A regime diagram for subduction dynamics from thermo-mechanical models with a mobile trench and an overriding plate

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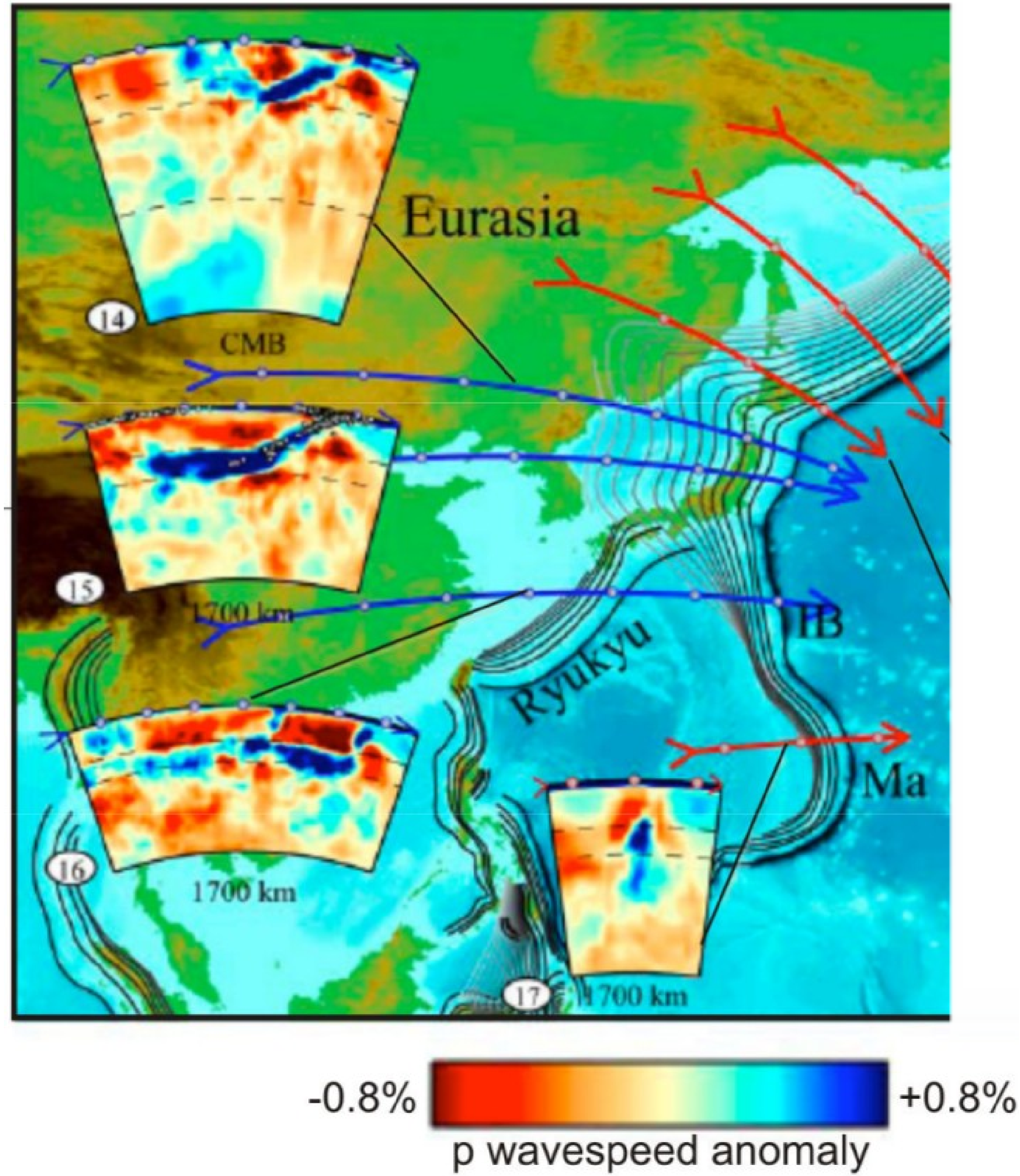
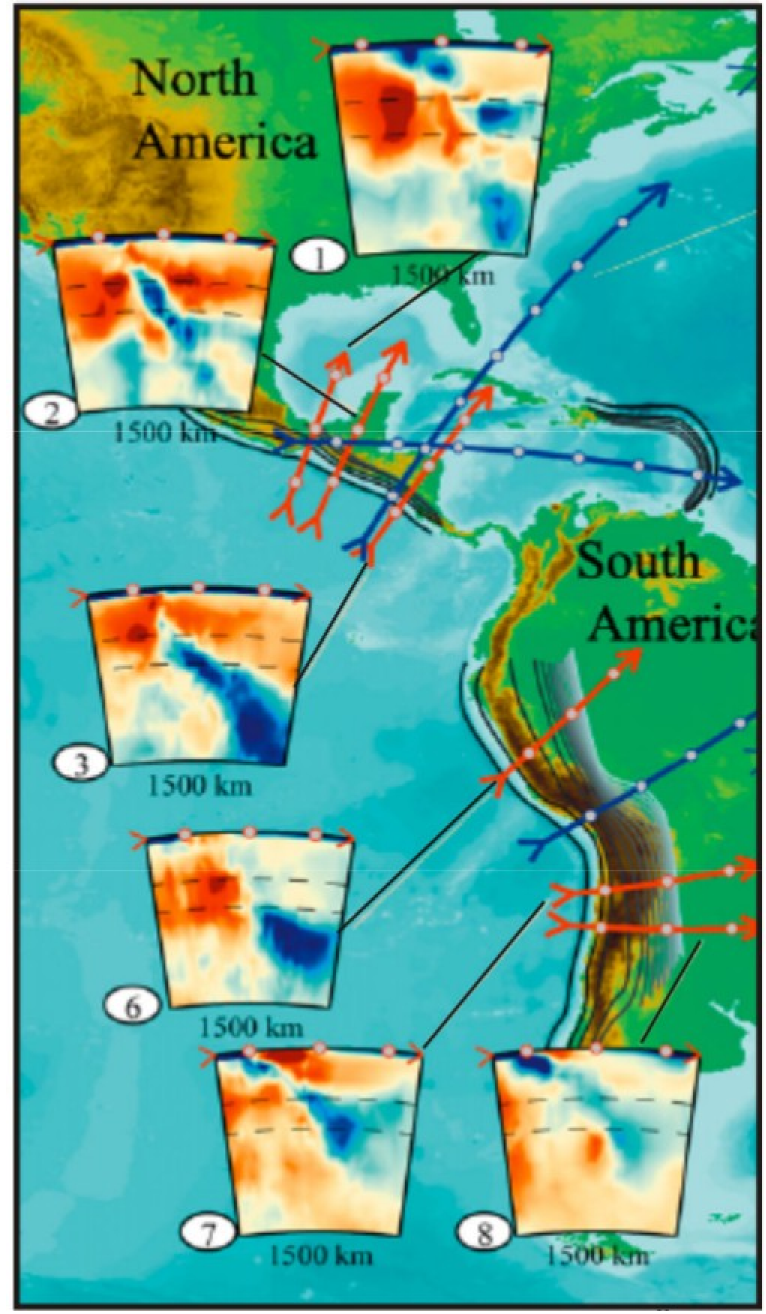
Mantle Ge Dynamics Deinameg y Fantell

Imperial College London

European Geosciences Union

Diversity of slab-mantle interaction





West vs. East Pacific slabs

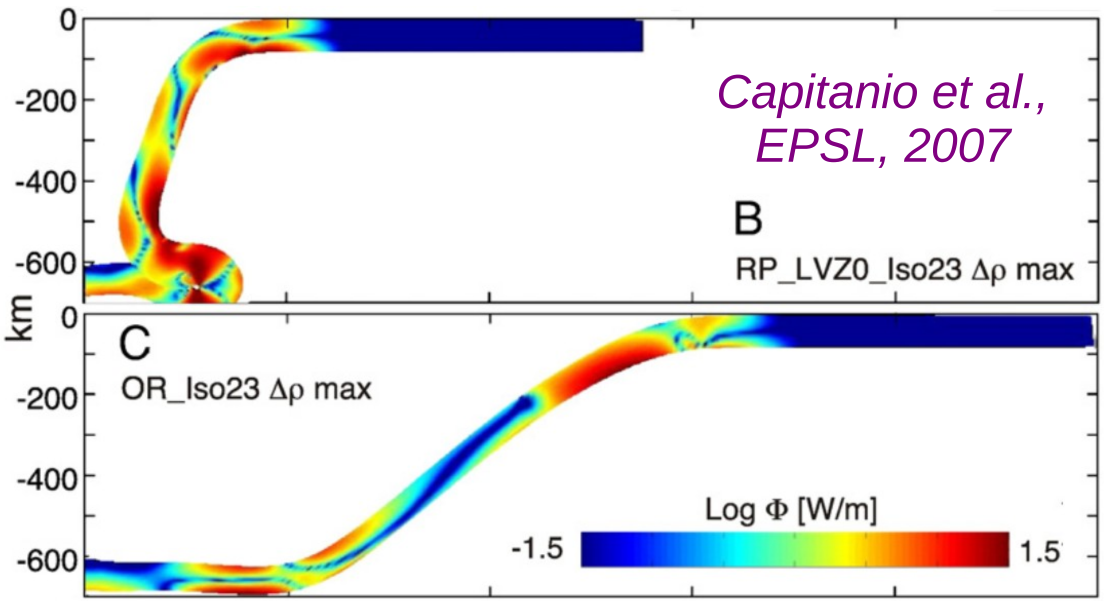
(Li et al., G3, 2008)

Subduction models:
compositional vs. thermo-mechanical

Feedbacks!

