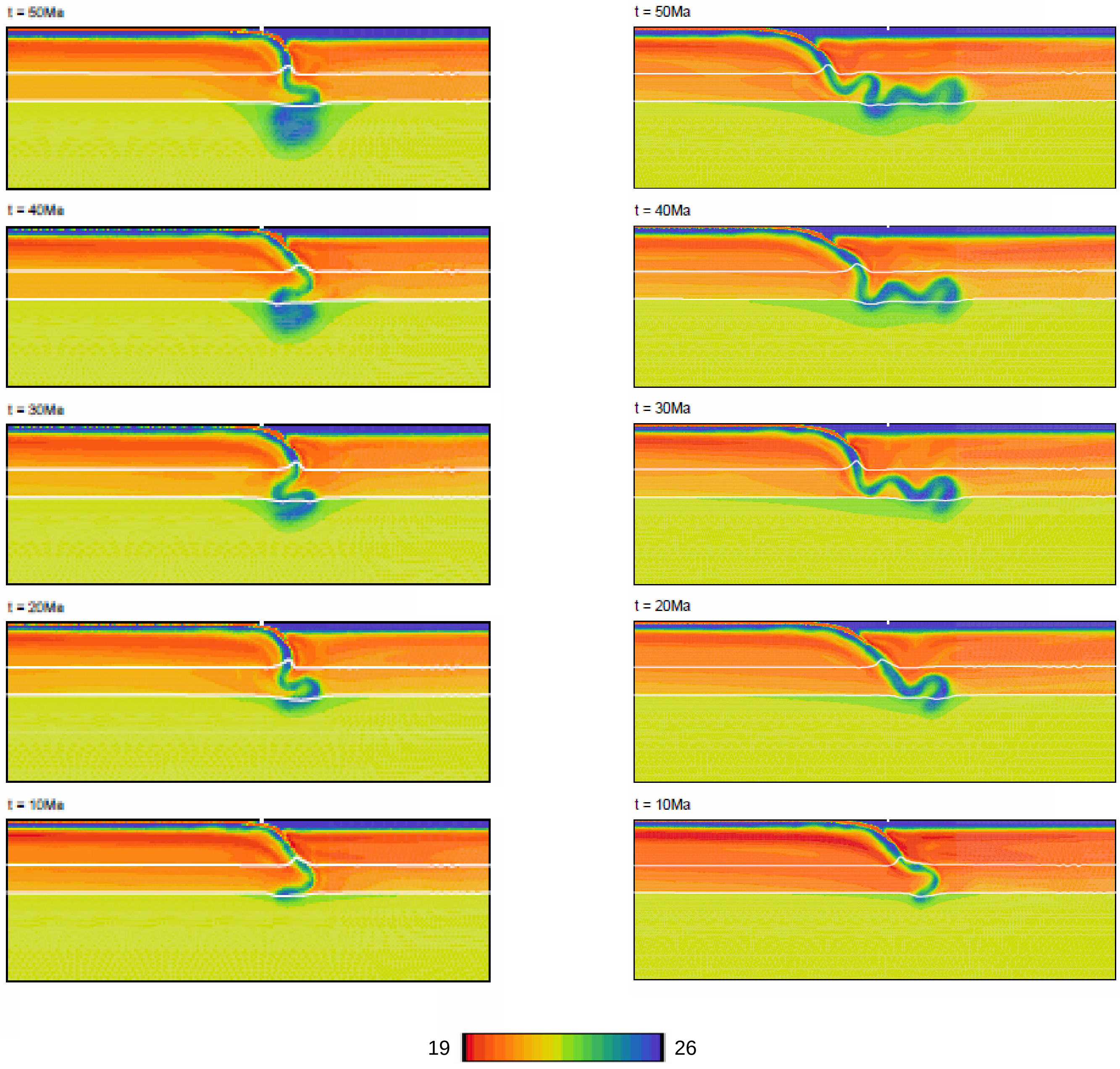
MODEL SETUP – ROLLBACK AND SLAB STAGNATION STUDY



