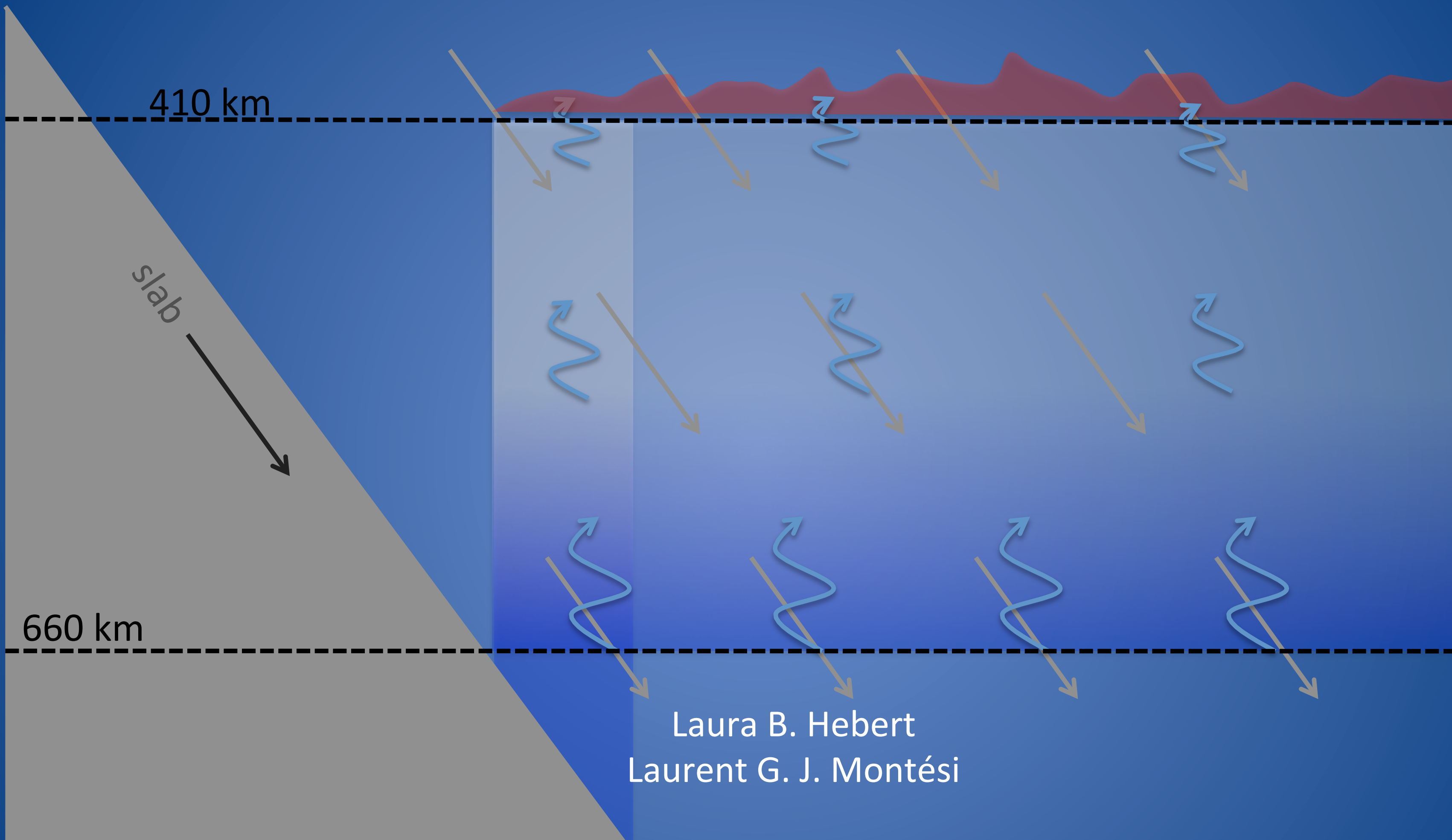
Implications of deep transport of slab-adjacent hydrated material at subduction zones



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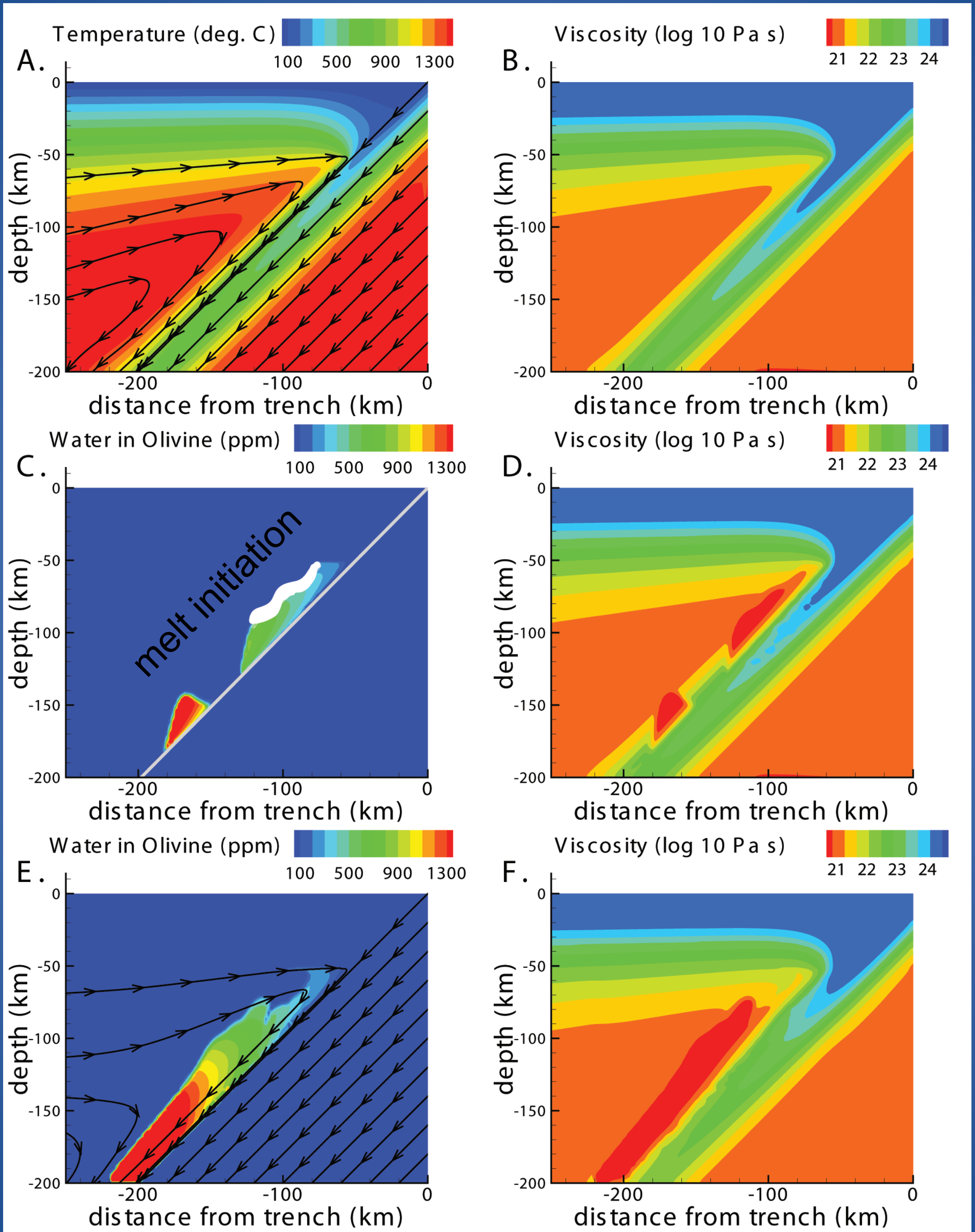
GeoPRISMS SCD Implementation Workshop
January, 2011

Development of a low-viscosity channel:



advection leads to coherent layer of hydrated NAM

LVC is defined by the zone of water-weakening

(1) initial state of the wedge

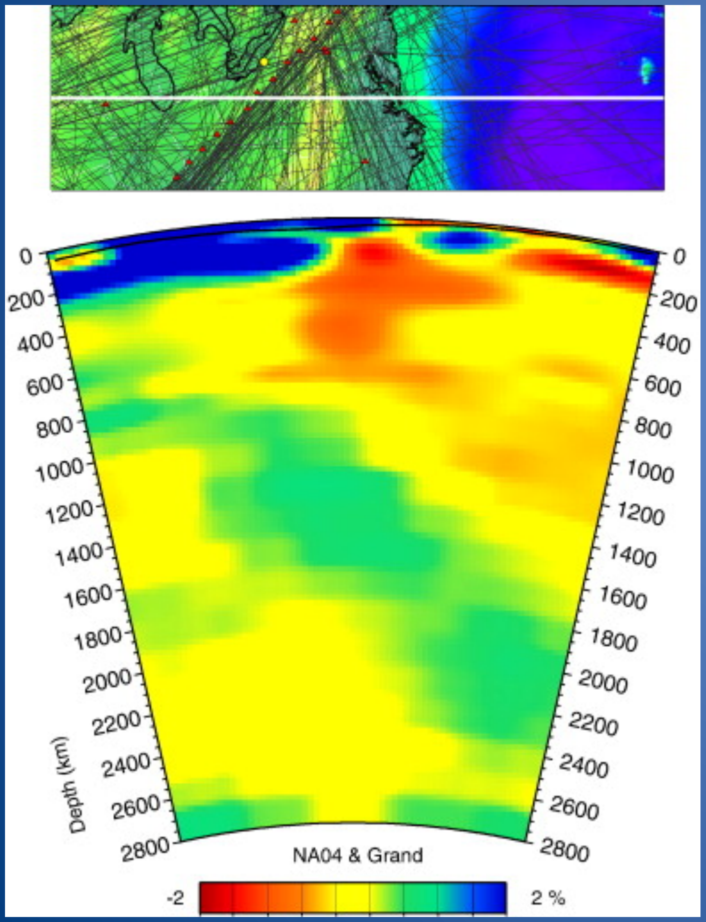
(2) initial influx of fluids

(3) mature development of the wedge

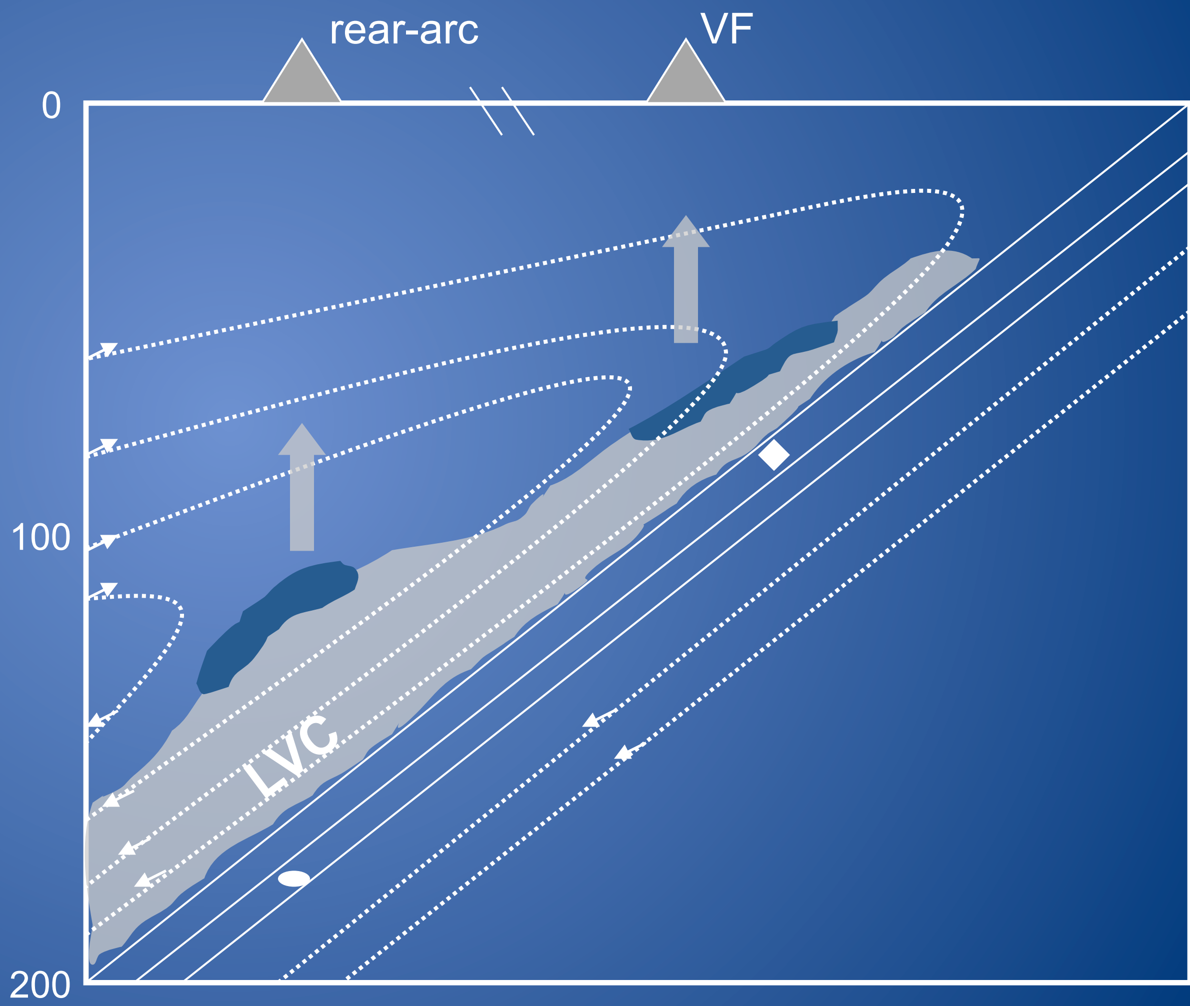
Hebert et al., 2009

Motivation:

- Potentially important dynamical implications for deep (> 200 km) introduction of fluids
- Source of chemical enrichments
- Water addition can effect locations of partial melting



Van der Lee et al., 2008

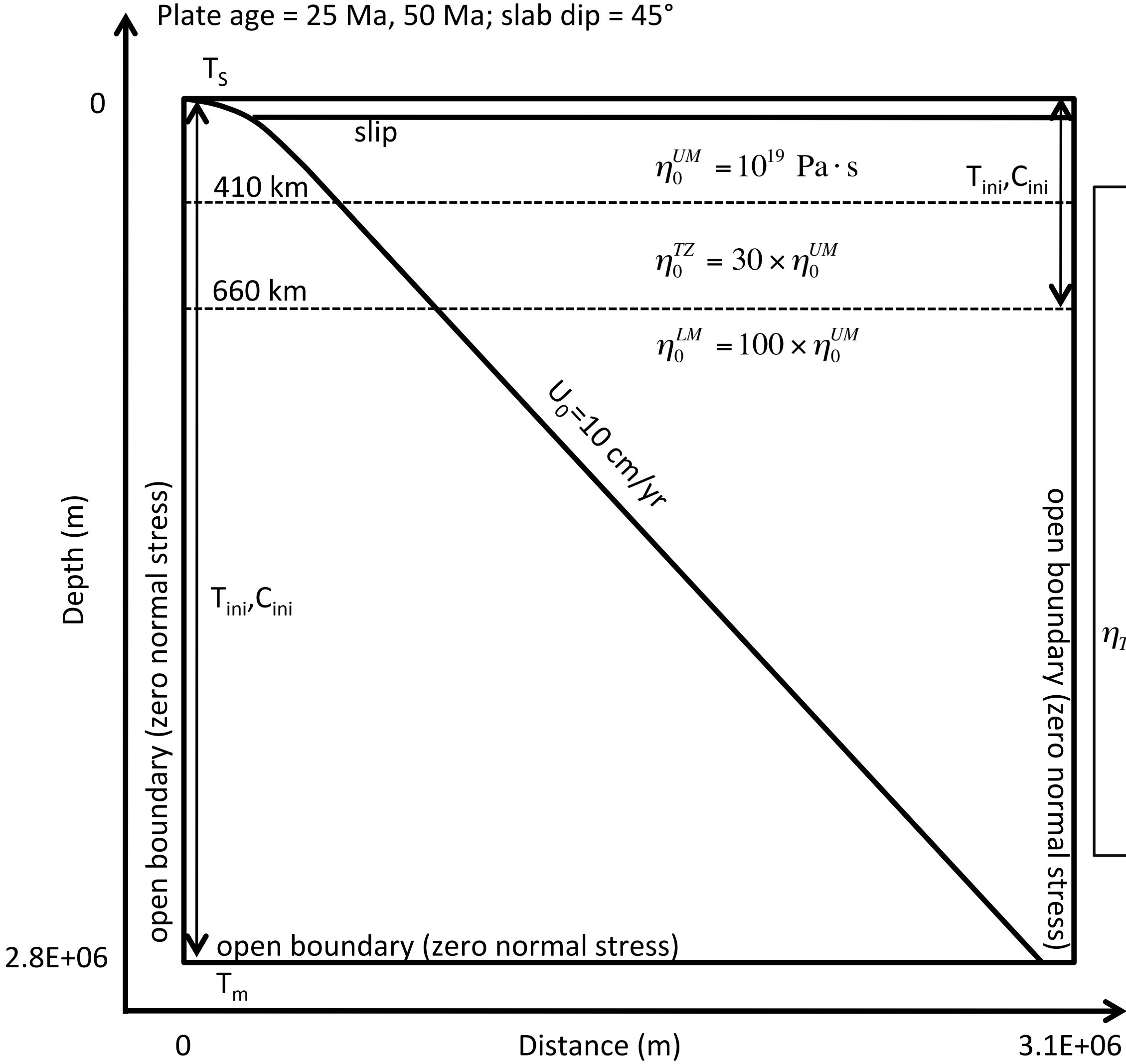


Hebert et al., 2009

Model Schematic

$\eta_{\max} = 10^{25}\ \mathrm{Pa \cdot s}$

Plate age = 25 Ma, 50 Ma; slab dip = 45°



Using COMSOL Multiphysics® 3.4 in 2-D:

$$\nabla \cdot \mathbf{u} = 0$$

$$-\nabla \cdot \left[\eta\left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T\right)\right] + \rho(\mathbf{u} \cdot \nabla)\mathbf{u} + \nabla p = \mathbf{F}$$

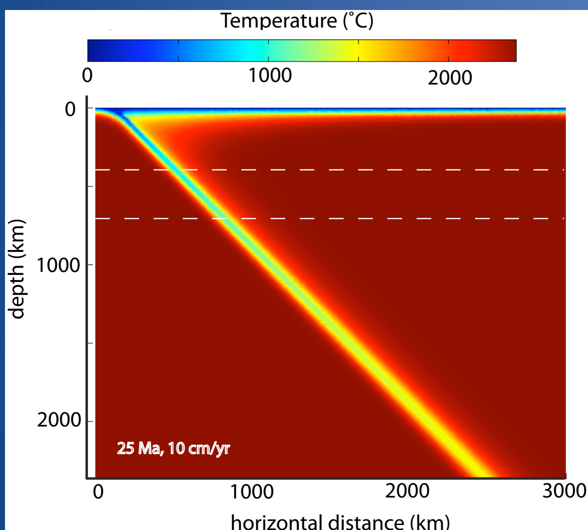
$$\nabla \cdot (-k\nabla T) = \rho C_P (\mathbf{u} \cdot \nabla) T$$

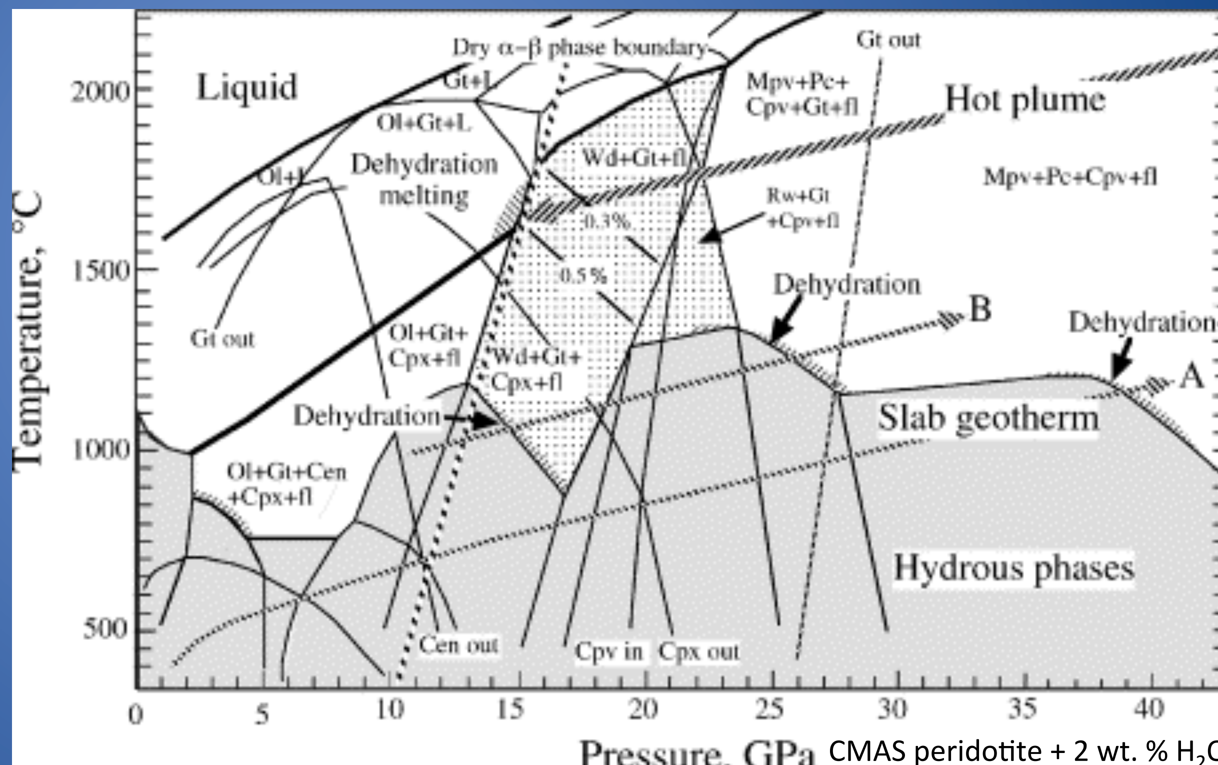
$$\eta_{T,C} = \min\left(\eta_0^{region} \exp\left[\frac{Q}{R}\left(\frac{1}{T} - \frac{1}{T_m}\right)\right] * \left(\frac{C_{OH}}{C_{OH}^{thres}}\right)^{-1}, \eta_{\max}\right)$$

$$\mathbf{F}_y = \mathbf{g} * \left[\rho_0 - \left(V_{fluid} * (\rho_{fluid}) + (1 - V_{fluid}) * \rho_{solid}\right)\right]$$

Determining Dehydration Locations within the Slab

- Map P-T trajectories from model thermal result (assuming by 200 km depth, lithospheric serpentinite is sole water source)

