Subducted material at the bottom of the mantle

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1. Original motivation: - PPV observed in the lower mantle in paleoslab areas
- presumably weak

What may be the dynamic consequences?

2. Realistic model to study weak/strong PPV implications for slab dynamics

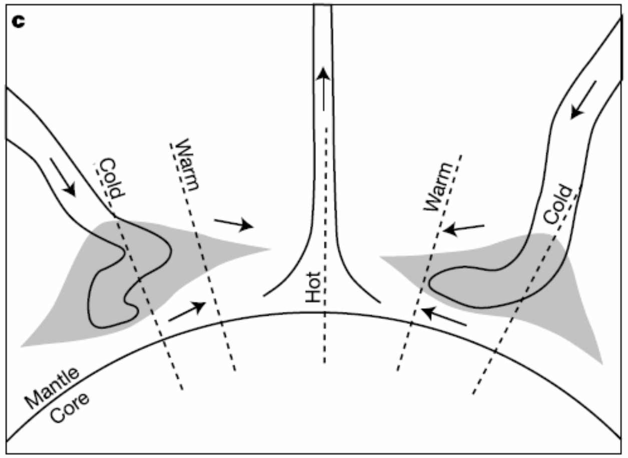
BUT

'realistic' expansivity does not allow for PPV formation

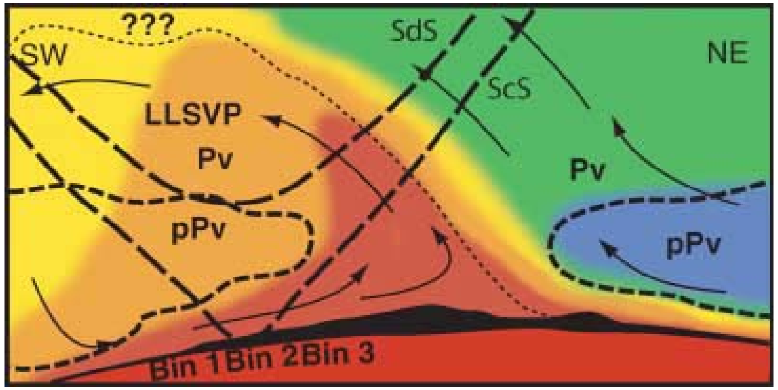
↓

3. Lower mantle slab deformation scenarios regardless PPV (comparison with subduction reconstructions)

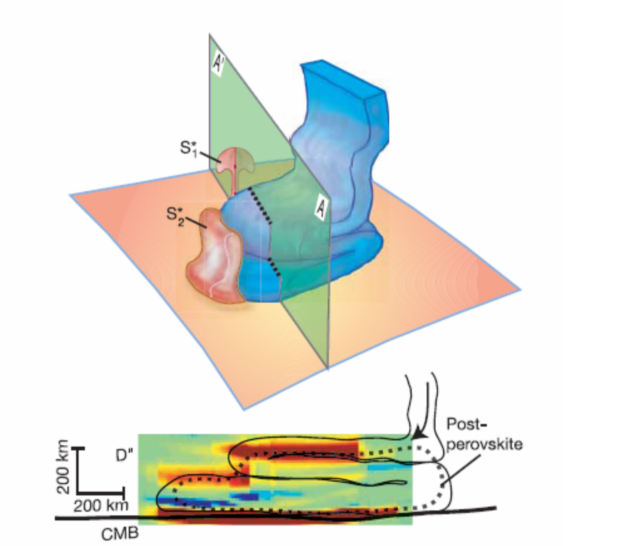
PPV: OBSERVATIONS



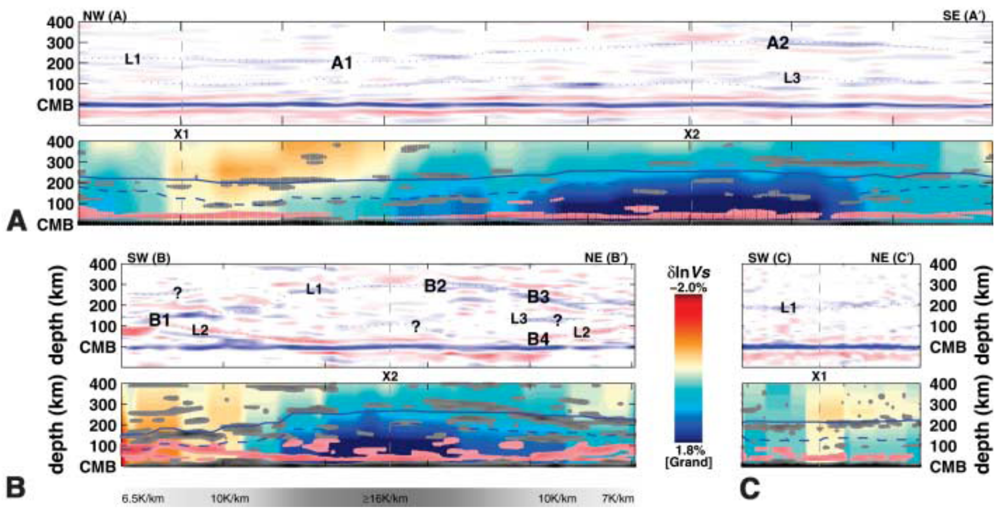
Hernlund et al., Nature 2005



Lay et al., Science 2006

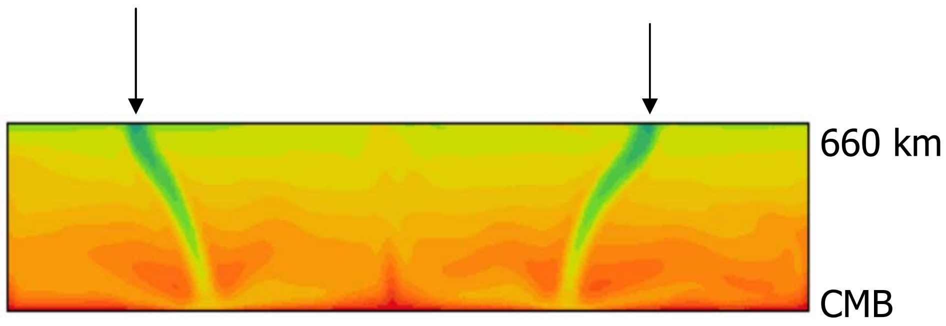


Hutko et al., Nature 2006



Van der Hilst et al., Science 2007

HOW DOES PPV RHEOLOGY INFLUENCE THE SLAB DEFORMATION AND D” DYNAMICS WITHIN THE COMPOSITE RHEOLOGICAL MODEL?



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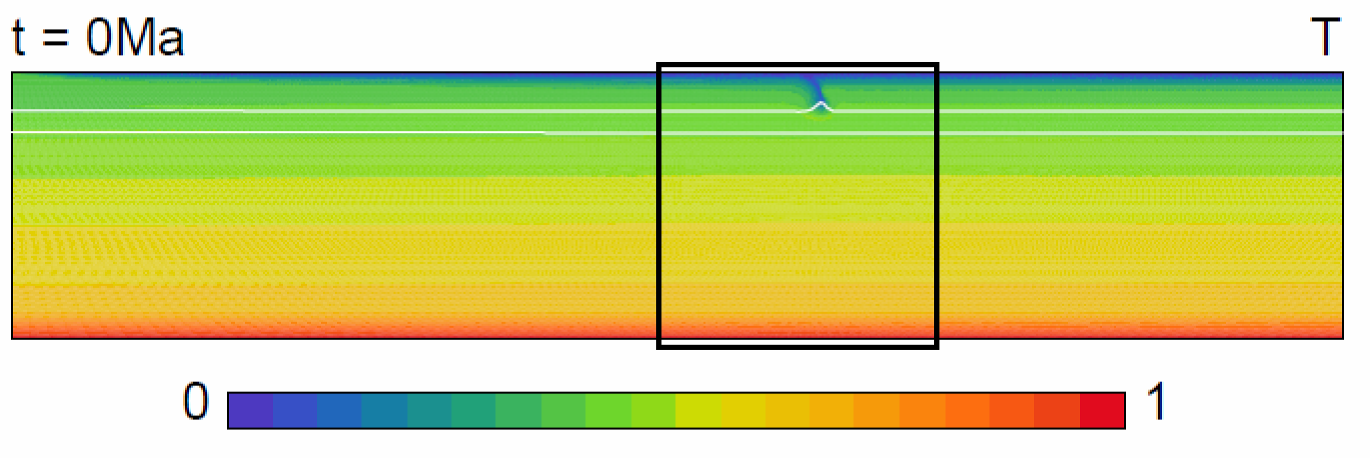