MODEL SETUP – ROLLBACK AND SLAB STAGNATION STUDY



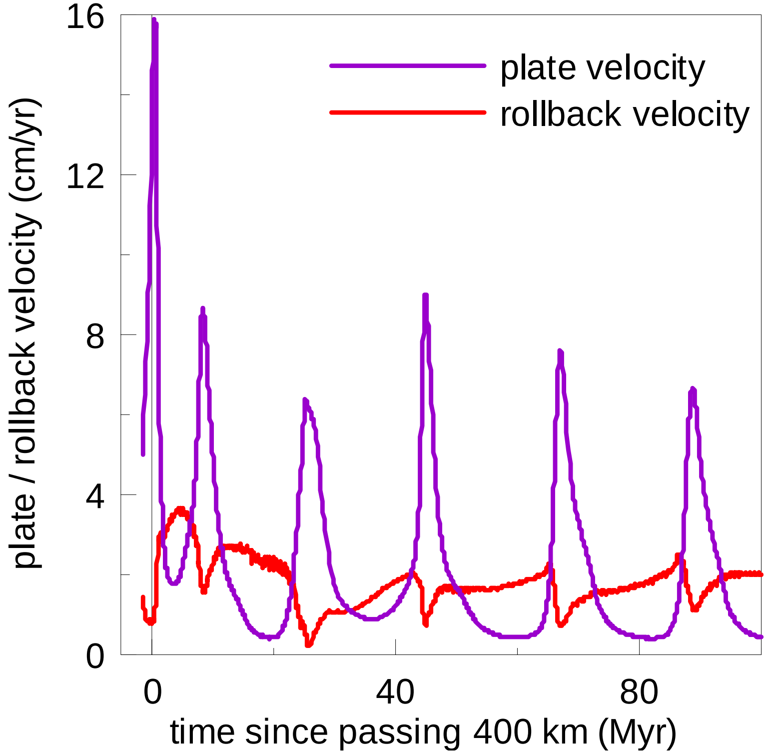
RESULTS

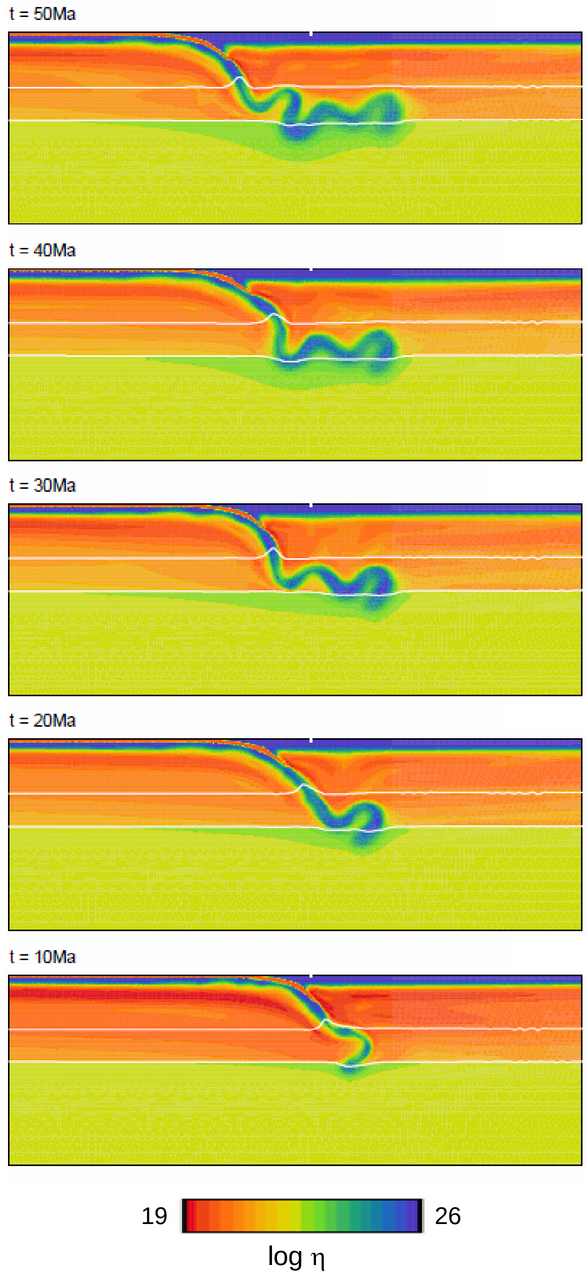


rollback not allowed

rollback

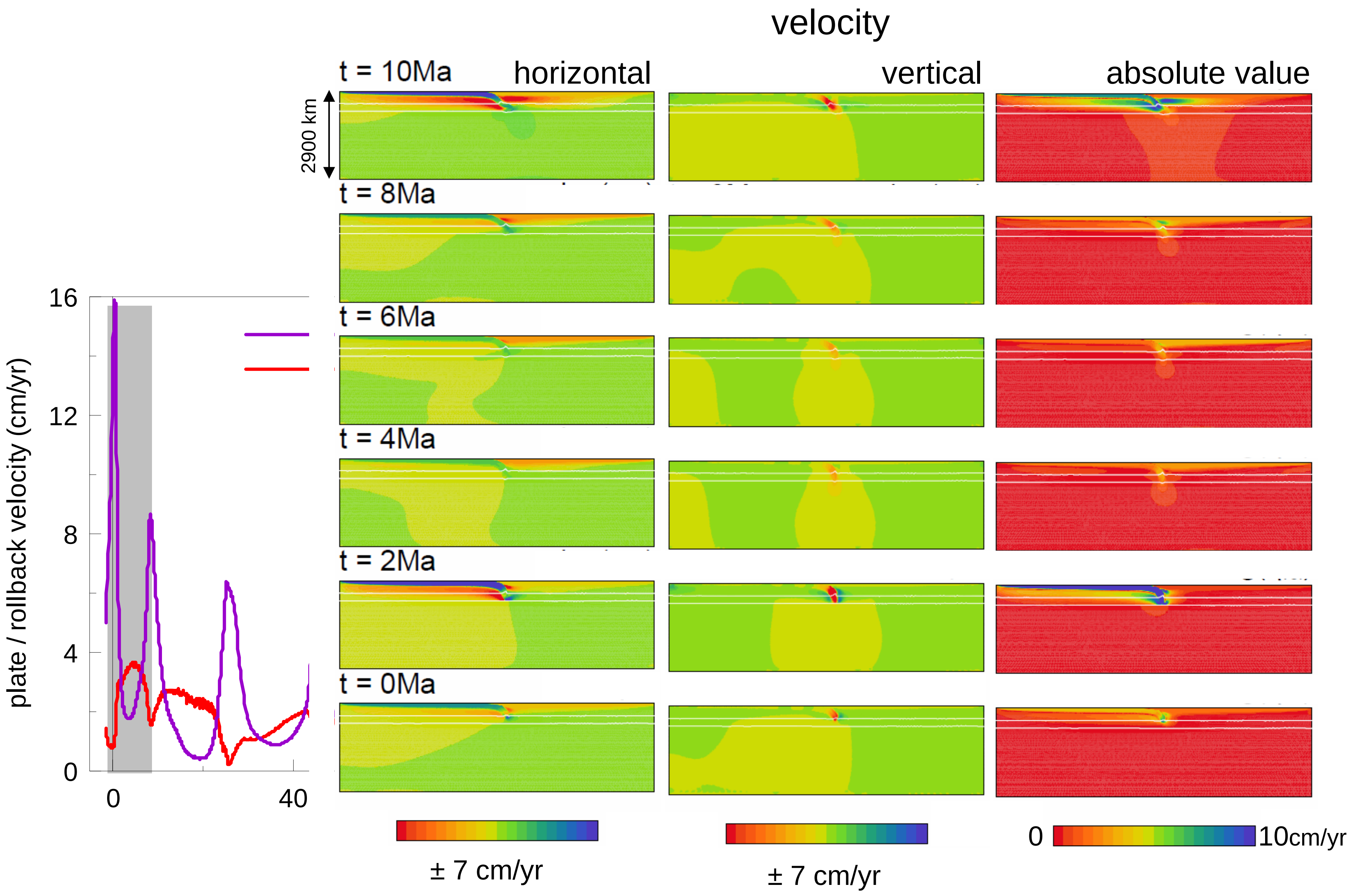
RESULTS



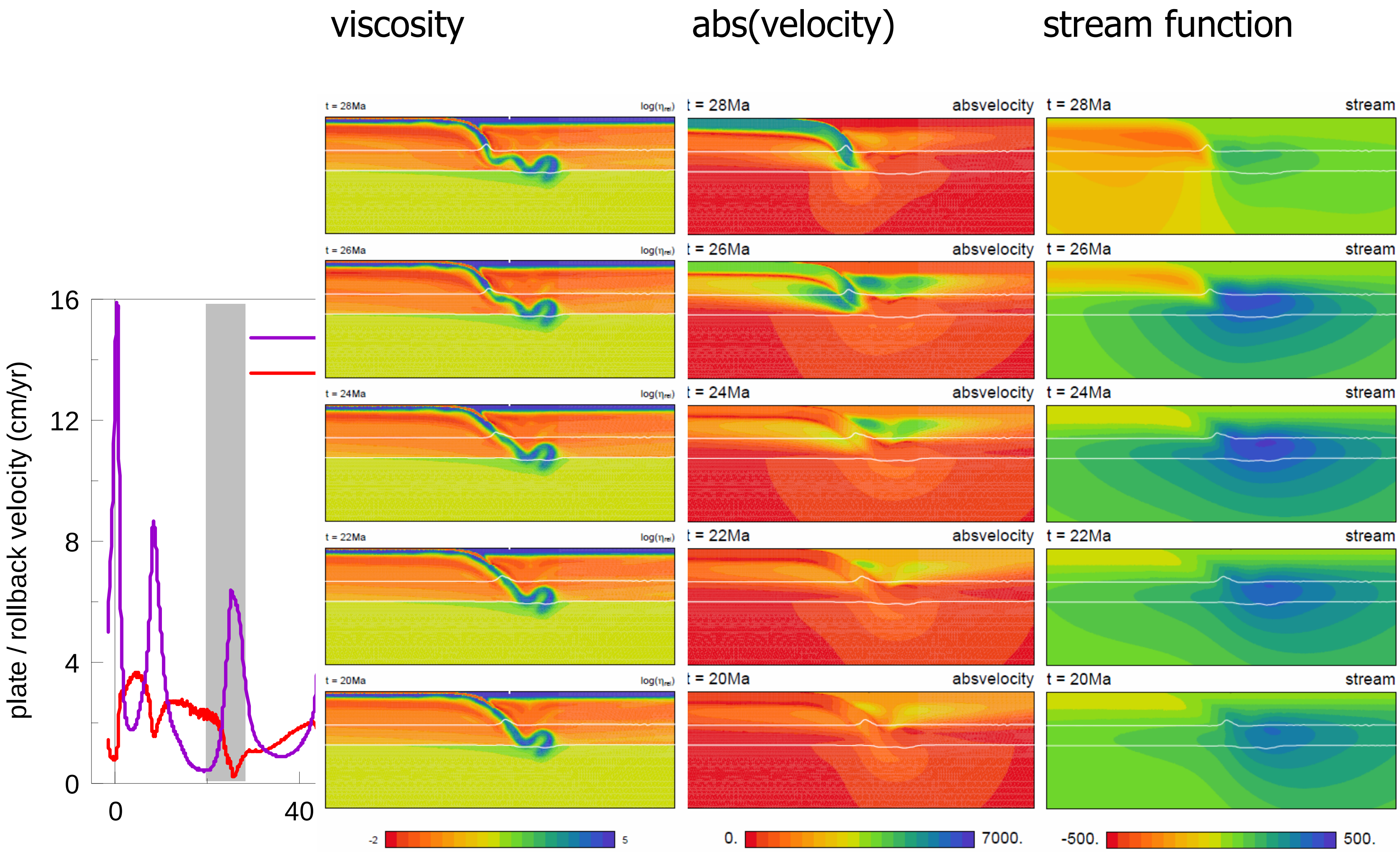


