Data Repository Item

Methods

We solve the model equations shown in Fig. 1 using a combined 4-node penalty-method finite element method to solve for viscous flow, finite differences to solve for heat transport, and a tracer particle algorithm to solve for transport and dewatering of hydrous phases. To enhance resolution we use an asymmetric mesh with a maximum resolution of 4km in the region of interest (Fig. 2). The flow field formulation is based on the Stokes equation for creeping flow (eq. 2&3) solved using finite elements (Zienkiewicz and Taylor, 2000). For boundary conditions we assume: on the left-hand side of the box the horizontal velocity decreases linearly from the convergence rate at the top to zero at the bottom of the box; the bottom of the region is assumed to be stress free; the right-hand side of the region is a symmetry plane; the top surface has zero vertical velocity with the horizontal velocity of the overriding plate set to zero; the horizontal velocity of the incoming plate is set to the convergence rate (see Fig. 2). Experiments with different kinds of boundary conditions show that the box is sufficiently large (1800kmx750km) to minimize the influence of possible boundary effects on the solution within the dewatering region. To decouple the motion of the overriding plate from the subducting plate we prescribe "weak nodes" along the trench (Kincaid and Sacks, 1997) according to the initial slab dip. We parameterise the viscosity using a slight extension of a previous method (Kincaid and Sacks, 1997); the temperature-dependence of the viscosity follows an Arhennius relation, and the pressure-dependence results in a factor of 250 increase from the upper to the lower mantle. The temperature solution is based on the heat transport equation including the latent heat, $L*\partial\phi/\partial t$, of water release (eq. 1) which is solved with finite differences (Smolarkiewicz, 1984). To calculate the dewatering rate, $\partial\phi/\partial t$, we use look-up tables of water content for a range of pressure-temperature conditions and different slab fluid sources, i.e. sediment, altered ocean crust, and serpentinized mantle. We create the look-up tables using the PERPLEX program (Connolly, 1990) and the compositions shown in

Figure 1. To account for compositional differences we use differing values of the depletion dp, of mantle, incoming plate, and overriding plate material. Here the depletion is the amount of post melt extraction, a value that stays constant throughout the model runs since we do not solve for melting. To initialise the depletion field we assume that the degree of depletion rises linearly from a depth of 70km to 20% depletion for the incoming plate and from a depth of 70km to 30% for the overriding plate. For self-consistency we use an inner loop with a sequential iterative scheme to treat the dependence of each of these equations upon each other.

From a series of model runs we picked the ones that best fitted the seismically-inferred locations of the subducting plate beneath Nicaragua and Costa Rica.

REFERENCES CITED

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Kincaid, C., and Sacks, I.S., 1997, Thermal and dynamical evolution of the upper mantle in subduction zones: Journal of Geophysical Research, v. 102, p. 12,295-12,315.

Smolarkiewicz, P.K., 1984, A Fully Multidimensional Positive Definite Advection Transport Algorithm with Small Implicit Diffusion: Journal of computational Physics, v. 54, p. 325-362.

Zienkiewicz, O.C., and Taylor, L.R., 2000, The Finite Element Method Vol 3: Fluid Dynamics: Oxford, Butterworth-Heinemann, 320 p.

Figure 1 Model formulation with the pressure-temperature dependent water contents for hydrated sediment, altered ocean crust, and serpentinized mantle.

Figure 2 The boundary conditions we use to solve the temperature and flow equations. To decouple the motion of the overriding plate from the subducting plate, we assume a low viscosity layer along the fault by prescribing “weak nodes” along it (Kincaid and Sacks, 1997).