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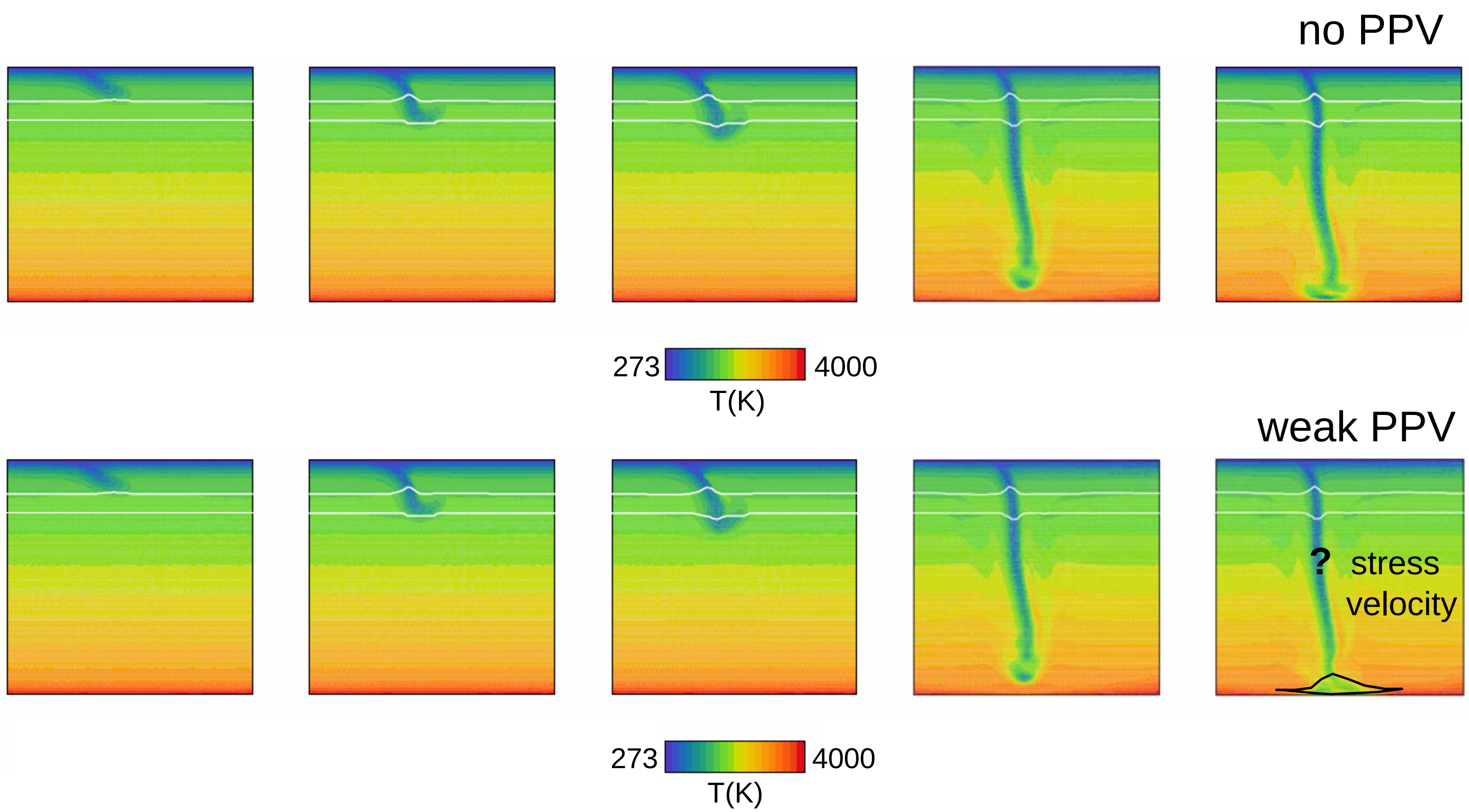
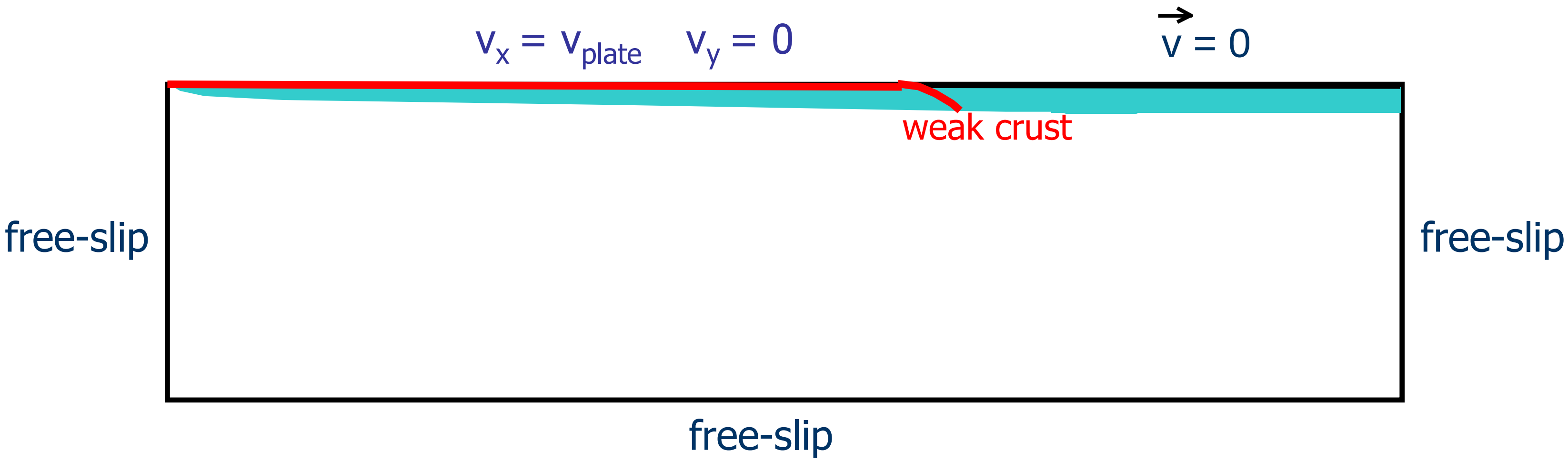


HOW DOES PPV RHEOLOGY INFLUENCE THE SLAB DEFORMATION AND D” DYNAMICS WITHIN THE COMPOSITE RHEOLOGICAL MODEL?

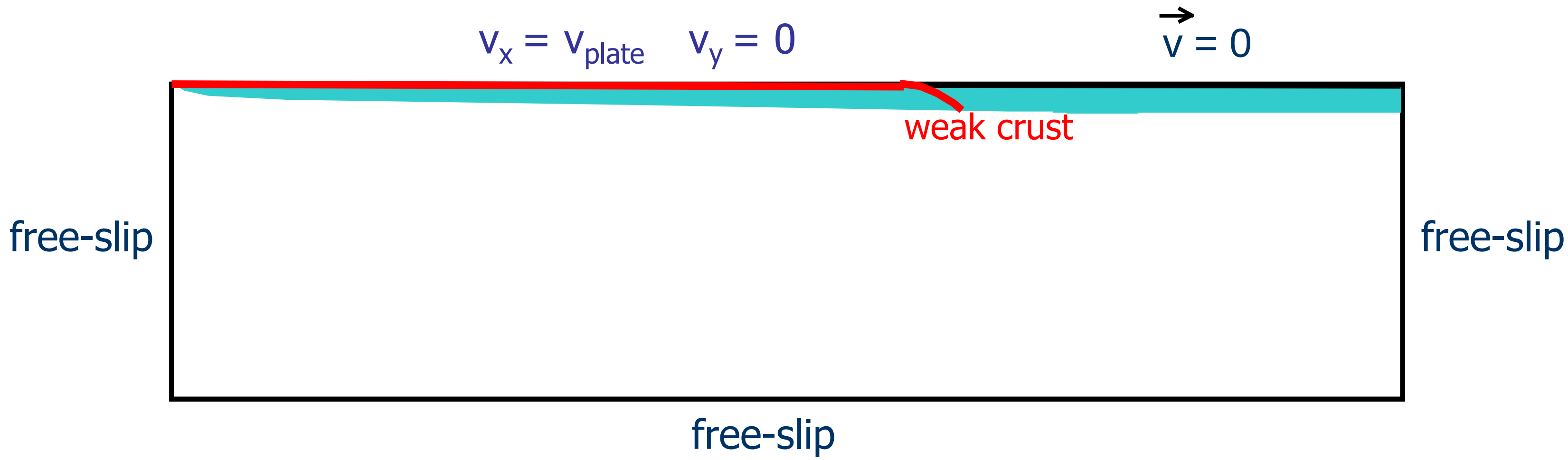
MODEL

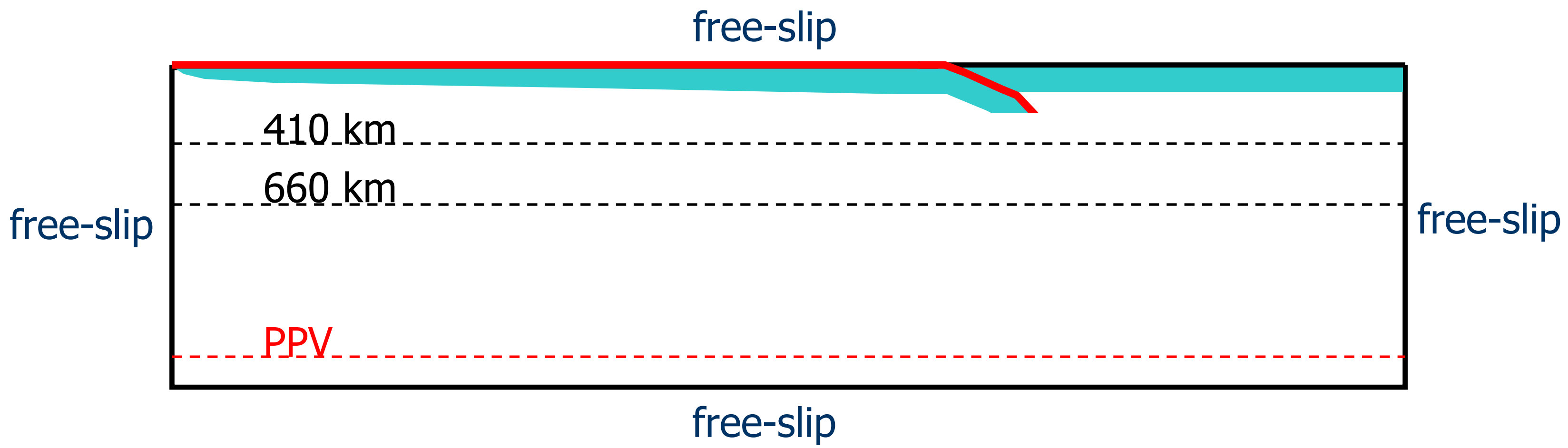
- 2D Cartesian box
- incompressible, extended Boussinesq
- viscous composite rheological model
- finite element code SEPRAN (Segal & Praagman, 2005)

MODEL DOMAIN



MODEL DOMAIN





RHEOLOGY

viscous model: $\dot{\varepsilon} = \dot{\varepsilon}_{diff} + \dot{\varepsilon}_{disl} + \dot{\varepsilon}_{P}$

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

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

Peierls creep $\dot{\varepsilon}_{P} = A_{P}\ \exp\left[-\frac{H}{RT}\left(1 - \frac{\sigma}{\sigma_{P}} \right)^{q} \right]$

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power-law stress limiter

Van Hunen et al., EPSL 2004

RHEOLOGY

viscous model: $\dot{\varepsilon} = \dot{\varepsilon}_{diff} + \dot{\varepsilon}_{disl} + \dot{\varepsilon}_{P}$

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

power-law stress limiter $\dot{\varepsilon}_{sl} = C_L \left(\frac{\sigma}{\sigma_L}\right)^{n_L}$

stress in the model can not exceed prescribed value of the yield stress (σ_L)

CREEP PARAMETERS

UPPER MANTLE

$A_{diff} = 1.0x10^{-10}\ Pa^{-1}\ s^{-1}$ | $A_{disl} = 1.13x10^{-17}\ Pa^{-1}\ s^{-1}$