rollback

RESULTS

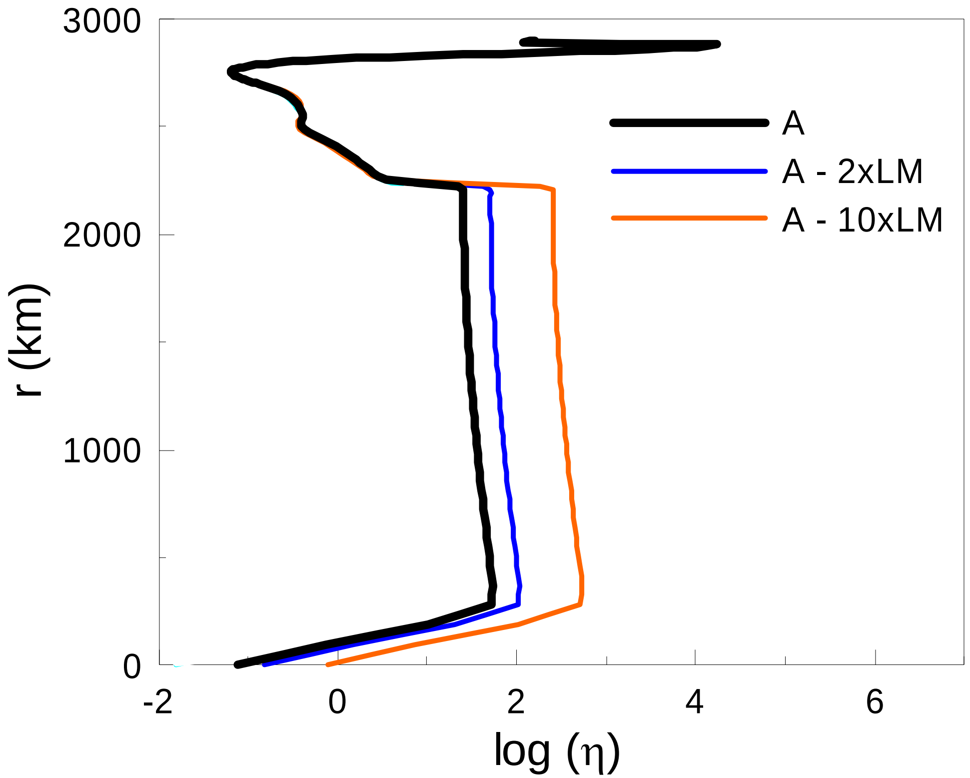

velocity
t = 10Ma
horizontal
vertical
absolute value
2900 km
t = 8Ma
t = 6Ma
t = 4Ma
t = 2Ma
t = 0Ma
± 7 cm/yr
± 7 cm/yr
0
10cm/yr
plate / rollback velocity (cm/yr)
16
12
8
4
0
0
40

