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The evolution of the frictional properties of faults during the seismic cycle

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Earthquake nucleation occurs during the pre-seismic period when slow, stable sliding initiate on a small patch (asperity) of a pre-existing fault. In fault rocks displaying velocity weakening behaviour, slip can spread out in the surrounding regions of a fault at accelerating sliding velocities, leading to unstable sliding and rupture propagation at seismic slip rates. During the post-seismic period, significant amount of slip can still occur on the main fault at slow slip rates (afterslip), before fault healing begins during the interseismic period.

In order to understand rupture processes during the seismic cycle, we investigated the evolution of the frictional properties of a range of rock materials, typical of the brittle crust, at sub-seismic and seismic slip rates. Laboratory experiments have been performed in a low to high velocity rotary shear apparatus (LHVRS), on gouge materials with grainsize up to 200 microns, at slip rates ranging from 10 micron/s up to 1 m/s and normal load up to 20 MPa. Cyclic slide-hold-slide experiments on carbonate gouges show that, after sliding at sub-seismic slip rates, static friction increases with time according to a logarithmic relationship (fault healing). Velocity step experiments performed at sub-seismic slip rates (< 1mm/s) show that velocity strengthening behaviour evolves to velocity neutral/weakening behaviour after a critical amount of displacement of a few tens to hundreds of mm is attained. Such critical displacement is inversely proportional to the applied normal load. Experiments performed at seismic slip rates show dramatic weakening, with measured friction coefficients which are as low as 0.1. Velocity step experiments performed on samples which first experienced sliding at seismic slip rates show that: 1) velocity strengthening behaviour is much weaker, in some cases being velocity neutral/weakening, than that shown at sub-seismic slip rates; 2) fault healing occurs at a much lower rate than that observed after sliding at sub-seismic slip rates.

These preliminary results may have strong implications for earthquake nucleation processes, as they show that the propagation of a seismic rupture through velocity strengthening fault patches may change their behaviour to velocity neutral/weakening. This could allow the nucleation of the next rupture at these sites or would facilitate its through-going propagation. Our results also have significant implications for the dynamics of tsunamogenic megathrusts, which are known to repeatedly rupture through the same fault many times during the same event, accumulating large amounts of slip (e.g. Sumatra Earthquake Mw =9.4 and Tohoku-Oki Earthquake Mw = 9). This behaviour could be favoured by the development of fault patches characterized by low fault healing rates, due to accumulation of large displacements at high slip rates, which would offer less resistance to repetitive slip during the short timescales of rupture propagation. Finally, the large amounts of displacements accumulated at low slip rates in areas of co-seismic slip deficit of large earthquakes, may cause the change of their behaviours from velocity strengthening to velocity weakening. On the long term, these areas could host the nucleation of the next earthquake or, if located at shallow depths, facilitate its rupture propagation to the surface.