$E_{diff} = 3.35x10^{5}\ J\ mol^{-1}$ | $E_{disl} = 4.8x10^{5}\ J\ mol^{-1}$

$V_{diff} = 4.8x10^{-6}\ m^{3}\ mol^{-1}$ | $V_{disl} = 11x10^{-6}\ m^{3}\ mol^{-1}$

based on
Hirth and Kohlstedt (2003)

LOWER MANTLE

$A_{diff} = 9.25x10^{-16}\ Pa^{-1}\ s^{-1}$

$E_{diff} = 2.0x10^{5}\ J\ mol^{-1}$

$V_{diff} = 2.5x10^{-6}\ m^{3}\ mol^{-1}$

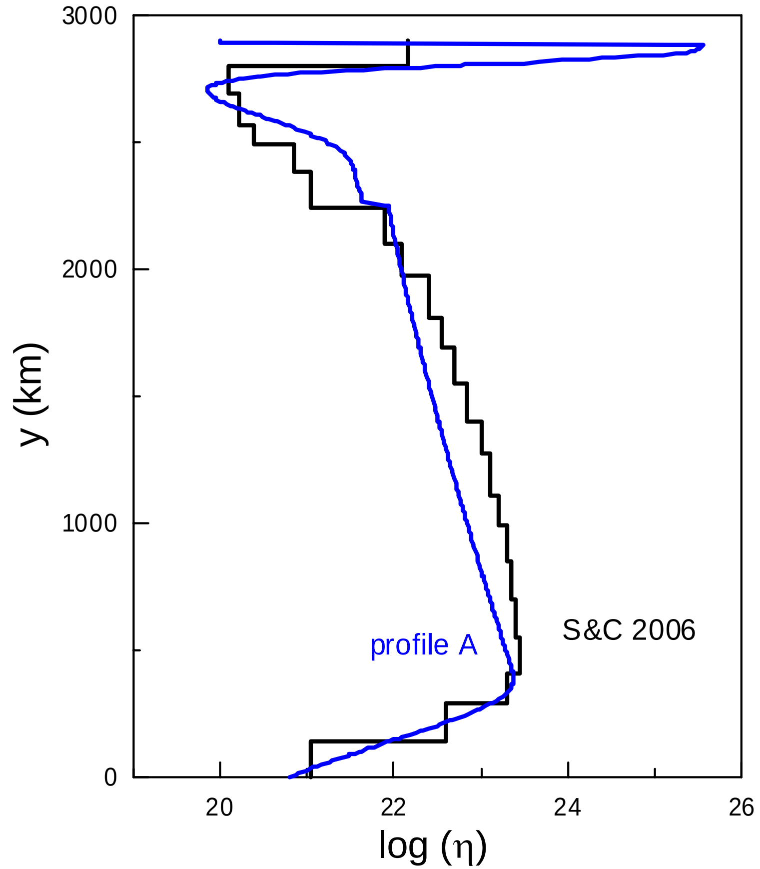
based on
Yamazaki and Karato (2001)

+ power-law stress limiter with the yield stress $\sigma_L = 10^8$ Pa – 10^9 Pa

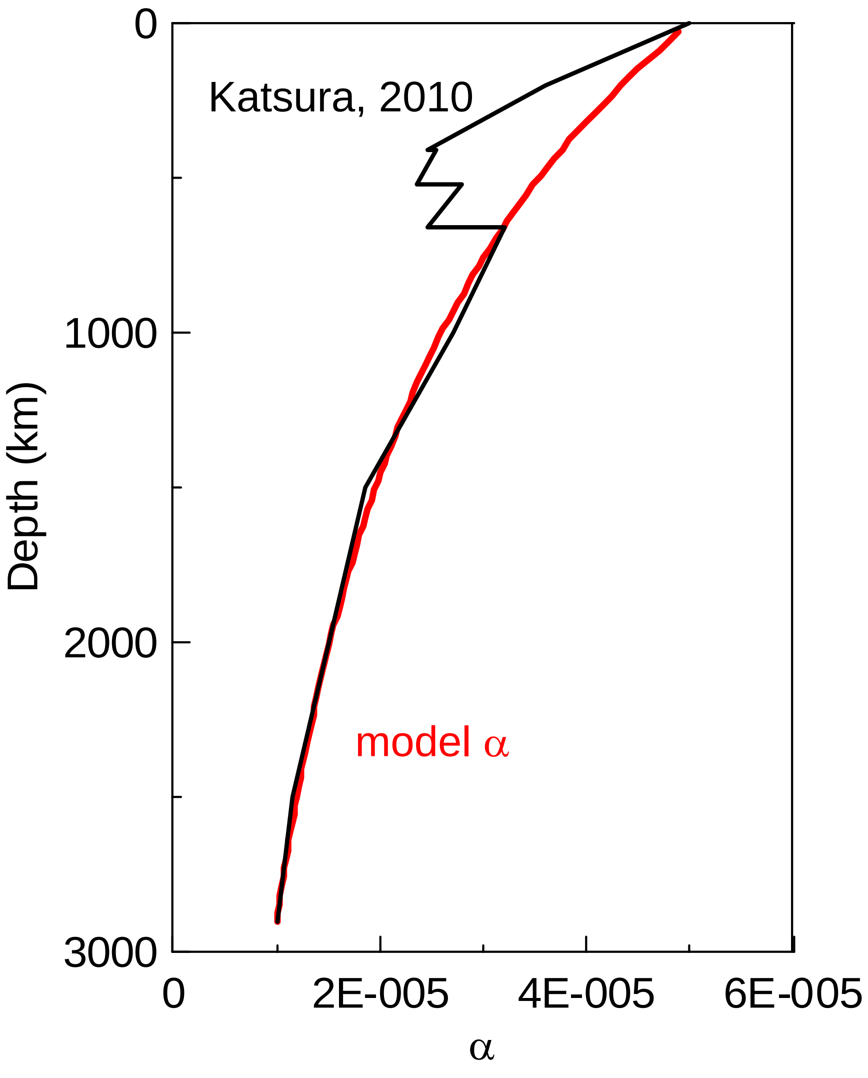
CRUST: constant viscosity $\eta_C = 10^{20}$ Pas

