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Kinematics of formation of stagnant slab

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Stagnation of subducted slab at 660 km phase transition zone is suggested by the seismic tomography images. Recent numerical studies of mantle convection included the effect of phase transition have been clarified the condition of formation of stagnant slab. However, the physics of the stagnation has not been well discussed yet. In this study, we discuss the conditions of stagnation of slab on 660 km phase transition zone considering kinematic balance of slab.

In order to stay the slab at 660 km depth, time scale of thermal relaxation of cold slab should be larger than that of the Rayleigh-Taylor instability of dense slab to surrounding mantle. Time scale of gravitational instability may be estimated by the force balance of slab laying on the 660 km phase transition zone. The vertical forces acting on the slab on the 660 km phase transition zone are mainly as follows:

(1) Negative buoyancy of high dense slab due to the lower temperature of the slab than surrounding mantle.
(2) Positive buoyancy because of the increasing of the phase transition depth, and.
(3) Negative buoyancy by pushing of slab subduction.

Using subduction velocity and width of the slab estimated by the boundary layer theory, we find that the critical phase buoyancy parameter for stagnation is in inverse proportion to the cube root of Rayleigh number, and depends upon the plate velocity, dip angle of subduction, viscosity ratio of slab to mantle, temperature of slab, and so on. This criterion shows good agreement with the results of simple 2-dimensional numerical simulation of mantle convection included the phase transition effect.

Our criterion indicates that the stagnant slab may be formed when the effective subducting velocity is slow, dip angle of slab is shallow, and the viscosity contrast between mantle and slab is small. Slow subduction velocity may occur with the trench retreat and the slab viscosity may decrease with the grain size reduction of mantle minerals with the 660 km phase change. These support the results of numerical simulations of mantle convection. These phenomena may decrease the downward force on the horizontally lying slab which elongates the time scale of the gravitational instability. Our model suggests that if the Rayleigh number is ~10^7 and the phase buoyancy parameter is ~-0.05, which correspond to the earth's mantle, the stagnant slab may be formed when the effective subducting velocity is almost zero (trench retreat velocity ~plate velocity) or the viscosity of the slab is 1/10 of that of mantle.