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

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Earthquakes occurring in plate interiors are generally less frequent but highly hazardous. Crustal deformation around source faults of intraplate earthquakes is slow and distributed, which make it difficult to understand physical mechanisms of stress accumulation and structure evolution associated with intraplate earthquakes.

In this study, we explore evolution of stress, strain, and of 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 viscoelastic materials whose effective viscosity depends on shear stress, temperature, pressure, and type of mineral. We assume wet quartz rheology and wet olivine rheology for the crust and the upper mantle, respectively. Stress accumulation process is calculated in an initially unstressed crust and mantle with velocity boundary condition of 0.5mm/yr at 50km away from the fault. Frictional coefficient and the maximum coseismic stress drop are assumed to be 0.2 and 5MPa, respectively.

In the early stage, deformation of the crust and the upper mantle is dominated by uniformly distributed simple shear. Earthquakes rupture the shallowest portion of the crust and only a small portion of accumulated elastic energy is released by earthquakes. As a result, the geological slip rate on the fault is smaller than the far field velocity in the early stage of stress accumulation.

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 from 16,000 to about 1,500 years. A basal drag originated from localized plastic flow of the lower crust 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. Such kind of steady state can be reached in a several hundred thousand years since the beginning of stress accumulation and a matured shear zone can develop in a few million years, providing that far field velocity does not change with time. Our time-dependent model suggests that young intraplate strike slip faults may not have localized shear zone in the lower crust under the fault. The structural maturity of the lower crustal shear zone therefore should be considered when studying the interseismic deformation of an intraplate strike slip fault with a simple dislocation model which simplifies the lower crustal shear zone deformation into a steadily creeping fault at depth.

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