PPV: constant viscosity $\eta_{PPV} = 10^{20}$, 10^{21} Pas

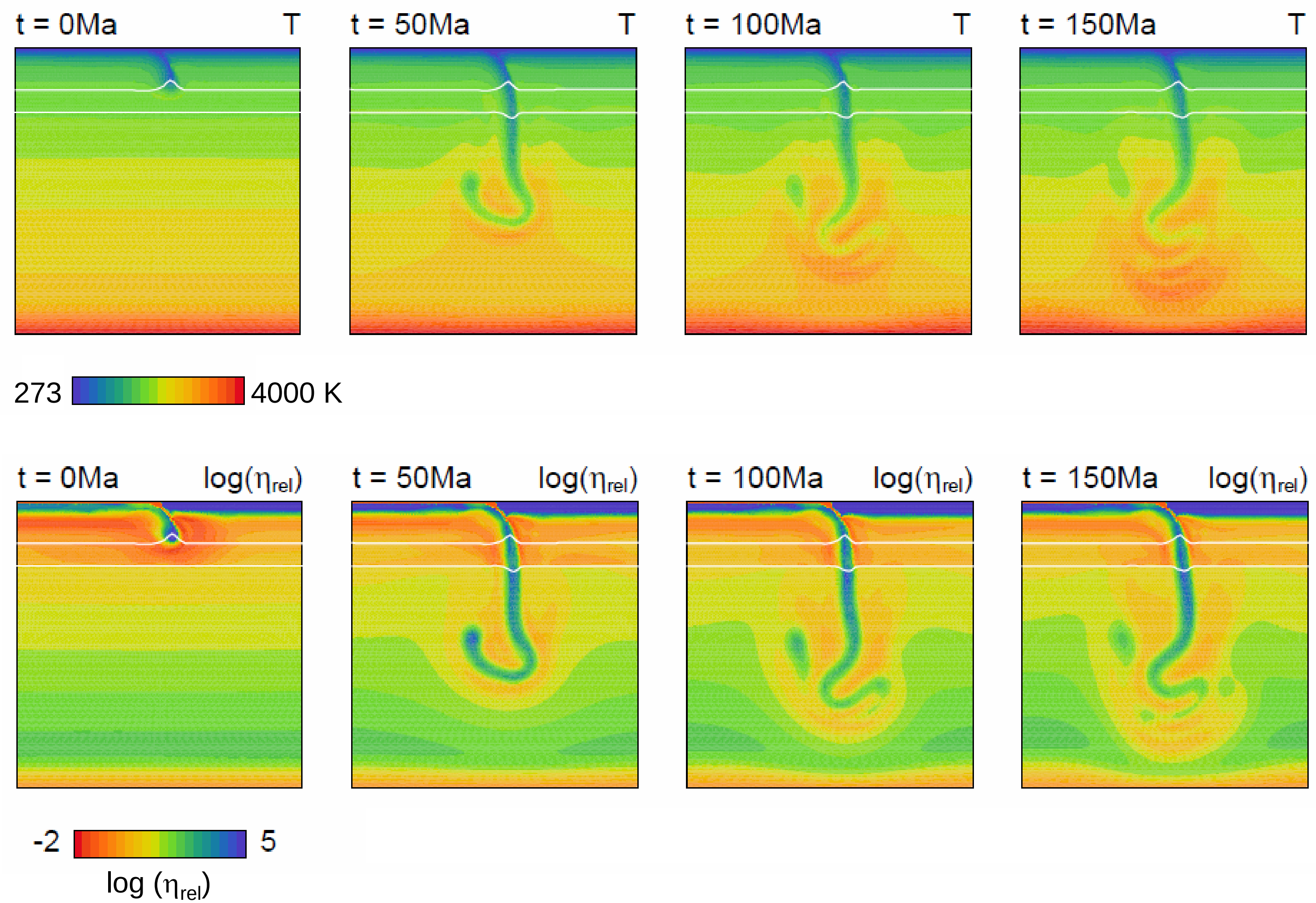
VISCOSITY PROFILE



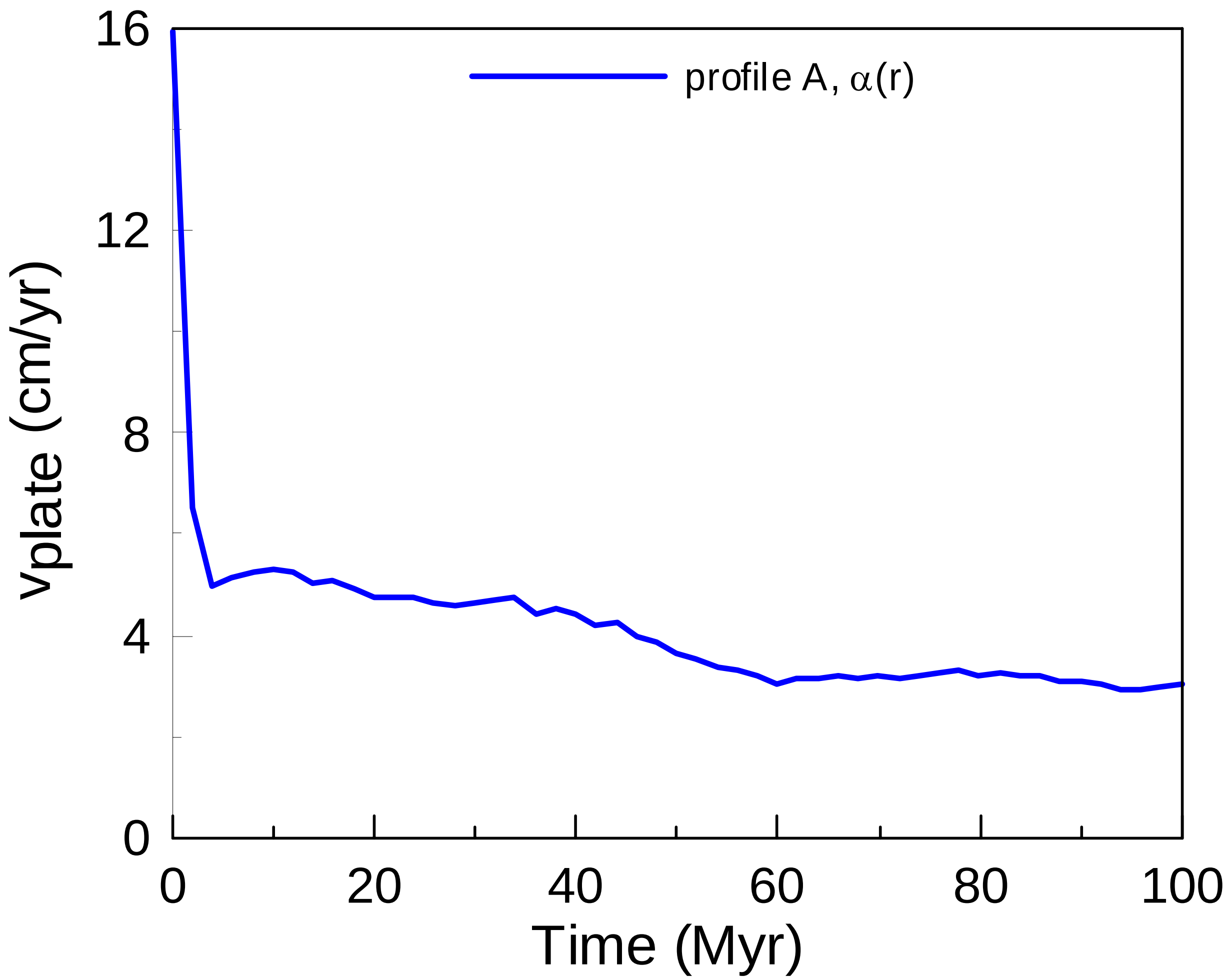
EXPANSIVITY PROFILE



VISCOSITY PROFILE A: TIME EVOLUTION



VISCOSITY PROFILE A: PLATE VELOCITY



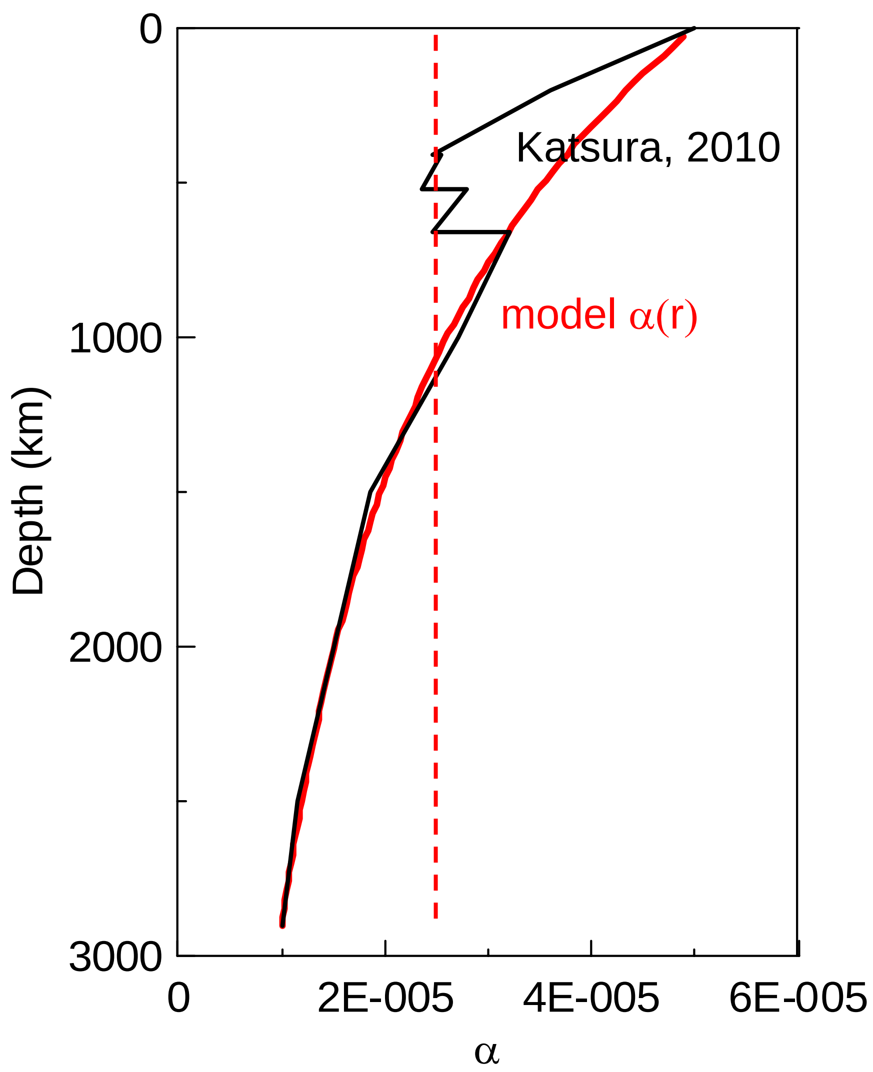
Slab in the lower mantle is too warm to transform to PPV

How we could reach the PPV stability conditions?

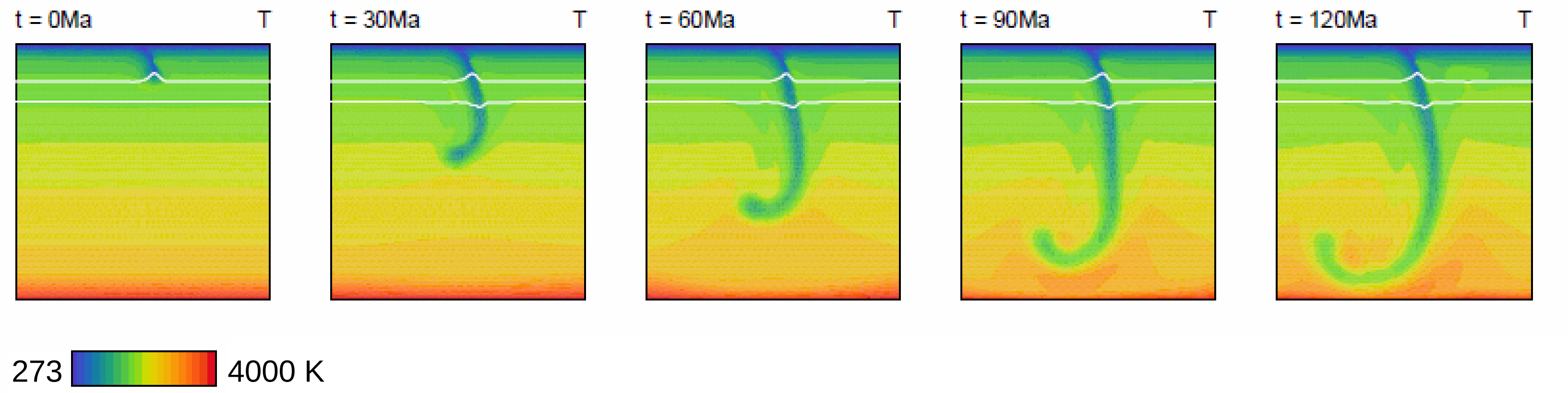
We need colder slab arriving to the CMB
– we need to get rid of the viscous heating due to the slab slowing down

Constant expansivity?

