Two-dimensional numerical simulations on the dynamics of cold descending slabs in the mantle: important roles of trench migration

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We conducted numerical simulations of thermal convection of highly viscous fluid in a two-dimensional cylindrical geometry, in order to study what mechanisms control the dynamic behaviors of subducting slabs such as the formation of ``stagnant slabs'' in the mantle transition zone (MTZ) and their avalanche into the lower mantle. Two series of experiments are performed in this study, by varying the history of migrating motion of ``trench'' where the slab of cold fluids descends from the top surface.

In the first series of experiments where the migration rate of trench is assumed to be constant with time, our model successfully reproduces the diverse morphology of subducting slabs which can be well compared with those of natural slabs, by carrying out calculations with systematically varying the velocities of subducting slabs and trench migration, the Clapeyron slope at around 660 km depth, and the viscosity jump between the upper and lower mantle. In particular, the dynamic behaviors of slabs around the MTZ can be classified into five types depending on the delicate combinations of varying parameters: (1) Penetrating, (2) Accumulating, (3) Floating, (4) Long-term Stagnation, and (5) Short-term Stagnation.

In the second series of experiments where we take into account the temporal changes in the rate of trench retreat, we found that the dynamic behavior of already-formed stagnant slabs is strongly affected by a sudden deceleration of trench retreat. In particular, by appropriately choosing the rate of trench retreat and its temporal change, our model successfully reproduces various types of avalanches of stagnant slabs, including those observed in Northeast Japan, Izu-Bonin, Mariana, Tonga, and Java subduction zones.

From the results of the two series of our experiments, we demonstrated that the formation and avalanche of stagnant slabs are strongly related with the trench retreat particularly through its temporal changes. These findings may further imply that our study can offer important clues to the understanding of tectonic histories of subduction zones (such as the trench migration and back-arc opening), by properly combining with the observations on the morphology and behavior of subducting slabs in the MTZ beneath them.

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