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Laboratory and SAFOD Investigations Pertaining to the Origin of Low-Strength, Creeping Faults of the San Andreas System, California, USA

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Serpentinized ultramafic rocks are closely associated with creeping faults of the San Andreas system in central and northern California. Although serpentinite has been invoked as the cause of the creep, serpentine minerals can exhibit unstable (seismogenic) slip under certain conditions. The serpentine varieties lizardite and antigorite also are two of the stronger phyllosilicate minerals, with coefficients of friction, μ = 0.5-0.6 when sheared between ultramafic rocks at 100 MPa effective normal stress (dry serpentinite is a 'Byerlee's Law' material, with μ = 0.7-0.8). However, the serpentinites entrained in the creeping faults typically are juxtaposed against quartzofeldspathic rather than ultramafic rocks. In a series of triaxial friction experiments conducted under hydrothermal conditions (200-350°C, 3.6-360 cm/yr shearing rates), we demonstrated that this contrast in rock chemistry can promote fluid-assisted reactions that influence the mechanical properties of these faults. When lizardite- or antigorite-serpentinite gouges are sheared between blocks of granite or quartzite, their strengths are reduced by as much as 40% to $\mu \sim 0.3$, with the greatest strength reductions at the highest temperatures (temperature weakening) and slowest shearing rates (velocity strengthening, which is inherently stable). The strength reductions accompanying decreasing velocity were reversible when the rates were increased during these relatively short experiments ($\leq$14 days), and we found textural evidence that some serpentine minerals recrystallized during the experiments. This suggests that the cause of the weakening in these experiments is a shearing-enhanced, solution-transfer process driven by pore fluids whose chemistry was modified by interaction with the quartzofeldspathic wall rocks. Solution-transfer processes involving dissolution and reprecipitation of serpentine minerals have been described in serpentinite-bearing faults in California (e.g., Andreani et al., 2005), and they may contribute to aseismic slip and weakening in those faults. Over time, chemical diffusion between serpentinite and quartzose rocks should lead to the growth of new minerals that will also influence the mechanical behavior of the faults. Evidence for the initiation of such reactions was seen in our 14-day experiments at 250°C, in which traces of Mg-rich, saponitic smectite clay grew on shear surfaces. We have identified similar saponitic clays ($\mu \leq 0.1$?), along with the Mg-rich phyllosilicates corrensite, talc ($\mu < 0.2$), and chlorite ($\mu \sim 0.35$) as alteration products of serpentine in cuttings from the gouge zones that mark the two actively creeping strands of the San Andreas fault in the SAFOD drillhole. Examination of recently distributed SAFOD Phase 3 core samples will improve our understanding of the processes involved in the development of the gouge zones.