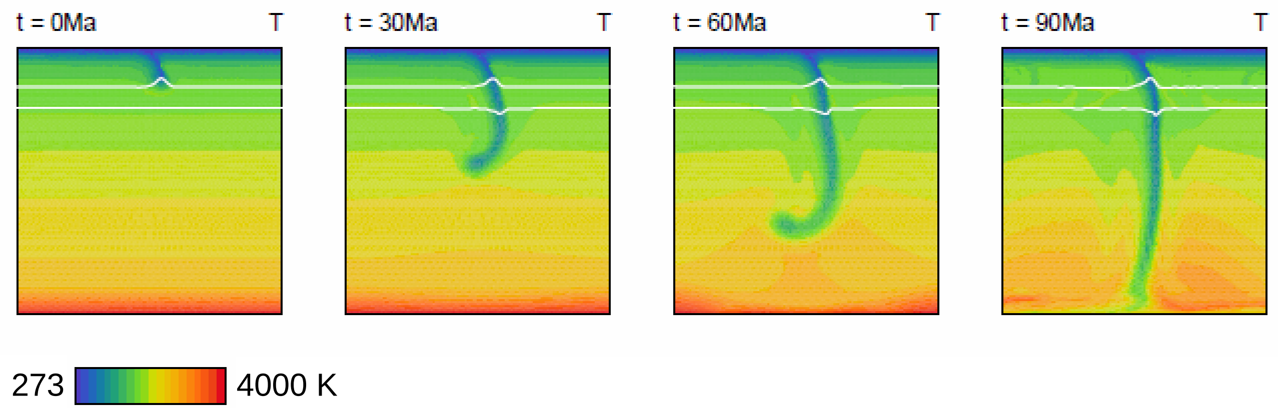
EXPANSIVITY PROFILE 2



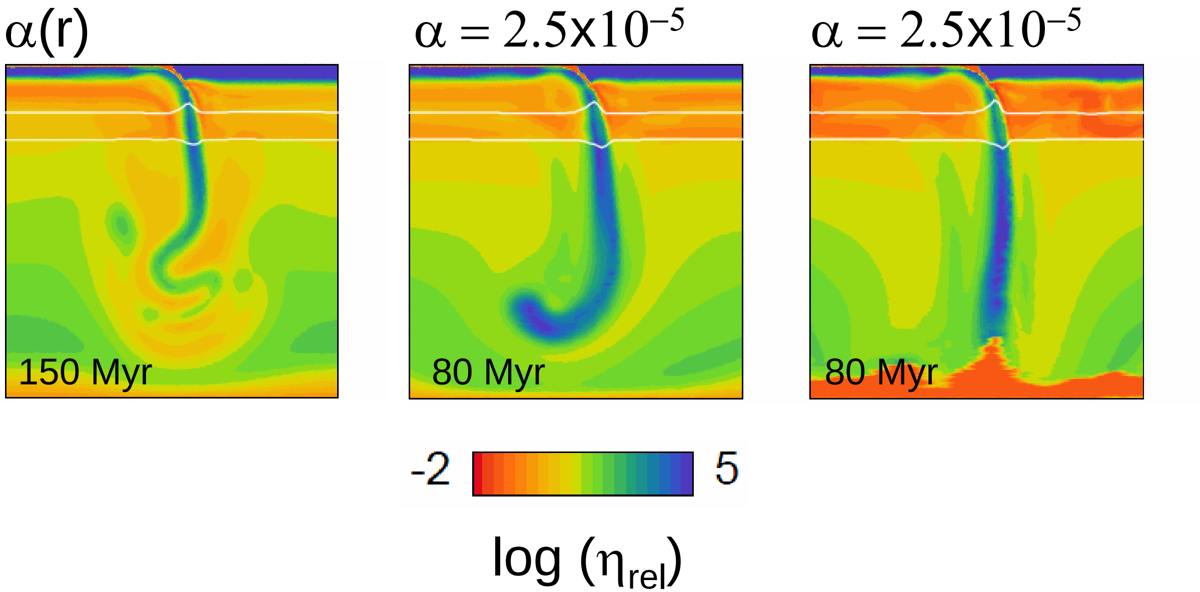
VISCOSITY PROFILE A + CONSTANT α : TIME EVOLUTION



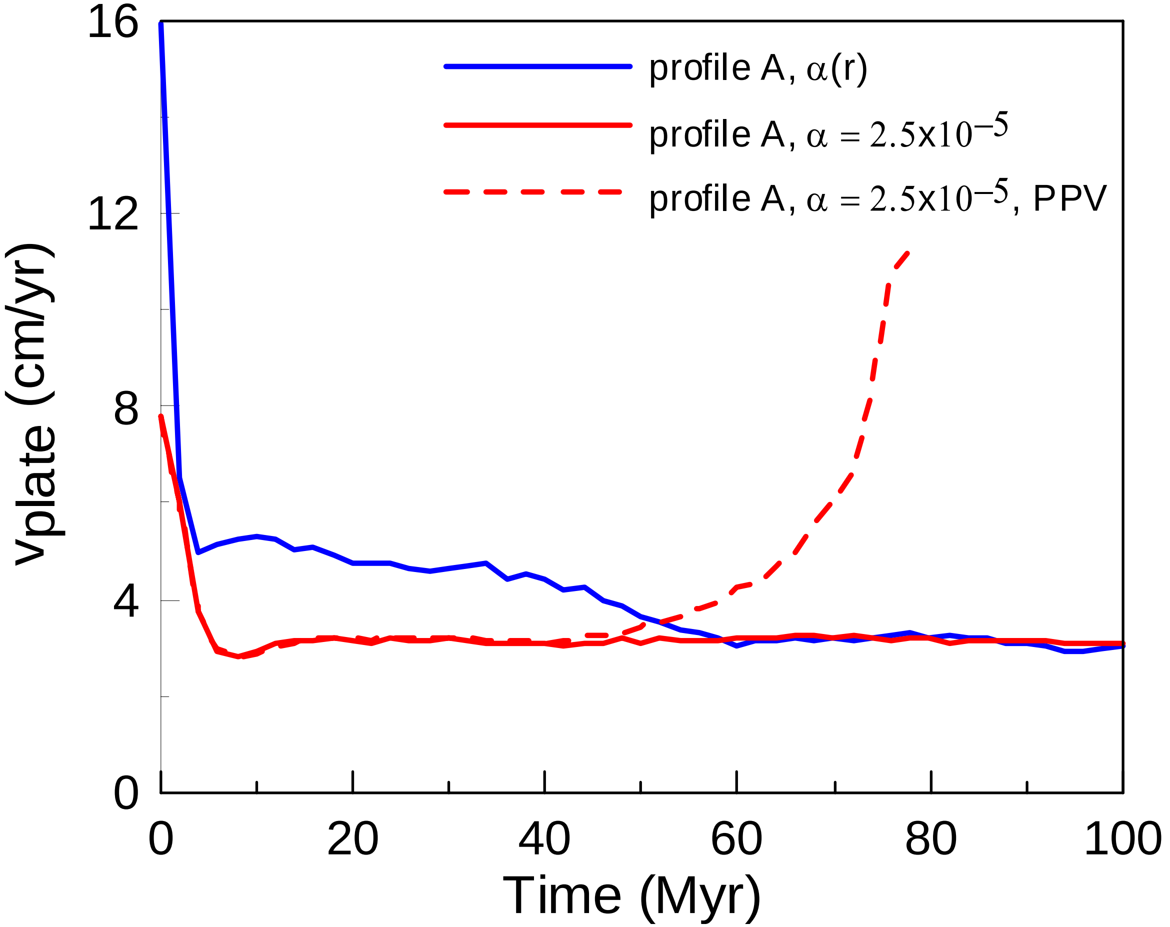
+ WEAK PPV ($\eta = 10^{20}$ Pas)



VISCOSITY PROFILE A



VISCOSITY PROFILE A: PLATE VELOCITY



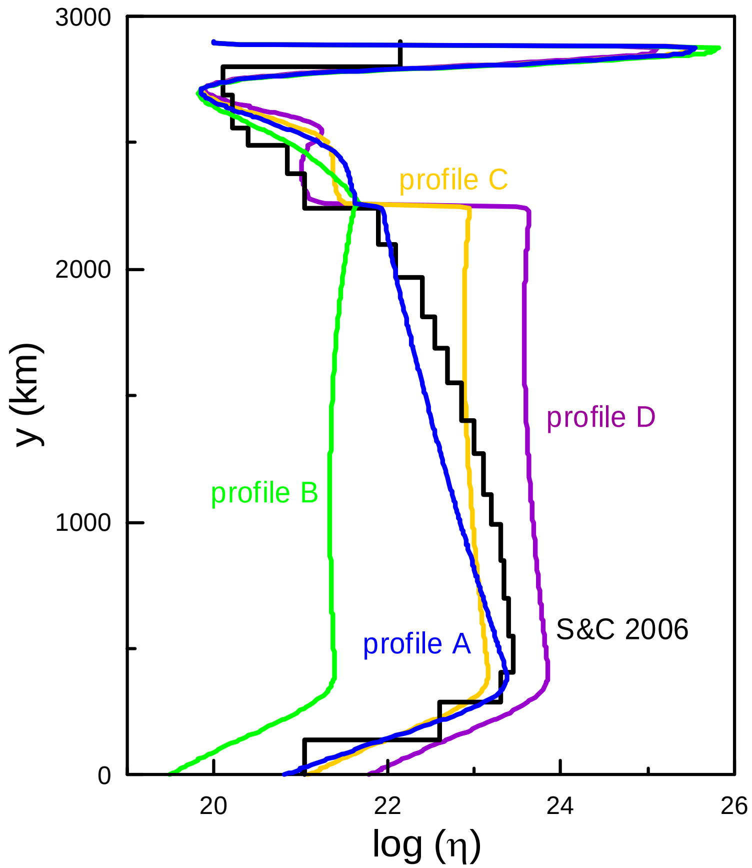
Constant expansivity allows for PPV formation