- Constant excess density
- Constant or strain-rate dependent viscosity

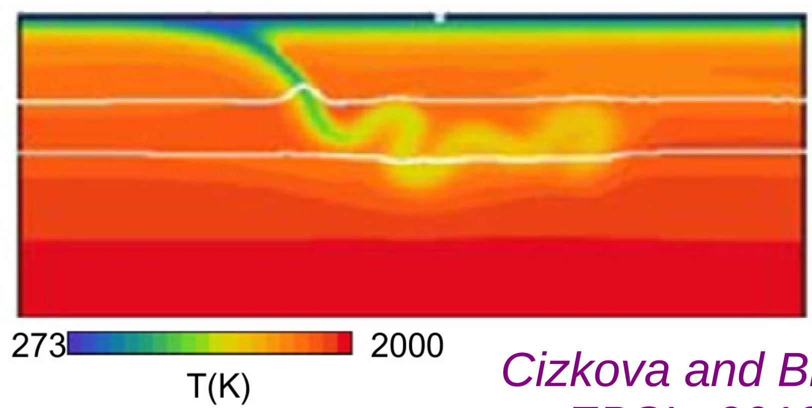
→ slab strength (and buoyancy) control subduction style



Capitanio et al., EPSL, 2007

Funiciello et al., JGR, 2003
Schellart et al., Nature, 2007
Stegman et al., Tectonophysics, 2010
Ribe, GJI, 2010...

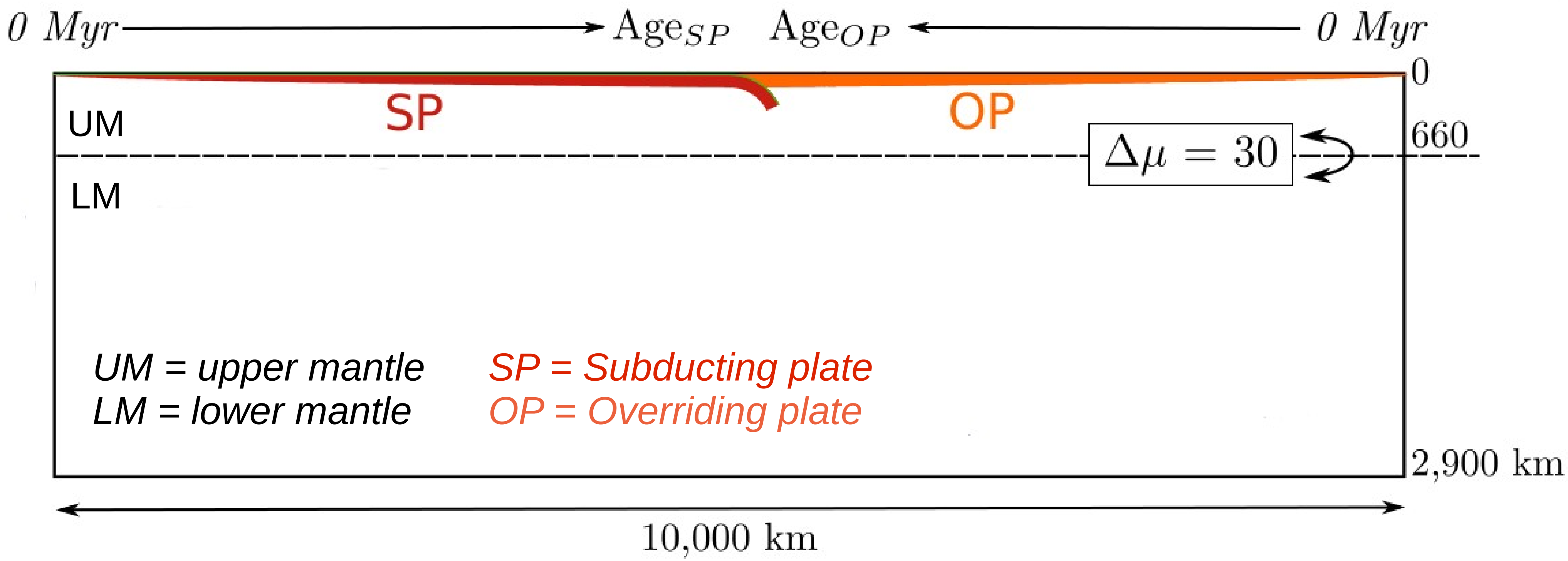
- Temperature-dependent density
- Temperature- and strain-rate dependent viscosity
- Overriding plate
- Plate renewal at the surface through thermal diffusion

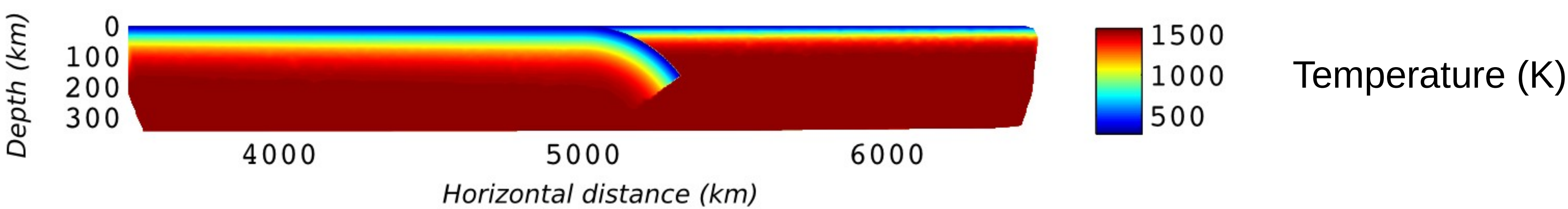


Cizkova and Bina, EPSL, 2013

Zhong and Gurnis, Nature, 1996
Schmeling et al., EPSL, 1999
van Hunen et al., EPSL, 2000
Billen et al., PEPI, 2010...

Model set-up



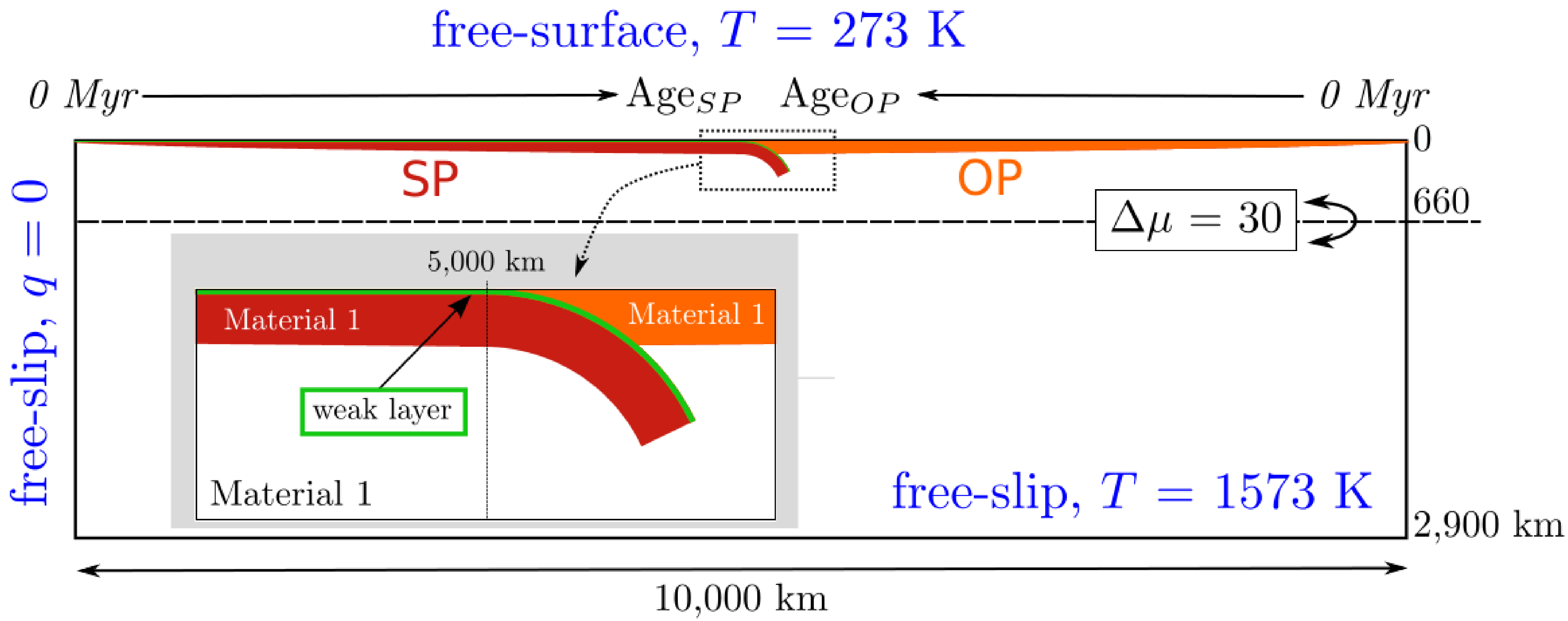


Initial thermal structure
(half-space cooling model)

