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Implications for strength of the San Andreas Fault Zone from SAFOD cuttings and core

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The San Andreas Fault Observatory at Depth (SAFOD) scientific drilling project successfully penetrated the fault zone at a seismogenic depth of 3 km in 2005, acquiring 22 m of core, 52 side-wall cores at intervals near the main trace, and cuttings for the entire 4.0 km hole. Arguments for a weak SAF, based on surface heat flow and stress orientations, suggest coseismic frictional strength of μ = 0.1 to 0.2. To test the plausibility of these arguments we conducted laboratory tests on SAFOD core samples. We selected core samples that were representative of primary lithologic units and significant shear zones, including candidates for the currently active SAF where possible, and complemented the lithologic coverage with washed cuttings, based on XRD clay mineral analysis and velocity and gamma logs. Triaxial strength tests were conducted on limited numbers of intact core samples at effective pressures of 10 to 160 MPa at constant pore pressure. The samples were deformed at a constant strain rate of 10^{-5} s^{-1} and generally failed by brittle faulting.

To determine frictional properties, triaxial sliding experiments were conducted washed drill cuttings spanning the main hole from 1.8 to 3.8 km measured depth. The samples were crushed and sieved to obtain particle sizes of $<$149 μm. Tests were run on cylindrical granite/sandstone blocks containing saw-cuts inclined at 30º and filled with 1 mm-thick sample gouge layers at constant effective normal stresses of 10 and 40 MPa and constant pore pressure of 1 MPa. Samples were sheared up to 10.4 mm at room temperature and velocities of 1, 0.1 and 0.01 μm/s. Stable sliding behavior and overall strain hardening were observed in all tests. The coefficient of friction typically showed a modest decrease with increasing effective normal stress and mostly velocity strengthening was observed. Preliminary results yield coefficients of friction, μ, which generally fall into two clusters spanning the range of 0.45 to 0.8. The higher values of μ ($\sim$0.7 – 0.8) correspond to quartzofeldspathic samples derived from granodiorites and arkoses encountered in the drill hole, comparable to sliding frictional strength of 0.68 measured during sliding on faults formed in fracture tests on intact SAFOD granodiorite samples. Lower values of μ (0.45 – 0.55) were observed at depth intervals interpreted to be broad shear zones based on enriched clay content, reduced seismic velocities and increased gamma radiation.

To test the validity of these experiments, sliding tests were also conducted on core samples obtained from a narrow prominent fault zone at 3067 m measured depth. Coefficient of friction was measured to be 0.40-0.45, and were notably weaker than that for cuttings ($\sim$0.6) tested at this same depth but similar to the values obtained for other shear zones. This difference between core and cuttings from the equivalent depth is likely due to mixing of material in the cuttings, resulting in the averaging of mechanical properties over a 1 to 3 m interval. Nevertheless, we find good agreement in the strength of materials obtained from shallow shear zones, indicating that some weak mineral phases are preserved in the cuttings.

Our study of fault-derived materials provides the best SAF fault zone strength data to date and indicates frictional strengths exceeding 0.4. If the SAF is indeed unusually weak, then the presence of weak alteration minerals appears to account for only a portion of this reduced strength and other mechanisms such as elevated pore fluid and dynamic weakening processes would still be required. Many of the unresolved questions raised by this study emphasize the importance of collecting continuous core in Phase 3 drilling planned for 2007.