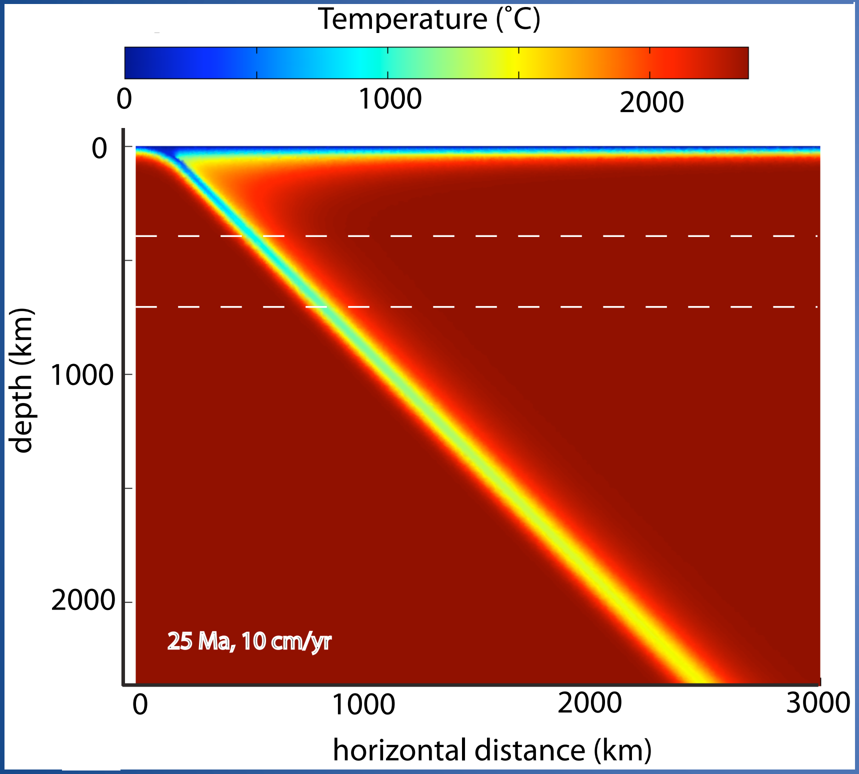


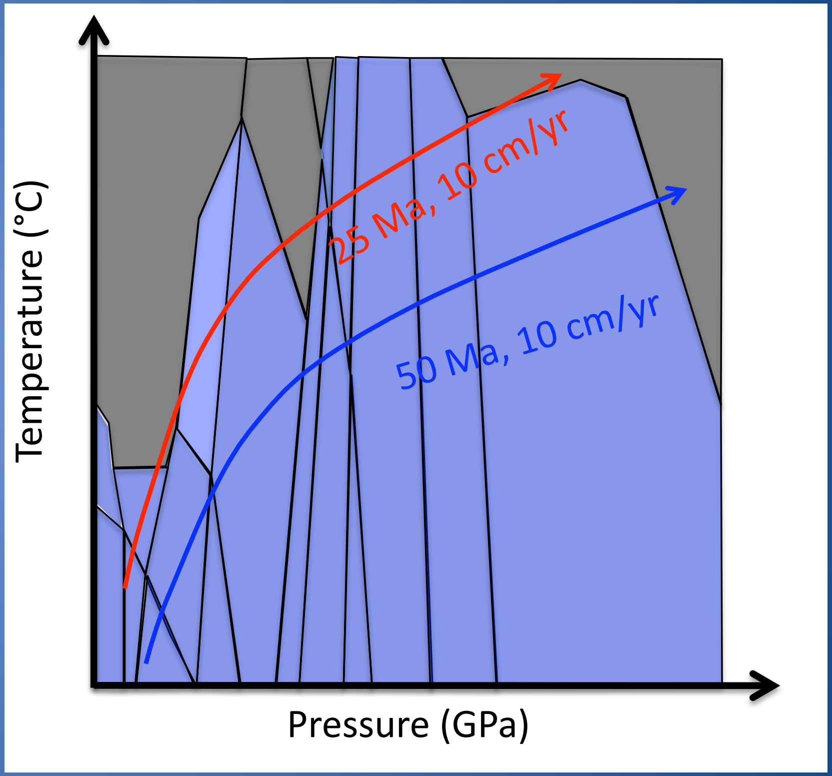


Ohtani et al., 2004

- 6 km of hydrated lithospheric serpentinite beneath 7 km of dehydrated AOC

Determining Dehydration Locations within the Slab





•Changing slab age leads to a changing thermal structure and therefore a change in dehydration location within the slab

Including Fluid Sources and Sinks into models

$$\nabla \cdot \left(-\alpha_{NAM} \nabla c_{NAM}\right) = R - \mathbf{u}_{solid} \cdot \nabla c_{NAM},$$

$$0 = R - \mathbf{u}_{fluid} \cdot \nabla c_{fluid},$$

$$R = (source + sink)$$

- Utilizing multiple COMSOL Multiphysics Applications

Determining Fluid Velocity and Trajectory

$$\mathbf{u}_{fluid} = \mathbf{u}_{solid} + \frac{\mathbf{S}}{\phi},$$

$$\mathbf{S} = \frac{\Delta\rho \mathbf{g} k}{\mu_{fluid}},$$

$$k = \frac{\phi^3 d^2}{270}$$

$$\Delta\rho = 2300 \mathrm{kg} \cdot \mathrm{m}^3$$

$$\phi = 0.0005 - 0.01$$

$$d = 3 - 10 \mathrm{mm}$$

$$\mu_{fluid} = 0.001 \text{ - } 10 \mathrm{Pa} \cdot \mathrm{s}$$

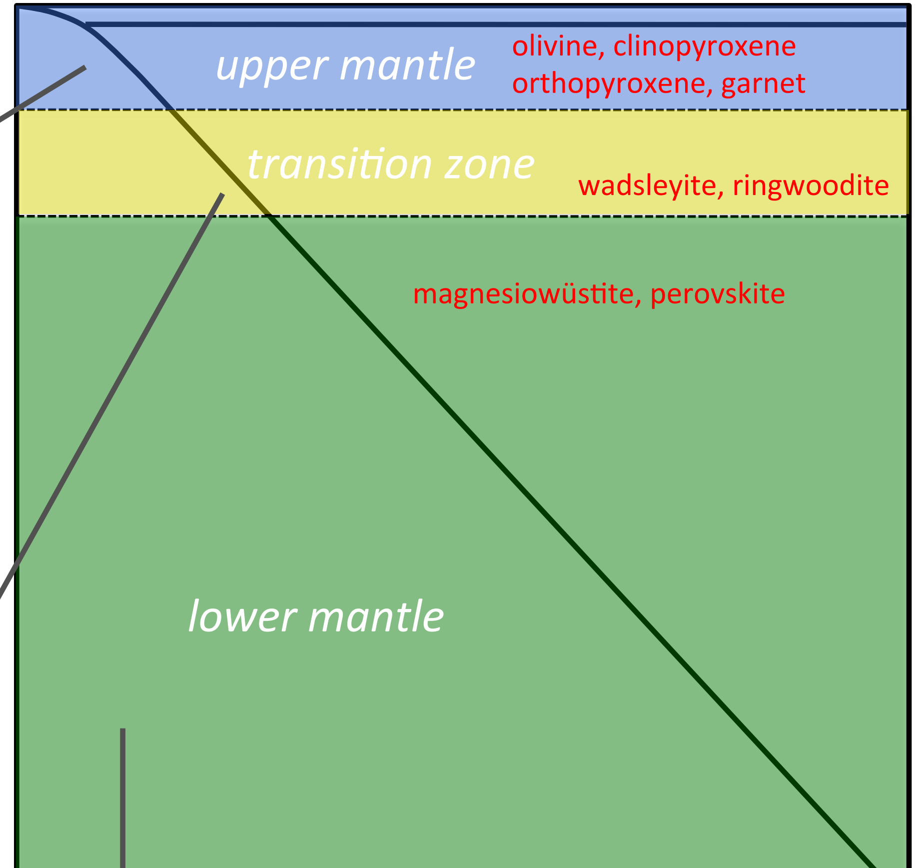
Investigate a range of $\frac{\mathbf{S}}{\phi}$ ~ 10^{-11} to 10^{-6} m/s

After Cagnioncle et al. (2007), Wark et al. (2003), and Audetat and Keppler (2004)

Water storage capacity

After Hirschmann et al. (2005), we estimate the storage capacity of the upper mantle based on:

- the storage capacity of olivine
- Partitioning of H_2O between olivine and other mantle minerals
- Variation in modal mineralogy with depth



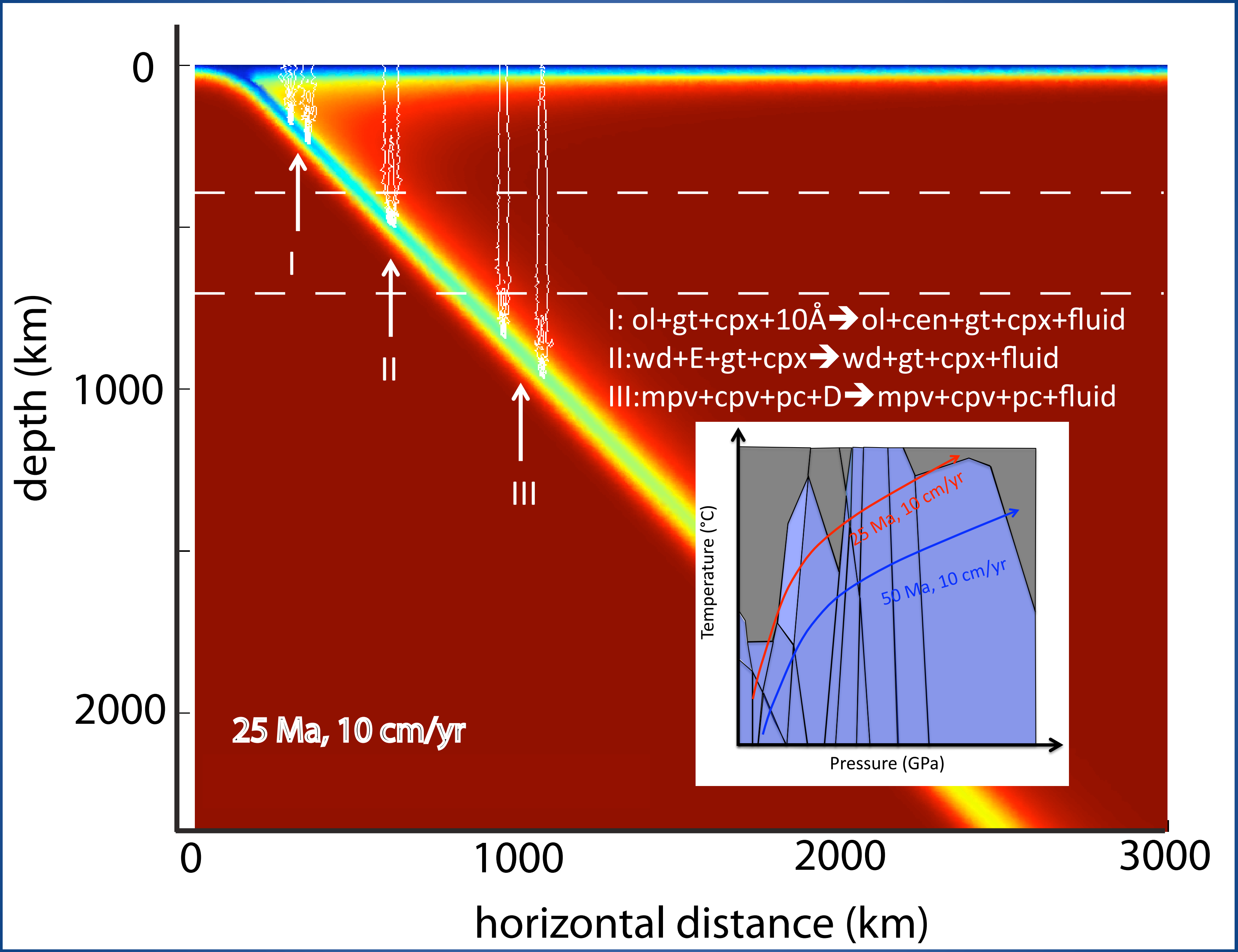
$$sol_{OH}^{TZ} = 2.5\text{wt.\%}$$

Murakami et al. (2002)

