Intraplate faulting, stress accumulation, and shear localization of a crust-upper mantle system with nonlinear viscoelastic rheologies

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Crustal deformation around source faults of intraplate earthquakes is slow and distributed, which makes it difficult to understand physical mechanisms of stress accumulation and structure evolution associated with intraplate earthquakes.

In this study, we conduct numerical simulations about 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. We assume that both crust and the upper mantle are composed of nonlinear Maxwell viscoelastic materials whose effective viscosity is controlled by power law rheologies. Rheology model for quartz or anorthite is assumed for the crust and that of olivine is assumed for the mantle. In this model, stress evolution due to far-field loading is simulated starting from an initial stress-free condition. Also, recurrence of earthquakes is modelled based on the Mohr-Coulomb failure criterion.

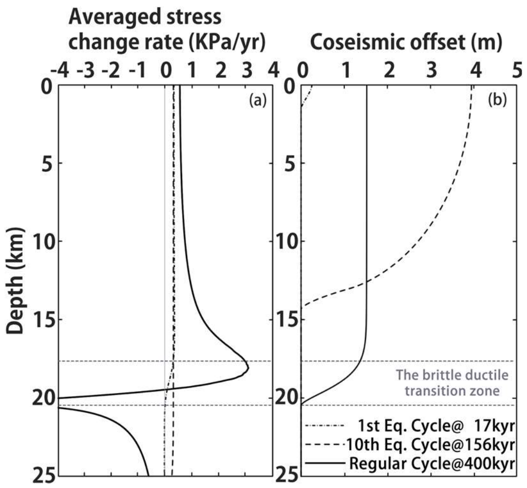

Figure 1 Stress change rate averaged over an earthquake cycle (a) and coseismic offset on fault surface (b). Far field velocity is assumed to be 1mm/yr in this case.

In the early stage of the 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 intervals decrease by an order of magnitude. A basal drag originated from a localized plastic flow of the lower crust (Solid line in Figure 1a) plays an important role in loading the upper crust afterward. The recurrence interval depends on the degree of strain localization in the lower crust which is correlated with the crustal rheologies.

After the shear zone is fully developed in the lower crust, the fault slip rate catches up with the far field velocity and earthquakes starts to occur periodically (~1.5 m coseismic offset occurs every ~1500 years, Solid line in Figure 1b). Such a steady state can be reached after the cumulative offset on the fault become larger than few hundreds of meters. However, because a shear zone with large cumulative strain is likely to be found under a strike slip fault with more than few kilometres of cumulative offsets. Therefore, shear zone under a young intraplate strike slip fault may not be visible by the geophysical observation. The model successfully reproduced evolution of tectonic stress around an intraplate strike-slip fault, interacting with the development of localized shear zone in the lower crust. The model demonstrates the importance of considering the whole mechanical system in which rheological structure and fault activities interacting each other for the better understanding of the intraplate earthquakes.