RESULTS



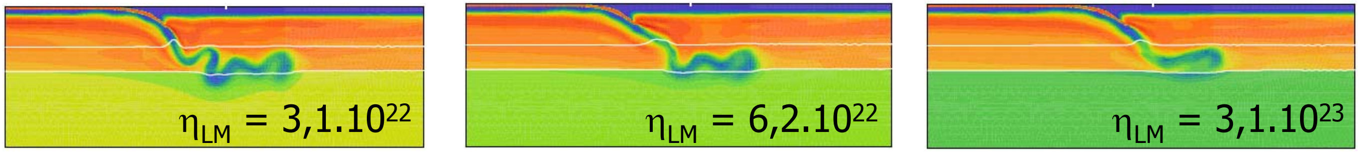
viscosity
abs(velocity)
stream function
plate / rollback velocity (cm/yr)
16
12
8
4
0
0
40
t = 28Ma
log(η_re)
t = 28Ma
absvelocity
t = 28Ma
stream
t = 26Ma
t = 26Ma
t = 26Ma
t = 24Ma
t = 24Ma
t = 24Ma
t = 22Ma
t = 22Ma
t = 22Ma
t = 20Ma
t = 20Ma
t = 20Ma
-2
5
0.
7000.
-500.
500.

RESULTS: EFFECT OF THE LOWER MANTLE VISCOSITY

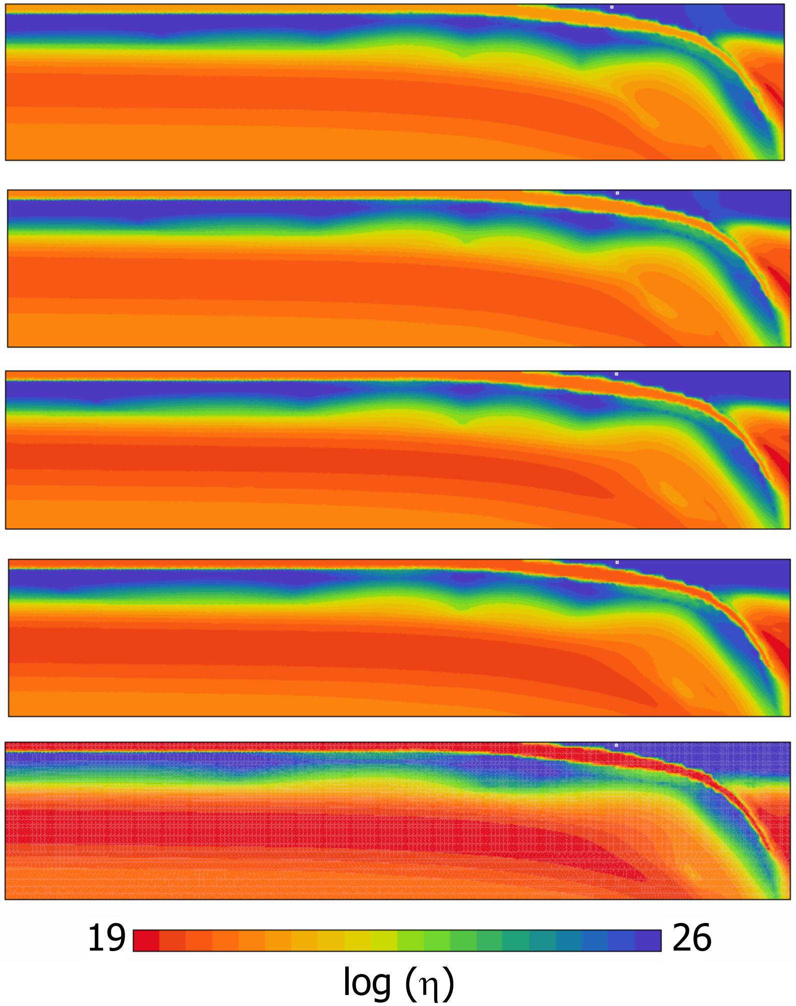


RESULTS – snapshot after 50 Myr

Effect of the lower mantle viscosity



RESULTS: EFFECT OF THE CRUSTAL VISCOSITY



η_{crust} = 10^{21} Pas

η_{crust} = 5.10^{20} Pas

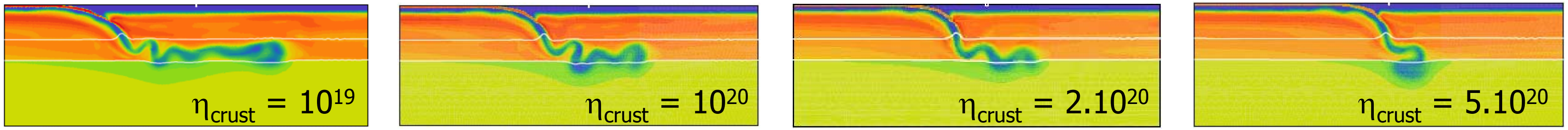
