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主　論　文　の　要　旨

論文題目 Modeling of intraplate strike slip faulting and shear zone evolution in the lower crust based on nonlinear rheological laws
非線形流動則に基づく内陸横ずれ断層運動と下部地殻剪断帯発達のモデル化

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論　文　内　容　の　要　旨

Intraplate earthquakes occurring at active faults are highly hazardous. But physical mechanisms of their occurrences are still not well understood. In order to tackle this problem, I investigate mechanical processes regarding tectonic loading of intraplate vertical strike slip faults and associated structural developments such as localized shear zone in the lower crust in terms of numerical simulations.

In the lower crust under interplate and intraplate strike slip faults, existence of localized deformation has been suggested by geophysical and geological studies. Several different shear strain concentration mechanisms such as shear and frictional heating, power law creep, and grain size reduction have been proposed to explain the formation and maintenance of the shear zone under an interplate strike slip fault such as the San Andreas fault. However, since intraplate strike slip faults have small slip rates less than 1 cm/yr, the controlling mechanisms of shear strain concentration in the lower crust may be different from the one for the interplate fault. To better understand the mechanism and boundary conditions that influence the deformation of the lower crust, two-dimensional numerical experiments are conducted for the deformation of the lower crust under an intraplate strike slip fault based on laboratory-derived power law rheologies considering the effects of grain size and water.

The result shows that the power law rheology is the most important mechanism controlling the deformation of the lower crust. Compared to the case with a linear rheology, the degree of the shear strain localization in the cases with nonlinear rheology is significantly higher. The maximum value of the shear strain rate in the nonlinear case is ~ 2 times larger than the linear case. On the other hand, there is almost no difference between the case with constant and non-constant grain size. In the case with non-constant grain size, as a result of competing effects of grain size reduction and grain growth, characteristic spatial distribution of the grain size appears as a function of depth and distance from the fault. This grain size distribution plays a role of maintaining the shear localization under the fault. In the previous studies for interplate strike slip fault, effective viscosity reduction due to thermal weakening has been considered to play a central role to develop shear zone in the lower crust. On the other hand, in the case of intraplate strike slip fault, owing to the slow slip rate (1 mm/yr), shear and frictional heating has negligible effects on the deformation of the shear zone. The heat production rate depends weakly on the rock rheology; the maximum temperature increase over 3 Myr is only about several tens of degrees.

Unlike the lower crust where aseismic plastic deformation occurs, elastic deformation and brittle fracture occur in the upper crust. Mechanical interaction between different parts of the crust is important to understand crustal deformation and seismogenic processes around crustal faults. Therefore, I further investigate the evolution of tectonic background stress, elastic as well as the inelastic strain in a crust-upper mantle system around an infinitely long vertical strike slip fault. Based on the previous 2 results, I assume that both the crust and the upper mantle are composed of nonlinear viscoelastic materials whose effective viscosity is controlled by power law rheologies. In this model, stress evolution is simulated starting from an initial stress-free condition, and stress accumulates due to a constant far-field loading at 50 km away from the fault. As the stress accumulates, brittle fracture occurs in the upper crust. Also, recurrence of earthquakes is modeled based on the Coulomb failure criterion. The frictional cohesive strength is assumed to be 5 MPa.

In the early stage of stress evolution, deformation of the crust and the upper mantle is dominated by a uniform simple shear. Shear localization in the lower crust starts when coseismic rupture extends to the entire brittle upper crust. Together with this transition, the earthquake recurrence interval decreases by an order of magnitude from ~ 16 to ~ 1.6 kyrs. A basal drag originated from the localized plastic flow of the lower crust plays an important role in tectonic loading of the crustal faults by increasing the stressing rate from ~ 300 to ~ 3000 kPa/yr. The recurrence interval and the maximum stressing rate after the start of regular cycle depend on the degree of strain localization in the lower crust which is correlated with the crustal rheologies.

After the localized deformation is fully developed in the lower crust, the fault slip rate catches up with the far field velocity and earthquakes start to occur periodically. In the case of an intraplate strike slip fault, such a steady state can be reached in a several hundred thousand years from the beginning. A shear zone with large cumulative strain needs few million years to develop under an intraplate strike slip fault, which is much longer than the time for shear strain rate to be localized. The shear strain in the shear 3 zone under the fault linearly depends on the cumulative fault offset at the surface. Under a strike slip fault with a cumulative offset longer than few kilometers, a shear zone with large shear strain is likely to exist in the lower crust and it can be observed by geophysical means.

The model successfully reproduced evolution of intraplate strike slip faulting, development of a shear zone in the lower crust under the fault, and tectonic stress buildup in the bulk of the crust around an intraplate strike slip fault. The results of this model provide important clues to understand the problems associated with the intraplate strike slip faulting such as the degree of the shear strain concentration in the lower crust under the fault and the discrepancy between geodetic and geologic fault slip rates. The model demonstrates the importance of considering the whole mechanical system of the crust in which rheological properties, thermal structure, and fault activities are interactive one another for better understanding of crustal seismogenesis.