100 Myr → isotherm 1300 K at 100 km depth

40 Myr → ———————— at 63 km depth

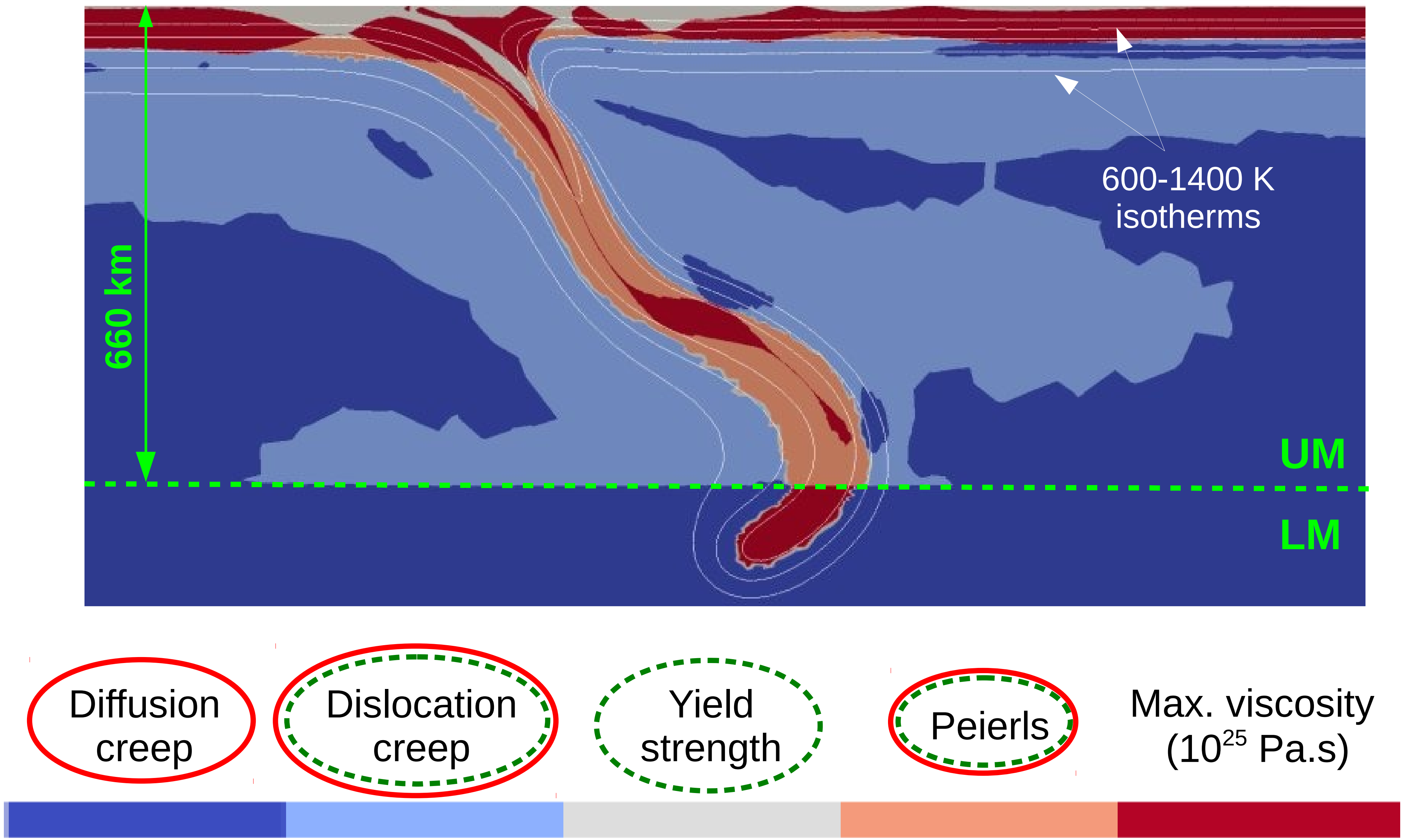
Model set-up



- renewal of cold material by thermal diffusion at the surface
- 5-km thickness decoupling weak layer (sediments, oceanic crust)
- no external velocity imposed for subduction initiation
- **"free" trench motion** in response to subduction dynamics
- **no compositional difference** between plate and mantle (thermal threshold)

Composite rheology:

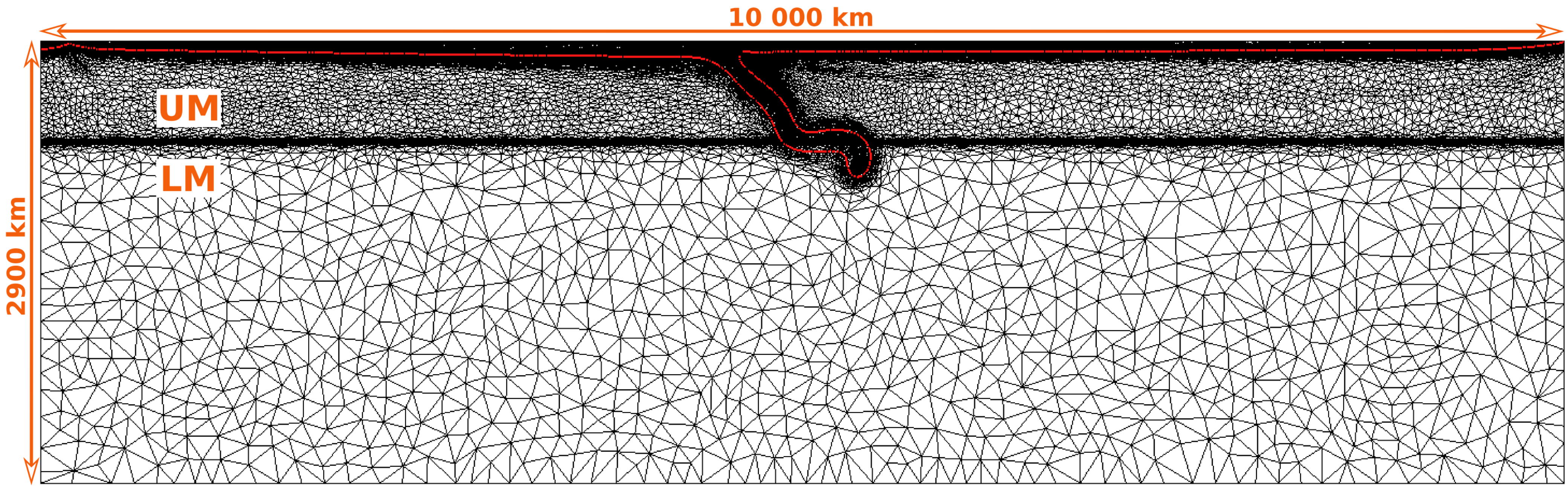
temperature and strain-rate dependent viscosity



Fluidity code

- developed by the AMCG group at Imperial College
  (*Davies et al., G3, 2011; Kramer et al., PEPI, 2012)*

- Auto-adaptive meshing → multi-scale systems
  → element size between 400 m and 200 km



