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Fault weakening due to CO_2-fluid-rock interaction – evidence from deformation experiments of carbonated serpentinites

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To assess the seismogenic potential of fault zones it is crucial to understand fluid-rock interactions in these zones, because alteration affects the fault strength and stability, as well as the deformation mechanisms.

The San Andreas fault (SAF) system is known for infrequent large magnitude (M≥7) earthquakes, whereas some segments lack such strong seismic events [1]. Here, strain is largely accommodated by creep motion. Aseismic creep can be enhanced by the presence of fluids, which may additionally drive mineral reactions. For example, fluid composition and magnesite deposits in the SAF segment between San Juan Bautista and Parkfield suggests carbonation due to infiltration of CO_2-bearing fluids into the fault [2]. Carbonation of ultramafic rocks leads to the formation of talc, which is known to be frictionally weak and promotes creep when wet [3]. However, our thermodynamic fluid-infiltration calculations show that carbonation will not produce pure talc but lizardite-talc-magnesite (LTM) and talc-magnesite rocks (soapstone) and, with increasing extent of reactive fluid flow, talc-magnesite-quartz (TMQ) and magnesite-quartz rocks (listvenite). The strength and seismogenic potential of serpentinite fault zones undergoing carbonation thus may change dynamically as the mineral proportions and assemblages change, but the respective frictional behaviour of these assemblages is unknown.

We performed rotary-shear experiments on gouge layers with compositions ranging from lizardite-serpentinite to LTM, soapstone, TMQ and listvenite at pressure, temperature and pore fluid pressures corresponding to a depth of about 10 km (300 °C, 250 MPa normal stress and 100 MPa pore pressure). We measured the frictional strength within the velocity range of 0.002 μm/s to 10 μm/s.

Our data show that lizardite gouges are relatively strong and slightly velocity-weakening. The friction coefficient dropped from 0.45 at 0.002 μm/s to 0.42 at 10 μm/s. A similar velocity-dependence is observed for soapstone gouges, although at lower absolute friction coefficients of 0.3 to 0.28. Interestingly, listvenite gouges show the opposite behavior, with friction coefficients increasing from 0.25 at 0.002 μm/s to 0.48 at 10 μm/s. Stick-slips were only observed in serpentinite and soapstone gouges at low velocities. Increasing velocities and progressing carbonation causes stable slip behavior. Microtextural observations indicate strong grain-size reduction and basal cleavage in serpentinite gouges. On the contrary, soapstone and listvenite gouges show a fine-grained magnesite matrix surrounding the silicates.

Our results suggest that serpentinized fault zones have the potential to nucleate unstable slip. The results further confirm the strong weakening effect of carbonation. CO_2-fluid-rock interaction in ultramafic fault gouges may effectively suppress the nucleation of earthquakes. Since also listvenite gouges deformed aseismic and are found to be frictionally weak at low velocities, we suggest that besides talc also magnesite plays an important role in the deformation behavior of carbonated ultramafic fault zones.

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