BUT

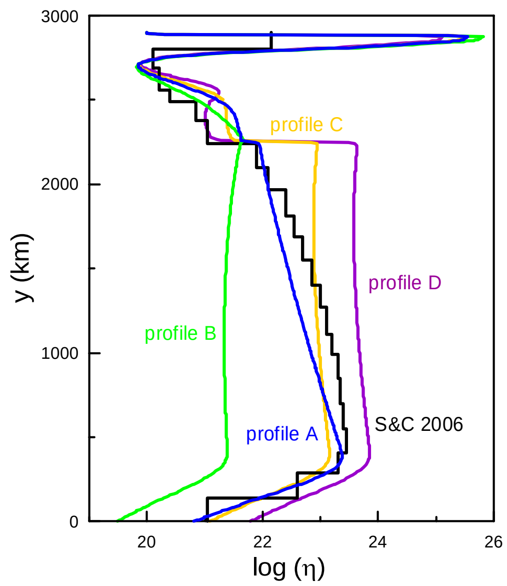
expansivity **should** be decreasing

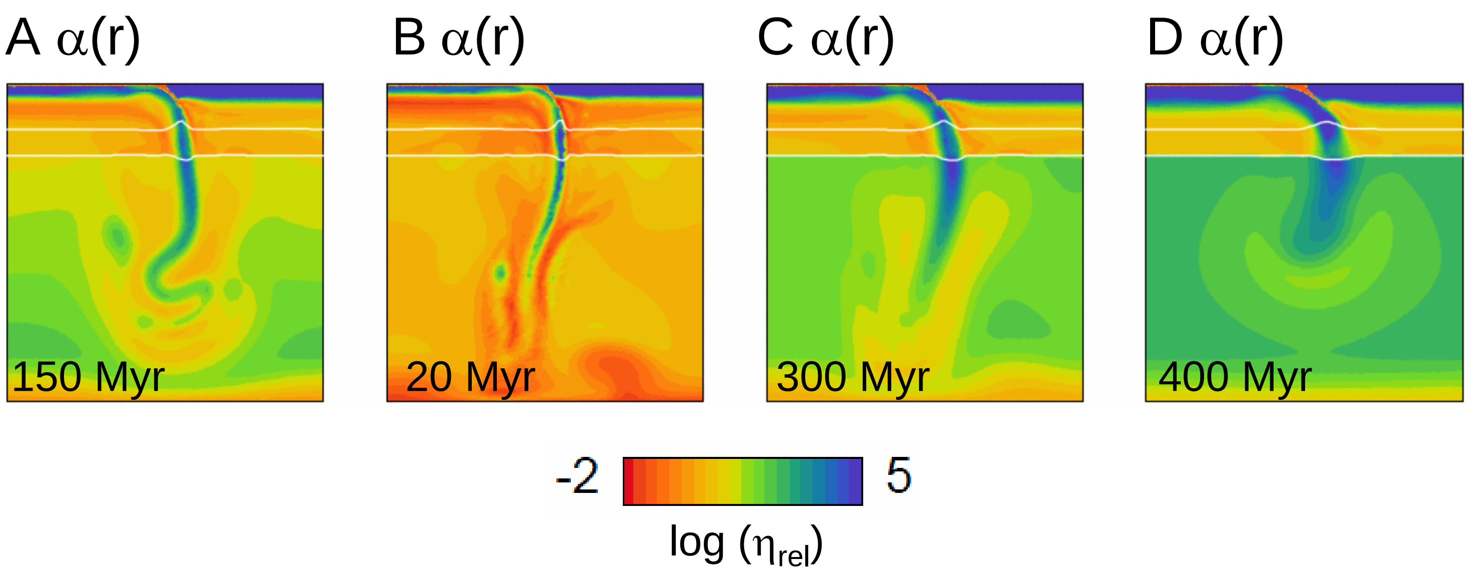
Could other viscosity profile help?

VISCOSITY PROFILES

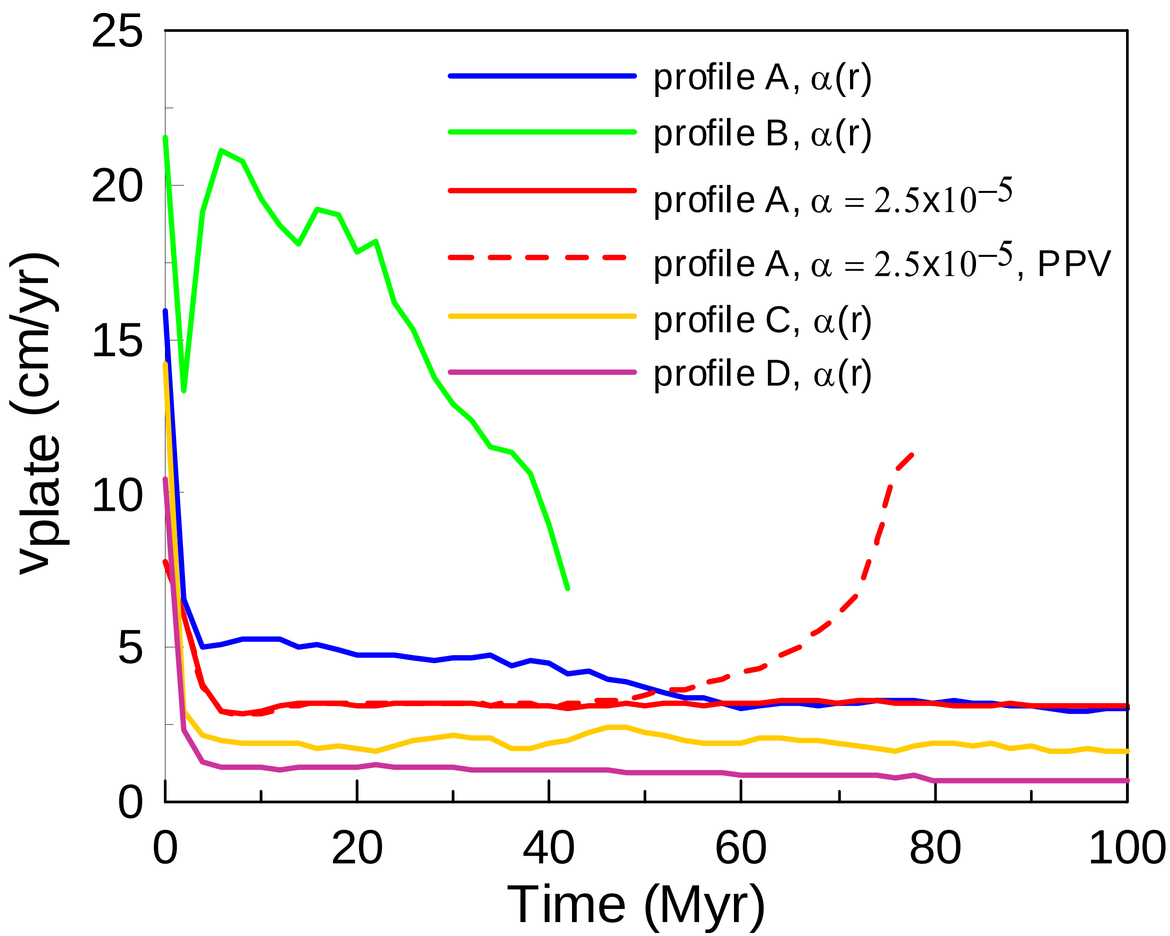


DECREASING EXPANSIVITY α(r): EFFECT OF VISCOSITY PROFILE

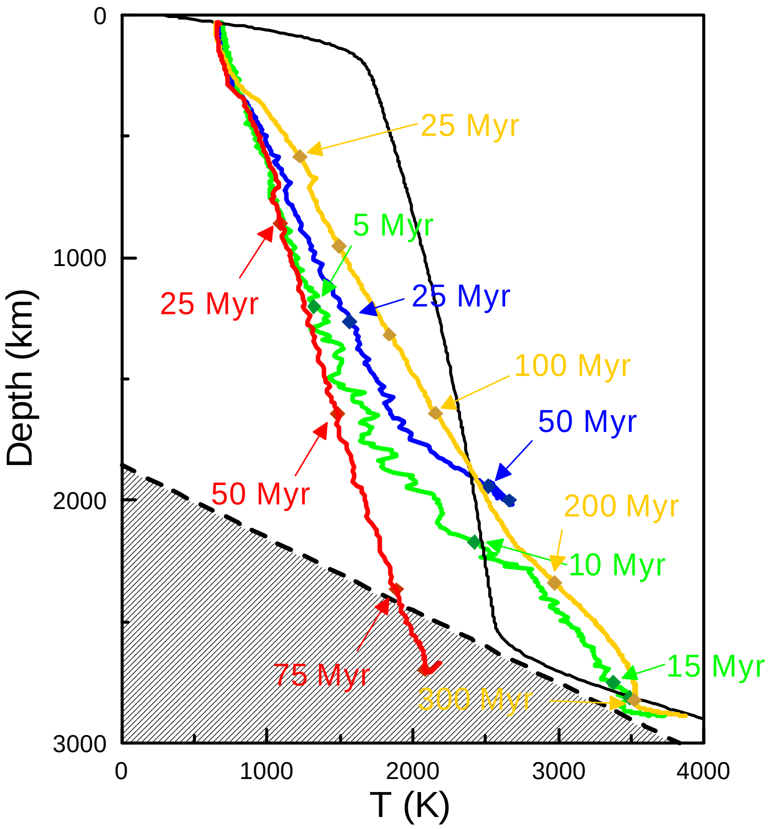


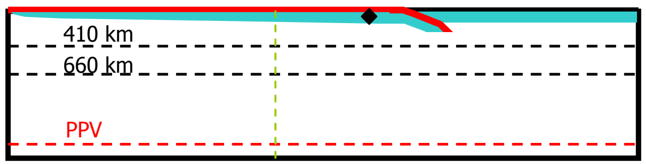


VISCOSITY PROFILES A-D: PLATE VELOCITY



TEMPERATURE OF THE MONITOR TRACER

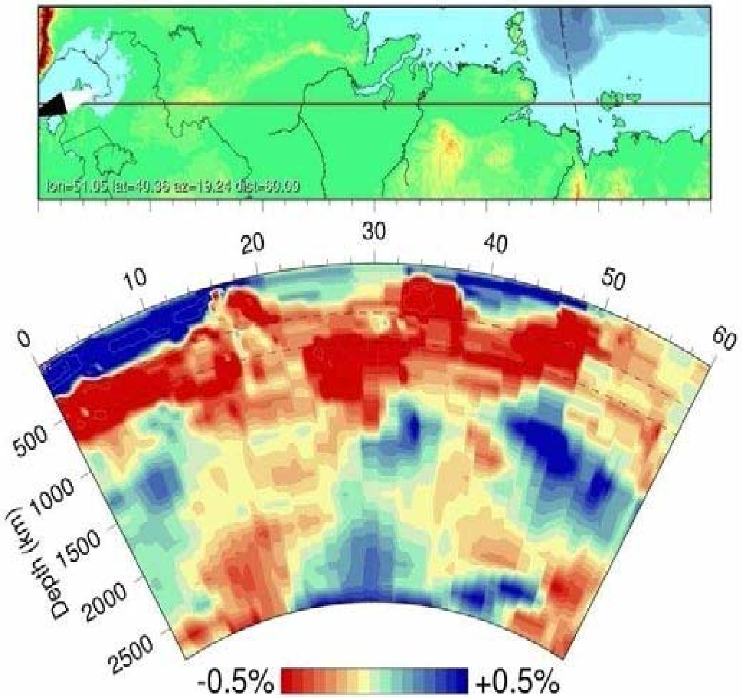


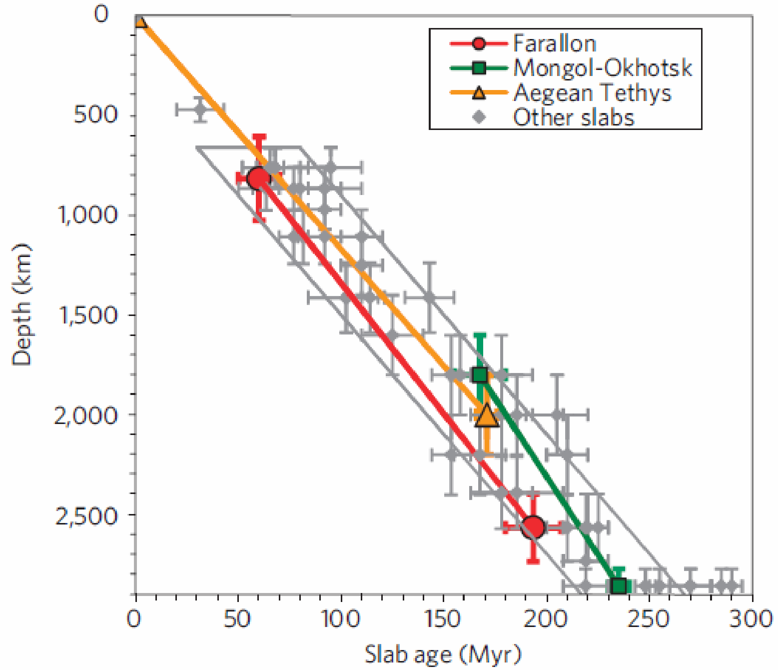


Tracer temperature (K)

