Friction behavior of gabbro under hydrothermal conditions

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Fault friction is one of the most significant parameters controlling fault slip behavior and earthquake mechanics. Great success has been achieved in understanding the stability of fault slip, nucleation of earthquake and dynamic weakening mechanism in the past decades by performing low (~1 μm/s, sub-seismic conditions) to high (~1 m/s, seismic conditions) velocity friction experiments. However, extrapolating these experimental results to nature remains limited. In fact, for low velocity experiments, usually performed with tri-axial machines, though the hydrothermal conditions can be imposed, the shear displacement is limited to several millimeters neglecting the effect of cumulative displacement. For high velocity experiments aiming at reproducing coseismic fault slip, the implementation of hydrothermal conditions has been hindered by technical difficulties leaving high-velocity friction property of faults under realistic crustal conditions still ambiguous.

Here we exploited a Low to High Velocity rotary shear apparatus (LHV) equipped with a dedicated hydrothermal pressure vessel installed at the Institute of Geology, China Earthquake Administration, to investigate the frictional behavior of gabbro under realistic hydrothermal conditions. The samples were sheared at effective normal stresses of 10 MPa and 20 MPa, velocities (V) spanning from 1 μm/s to 0.1 m/s, displacement up to 3 m, under temperature conditions (T) up to 400 ℃ and pore pressure (Pf) up to 30 MPa. Our results showed that at \( T = 300 \) ℃ and \( Pf = 10 \) MPa (pore fluid as liquid), dramatic slip weakening happened at all tested velocities. At slip initiation the friction coefficient increased sharply to a peak value (~0.7±0.05), then decayed toward a residual value of ~0.35. Instead at \( T = 400 \) ℃ and \( Pf = 10 \) MPa (pore fluid as vapor), we observed that friction remained high (~0.7) at \( V < 10 \) mm/s and slip weakening only occurred for \( V \geq 10 \) mm/s. For experiments at \( T = 400 \) ℃ and \( Pf = 30 \) MPa (pore fluid in supercritical conditions), slip weakening behavior occurred in most cases. The evolution of friction coefficient with displacement was complex, e.g., two peaks, large variations. Moreover, comparative experiments conducted at relatively low temperature suggested that mechanisms leading to the dramatic weakening under such a wide velocity range could be closely linked with both fluid-rock interactions and the physical state of the fluid. However, what exact fluid-rock reactions are involved is still an open question, which will be investigated by further microstructural and mineralogical analysis. The unique frictional behavior observed in this study challenges the results obtained from small-displacements experiments in many aspects and improves our understanding of fault friction in nature.
understanding on friction behavior of faults in geothermal applications.