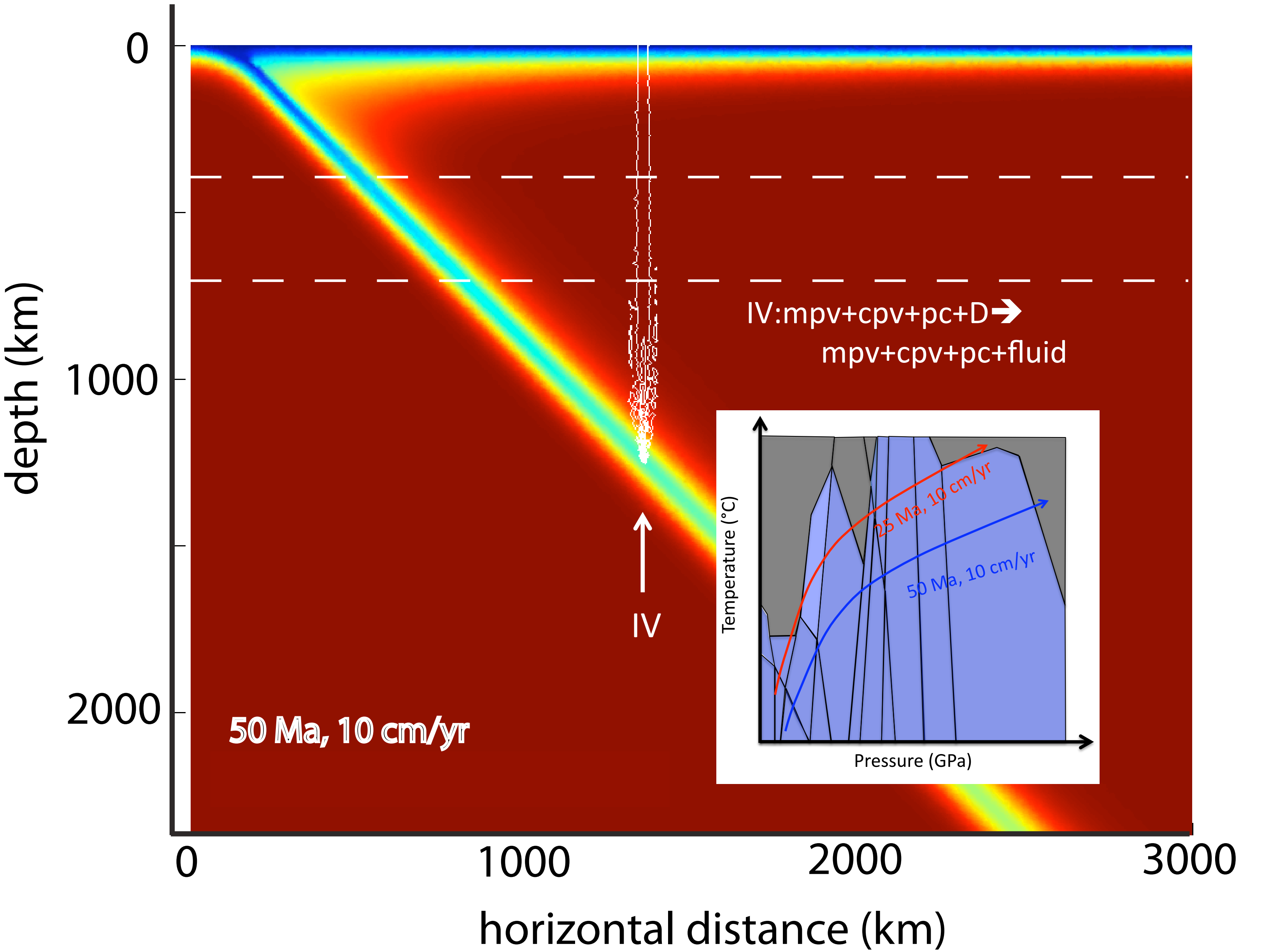
$$sol_{OH}^{LM,HIGHEST=1} = 0.2\text{wt. \%}$$

$$sol_{OH}^{LM,HIGHEST=0} = A(T) f_{H_2O}^{0.5} \exp\left[\frac{\left(-P\Delta V^{solid}\right)}{RT}\right]$$

Bolfan-Casanova et al. (2002)



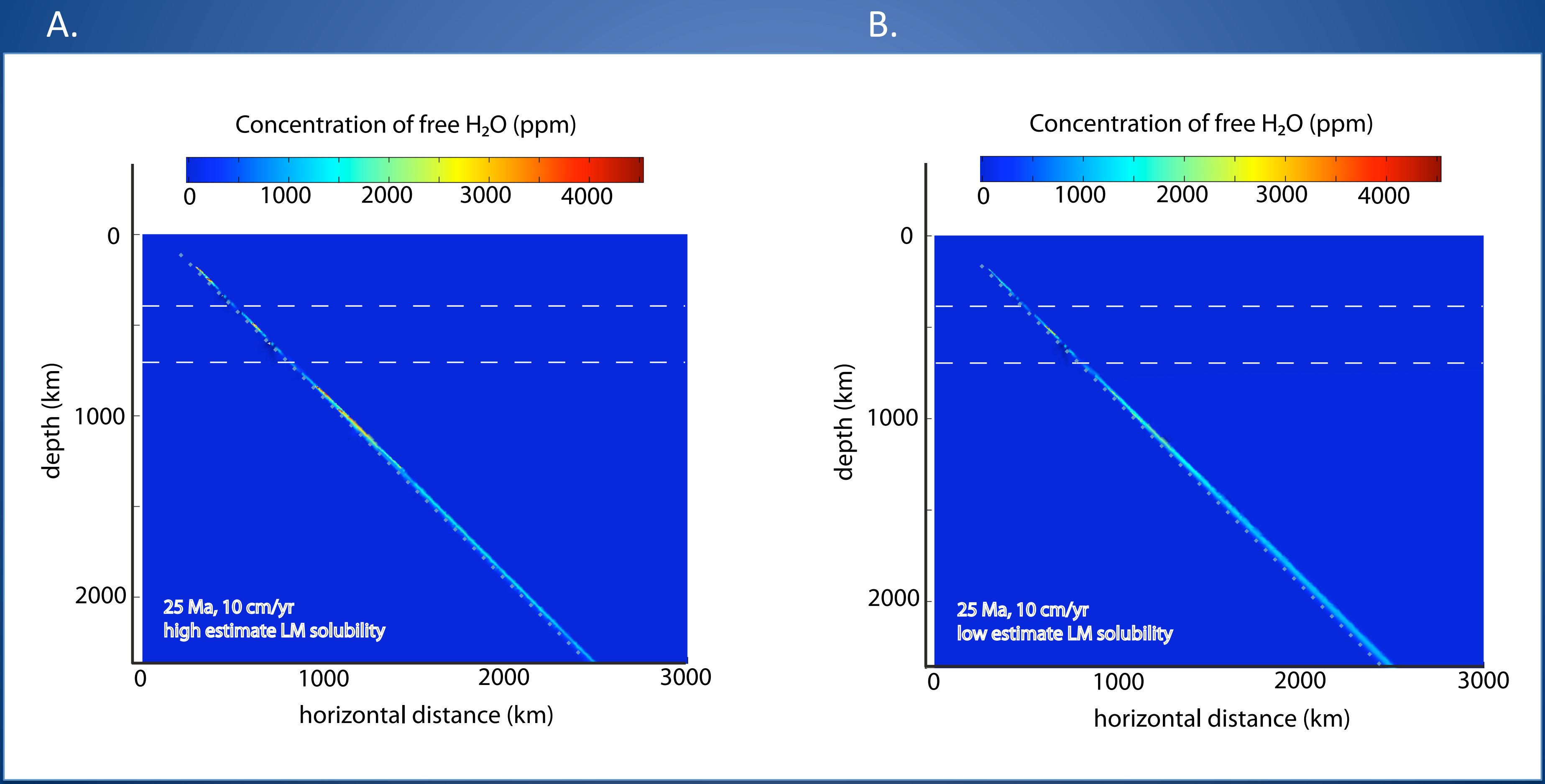
0
1000
2000
depth (km)
0
1000
2000
3000
horizontal distance (km)
I
II
III
I: ol+gt+cpx+10Å→ol+cen+gt+cpx+fluid
II:wd+E+gt+cpx→wd+gt+cpx+fluid
III:mpv+cpv+pc+D→mpv+cpv+pc+fluid
25 Ma, 10 cm/yr
Temperature (°C)
Pressure (GPa)
25 Ma, 10 cm/yr
50 Ma, 10 cm/yr



depth (km)
0
1000
2000
IV:mpv+cpv+pc+D➔
mpv+cpv+pc+fluid
IV
50 Ma, 10 cm/yr
Temperature (°C)
25 Ma, 10 cm/yr
50 Ma, 10 cm/yr
Pressure (GPa)
0
1000
2000
3000
horizontal distance (km)

Results: Free Water
(fluid velocity ~ 10^{-11} m/s)

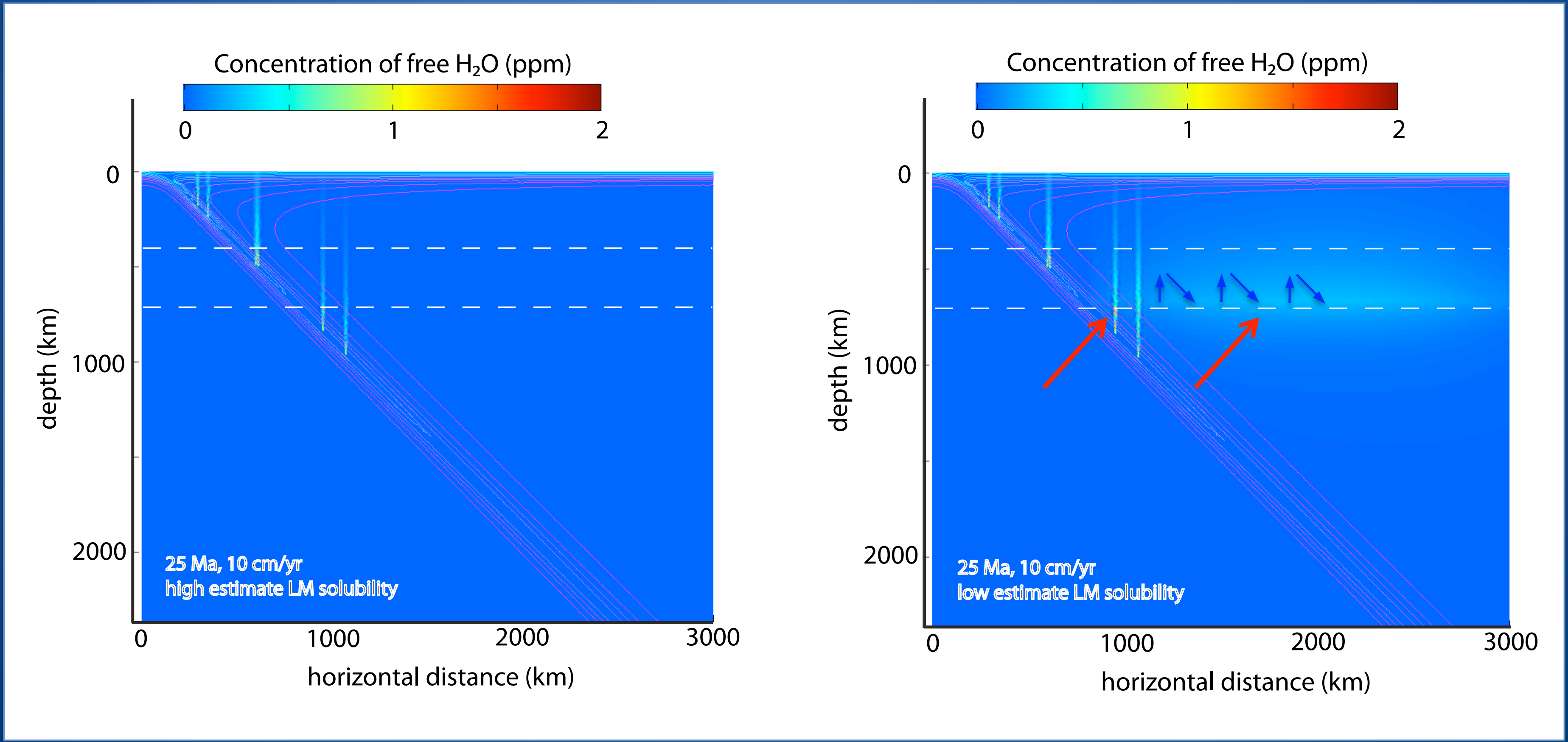
- Dehydration results in a near-slab-parallel fluid trajectory
- Fluids are transported with the solid flow field



