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Effects of confining pressure and mineral property on rupture propagation process revealed by unstable-slip experiments

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Episodic slow slip events, as defined by anomalously low rupture velocity within a range of 5 to 15 km/d (0.06 to 0.17 m/s), have been observed in subduction zones, and occur as shear slip on the plate interface downdip of the seismogenic zone. A considerable body of evidence points to high fluid pressures on the plate interface that may reduce effective normal stress and enable slow slip. Laboratory observations on rocks have shown that nucleation of unstable slip consists of an interval of fault creep that localizes and accelerates to a dynamic rupture, with propagating velocity comparable to shear wave velocity of the material. However, in spite of the importance of low effective normal stress in causing slow slip events, the effect of normal stress on the rupture properties of the fault has been yet explored.

In this study, unstable-slip experiments were conducted in a gas-medium apparatus at room temperature, confining pressures of 60-180 MPa, and a nominal strain rate of 1 x 10-3 s-1. We used powders of lizardite/chrysotile (liz/ctl), antigorite, and olivine as the starting material, producing a ~0.7-mm-thick layer of simulated fault gouge between two gabbroic forcing blocks. To monitor directly the strain field parallel to the fault surface, four strain gauges were mounted onto the lower gabbro cylinder along the fault. The friction coefficient was 0.48-0.58 for liz/ctl and 0.67-0.72 for antigorite, while olivine has a friction coefficient of 0.72-0.73.

The stress-strain curves exhibit an initial linear elastic portion, a strain-hardening range in which stress increases with strain and, finally, a range in which the stress levels off or drops off until one sudden, large unstable-slip occurs. At P_c = 100 and 140 MPa for antigorite and olivine, the shear stress dropped to a residual value at least within 50 us during the unstable-slip event. The rupture propagated bilaterally at speeds ranging from a few hundreds meters to a few kilometers per seconds. At P_c = 100-180 MPa for liz/ctl and P_c = 60 MPa for antigorite and olivine, the local strains show that a rupture started to propagate slowly at speeds in the range of 0.7 to 2.0 m/s. Eventually, a rupture propagates at fast speeds. At P_c = 60 MPa for liz/ctl, the shear stress decreased very slowly towards a residual value within ~1 s. The local strains show that a rupture nucleated just before the onset of stress drops, and then propagated at speeds ranging from 0.07 to 0.25 m/s.

There is no systematic dependence of confining pressure on the observed rupture velocity during the fast stress drops. In contrast, the rupture velocity during the slow stress drops appears to decrease with decreasing confining pressure. We thus conclude that the slow rupture propagation process along the gouge-bearing fault is affected by intrinsic material property and confining pressure. A series of slow earthquakes including slow slip may reflect differences in the size and duration of slow rupture phase, which becomes dominant if the weak material exist on the fault at low effective normal stress. In particular, the rupture property characterized by a slow stress drop with anomalously low rupture velocity observed at P_c = 60 MPa for liz/ctl might be analogous to that of slow slip events in nature.