論文内容の要旨

A numerical study of subduction initiation with deformation analysis of lithosphere in convergent system using Discrete Element Method

(個別要素法を用いたリソスフェアの変形シミュレーションによるプレート収束帯の発達過程に関する研究)

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The plate convergent system is the main driving force for plate tectonics. Some numerical studies have been conducted to reveal how the convergent system was formed. However, the formation of faults that cut through the entire lithosphere has not been adequately described in previous studies. In some studies a weak zone or a fault was set numerically without considering fault initiation (Toth and Gurnis, 1998; Doin and Henry, 2001; Gurnis and Hall, 2004). In this dissertation I solve the problem of fault formation and subduction initiation in the lithosphere using DEM (Discrete Element Method, Distinct Element Method) numerical techniques. DEM numerical methods have great advantages when simulating processes in discontinuous phenomena such as deformation, destruction and faulting. In this method the matrix is composed of many discrete elements, and the deformation of the assemblage is computed by solving the motion equations for each element. The conventional DEM is extended to construct numerical models of a plate convergent system that are composed of layers with different characteristics. Two new models, the "strain model" and the "balloon model" are developed to simulate brittle and ductile layers of the lithosphere. The strain model uses the strain of elements and the Young's modulus instead of the compressional distance and the elastic coefficient. The balloon model treats each element as a balloon filled by gas, and the assemblage of these elements exhibit a ductile-like character: the yield strength of the assemblage is near constant at various pressures. The characteristics of the assemblages modeled using these extended DEM are tested by numerical geotechnical tests.

The numerical simulations of the development of convergent systems are conducted under four different conditions: a continental plate adjacent to an oceanic plate under a compressional stress regime (Experiment 1), a uniform oceanic plate in compressional stress regime

(Experiment 2), two adjacent oceanic plates with different thicknesses under a compressional stress regime (Experiment 3), and adjacent continental and oceanic plates under variable stress regimes from extensional to compressional (Experiment 4). The continental plate is modeled as a 3-layered assemblage composed of the following DEM elements: a brittle upper crustal layer, a ductile lower crustal layer and a brittle mantle layer. The oceanic plate is modeled as a 2-layered assemblage: a brittle crustal layer and a brittle mantle layer. The low-strength layers such as the lower continental crust and the asthenosphere are comprised of assemblages of elements simulated using the balloon model, and other brittle layers are simulated using the strain model. Lateral compression and extension in the numerically modeled convergent systems are controlled by lateral motions of the compressional boundary. Plate subduction occurs in Experiment 1, Experiment 3 and Experiment 4. The homogeneous oceanic plate in Experiment 2 shows only thickening and folding, and plate subduction does not occur in this experiment. The forces exerted near the compressional boundary are small in Experiment 4 compared to other experiments. This might be because the extensional stage that occurred before compression in Experiment 4 results in gravitational instability of the slab, and subduction occurs more easily in this experiment.

The plate subduction process is classified in three stages: the plate boundary is rotated by the density contrast or lateral compression between the modeled plates (Stage 1), the slab is deformed along the inclined plate boundary and the denser plate begins to subduct, intitiating the formation of a mantle wedge (Stage 2), and the denser plate subducts under the other plate continuously, taking crustal materials into the deeper part of the Earth (Stage 3). The results of deformation show that the plate can start to subduct during the initial stages of formation and deformation along the plate boundary, and no other weak zones are needed to form a plate convergent system. The stages of plate subduction might be constrained by the shortening ratio of the convergent system. The internal dynamics and deformation of the slab are analyzed by detecting the stress chain network and the slip events. The stress chain network is shown by the extent of more compressed elements and slip events, and represents the locations of apparent excess shear force compared to frictional force. During plate subduction, the orientation of stress chain network tends to be normal to the slab, and many slip events are detected beneath the plate boundary and upper half of the subducting slab. The slab-normal compressional stress regime of the modeled slabs shows that the internal stress regimes of descending young slabs are under down-dip extension. Such stress regimes in short slabs were shown by Isacks and Molnar (1971): the stress regimes in short slabs are observed predominantly as down-dip extension. The distribution of slip events in the slabs modeled in this study might reveal the characteristics of a Wadati-Benioff zone of a young slab.