Results: Free Water
(fluid velocity ~ 10^{-6} m/s)

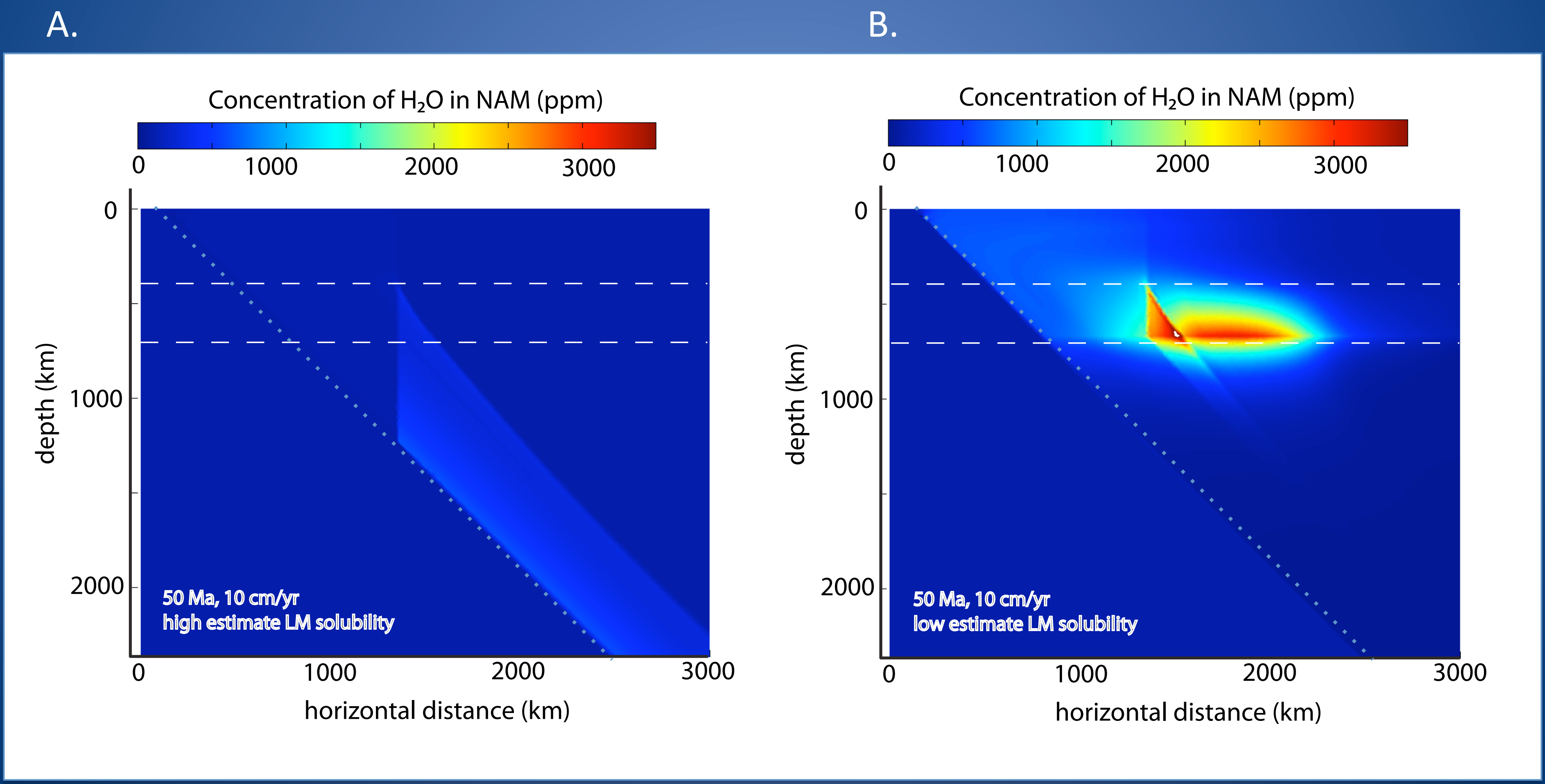
- Dehydration results in rapid, nearly vertical fluid migration
- Secondary dehydration occurs at the base of the transition zone, resulting in additional fluid sources, similar to Davies and Stevenson (1992) concept

A. B.



Results: *Held Water*

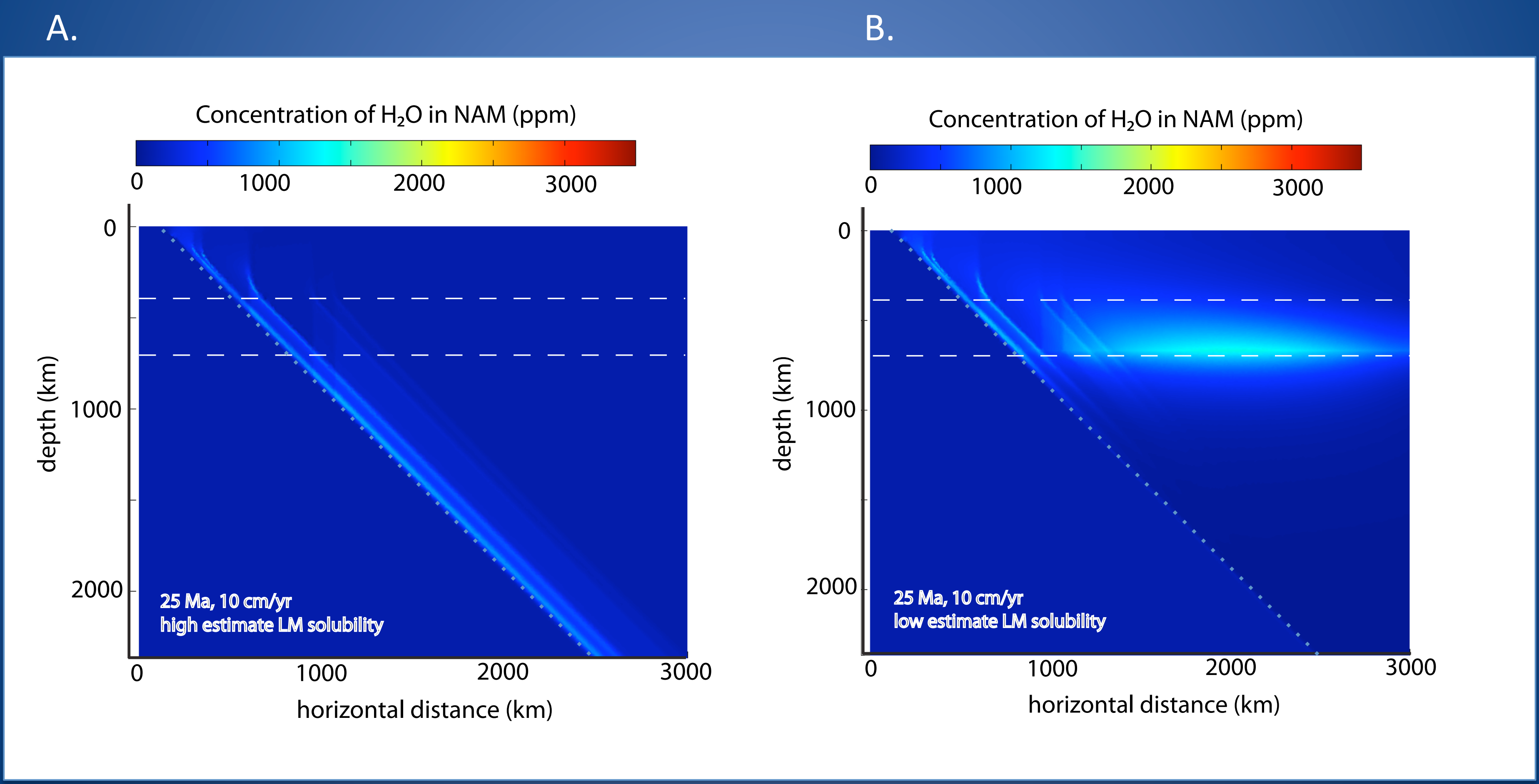
•Fluid migrating up into the wedge is taken up by nominally-anhydrous minerals, and then advected with the solid flow field



•Upward percolation of fluid expelled from the slab as well as adjacent down-dragged mantle entering the lower mantle act to hydrate the transition zone local to the subducting slab