- viscosity A, $\alpha = 2.5 \times 10^{-5}$
- viscosity A, $\alpha(r)$
- viscosity B, $\alpha(r)$
- viscosity C, $\alpha(r)$
- initial geotherm

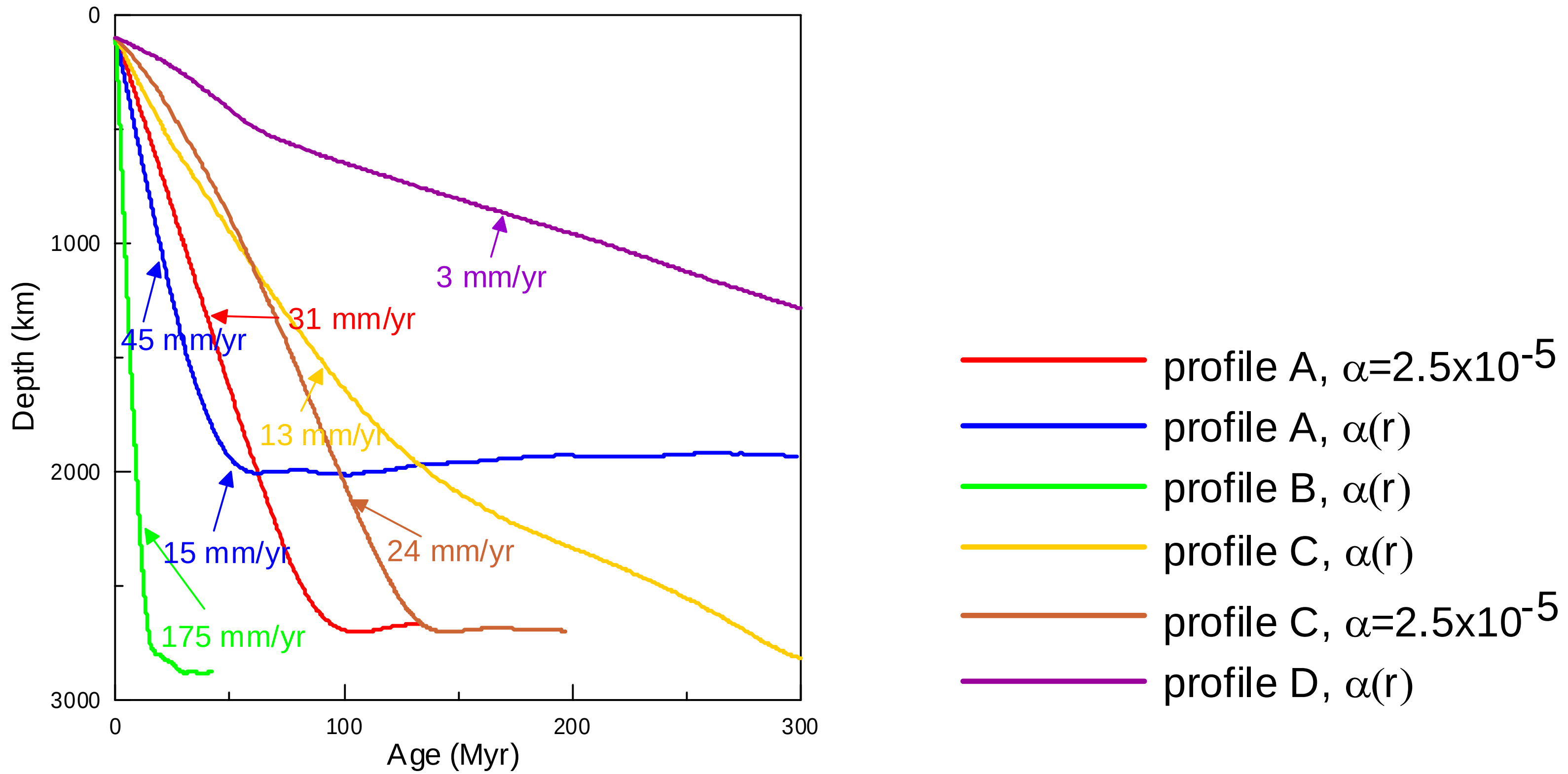
VAN DER MEER ET AL. (2010)





SINKING VELOCITY ~ 12 mm/yr

DEPTH vs. AGE: SINKING VELOCITIES



Viscosity profile C produces sinking velocity of about
1 cm/yr

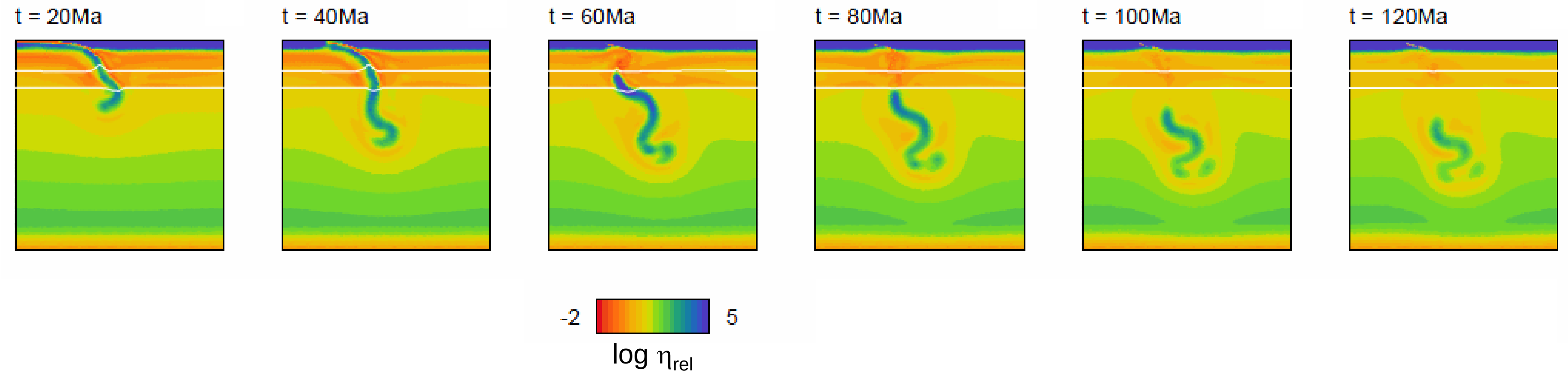
BUT

Van der Meer et al. (2010) derived it for the **detached** slab

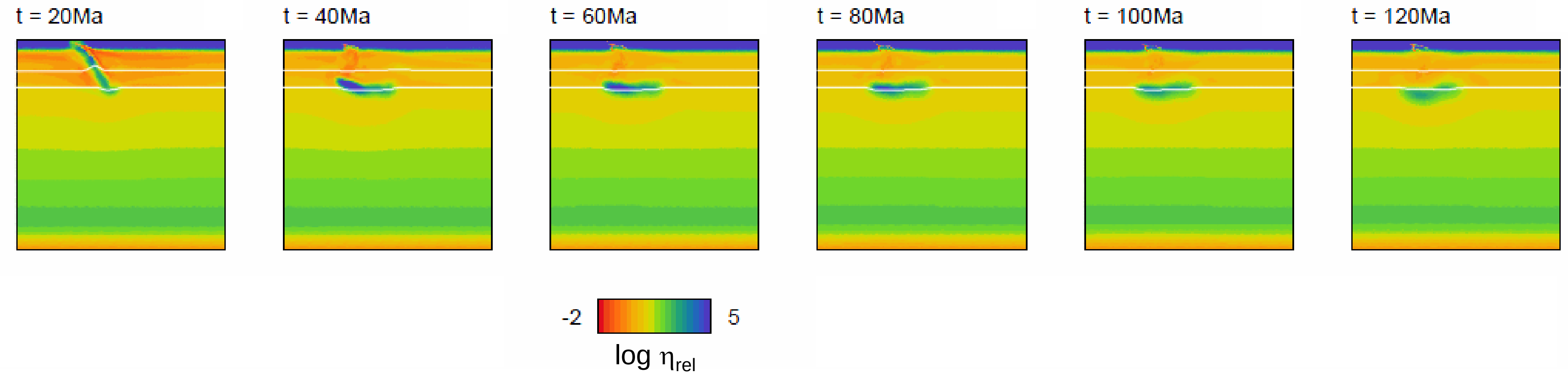
What would be the sinking velocities of the detached slabs?