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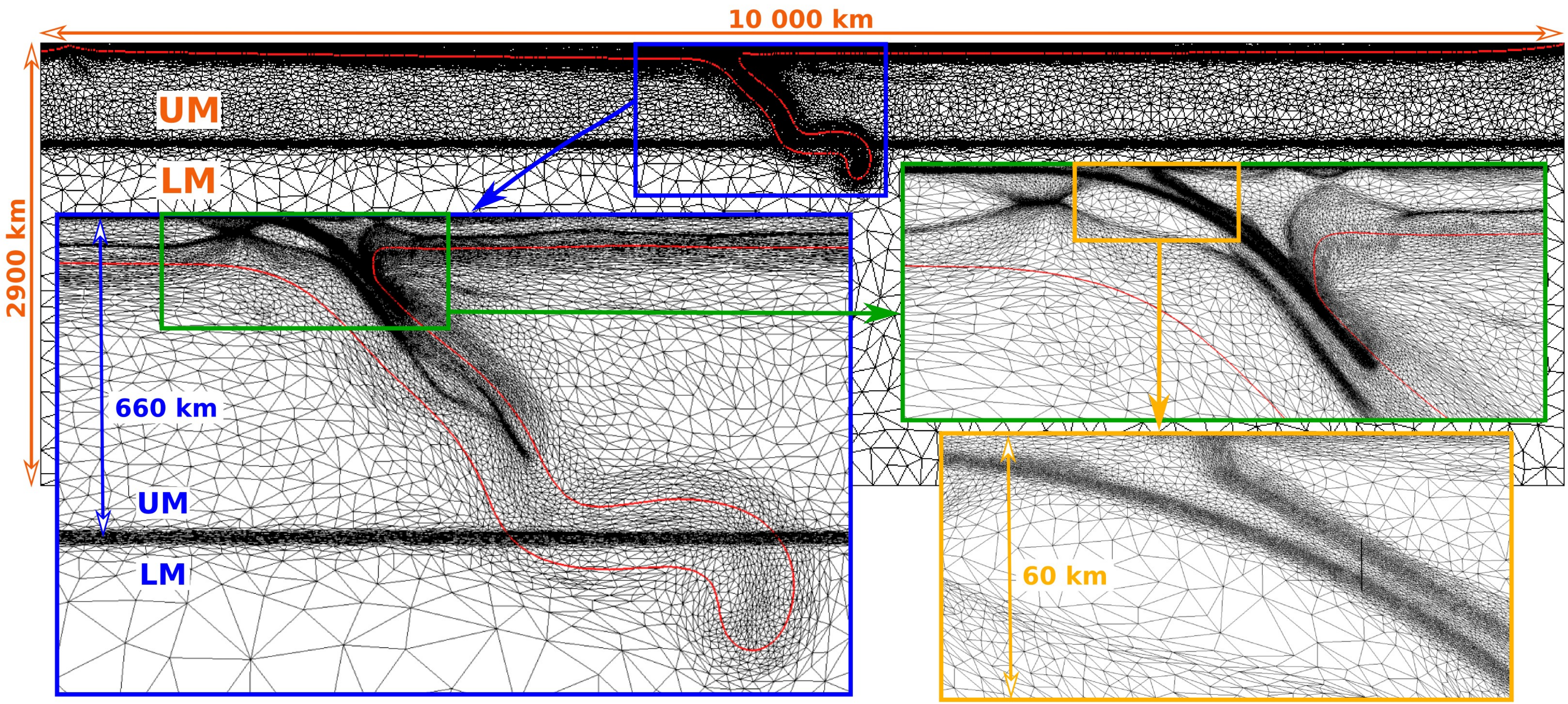
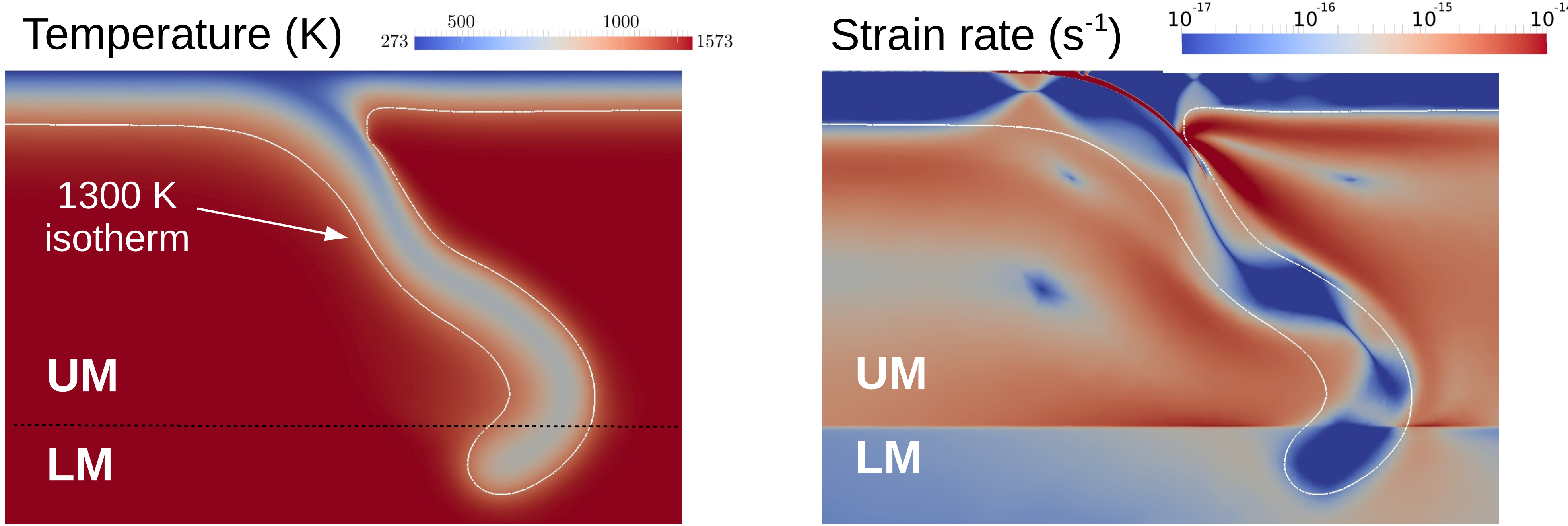
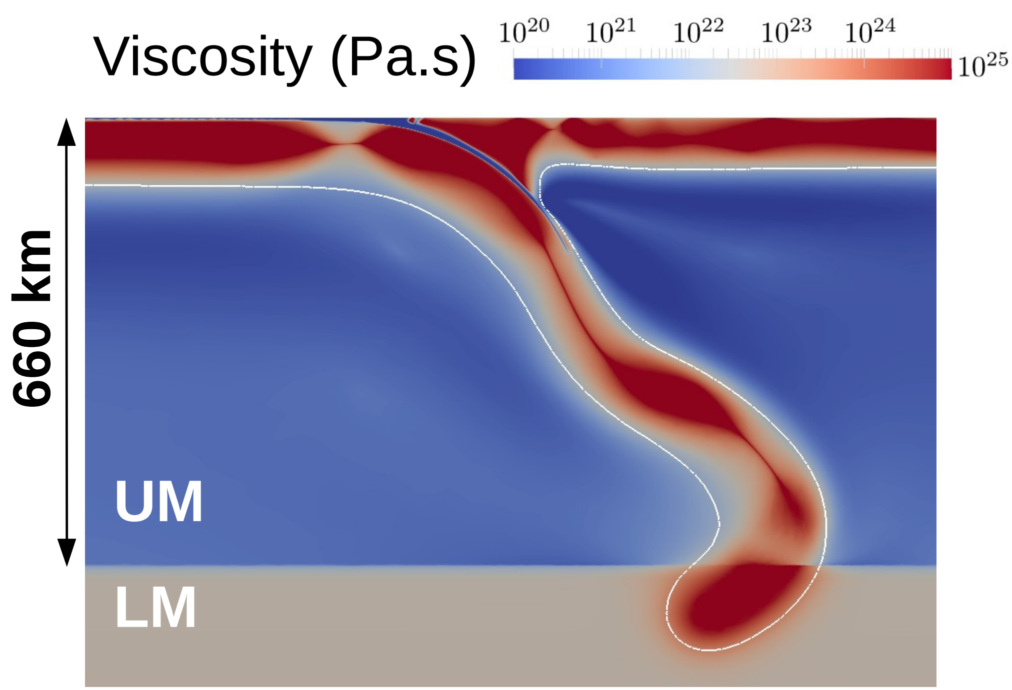


Thermal vs. mechanical slab





Regions of strain-rate weakening in mantle and in slab

Model evolution (1)

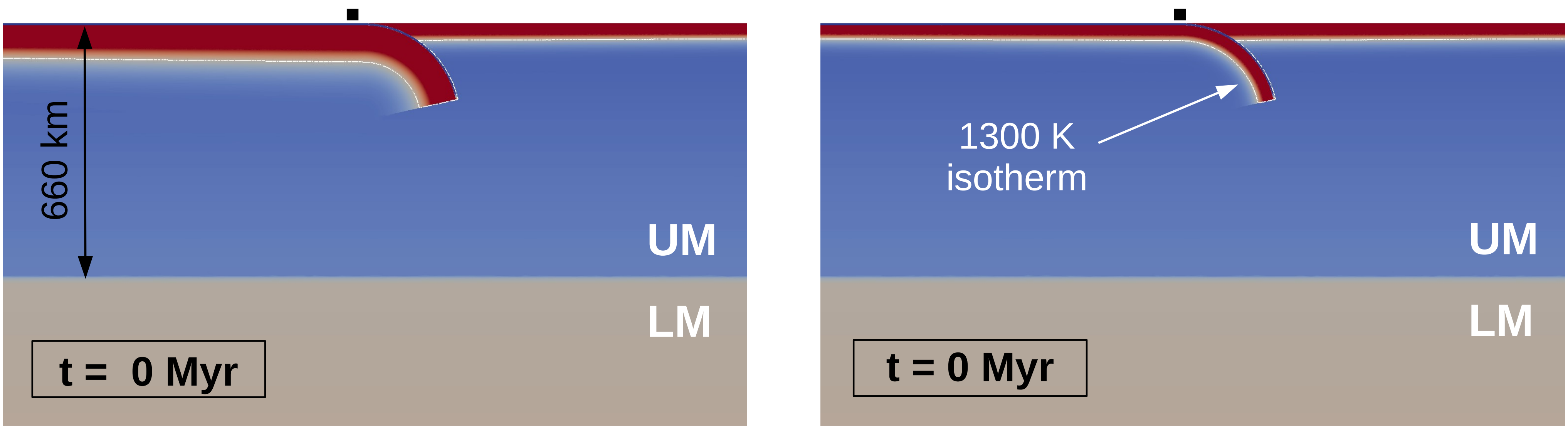
Old, thick SP

SP initial age at trench = 100 Myr

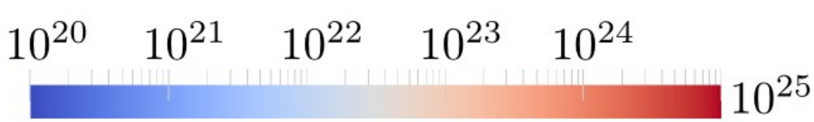
Young, thin SP

SP initial age at trench = 20 Myr

OP initial age at trench = 20 Myr



Viscosity (Pa.s)



▪ = initial trench location

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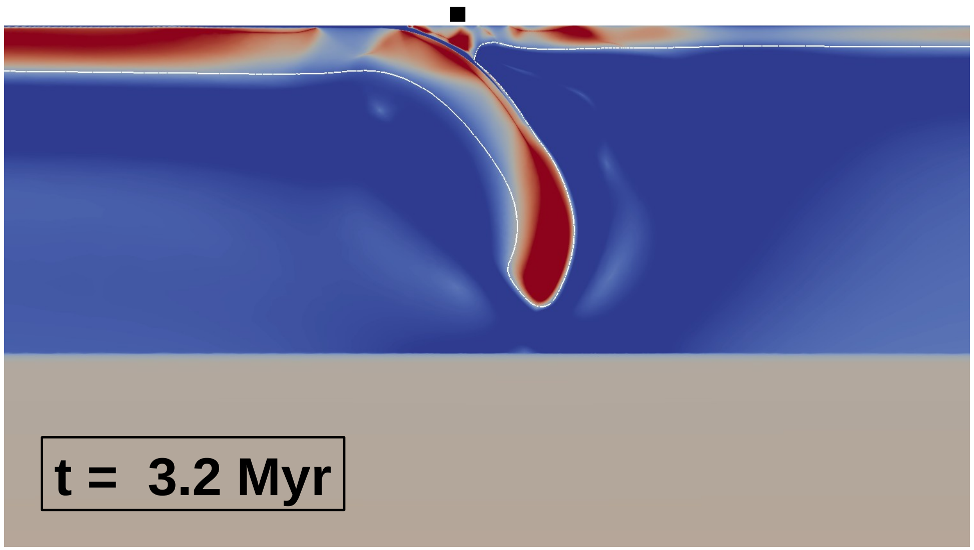