Results: *Held Water*

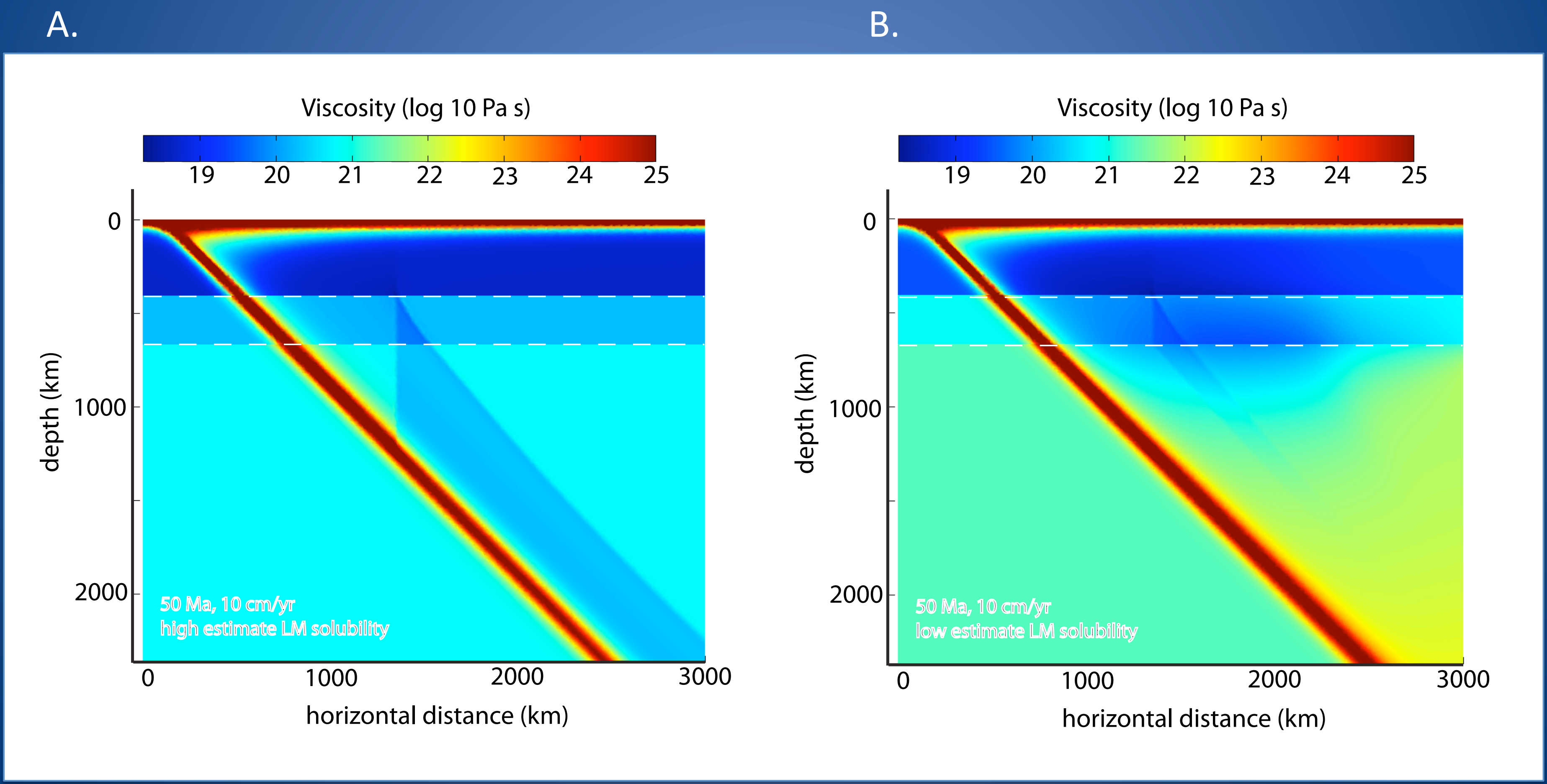
- Fluid migrating up into the wedge is taken up by nominally-anhydrous minerals, and then advected with the solid flow field



•Evaluate: high or low storage capacity estimate for water in lower mantle NAM

Results: Viscosity

- Water held in NAM may strongly influence the viscosity structure-leading to overall changes in the flow structure



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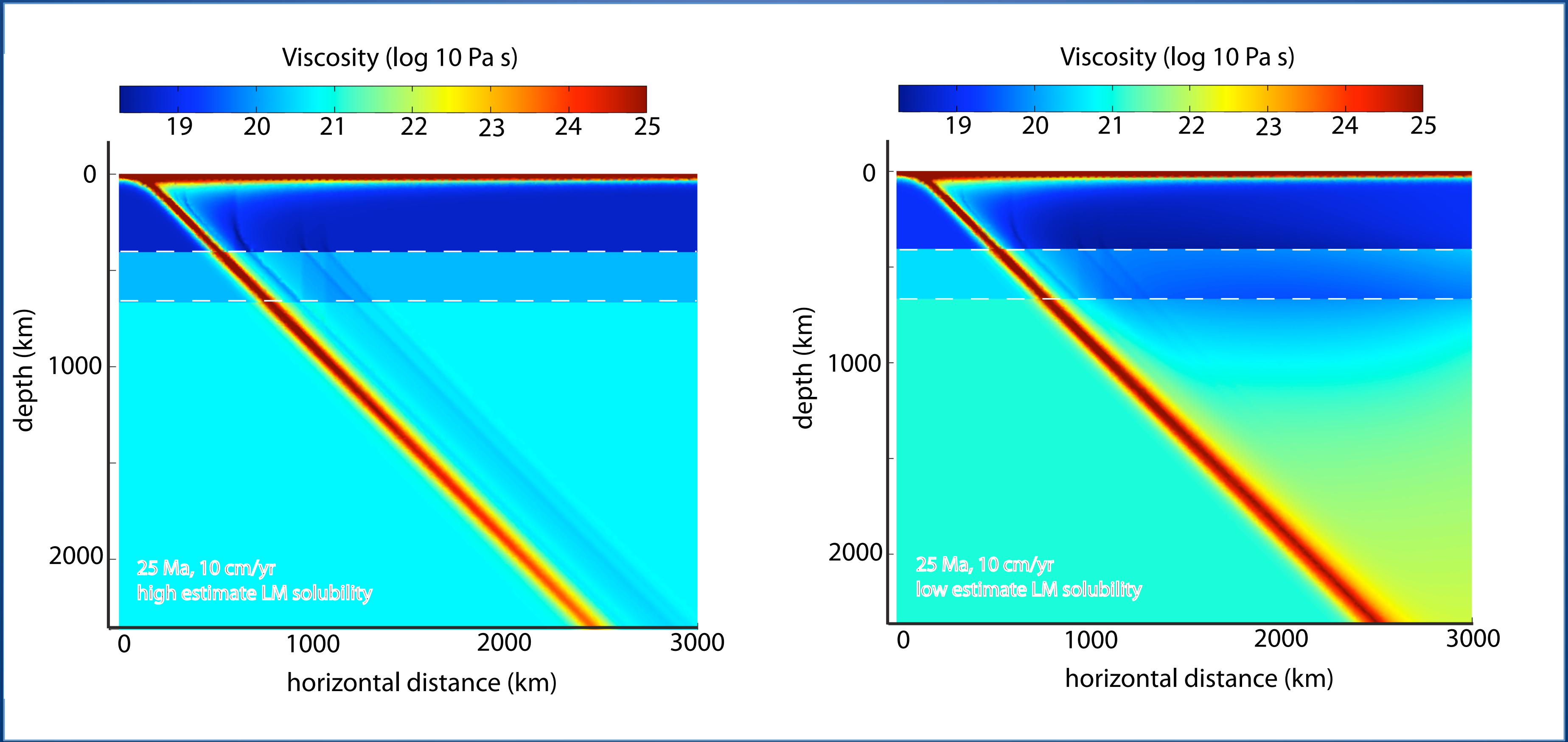
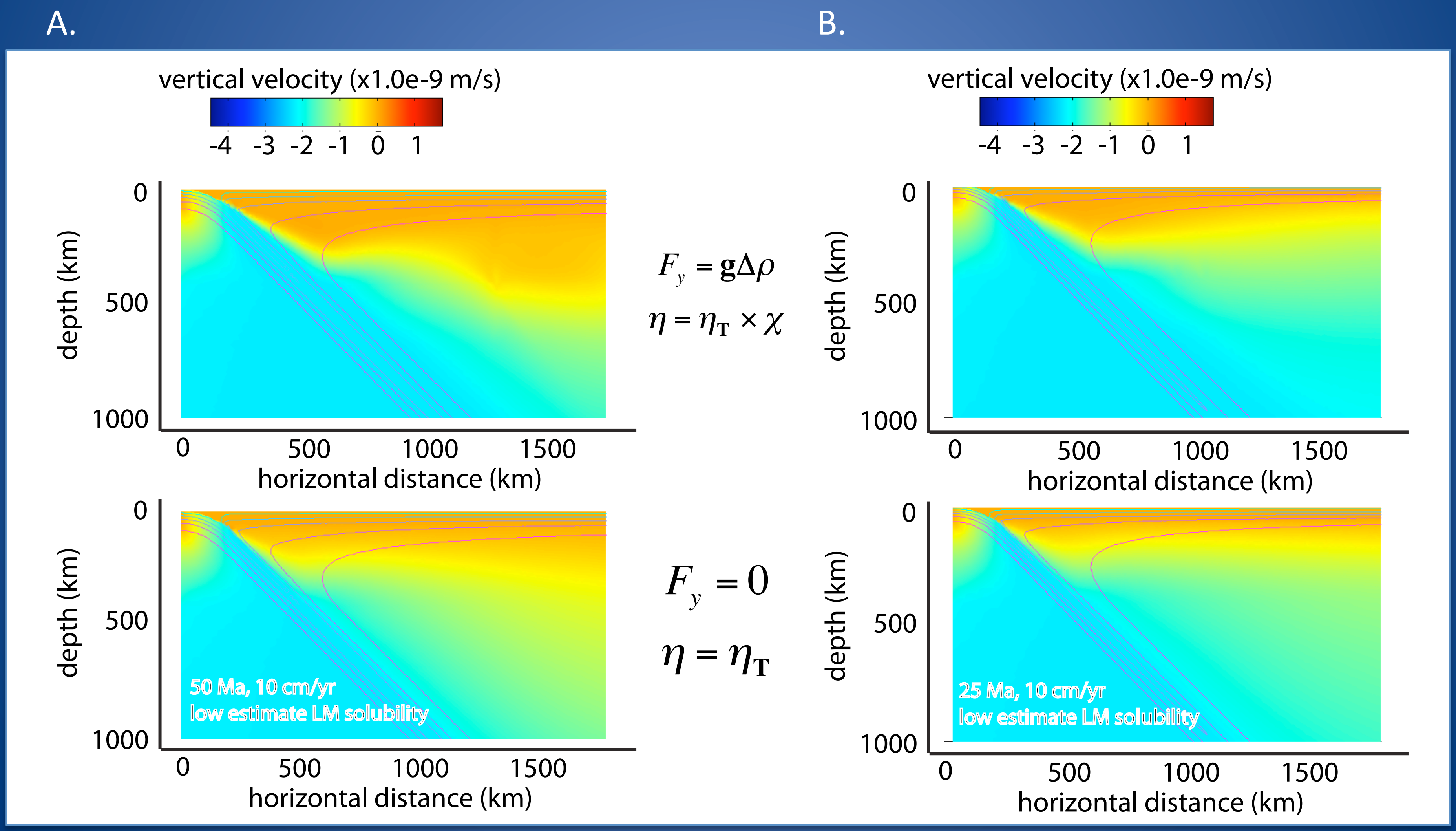
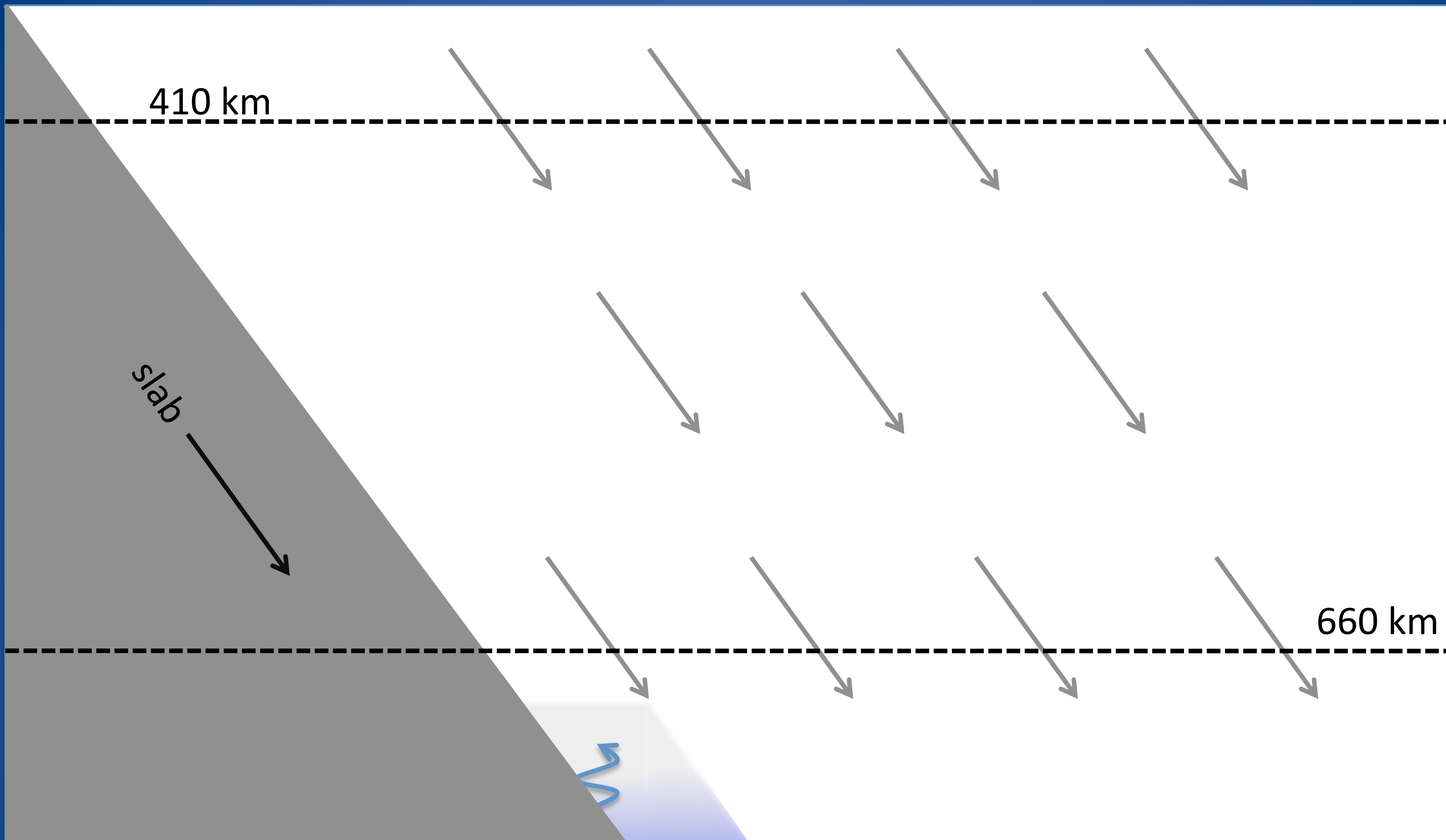


