Finite Element Simulation for the Development of Mechanical and Thermal Structure in Subduction Zones

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Topography in plate subduction zones is formed as the result of interaction between the internal crustal processes such as igneous activity and tectonic deformation due to plate subduction and the external surface processes such as erosion and sedimentation controlled by climate and environment. The purpose of this study is to reveal the mechanism governing the development of mechanical and thermal structure in plate subduction zones through numerical simulation with a mechanical-thermal interaction model.

In the numerical simulation of mechanical and thermal structure development in plate subduction zones, the following points are essential: 1) rational representation of plate-to-plate interaction, 2) realistic modeling of rheological structure, and 3) interaction between mechanical and thermal processes. In this study, we rationally represented the plate-to-plate interaction by the increase of tangential displacement discontinuity (fault slip) at plate interfaces and modeled the realistic rheological structure of subduction zones with a finite element method (FEM). For mechanical processes we have already developed a FEM model and tested its validity through the computation of internal velocity fields due to plate subduction (Shikakura et. al., SSJ 2007 Fall Meeting). For thermal processes, we newly developed a FEM model considering both thermal diffusion and advection, and tested its validity through the computation of thermal structure development induced by steady plate subduction. Combining the thermal FEM model with the mechanical FEM model, we developed a mechanical-thermal interaction model.

With the mechanical-thermal interaction model, we numerically simulated the development of mechanical and thermal structure in a plate subduction zone. In this simulation, at a certain time step, we compute internal velocity fields due to plate subduction. Then, using the computed internal velocity fields, we evaluate temperature changes due to thermal diffusion and advection, and update the boundaries between the lithosphere and the asthenosphere to compute internal velocity fields at the next time step. Following such a computation algorithm, we revealed the evolution process of mechanical and thermal structure in the plate subduction zone over a span of 5 Myr. In the early stages of plate subduction (0-2 Myr), the cooling of the mantle wedge leads to the thickening of the continental lithosphere near the plate boundary and increases the uplift rates of the lithosphere beneath the island arc. Then, as time goes on, the thinning of the lithosphere beneath the island arc proceeds, and the uplift rates further increase there. This simulation result indicates that the mechanical-thermal interaction is crucial to understand the geomorphic evolution in plate subduction zones.