Spontaneous dynamic rupture propagation beyond fault discontinuities: Effect of thermal pressurization

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We investigate dynamic rupture propagation beyond fault discontinuities, on the basis of 3-D numerical simulations for spontaneous dynamic ruptures including thermal pressurization (TP), which is an increase in pore fluid pressure and reduction of effective normal stress due to frictional heating during earthquakes under wet conditions.

A range of several fault segments often sequentially ruptures during an earthquake. In previous numerical simulations on dry fault systems, a rupture sometimes fails to propagate to an unconnected fault, and the rupture, which succeeds to propagate, is usually triggered near the Earth's surface. These features of simulated ruptures disagree with those of real earthquakes. To overcome the gaps between the simulations and real earthquakes, we test effect of TP on spontaneous dynamic rupture processes on two fault segments.

We put two vertical strike-slip square faults in a semi-infinite, homogenous, and elastic medium. The second fault (Fault 2) is parallel to the primary (nucleating) one (Fault 1). We examine compressional and extensional cases of the fault geometry with some values of stepover width. Both faults reach the free surface. The lengths of Faults 1 and 2 are 6 and 3 km, respectively. The numerical algorithm is based on the finite-difference method by Kase and Kuge (2001). A rupture is initiated in a small patch close to a side edge of Fault 1, and then proceeds spontaneously, governed by a slip-weakening law with the Coulomb failure criteria. The friction coefficients and the initial stresses are uniform and the same on the two faults. On faults with TP, we allow effective normal stress to vary with pore pressure change by the formulation of Bizzarri and Cocco (2006).

We reveal that rupture can jump wider stepovers due to TP and that TP on Fault 1 enables rupture to jump at deep portions, which can explain the gaps between the previous numerical simulation results and real earthquakes, without introducing the heterogeneity of initial stress and/or friction. In our numerical simulations under depth-dependent stress, the same features of the effects of TP were also observed. If TP works on faults, not only fault geometry but hydraulic diffusivity can strongly control characteristics of rupture propagation at fault discontinuities. Our results imply that TP can have a significant role on rupture processes on real earthquakes.