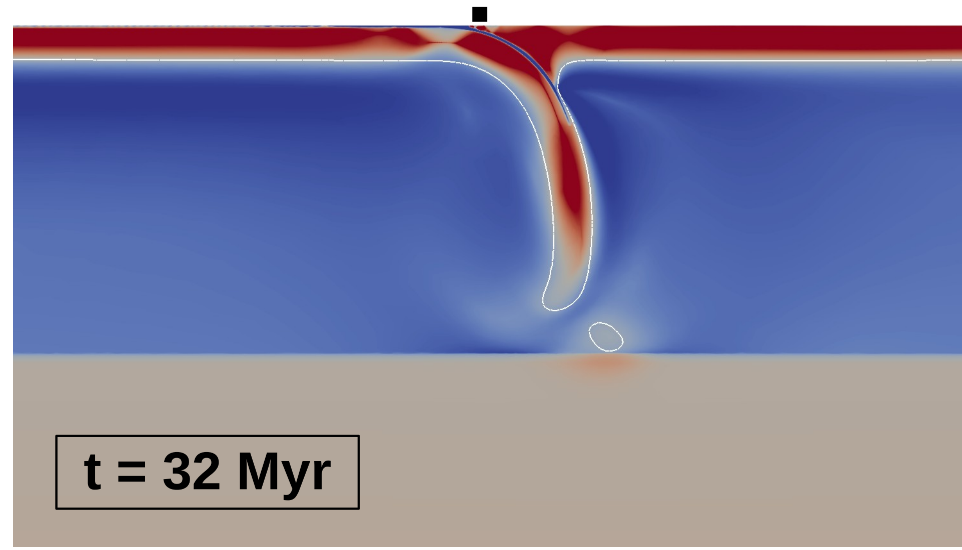

PHASE 1

Faster sinking of the old, more negatively buoyant plate

→ large mantle weakening

→ faster sinking

Slow sinking

→ important thermal diffusion

→ weaker slab

→ less pull, slower sinking

Model evolution (1)

Old, thick SP	**Young, thin SP**
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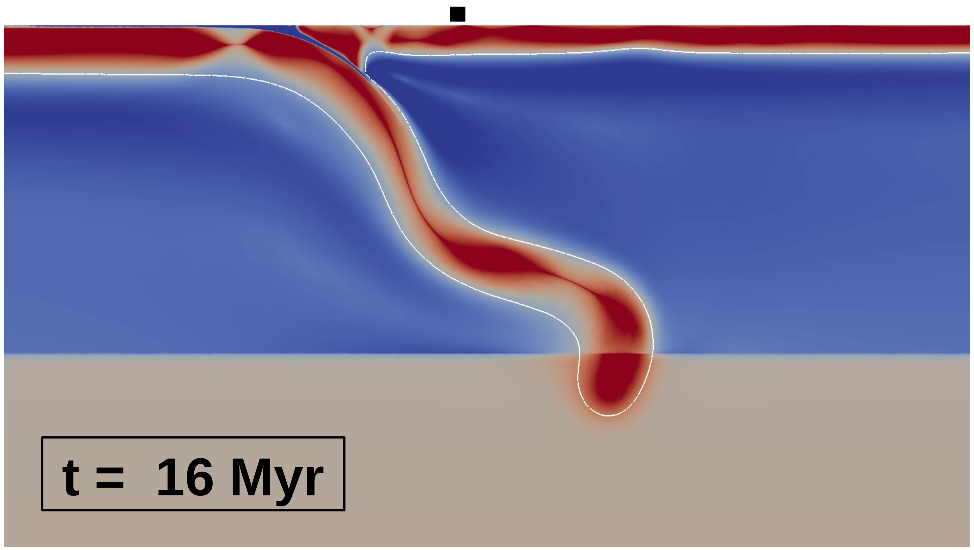

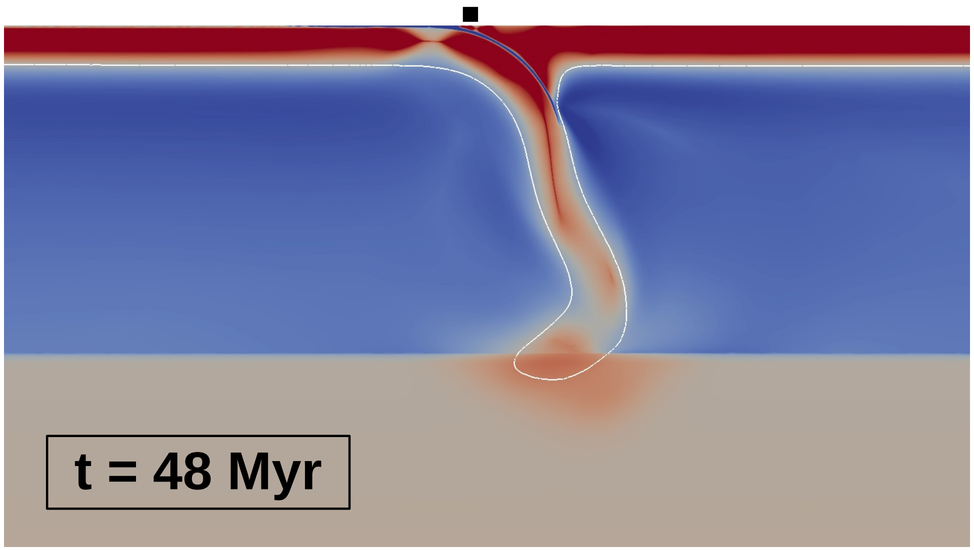

PHASE 2

- Tip anchored in the lower mantle
- Trench retreat lowers slab dip

Vertical impact on the viscosity jump + weak slap tip

→ piling and folding

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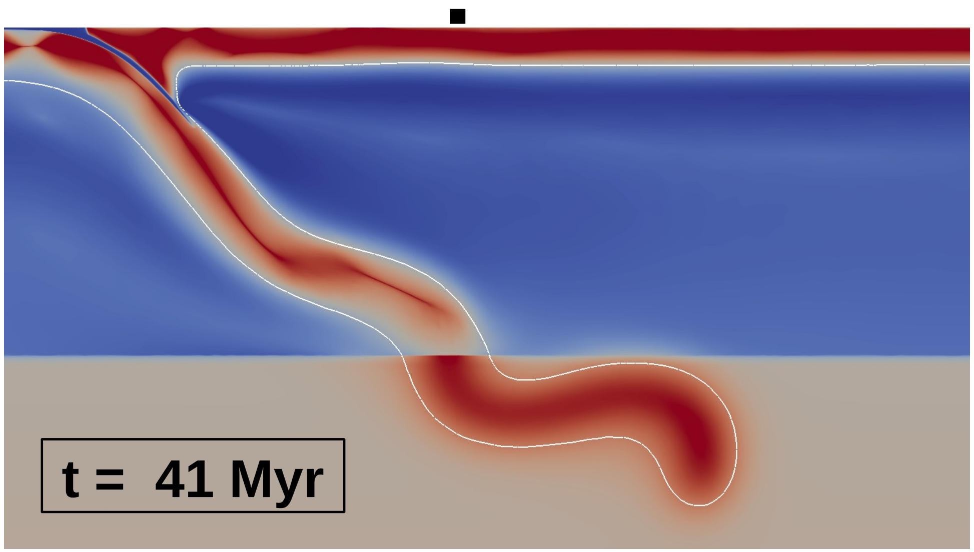
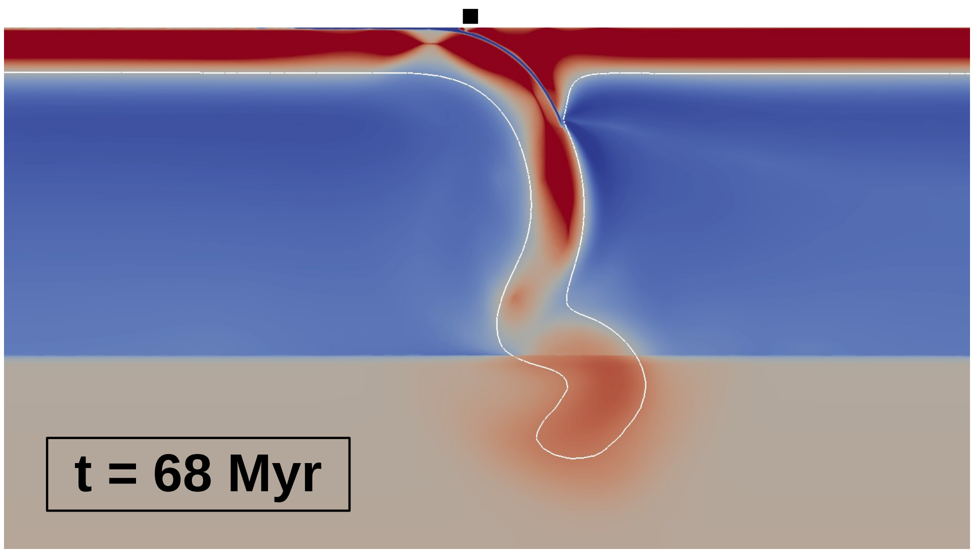




