Fluidmechanical modeling of plate boundaries to simulate mantle convection with plate-like motion at its top

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We present a theoretical framework for seismic tomography-based convection modeling to include the plates as an integral part of the mantle convection.

We model the lithosphere as a highly viscous, incompressible, Newtonian fluid layer and plate boundary (trench, ridge or transform fault) as fault or its conjugate set, across which tangential velocity is discontinuous. Not only tangential velocity but dynamic pressure are discontinuous across fault at trench to allow one-sided subduction. Fluidmechanical expressions of such faults have their exact analogies in the seismic source representation theory and can be derived by referring to it. The explicit expressions are given for the two-dimensional plate boundaries in a semi-infinite, homogeneous medium to examine their mechanical roles. A highly viscous subducting slab in the surface layer are activated by flow driven by the slab excess mass through the frictionless nature of the fault planes and along a chemical boundary across which no normal flow is allowed at trench and through the zero tensile strength nature at ridge. This model is a combination of tangential velocity discontinuity and pressure discontinuity both across the 45^o dip fault plane that cuts through the entire surface layer.

The resultant flow with one-sided convergence is plate-like in the surface layer if its viscosity is high enough relative to the asthenospheric viscosity. The surface flow is, however, stagnant in the case of large viscosity ratio between the surface layer and asthenosphere, and strongly depends on the viscosity ratio.

On the contrary to this result, the surface velocity independent of the viscosity of the surface layer with its contrast to the asthenosphere grater than 10^3 supports the assumption implicit in the cooling model of oceanic plate, which has a uniform velocity everywhere, although the viscosity largely changes according to temperature change in the lithosphere.

We then searched for a one-sided trench model having the same characteristics for the flow in the surface layer this assumption. A successful model has an extra reverse fault on the foot-wall side on the reverse fault in the first model, which are mutually conjugate and both frictionless. The extra fault acts as a week plane across which the horizontal flow in the surface layer can vend sharply to the descending flow parallel to the megathrust.

Appropriate fluid-mechanical representations of plate boundaries are essential to model plate motions as an integral part of mantle convection.

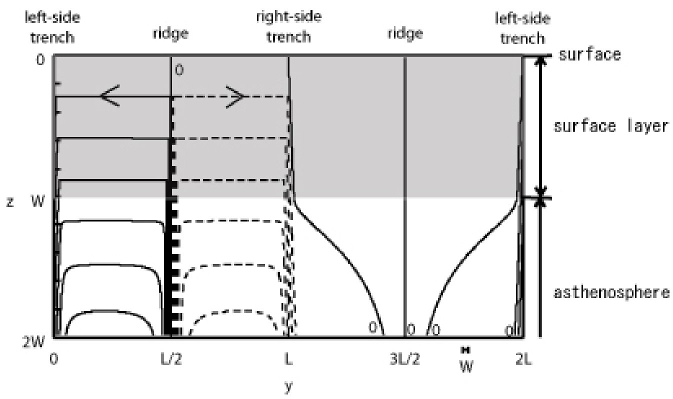

Fig. 1 Stream function, normalized by $|fo|W/\eta_1$, of the coupled convection with visocity ratio η_1/η_2=10, where W is the unit length and fo is vertical force density of slab excess mass, η_1 and η_2 are the viscosity of surface layer and asthenospher, respectively. L is 40.96W. The contour intervals is 10.