Fluid dynamic representation of plate boundaries-2D problem with symmetric ridge and asymmetric trench -

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Plate tectonics in the 1960s succeeded in explaining kinematically the Earth''s surface features. But the major question of what makes the surface layer move like plates remains to be answered. Results of seismic tomography have often been used in geodynamic modeling, where the three-dimensional seismic velocity anomaly distribution is converted to a density anomaly distribution to calculate mantle-wide convective flow driven by it.

Understanding of plate motions in terms of density-driven convective flow is difficult because 1) if the surface layer is highly viscous, it is not involved in the vigor of convective flow in the asthenosphere, 2) the density-driven flow cannot produce toroidal field, whereas kinetic energy of actual plate motions is almost equally partitioned into the poloidal component (motions associated with ridges and treches) and the toroidal component (motions associated with transform faults) and 3) fluid dynamic modeling of surface flow hardly realizes asymmetric convergence of surface flow (at trenches) in contrast to symmetric divergence (at ridges).

To overcome these difficulties, we introduce a concept familiar in the seismic source representation theory into the fluid dynamics of highly viscous, incompressible, Newtonian fluids. Starting from the point source representation of single force, we obtain the expressions for the flow field due to mass anomalies. Starting from the point source representation of double couple force, we obtain the expression for the flow field due to faulting (=parallel velocity discontinuity across fault plane). By appropriately combining these faults we obtain fluid dynamic representation of plate boundaries of ridges, trenches and transform faults.

Convection driven by mass anomalies in the asthenosphere accumulates stresses in the surface layer through its bottom boundary. The stresses accumulated in the surface layer are released by faulting at plate boundaries. Fluid motion associated with this faulting is a key to understand why the highly viscous surface layer is vigorously participated in the mantle convection. We consider the total system of mantle convection as a linear combination of the system driven by mass anomalies in the asthenospheric layer (System I) and the system driven by fault motion in the lithospheric layer (System II). So the total System = System I + A System II. Here weight A is the coupling coefficient, a measure of how efficiently System II is coupled to System I. We search for A that minimizes shear stresses on fault planes in the total system. We apply this concept to the two-dimensional problems, where the system consists of ridges and trenches in the absence of transform faults. Mass anomalies exist only in the asthenospheric layer and faults exist only in the lithospheric layer. The surface boundary condition is free-slip. All the velocities and tractions are continuous across the boundary between the two layers. We examine two cases of symmetric trench and asymmetric trench. In both cases, ridge is symmetric. In particular the flow pattern due to the asymmetric trench is discussed in detail. In System II, flow in the surface layer is plate-like if the layer is viscous enough. However, this plate-like flow is little induced by the flow in System I if the viscosity of the mass anomaly bodies is as low as the viscosity of the surrounding asthenosphere.

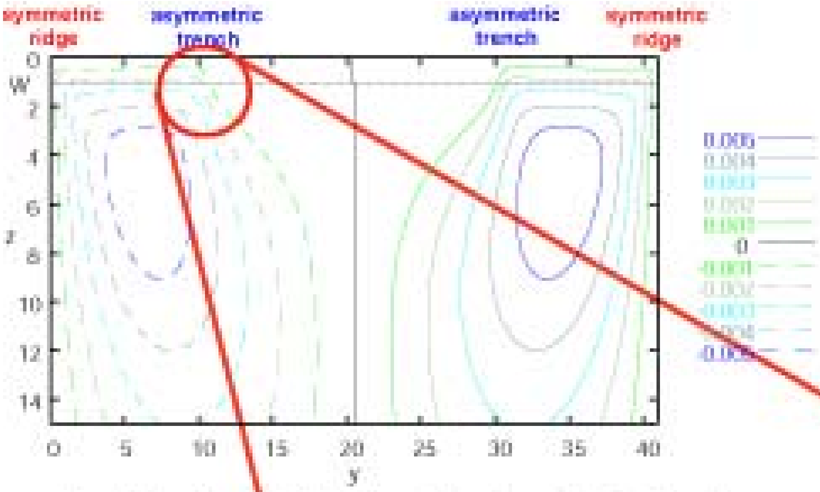

Fig.1 Stream lines for the flow due to ridge-trench fault system in case of large viscosity ratio (r=1000:1).

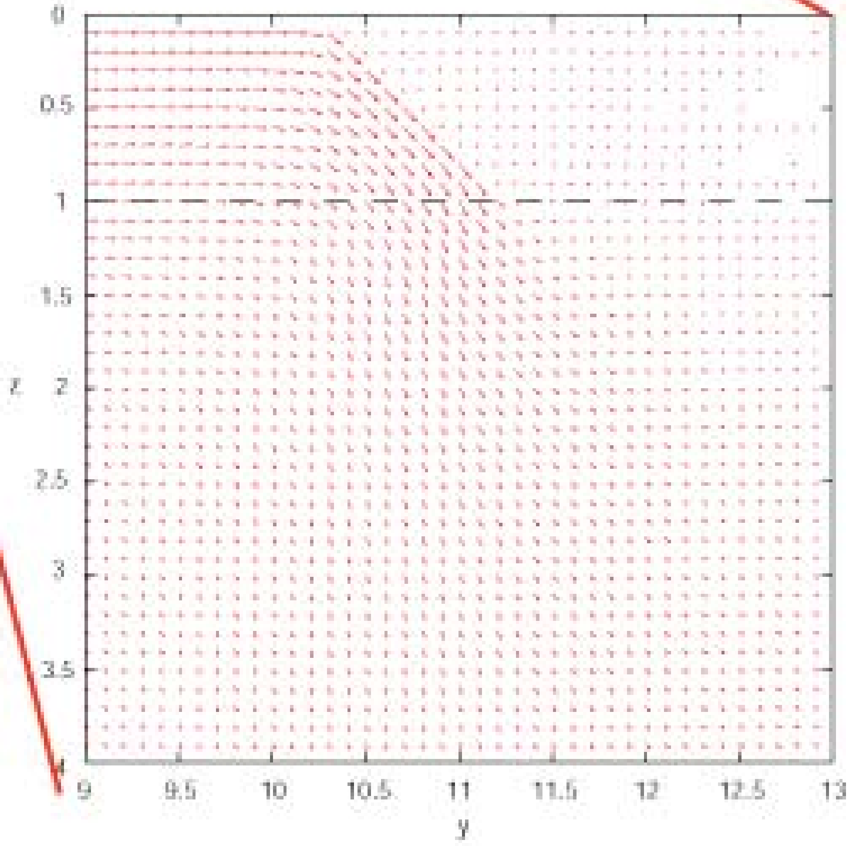

Fig.2 Vector field at right-dipping reverse fault in system II