Inclined, partly flattened slab
Strong retreat

Vertical folding

Model evolution (2)

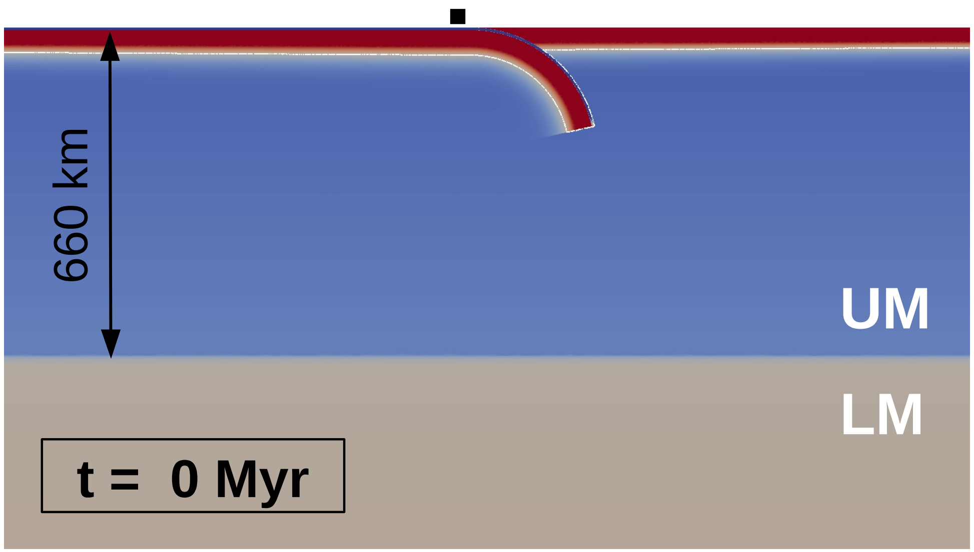
Young, thin OP

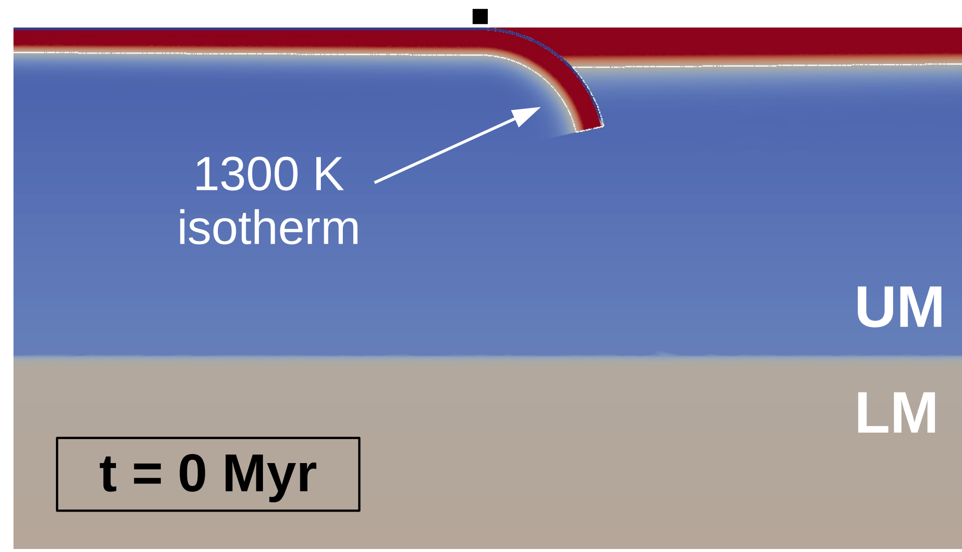
OP initial age at trench = 20 Myr

Old, thick OP

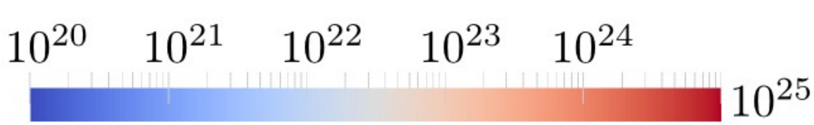
OP initial age at trench = 65 Myr

SP initial age at trench = 30 Myr





Viscosity (Pa.s)



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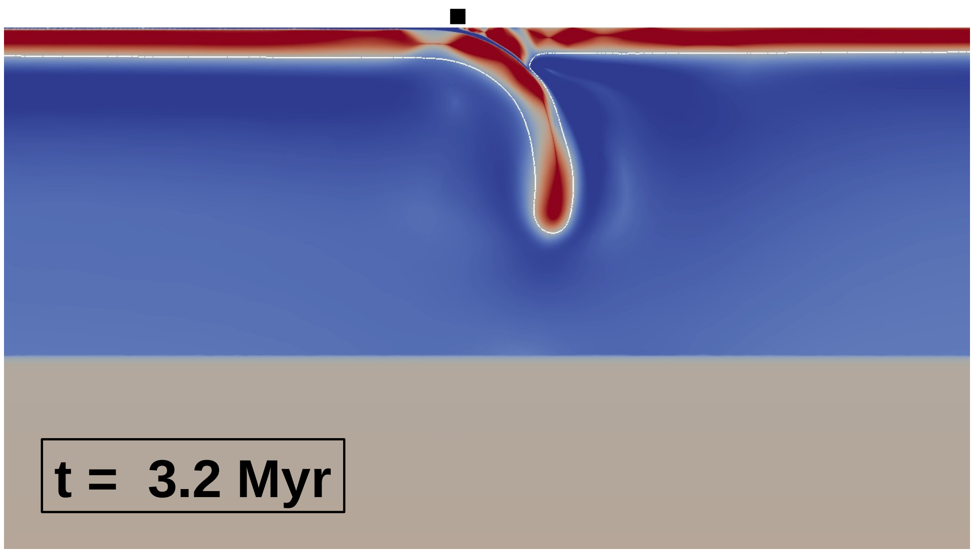

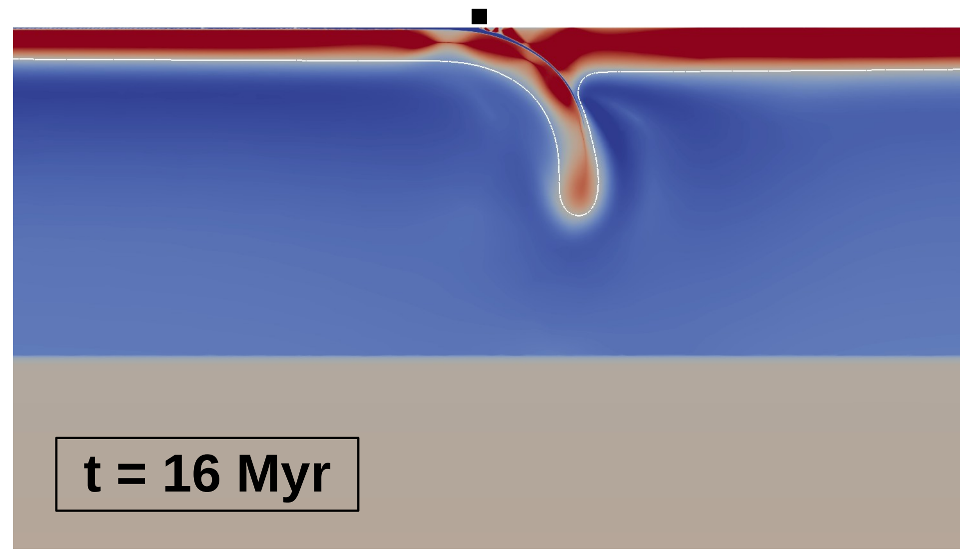

PHASE 1

A thicker overriding plate slows down slab sinking

→ warmer and weaker slab

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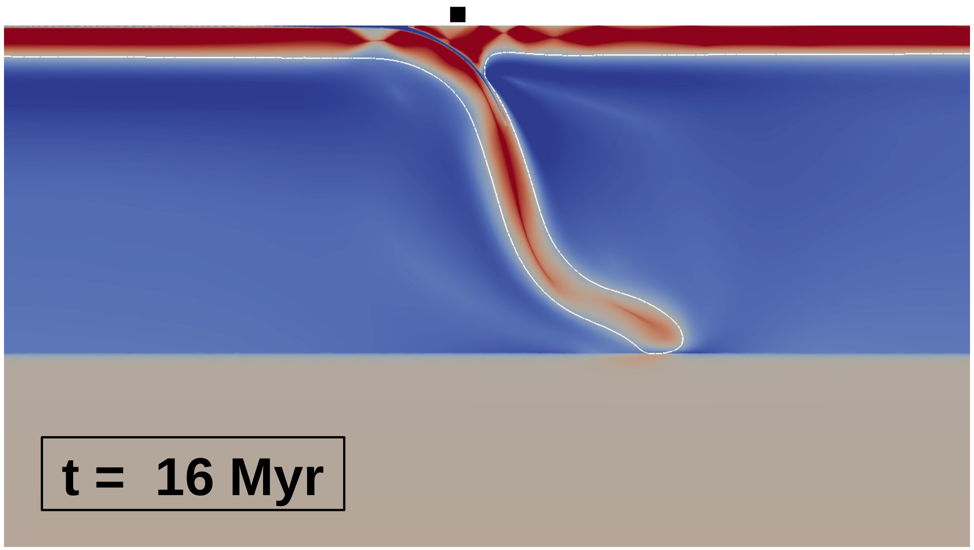
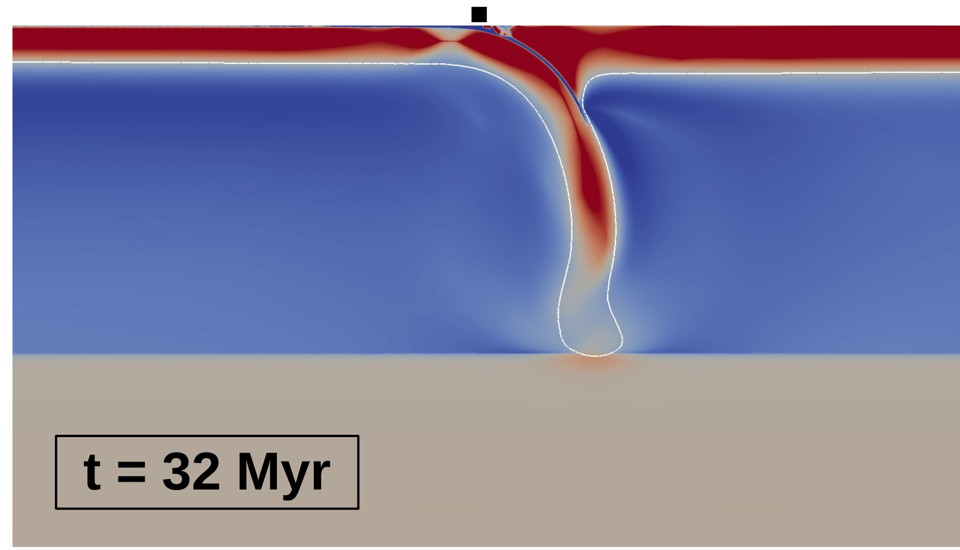
OP initial age at trench = 65 Myr