η_{crust} = 2.10^{20} Pas

η_{crust} = 10^{20} Pas

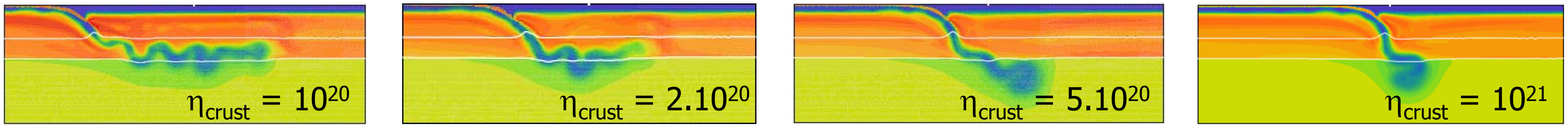
η_{crust} = 10^{19} Pas

RESULTS – snapshot after 50 Myr

Effect of the crustal viscosity



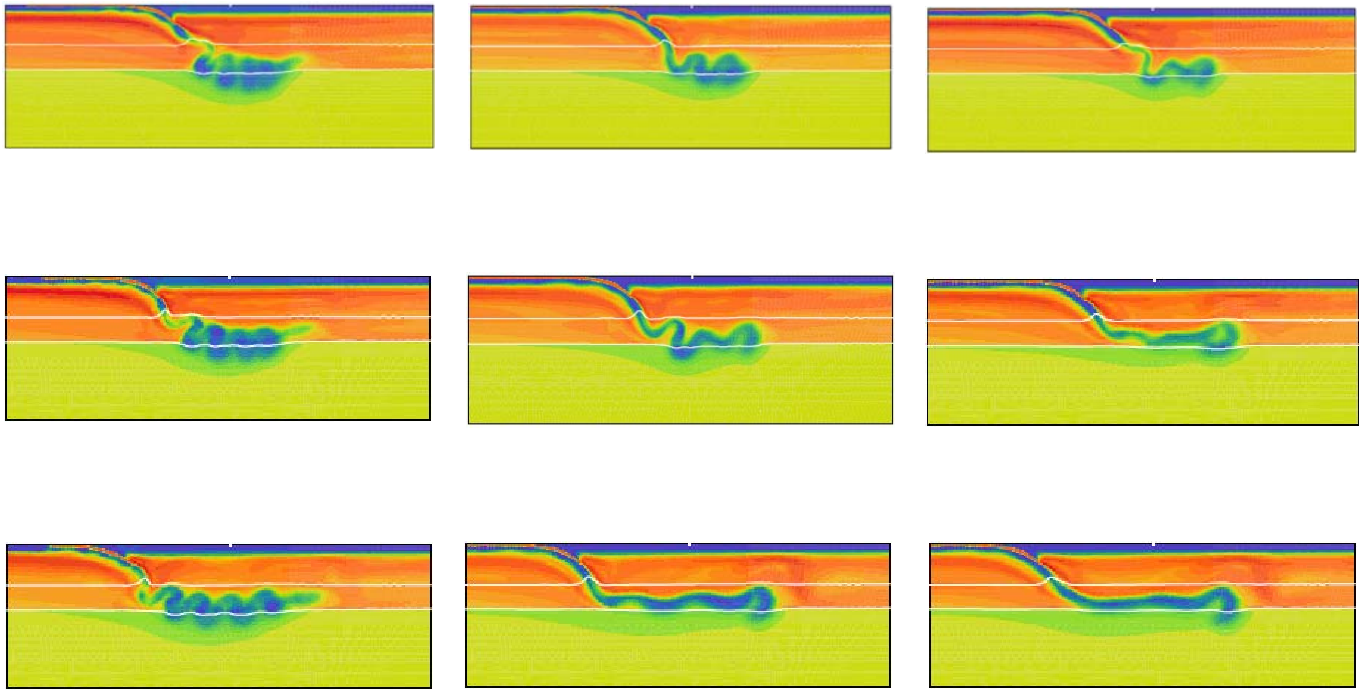
snapshot after 90 Myr



penetrating slabs

RESULTS – snapshot after 50 Myr

Effect of the yield stress



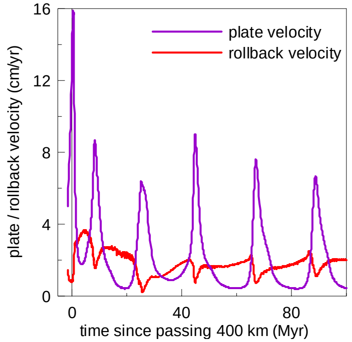
age 70 Myr

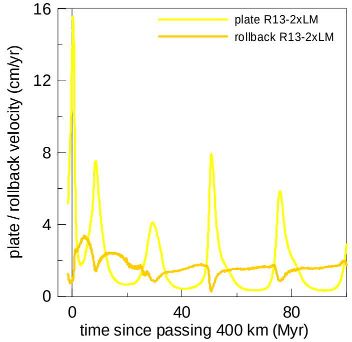
age 100 Myr

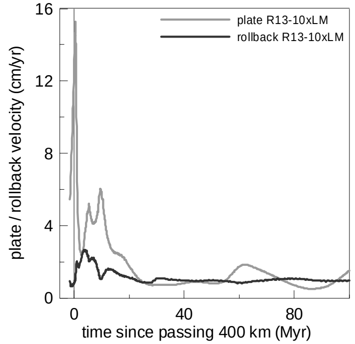
age 150 Myr

$\sigma_y = 2.10^8$ $\sigma_y = 5.10^8$ $\sigma_y = 10^9$

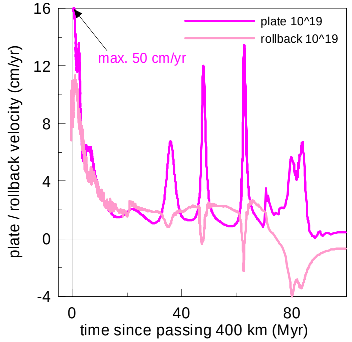
RESULTS – plate and rollback velocities

