TDS-based Porous Flow Modeling in Subduction Zone

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Introduction: Slab dehydration and fluid migration in subduction zone is important because it allows us to understand characteristics of the arc volcanism such as migration of the volcano front as well as the global circulation of water and carbon. However, slab dehydration and fluid migration have not been broadly considered in the numerical modeling because of technical difficulties in the implementation of the relevant governing equations expressed as partial differential equations (PDEs). To minimize the technical difficulties in the implementation of the slab dehydration and fluid migration, the COMSOL Multiphysics® is used.

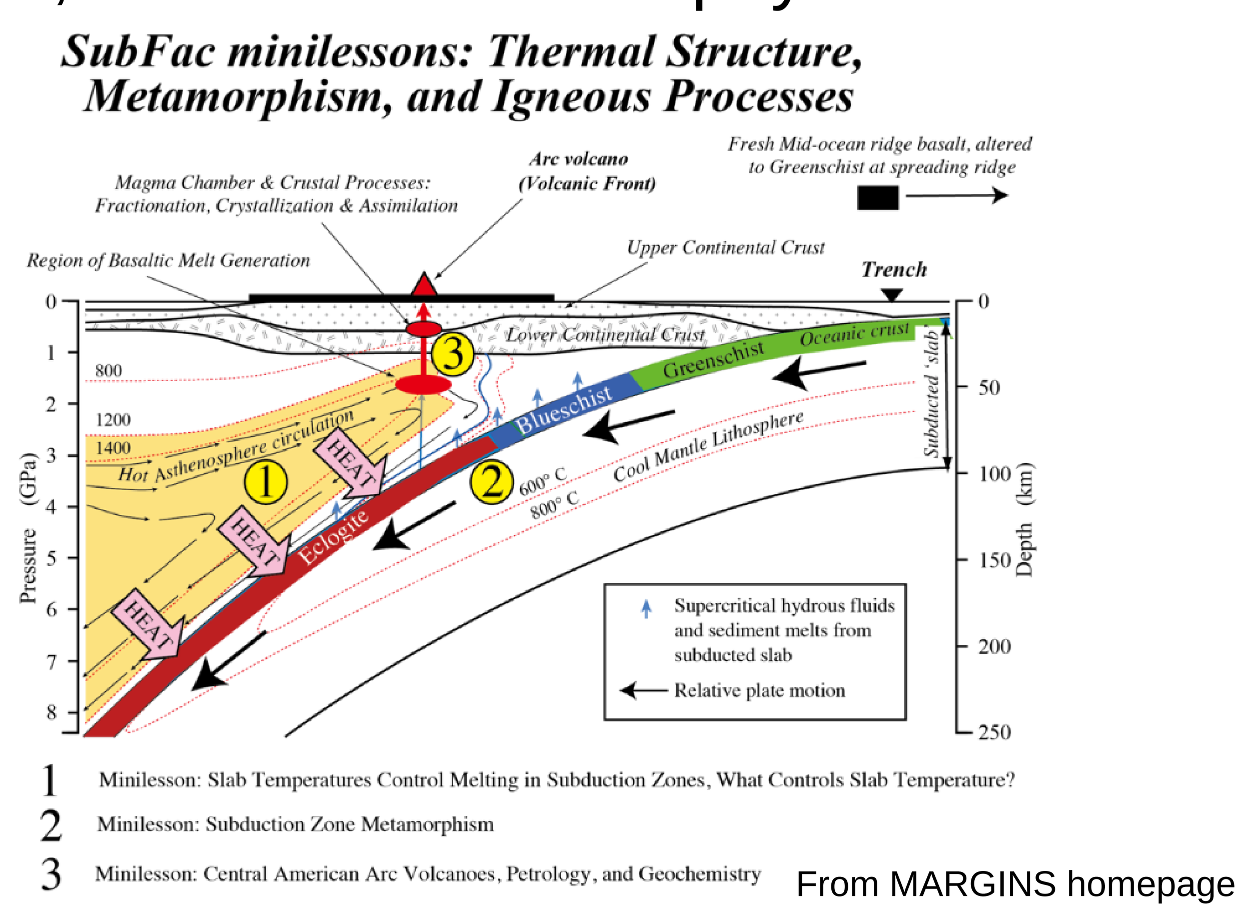

Figure 1. Schematic diagram which shows dehydration of the subducting slab in subduction zones. Dehydrated fluid from the slab enters the overlying mantle wedge and results in partial melting which is called flux melting.

Computational Methods: The CFD module of the COMSOL Multiphysics is used to consider solid convection of the mantle wedge. The TDS (Transport of Diluted Species) module is used to consider the porous behavior of the dehydrated water in the mantle wedge.