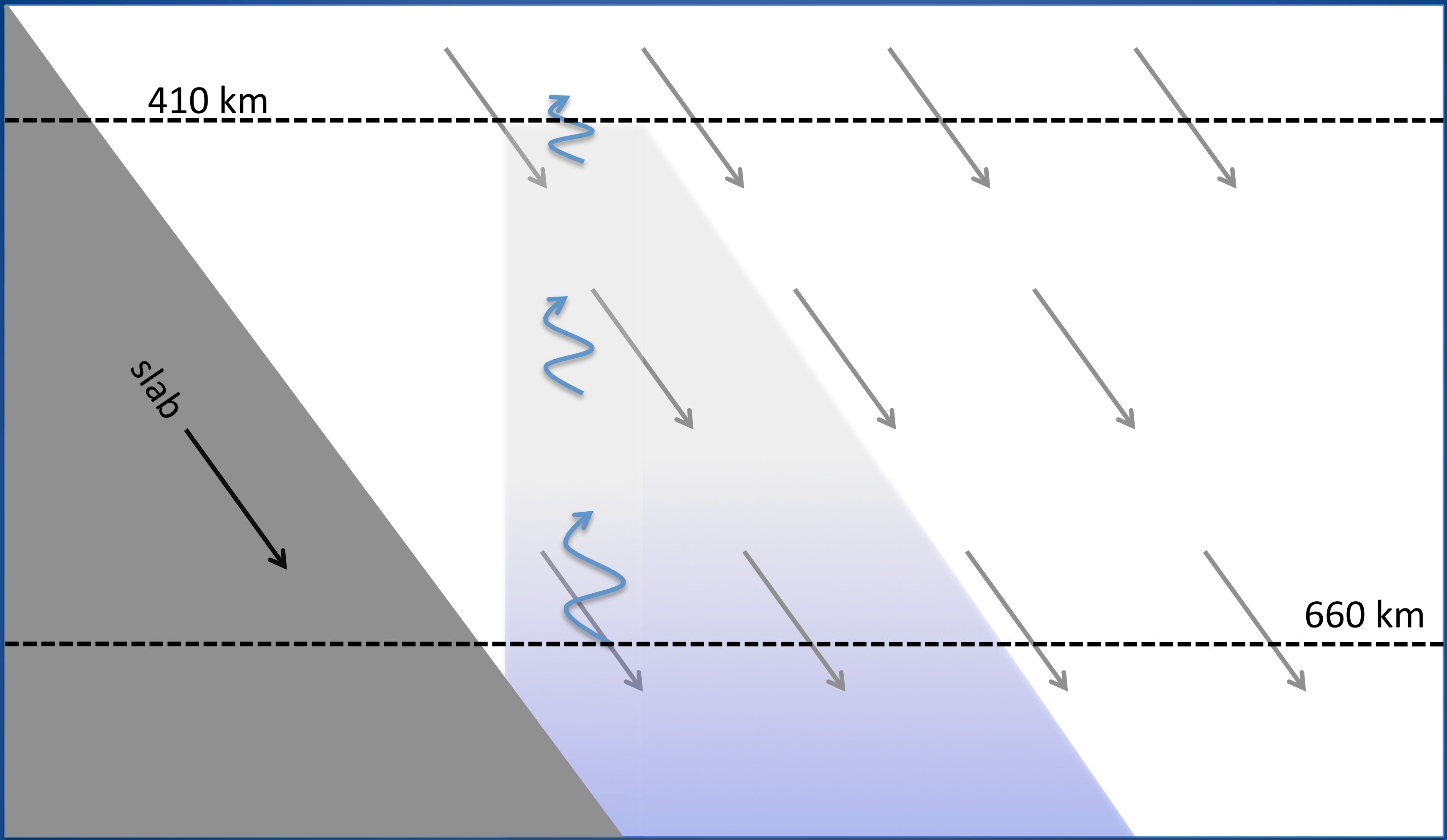
Results: *Vertical velocity*

• Enhanced upwelling is observed when compositional dependence in viscosity and buoyancy is taken into consideration

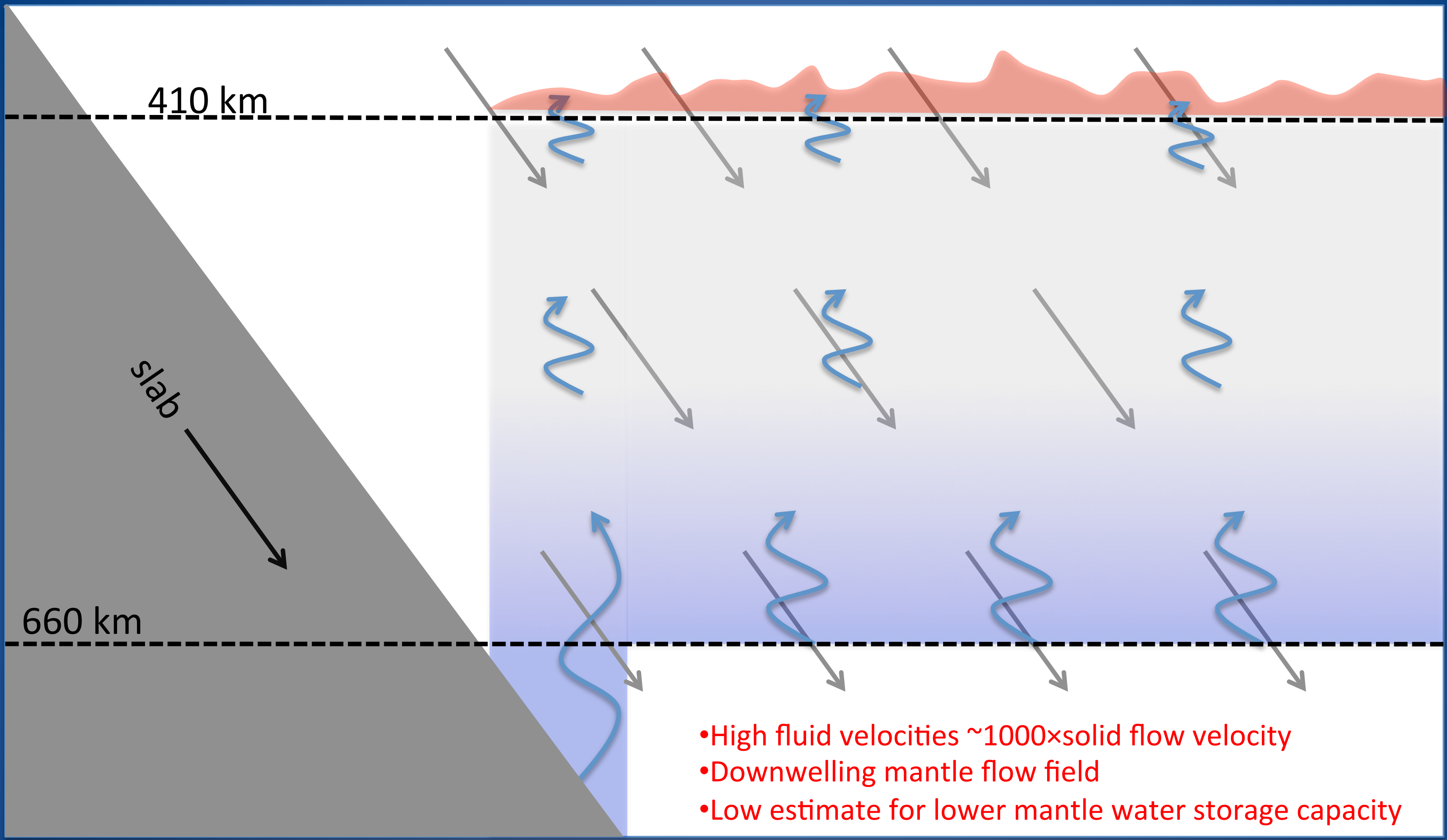




For lower estimates of fluid velocity, independent of lower mantle storage capacity, there is the potential for significant amounts of water to reach great depths in a relatively thin fluid envelope immediately adjacent to the slab.



With a higher estimate of lower mantle water storage capacity, and high fluid velocity estimates, there is no secondary dehydration at the base of the transition zone, leading to the potential for significant amounts of water to reach great depths stored in NAM.