SP initial age at trench = 30 Myr





PHASE 2

Young (thin) slab is deflected above the viscosity jump.

Slab is able to rollback.

Warm, weak slab tip gets much deformed by the viscosity jump.

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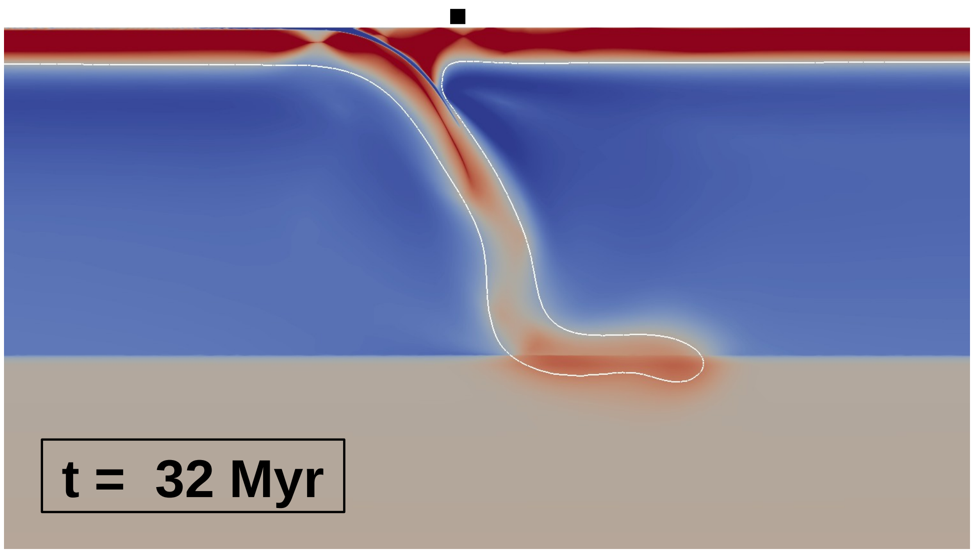
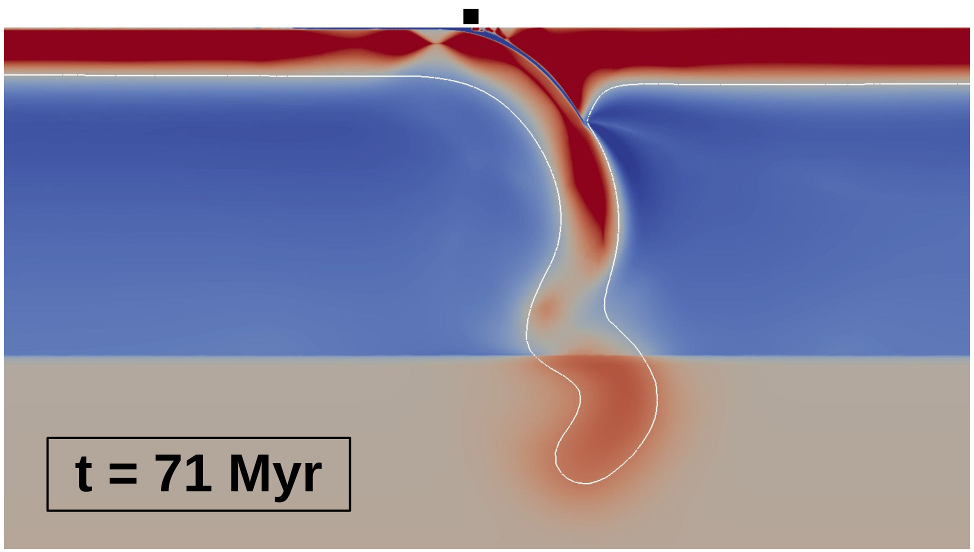
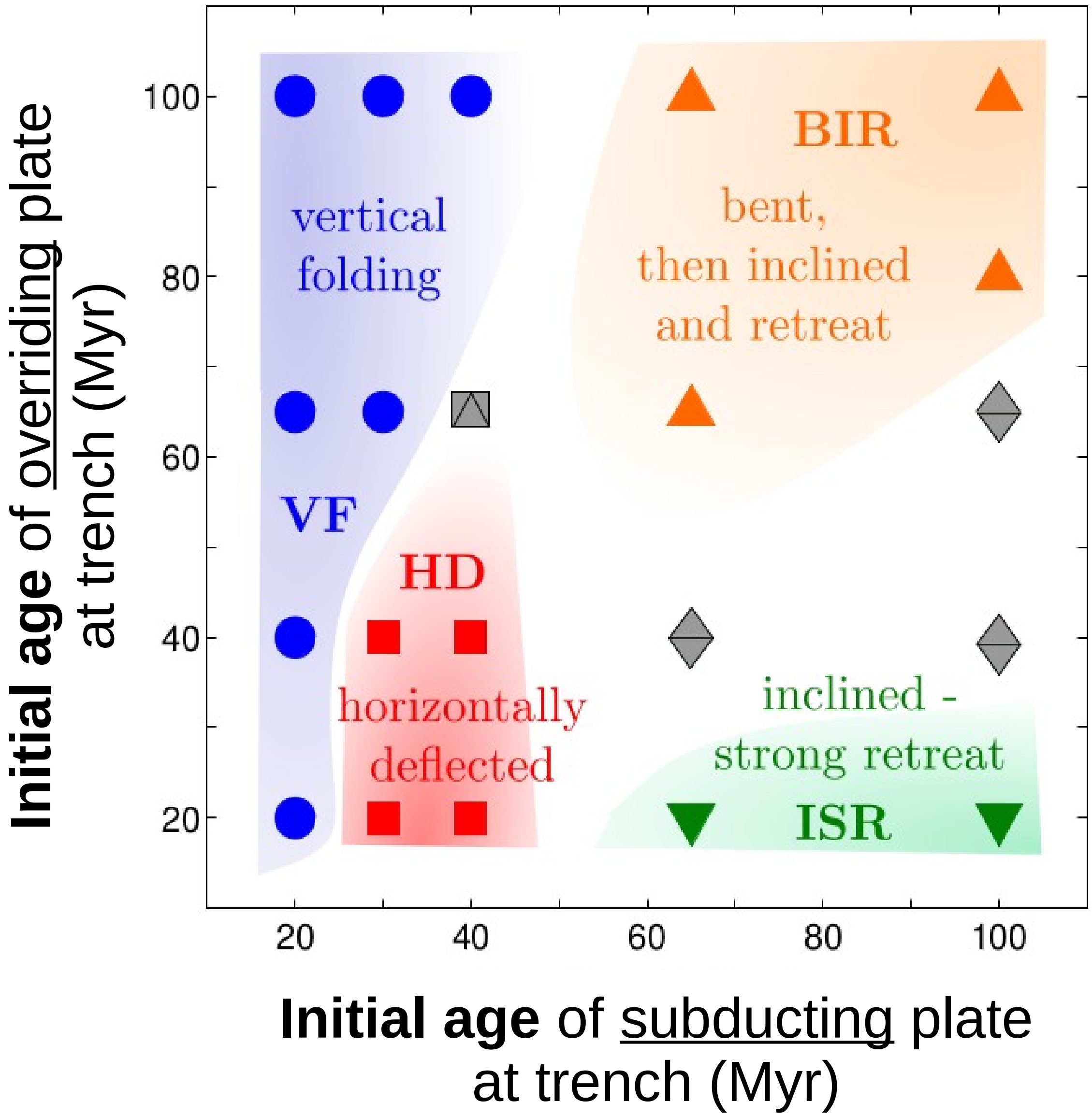