Deforming Solid + **Porous Flow in Deforming Solid**

- Solid flow of mantle

$$0 = \nabla \cdot \vec{V}_s$$

continuity equation

$$0 = -\nabla P_s + \nabla \cdot (2\eta_s \dot{\varepsilon})$$

momentum equation

$$\rho_s C_{p,s}\left(\frac{\partial T}{\partial t} + \vec{V}_s \cdot \nabla T\right) = \nabla \cdot (k_s \nabla T)$$

energy equation

- Mantle viscosity

$$\eta_s = \left(\frac{1}{\eta_{dif}} + \frac{1}{\eta_{dis}}\right)^{-1}$$

diffusion and dislocation creep

- Porous flow of water

$$\frac{\partial \phi_f}{\partial t} + \vec{V}_f \cdot \nabla \phi_f = \Gamma_{s \to f}$$

mass conservation of water

$$\vec{V}_f = \vec{V}_s + \frac{\vec{S}}{\phi_f}$$

fluid velocity

$$\vec{S} = -\frac{K}{\eta_f}(\Delta\rho\vec{g}),\ K = \frac{d^2\phi_f^3}{C_d}$$

Darcy velocity

$$\Gamma_{s \to f} = -\frac{\rho_s V_s (\phi_{s_{max}(P,T)} - \phi_{s,(P,T)})}{\rho_f h}$$

rate of mass transfer from solid to water

Figure 2. The porous flow of the convection solid mantle is based on the two-phase flows expressed as the Stokes equations and modified porous flow equations. Mass transfer from solid to water (fluid) is considered in the porous flow equations.

Model Setup: Numerical subduction models for the subduction zones were formulated by considering the equations relevant to two-phase flow in the mantel wedge. The fluid in the solid-phase in the subducting slab is migrated beneath the mantle wedge and expelled by dehydration due to increasing temperature and pressure.

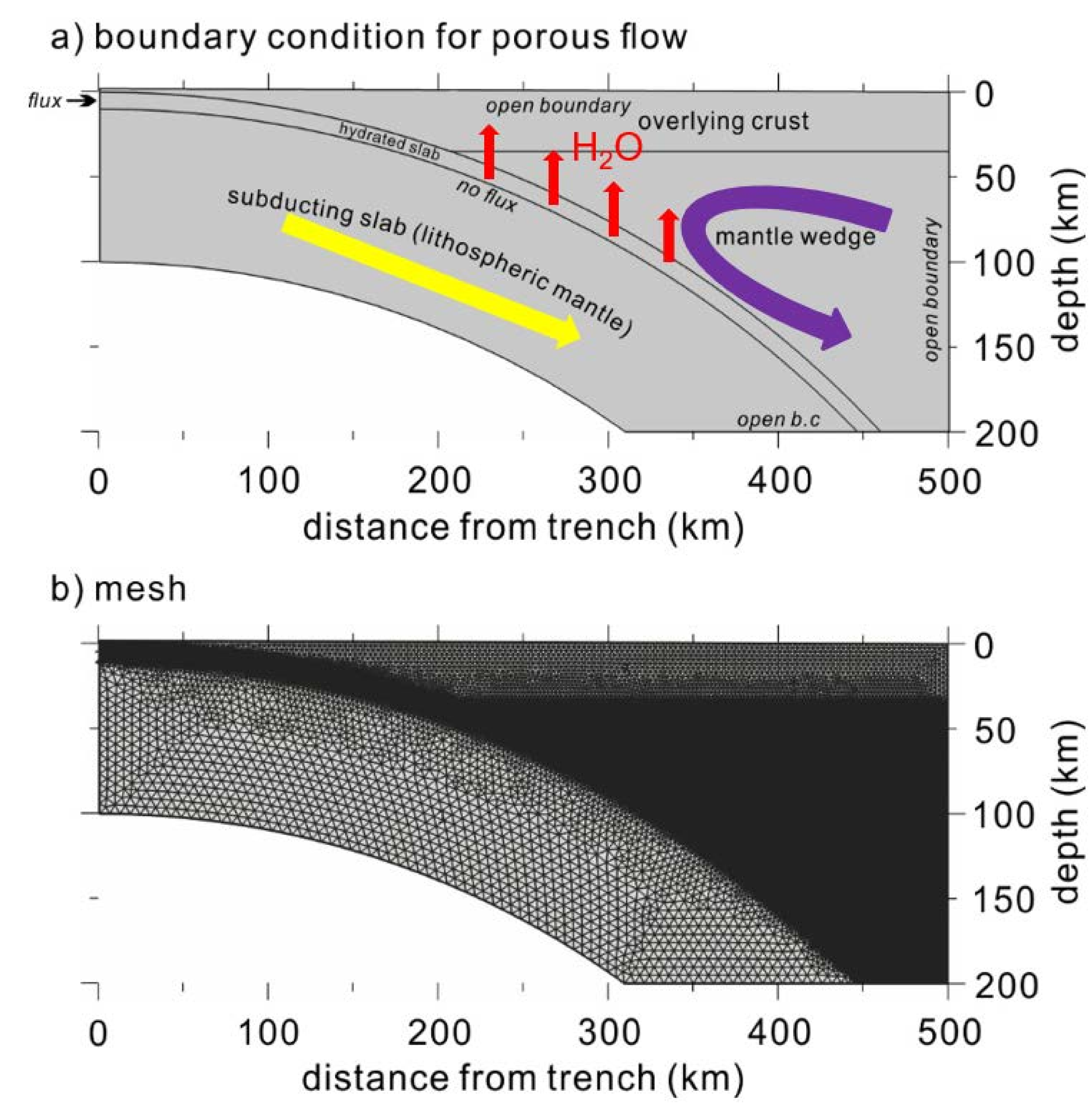

Figure 3. Two-dimensional numerical model experiments formulated using the COMSOL Multiphysics. Fluid is provided by the dehydration of the subducting slab.

