Plate strength drives trench motion: Insights from numerical models

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Subduction operates by bending of the lithosphere plate at trench. During the bending, the lithosphere weakens loosing some of its strength. The variation of the slab strength at trench has consequences on the kinematics and dynamics of subduction. Thus, the motion of the plate at convergent margin is partitioned on the Earth's surface between advancing and retreating modes and is susceptible to abrupt changes in velocity and direction.

Here we explore the idea that trenches motion represents the surface manifestation of the dynamics of subduction. We performed three-dimensional numerical models of self-consistent subduction zones in an attempt to understand the complex trench dynamics. Numerical models allow a quantitative investigation of a wide range of parameters and the assessment of derived quantities such as the amount of energy dissipated during the whole subduction process. The adopted model setup is as simple as possible.

Simulating a multilayered lithosphere-upper mantle system, we found that slabs with different geometries and rheological properties interact differently with the 660-km discontinuity, which is modeled in this case as an impermeable barrier. The main driving force is the slab pull deriving from the negative buoyancy of the downgoing lithosphere; the viscous resistive forces arise from the coupling of the mantle flow and the plate motion. Strong (thicker/high viscous/less dense) plates move in advancing style, while weak (thinner/less viscous/denser) plates move in retreating style. The energy dissipated in the system varies during the several phases of process and also, it is partitioned differently between slab and upper mantle depending on the subduction mode. In both advancing and retreating (rollback) modes, most of the total initial energy is dissipated by the mantle, around 60% and 70%, respectively. The extra 10% in the retreating mode is caused by a more vigorous backward toroidal flow compared with forward toroidal flow in the advancing style. Furthermore, the rollback motion is the favorable configuration from an energy point of view. In the intermediate situation, plates fold and pile up on the discontinuity. In this mode, the plate dissipates around 60-65% of the total energy, with an evident minor contribution of the surrounding mantle.

We conclude that the potential energy provided by the negative buoyancy of the subducting plate is mainly dissipated by the mantle viscous flow, and the remaining part to bend and deform the lithosphere.