SLAB BREAK-OFF: VISCOSITY PROFILE A

CRUSTAL SEGMENT 2000 KM

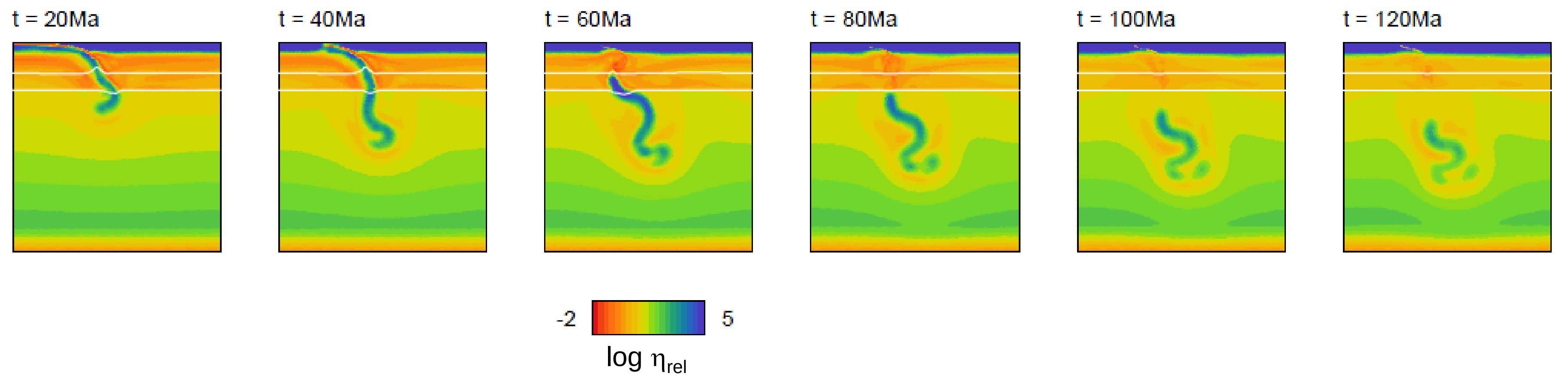


CRUSTAL SEGMENT 500 KM

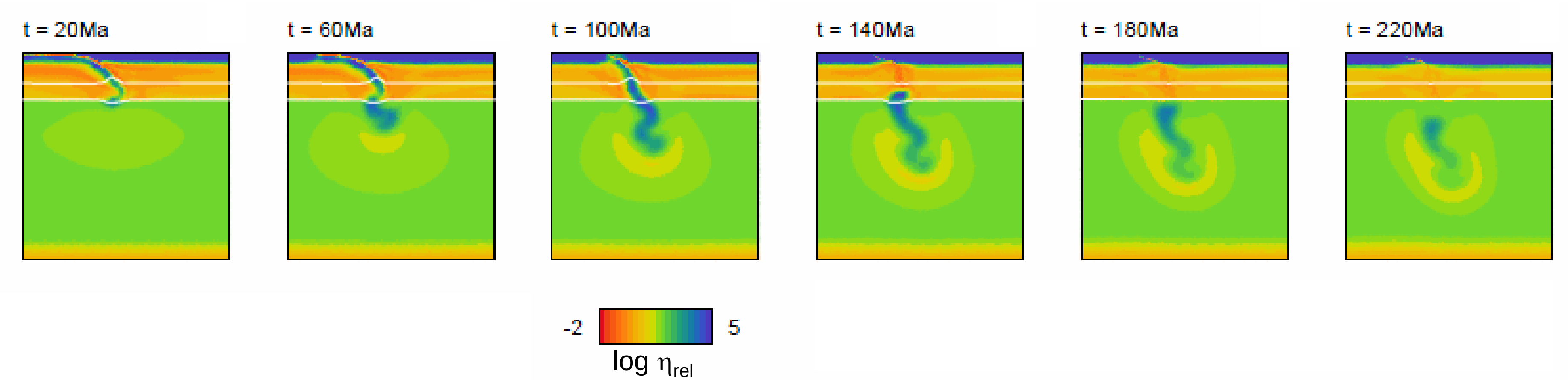


SLAB BREAK-OFF: CRUSTAL SEGMENT 2000 km

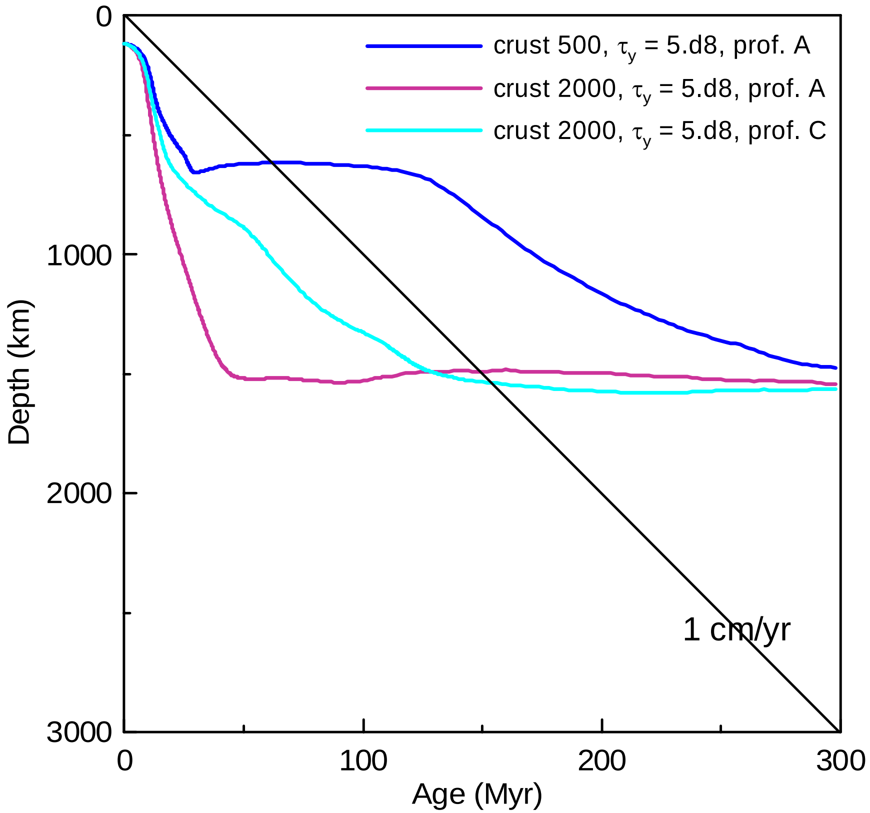
VISCOSITY PROFILE A



VISCOSITY PROFILE C

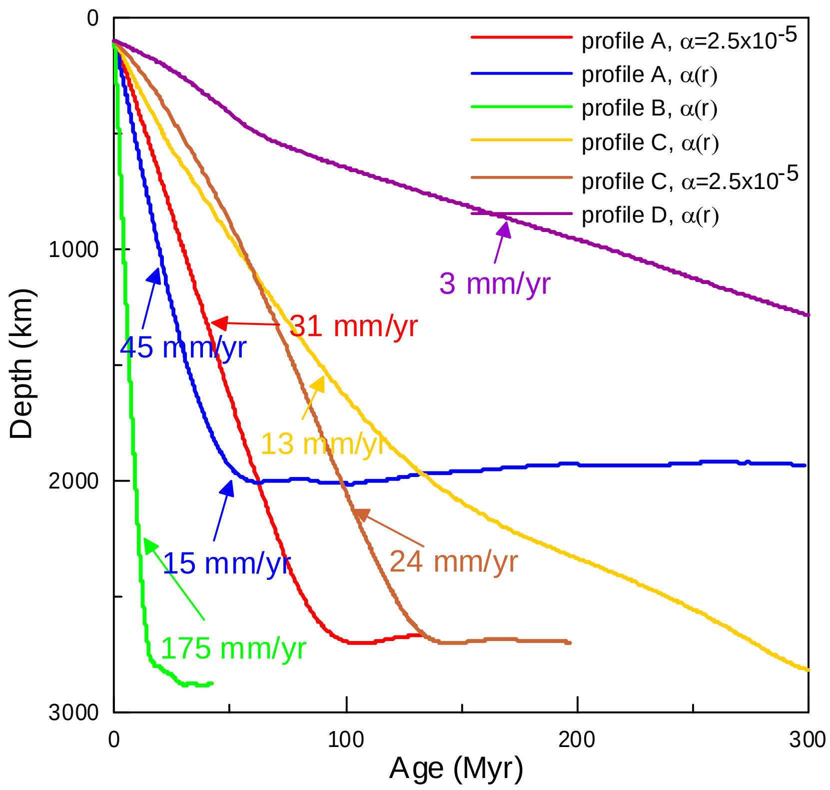


DEPTH vs. AGE: SINKING VELOCITIES

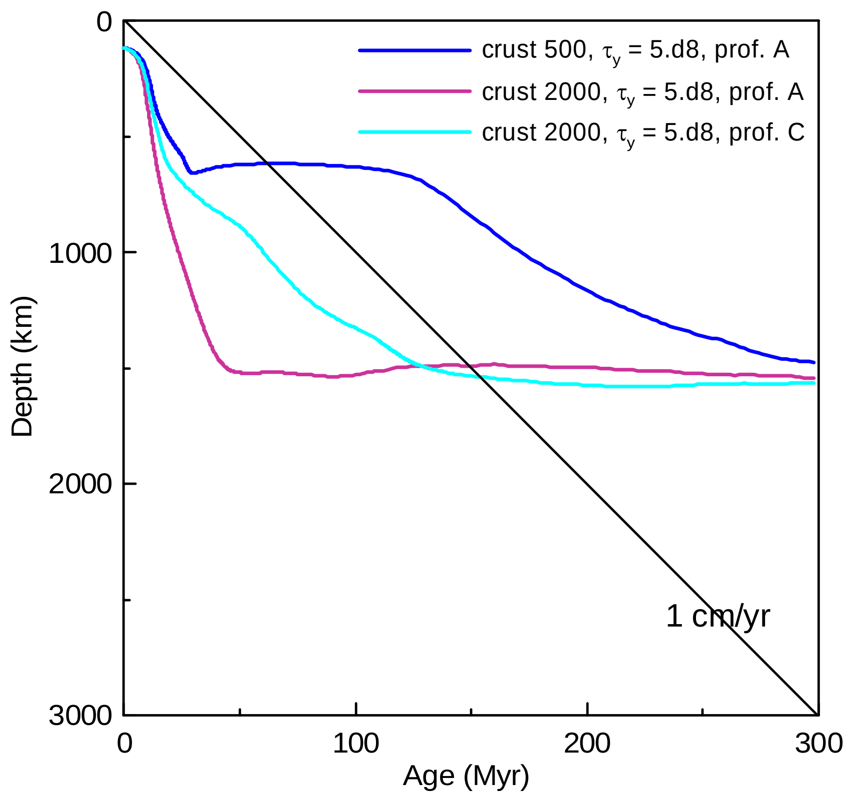


DEPTH vs. AGE: SINKING VELOCITIES

CONTINUOUS SLAB



DETACHED SLAB



CONCLUSIONS

The dynamics of the subducted slab in the lower mantle is very sensitive to the depth dependent expansivity and rheology

If the expansivity follows the curve by Katsura (2010), cold slab does not reach the base of the mantle and no PPV is formed

Slab sinking velocities are in agreement with the reconstructions by Van der Meer et al. (2010) for the lower mantle viscosity of about 10^{23} Pas

Detached slabs never reach the bottom of the mantle

Sinking velocities for the detached slab may differ from those for the continuous slab

↓

More detailed study of the combined effects of the lower mantle viscosity and expansivity will be necessary to obtain a reasonable fit to the slab reconstructions