Results: The model calculations show most of the water in the oceanic crust is dehydrated by a depth of 100 km and the effects of the convergence rate and age of the subducting slab on the dehydration of the subducting slab and behavior of the expelled water are not significant.

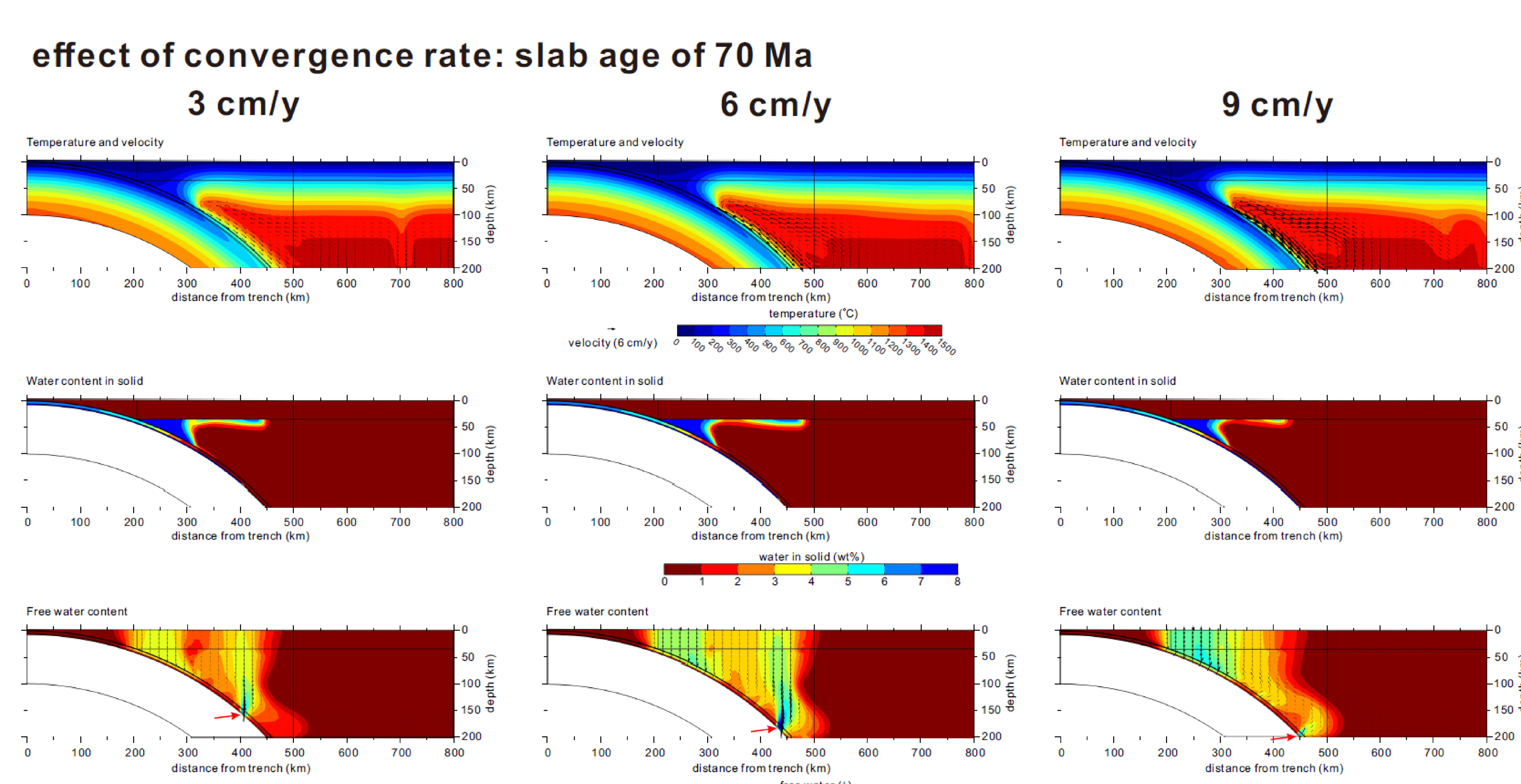

Figure 4. Distributions of temperature and velocity, water in solid phase, water in fluid phase (from top to bottom). Most of the water in the oceanic crust is dehydrated by a depth of 100 km depth and hydrate the overlying mantle wedge; serpentinization occurs at the corner of the mantle wedge. Dehydration of the serpentinite in the subducting slab is dehydrated in the deeper depth, depending on convergence rate.