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Role of fluids in experimental calcite-bearing faults at seismic deformation conditions.

M. Violay (1), S. Nielsen (1), D. Cinti (1), E. Spagnuolo (1), G. Di Toro (1,2), and S. Smith (1)

(1) Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy, (2) Università di Padova, Dipartimento di Geoscienze, Padova, Italy

Fluids play a fundamental physical (fluid pressure, temperature buffering, etc.) and chemical (dissolution, hydrolytic weakening, etc.) role in controlling fault strength and earthquake nucleation, propagation and arrest. However, due to technical challenges, the influence of water at deformation conditions typical of earthquakes (i.e., slip rates of 1 m/s, displacements of 0.1-5 m, normal stress of tens of MPa) remains poorly constrained experimentally.

Here we present results from high velocity friction experiments performed with a rotary shear apparatus (SHIVA: Slow to HIgh Velocity (friction) Apparatus) on Carrara marble. SHIVA is equipped with (1) an environmental/vacuum chamber to perform experiments in the absence of room-humidity, (2) a pressure vessel to perform experiments with fluids (up to 15 MPa confining pressure), including devices to determine fluid composition (Ca^{2+}, Mg^{2+}, $HCO_3{}^-$, etc).

Experiments were conducted on hollow cylinders (50/30 mm ext/int diameter) of Carrara (98% calcite) marble at velocities of 1–6.5 m/s, displacements up to a few meters, normal stresses up to 40 MPa and fluid pressures between 0 (under vacuum) and 15 MPa (fluid-saturated conditions, with H_2O in chemical equilibrium with the marble). Rock and fluid samples were recovered for post-run analysis to determine deformation mechanisms and changes in fluid composition.

Under these deformation conditions:

1) the friction coefficient decays rapidly from a peak (= static) $\mu_p \sim 0.8$ at the initiation of sliding towards a steady-state $\mu_{ss} \sim 0.1$. The absolute values of both peak and steady-state friction are not significantly influenced by the presence of fluids;

2) the decay from peak to steady-state friction is more abrupt in presence of fluids;

3) during deceleration of the friction apparatus, the friction coefficient recovers almost instantaneously to a value, μ_r, of 0.2-0.6 (strength recovery) resulting in a small static stress drop. Strength recovery is smaller in the presence of fluids.

4) the fluid (H_2O) after the experiment is enriched in Ca^{2+}, Mg^{2+} and $HCO_3{}^-$. This chemical evolution suggests breakdown reactions (decarbonation of calcite) promoted by frictional heating and controlled by the presence of H_2O.

We conclude that the large decrease in friction and abrupt weakening, especially in the presence of fluids, indicates that calcite-bearing rocks are prone to earthquake nucleation and seismic rupture propagation (see the L'Aquila 2009 earthquake sequence). The chemical changes observed in water springs after large earthquakes in carbonatic rocks is similar to those found in these experiments, suggesting that the weakening mechanisms triggered in the experiments might occur in nature.