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Slab induced flow and its controls on the back-arc basin formation

Tomoeki Nakakuki[1]

[1] Dept Earth Planet Syst Sci, Hiroshima Univ

Dynamical mechanisms for the back-arc basin formation are still controversial because we have not well understood the dynamics of the subducted lithosphere and the mantle flow around subduction zone. We have constructed 2-D integrated plate-mantle models in which the plate subduction is dynamically generated without imposed plate motion (Nakakuki et al. 2008) to study the dynamics of back-arc deformation. In our models, two end members of the overriding plate motion, i.e., fixed and freely movable, are considered. We also introduce a weak yield stress into the back-arc lithosphere and a low viscosity zone into the wedge mantle, which are modeled to simulate the dehydration of the slab. This allows freedom for the slab deformation and horizontal motion near the subduction hinge. The slab migration is expected to generate back-arc deformation.

In the case with the fixed overriding plate, back-arc extension occurs because of the slab's backward motion against the overriding plate fixed to the mantle. The back-arc spreading is initiated from the extension of the continental crust, and finally reaches ocean floor spreading. This slab backward motion is generated when the subducted lithosphere is deforming at the 660 km discontinuity and forming the stagnant slab. The gravity potential energy is transformed into the viscous dissipation energy to deform the subducted slab through the backward migration. When the slab tip is descending in the transition zone (410 to 660 km-deep) or the lower mantle, the slab is anchored or advances to the same direction as the plate motion. In the case with freely movable plate, the trench motion occurs as well as the case with the fixed overriding plate. The movable overriding plate, however, migrates towards the trench. This motion is induced not only by the slab suction force but also by the basal drag from the slab induced flow beneath the overriding plate. The latter becomes stronger when the slab descends in the deeper mantle. At that time, the overriding plate moves towards the trench even when the trench is fixed or advanced. As a result, the back-arc lithosphere becomes compression. The back-arc spreading is therefore hardly generated with a freely movable overriding plate.

We also examine the effect of the coupling strength between the subducting and overriding plates. The coupling is modeled by the friction coefficient at the plate boundary. The trench retreat occurs when the friction coefficient is smaller. On the contrary, the trench advance is generated when the friction coefficient is larger. This may explain that the back-arc basin was formed when the subducted lithosphere becomes older than 50 Ma (Sdrolias et al, 2005).

Our numerical models reproduce the classification of back-arc tectonics, i.e., Chile-type or Mariana-type (Uyeda, 1984). The dynamics is understood from interaction between the subducting slab and overriding plates in almost the same way as that pointed by Uyeda (1984). The former is generated when the overriding plate is freely movable (or moving to the trench direction), the deep slab genrates the wedge flow pushing the overriding plate to the trench direction, and the coupling at the plate boundary is strong (i.e., a young subducting lithosphere). The latter is when the the overriding plate is fixed (this may occur in the case of a large continental plate), the slab stagnates in the transition zone with backward motion, and the coupling at the plate boundary is weak (i.e., an old subducting lithosphere).