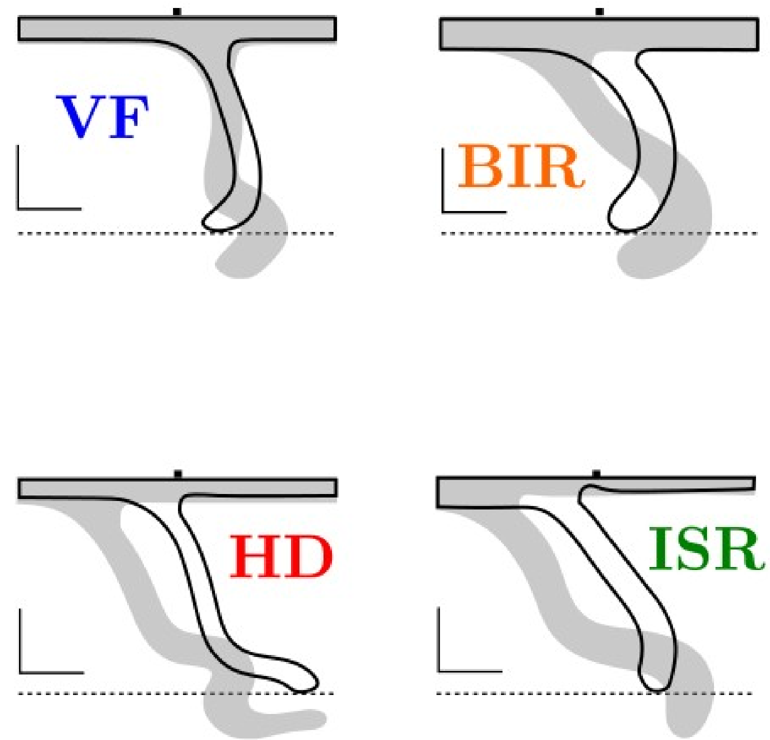


Horizontally deflected slab

Vertical folding

Slab morphology: a regime diagram





Garel et al., G3, 2014 (in press)

Slab deformation in the transition zone: a history-dependent process

Initial plate ages →

Slab Buoyancy
Slab strength
Overriding plate strength

→

Trench motion
Slab sinking rate
Slab bending rate

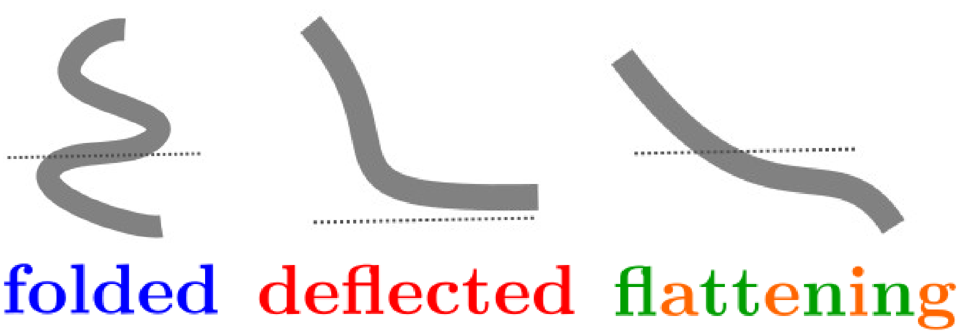
↓ *temperature*

Slab strength

Viscosity increase between UM and LM (10, 30, 100)

←

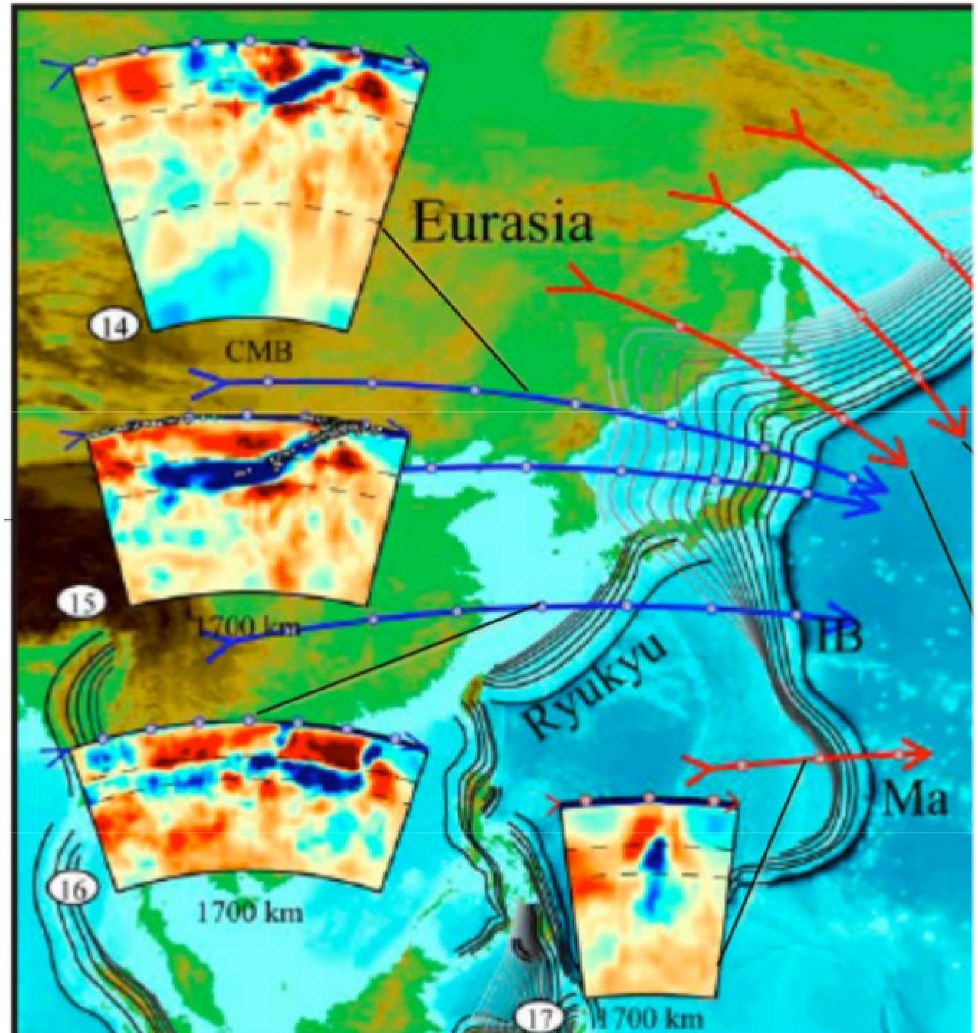
Slab deformation in the TZ

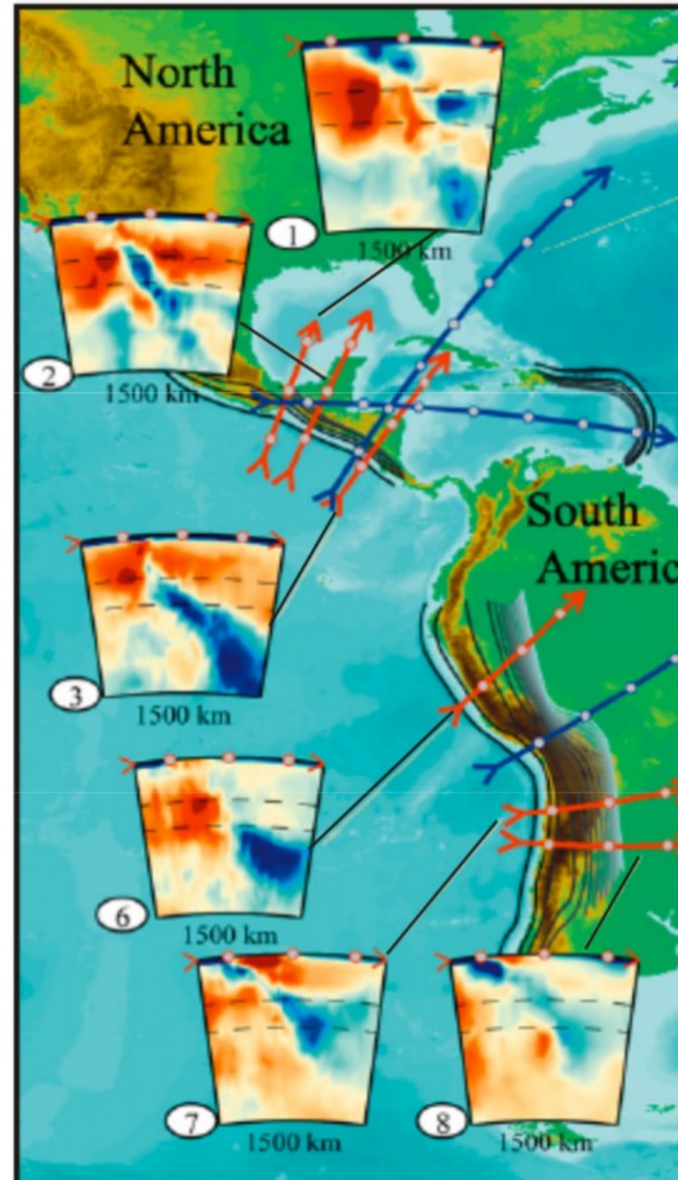


Garel et al., G3, 2014 (in press)

Relevance for Earth subduction zones

(*Li et al., G3, 2008*)





Horizontal-deflected morphologies

↔ young slabs?

Inclined / old slabs?

Present-day age	**OLD**	**YOUNG**
Cenozoic ages	**YOUNG?**	**OLD?**

Conclusions

Regime diagram

→ 4 subduction modes = f (initial plate ages)

→ key role of trench motion and strength evolution

→ compatible with compositional models

(slab buoyancy and strength dictate morphology)

→ additional effect subduction history

(sinking rate → slab temperature → slab strength)

→ 30-fold viscosity increase between upper and lower mantle give range of morphologies similar to seismically-images slabs

Results presented in Garel et al, G3, 2014 (in press)