Trench motion, slab geometry and viscous stresses in subduction systems .

Leigh H. Royden and Laurent Husson

Department of Earth Atmosphere and Planetary Sciences, MIT, Cambridge, MA, USA

A semi-analytic, three-dimensional model for subduction, which incorporates thin-sheet elastic slab within a Newtonian viscous upper mantle, provides a dynamically consistent means of computing viscous stress, trench motion and slab geometry. Although (negative) slab buoyancy provides the basic driving force for subduction, slabs that extend from the surface to the base of the upper mantle are over-supported by viscous stresses in the shallow (¡100 km) mantle and under-supported by viscous stresses at greater depth in the upper mantle. Thus deeper parts of the subduction system act as an engine for subduction while shallower parts act as a brake on trench motion. Trench migration rates and slab geometry reflect a competition between these two parts of the subduction system. During steady-state subduction, trench migration rates vary approximately linearly with slab buoyancy and model rates of trench motion are in good agreement with the range of observed. Because of asthenospheric toroidal flow, slab width has a significant effect on trench migration rates, although smaller than that of slab buoyancy; the effect of an applied velocity at the base of the upper mantle is even smaller provided that the slab is not anchored within the lower mantle. Steady-state slab geometry is not affected by slab buoyancy. Rather large effects on trench migration rates and slab geometry are exerted by the structure and density of the frontal prism and overriding plate. During non-steady-state subduction, rates of trench migration respond rapidly as variably buoyant lithosphere passes beneath the asthenospheric nose, reflecting the importance of the large magnitude viscous stresses at shallow depth. In the absence of other driving forces for convergence, trench migration rates can change by a factor of two or more in as little as 2 m.y. after anomalously dense or shallow lithosphere enters the subduction system. For example, rapid subduction of oceanic lithosphere slows dramatically within the first 3 m.y. after buoyant continental lithosphere enters the subduction boundary, and effective ceases within 10 m.y.. Slowing and cessation of trench migration rates are accompanied by steepening of the slab into a nearly vertical position. Our results indicate that the way in which subduction systems respond to the introduction of variably buoyant lithosphere into the trench is an important arena in which to test numerical subduction models against observations.

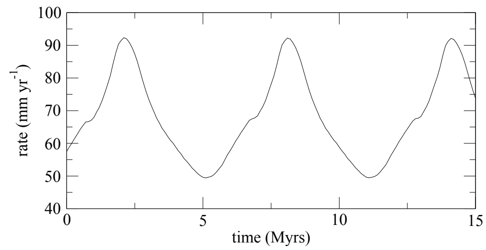

Figure 1. Rates of trench migration for subduction of alternating strips of high and low density lithosphere, with each strip being 200 km wide in a direction orthogonal to the trench. The buoyancy of each strip corresponds to oceanic lithosphere with pre-subduction water depth of 3.5 km (slight negative buoyancy) and 6.5 km (very negative buoyancy). Corresponding slab geometry in Figure 2.

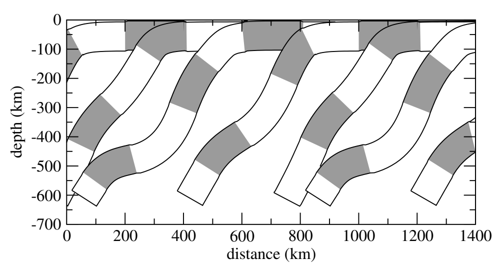

Figure 2. Geometry of subducted slab of alternating strips of high and low

density lithosphere as described in Figure 1, which shows corresponding rates of trench migration. Time interval between slab positions is 4 my. Shaded areas denote lower-density lithosphere.