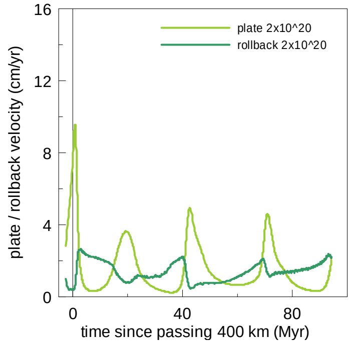


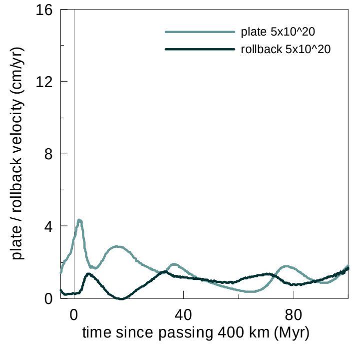


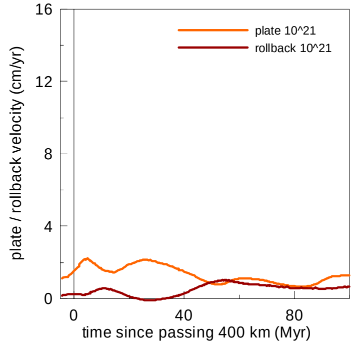


lower mantle viscosity

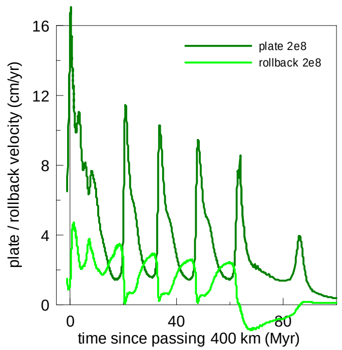


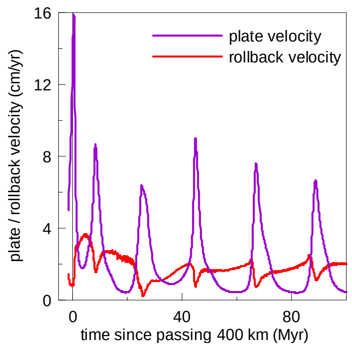


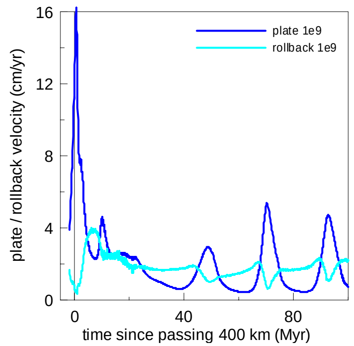




crust viscosity



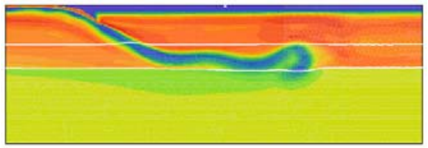




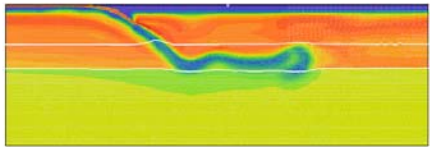
yield stress

RESULTS – snapshot after 50 Myr

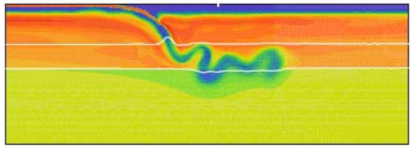
Effect of the Clapeyron slope



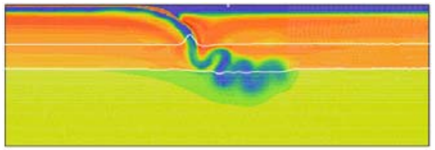
γ_{410} = 1 MPa/K



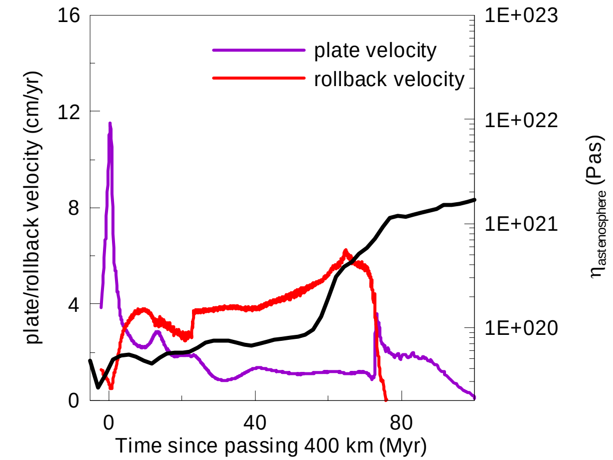
γ_{410} = 2 MPa/K

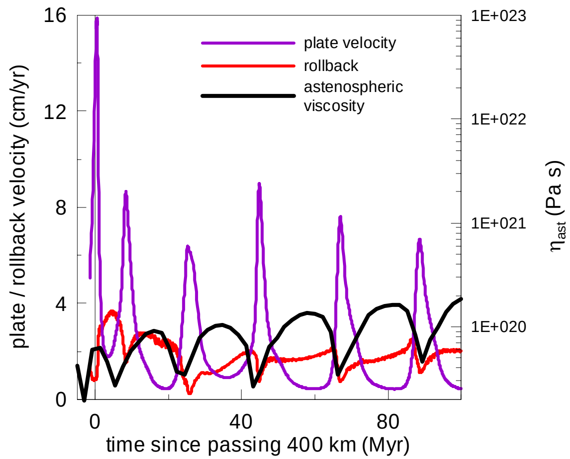