The Model:

Glossary of Variables:

T	- Temperature
ρ	- Density = 3300 kg/m^3
c_p	- Specific Heat = 1100 J/kgK
κ	- Thermal Diffusivity = 10^{-6}m^2/s
α	- Thermal Density Parameter = 3.0x10^{-5}K^{-1}
β	- Depletion Density Parameter = 0.005
μ	- Viscosity
$x_i = (x,z)$	- Spatial Coordinates
$u_i = (u,w)$	- Velocity (horizontal, vertical)
ϕ	- Fraction of Chemically Bound Water
dp	- Depletion (extent of melt extraction)
L	- (Latent Heat)/(Specific Heat)
P	- Pressure
t	- Time

Model Equations:

Energy Conservation:

$$\frac{\partial T}{\partial t} + \left(u\frac{\partial T}{\partial x} + w\frac{\partial T}{\partial z} \right) - \kappa\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial z^2} \right) + L\frac{\partial \phi}{\partial t} = 0 \qquad \text{-1-}$$

Volume Conservation and Constitutive Law:

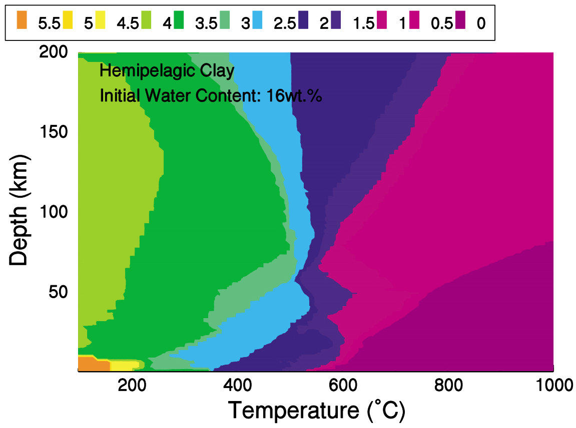
$$\frac{\partial u_i}{\partial x_i} = 0; \quad \tau_{ij} = \mu(x_i, x_j)\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \qquad \text{-2-}$$

Momentum Conservation (Force Balance):

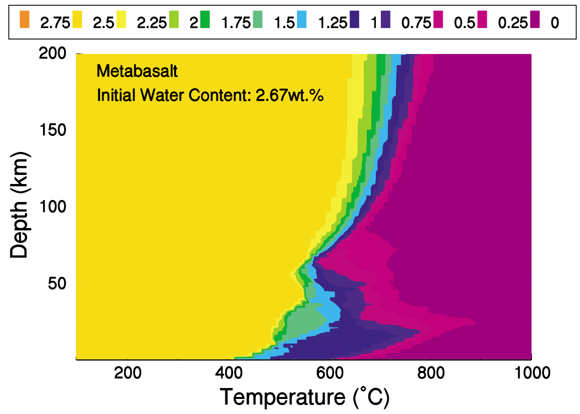
$$\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xz}}{\partial z} - \frac{\partial P}{\partial x} = 0; \quad \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{zz}}{\partial z} - \frac{\partial P}{\partial z} + \rho g = 0 \qquad \text{-3-}$$

Buoyancy and Viscosity Relationship:

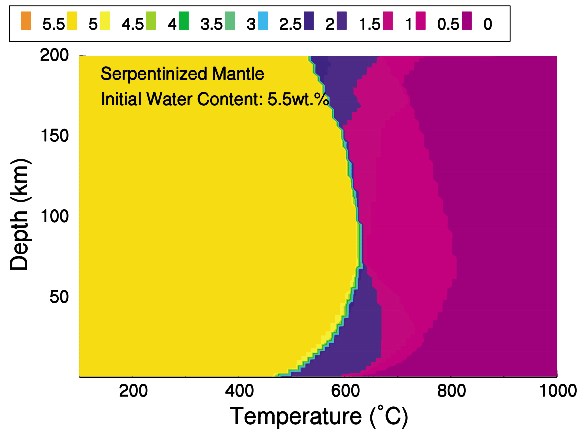
$$\mu(T,z) = \mu_0(z)\exp(15((\frac{1}{T}) - 1))$$
$$\mu_0(z) = 1 + [(120-1)/2][1 + \tanh(0.01(z-450))] \qquad \text{-4-}$$
$$\rho = \rho_0(1 - \alpha T - \beta dp)$$



