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Spontaneous dynamic rupture processes with thermal pressurization: Effect of heterogeneous fluid distribution and fault geometry

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We show that earthquake rupture processes can depend on a fluid distribution and a slip direction, by performing 3-D numerical simulations with thermal pressurization for spontaneous dynamic ruptures.

Fluid and pore pressure evolution can affect dynamic propagation of earthquake ruptures owing to thermal pressurization, because frictional heating caused by earthquake slip can increase pore pressure changing effective normal stress on a fault surface (e.g., Mase and Smith, 1985). However, the characteristics of the possible effects on dynamic rupture processes have not been examined well. In this study, we investigate the effects on spontaneous dynamic rupture propagation on a planar fault, especially where fluid partly exists. The rectangular fault is placed in an infinite, homogenous, and elastic medium. The length of the fault is 5km and the width is 3km. The numerical algorithm is based on the finite-difference method by Kase and Kuge (2001). Rupture is initiated in a small patch by decreasing shear stress to dynamic stress, and proceeds spontaneously, governed by a slip-weakening law with the Coulomb failure criteria. We allow effective normal stress to vary with pore pressure change due to frictional heating by the formulation of Bizzari and Cocco (2006). We examine three fault models, W, PWS, and PWD. In Model W, the strike-slip fault is entirely and uniformly saturated with fluid. The faults of Models PWS and PWD consist of two layers with and without fluid. The difference between Models PWS and PWD is the slip direction; a strike-slip and dip-slip for PWS and PWD, respectively.

Our numerical simulations show that the rupture processes are remarkably different for the three models, although the final slip distributions differ only slightly. At the beginning, the ruptures starting in a fluid region grow elliptically, irrespective of the models. The rupture of Model W continues to spread with an elliptical rupture front, which is similar to the one observed by Bizzari and Cocco (2006). On the other hand, the ruptures of Models PWS and PWD no longer propagate elliptically after the slipping areas reach the layer without fluid. The ruptures are delayed when the rupture fronts encounter the regions without fluid, and then proceed slowly within the region. In Model PWS, the rupture in the fluid region speeds up significantly along the strike direction, which makes a great difference of rupture front between regions with and without fluid. The variations observed in the rupture processes can be attributed to large static friction in a region without fluid, large stress drop in a fluid region, and predominant effect of thermal pressurization on propagation speed of in-plane (mode II) rupture. High static friction and small stress drop in a no-fluid region, which no pore pressure yields, can delay and slow down the rupture propagation. Rupture speed increase due to thermal pressurization can be distinct for in-plane rupture because in-plane rupture speed can increase up to P-wave speed but anti-plane rupture speed cannot exceed S-wave speed. The features observed in our numerical simulations might be useful to test whether or not fluid and its thermal pressurization has a significant role on dynamic ruptures of real earthquakes.