γ_{410} = 3 MPa/K



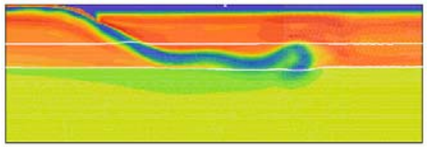
γ_{410} = 4MPa/K



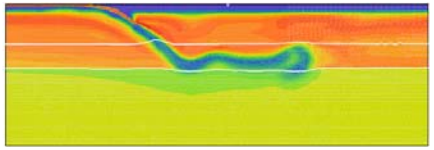


RESULTS – snapshot after 50 Myr

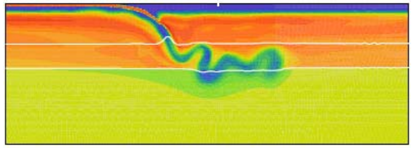
Effect of the Clapeyron slope



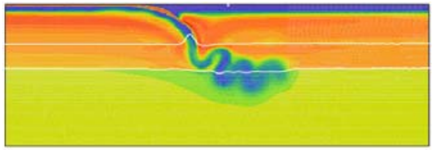
γ_{410} = 1 MPa/K



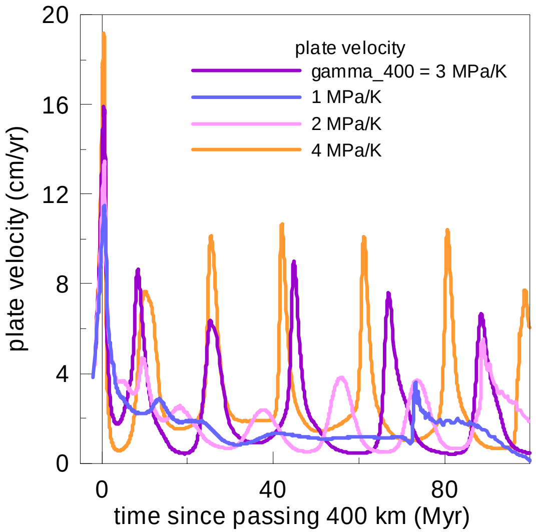
γ_{410} = 2 MPa/K

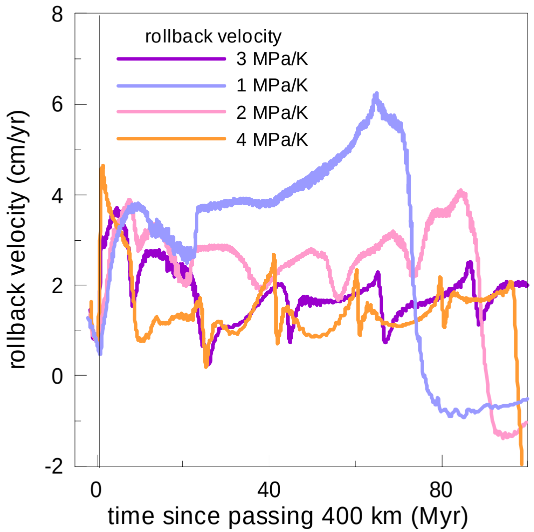


γ_{410} = 3 MPa/K

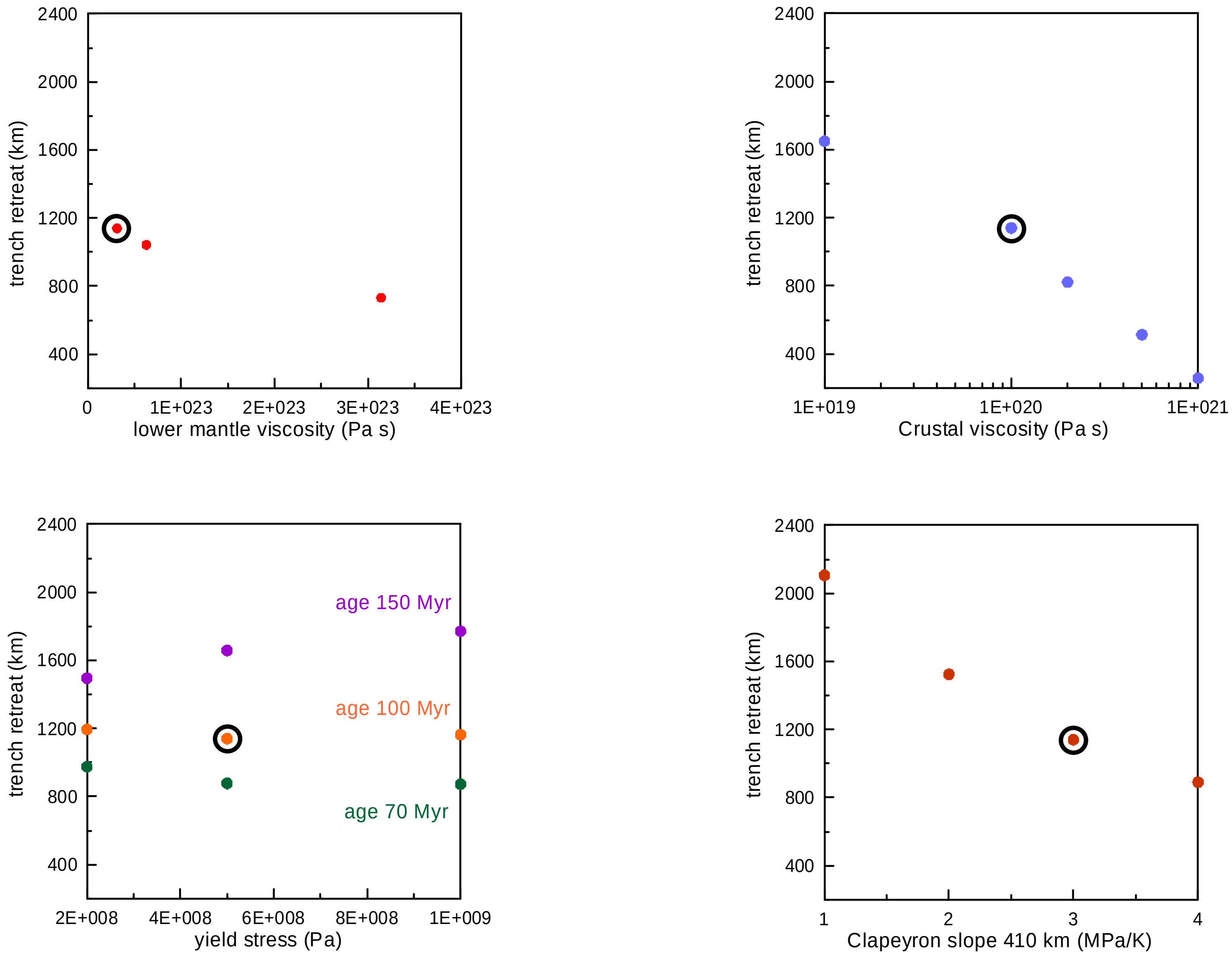


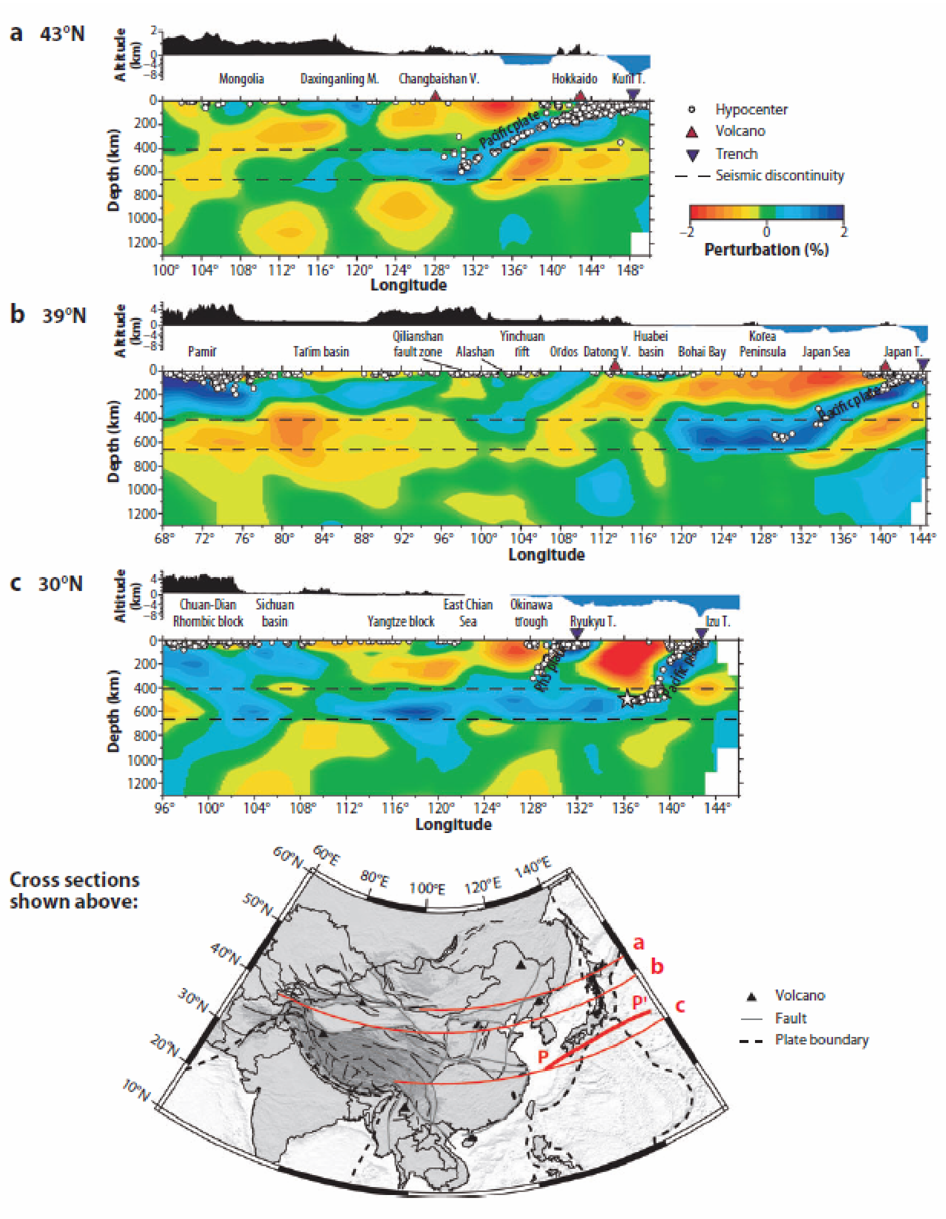
γ_{410} = 4MPa/K



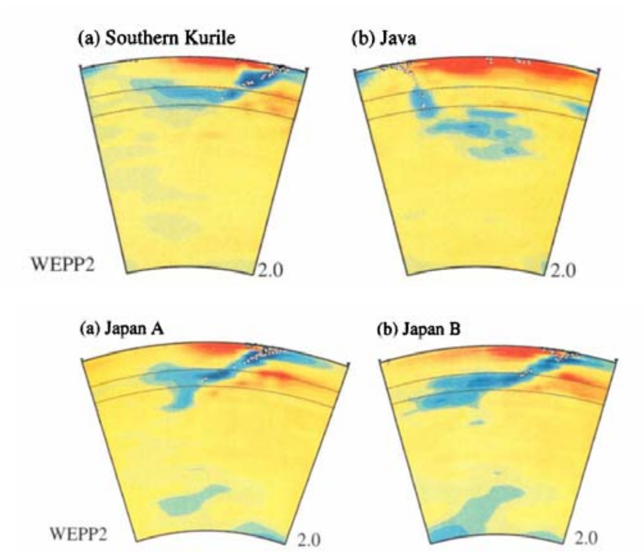


RESULTS – trench distance after 60 Myr

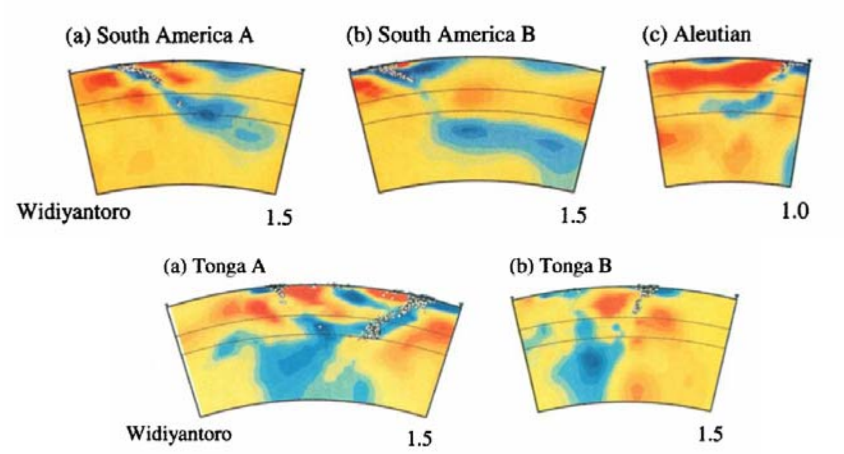




Huang and Zhao, 2006



Obayashi et al., 1997



Widiyantoro, 1997

CONCLUSIONS – SLAB STAGNATION AND ROLLBACK

- all modes display rollback (effect of ridge push?)
- relation between plate velocity and rollback
- most models predict slab stagnation in the transition zone
- slow slabs (due to higher friction on the contact) have slower rollback and penetrate to the lower mantle – effect of higher astenospheric viscosity?
- more negatively buoyant slabs have faster rollback
- stiffer slabs have faster rollback (no reduction due to the periods of increased subduction velocity)
- implications of rollback periodicity to exhumation