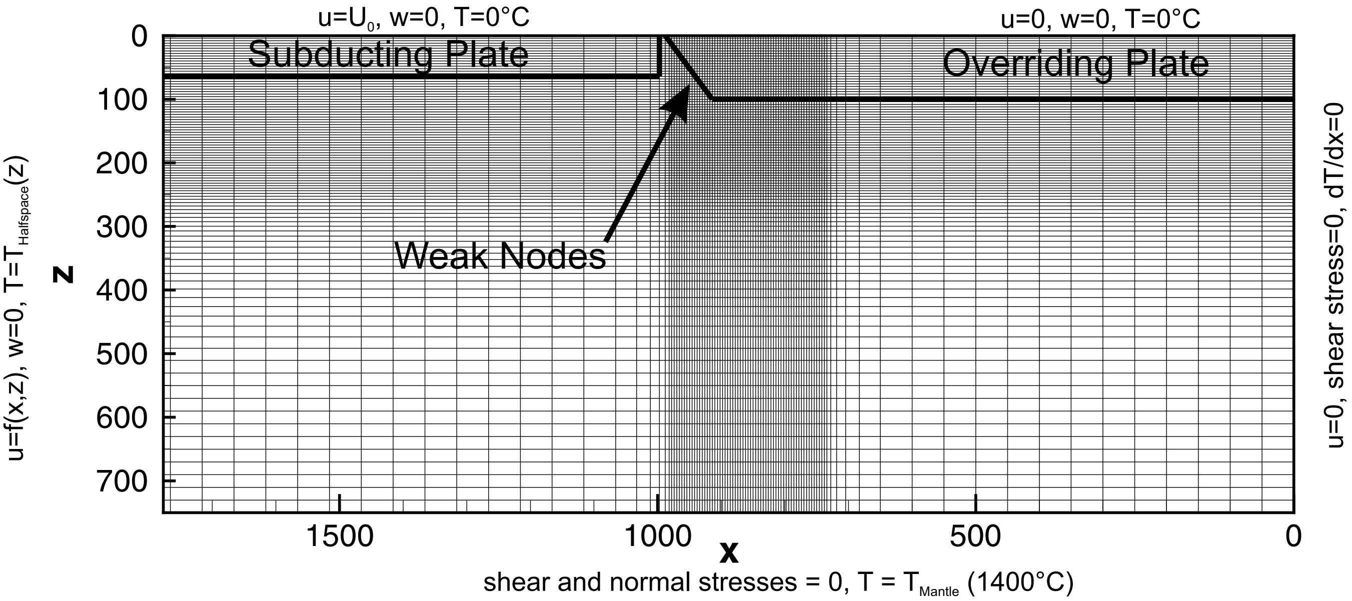
Initial Composition in wt.%: SiO2 55.78, Al2O3 11.82, FeO 5.62, MgO 2.20, CaO 2.70, Na2O 2.08, K2O 1.84, Co2 0.97, H2O 16.15



Initial Composition in wt.%: SiO2 45.8, Al2O3 15.53, FeO 10.02, MgO 6.66, CaO 12.88, Na2O 2.07, K2O 0.56, TiO2 1.12, CO2 2.95, H2O 2.68



Initial Composition in wt.%: SiO2 44.5, Al2O3 1.7, FeO 9.6, MgO 42.6, CaO 1.4, H2O 5.8



u=U0, w=0, T=0°C
u=0, w=0, T=0°C
Subducting Plate
Overriding Plate
Weak Nodes
0
100
200
300
400
500
600
700
z
1500
1000
500
0
x
u=f(x,z), w=0, T=THalfspace(z)
u=0, shear stress=0, dT/dx=0
shear and normal stresses = 0, T = TMantle (1400°C)