For the lower estimate of water storage capacity and high fluid velocity estimates, a balance between fluid advection and release allows for the development of a local hydrated transition zone, leading to <u>elevated water contents in NAM immediately above the transition zone</u> on the order of ~500 ppm-perhaps <u>allowing for the development of a partial melting layer</u> at 400 km depth

Conclusions

- We evaluated deep slab dehydration and the development of a hydrated region, which changes geometry based on subduction parameters, fluid velocity estimates, and lower mantle water storage capacity estimates

- We evaluated the modification of the velocity field using a compositional dependence within the viscosity formulation and compositional buoyancy

- A “wet” transition zone may be initiated near a subduction zone if lower estimates for water storage capacity in the lower mantle and rapid fluid velocities are correct

Applications for GeoPRISMS:

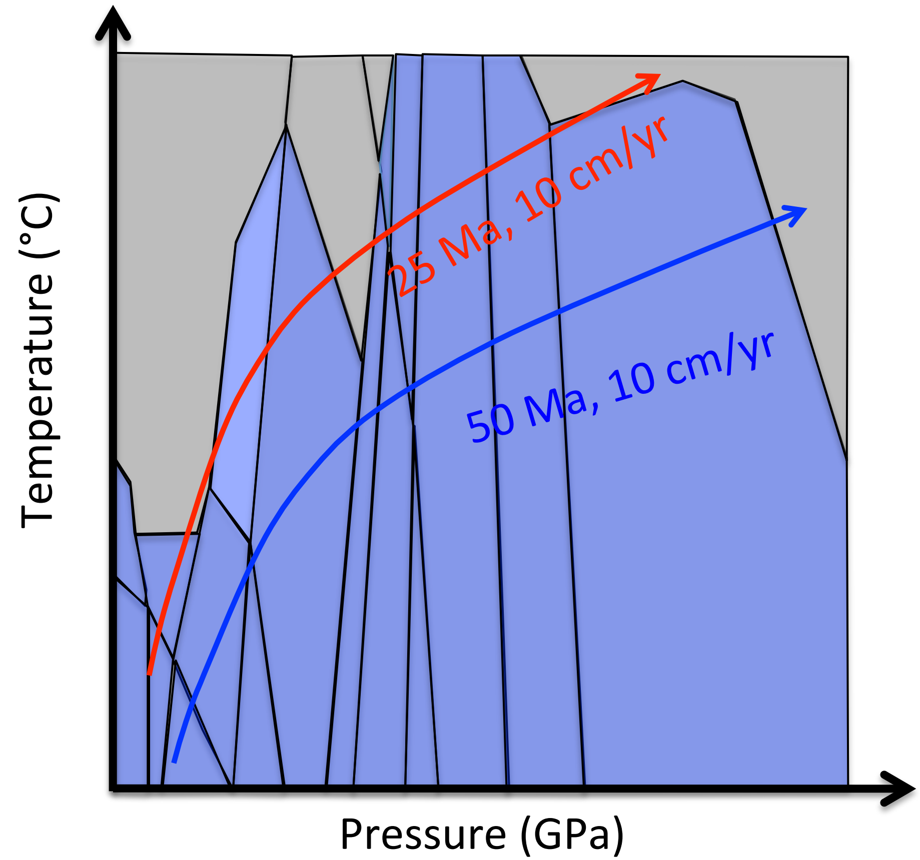
•How does volatile release from the slab influence mantle dynamics?

•How are volatiles and fluids stored, transferred, and released through the subduction system?

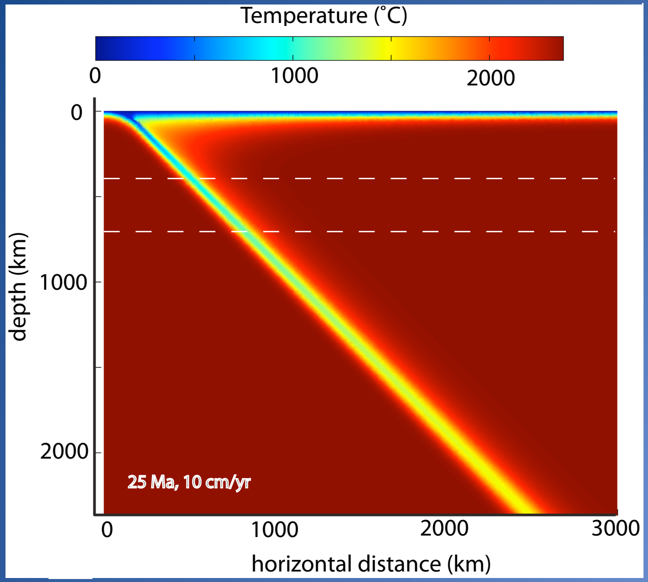
•What are the fluxes of volatiles delivered to the mantle from the subducting slab?

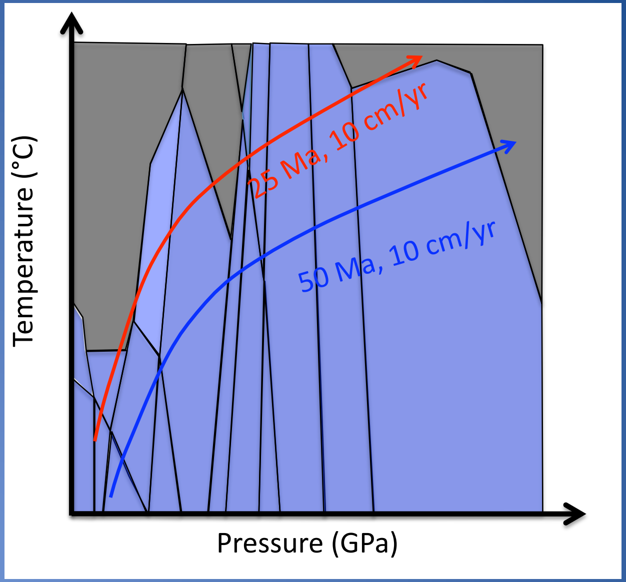
✓We have the numerical tools to provide a context for interdisciplinary studies

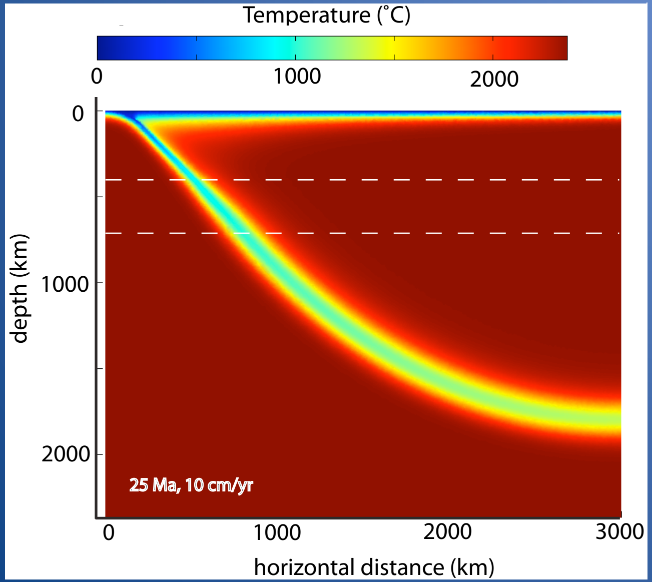
✓The scope of GeoPRISMS should be expansive enough to include (and to encourage) links between communities

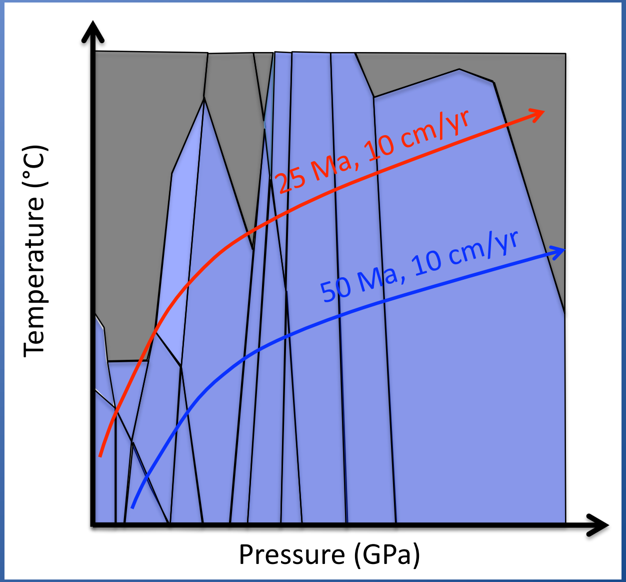

Temperature (°C)
Pressure (GPa)
25 Ma, 10 cm/yr
50 Ma, 10 cm/yr

Determining Dehydration Locations within the Slab









Water storage capacity

$$C_{OH}^{ol} = 10^{\left(-1.194+2.263*\left(\frac{-y}{1000}\right)^{0.128}\right)}$$

$$C_{OH}^{opx} = C_{OH}^{ol} * D_{H_2O}^{opx/ol}$$

$$C_{OH}^{cpx} = C_{OH}^{ol} * D_{H_2O}^{cpx/ol}$$

$$C_{OH}^{gt} = C_{OH}^{ol} * D_{H_2O}^{gt/ol}$$

$$X_{ol} = 0.6$$

$$\mathrm{X}_{\mathrm{cpx}}^{\mathrm{P<2.8GPa}} = 0.12$$

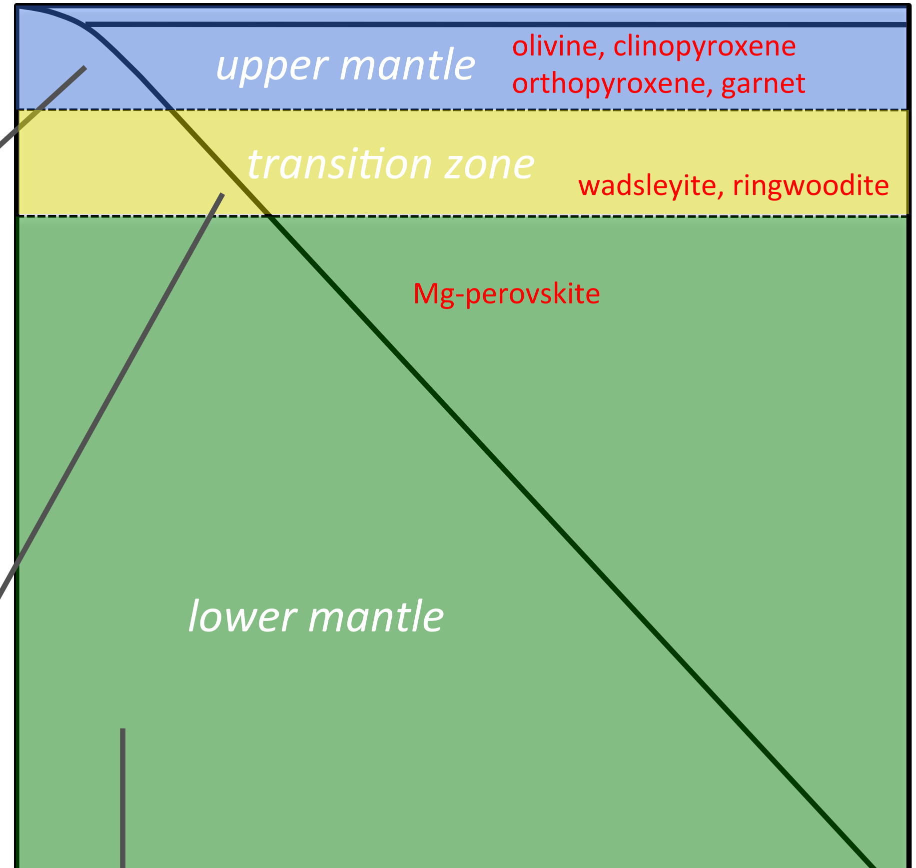
$$\mathrm{X}_{\mathrm{cpx}}^{\mathrm{P>2.8GPa}} = -0.0008*P^3 + 0.0174*P^2$$
$$-0.1022*P + 0.3067$$

$$\mathrm{X}_{\mathrm{gt}}^{\mathrm{2.8<P<3.2GPa}} = 13.5*\frac{P-2.8}{4}$$

$$\mathrm{X}_{\mathrm{gt}}^{\mathrm{P>3.2GPa}} = 0.000297*(P-3.2)^3 - 0.003128*(P-3.2)^2$$
$$+0.01545*(P-3.2) + 0.135$$

$$X_{opx} = 1.0 - \left(X_{ol} + X_{cpx} + X_{gt}\right)$$

$$sol_{OH}^{UM} = \left(X_{ol} * C_{OH}^{ol}\right) + \left(X_{opx} * C_{OH}^{opx}\right) + \left(X_{cpx} * C_{OH}^{cpx}\right) + \left(X_{gt} * C_{OH}^{gt}\right)$$



$$sol_{OH}^{TZ} = 2.5\mathrm{wt.}\%$$

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