Geophysical Research Abstracts
Vol. 14, EGU2012-8001, 2012
EGU General Assembly 2012

Frictional properties of Zuccale Fault rocks from room temperature to in-situ conditions: results from high strain rotary shear experiments

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The Zuccale fault is a regionally-important, low-angle normal fault, exposed on the Isle of Elba in Central Italy, that accommodated a total shear displacement of 6-8 km.The fault zone structure and fault rocks formed at less than 8 km crustal depth. The present-day fault structure is the final product of several deformation processes superposed during the fault history. Here, we focus on a series of highly foliated and phyllosilicate-rich fault rocks that represent the basal horizon of the detachment. Previous experimental work on foliated, intact samples, sheared in their in-situ microstructural (foliated) condition, demonstrated a markedly lower friction coefficient compared to homogeneously mixed powdered samples of the same material. In this study, we report results from a series of rotary shear experiments performed on 1 mm thick powdered gouges made from several fault rock types obtained from the Zuccale Fault. The tests were done under conditions ranging from room temperature to in-situ conditions (i.e. at temperatures up to 300 ºC, applied normal stresses up to 200 MPa and fluid-saturated.) The ratio of fluid pressure to effective normal stress was held constant at either λ=0.4 or λ=0.8 to simulate an over-pressurized fault. The samples were sheared at a constant sliding velocity of 10 μm/s for at least 5 mm, after which a velocity-stepping sequence from 1 to 300 μm/s was started to determine the velocity dependence of friction. This can be represented by the rate-and-state parameter (a-b), which was determined by an inversion of the data to the rate-and-state equations.

Friction of the various fault rocks is between 0.3 and 0.7, similar to values obtained in a previous study, and decreases with increasing phyllosilicate content. Friction decreases mildly with temperature whereas normal stress and fluid pressure do not affect friction values systematically. All samples exhibited velocity-strengthening, inherently stable behavior under room temperature conditions and (a-b) increases with increasing sliding velocity. In contrast, velocity-weakening, accompanied by stick-slips, is observed for the strongest samples at 300 ºC and sliding velocities below 10 μm/s. An increase in fluid pressure under these conditions leads to a further reduction in (a-b) for all samples, so that they exhibit unstable, stick-slip behavior at low sliding velocity.

The results suggest that phyllosilicate-bearing fault rocks can deform by stable, aseismic creep at low resolved shear stress and low shear rate conditions. An increase in fluid pressure or loading of stronger portions could lead to a runaway instability. However, this instability could be limited in size and velocity due to the observed strengthening at higher sliding velocities. This has important implications for potential rupture dimensions in this geometrically complex fault zone.