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Structure and Properties of the San Andreas Fault at Seismogenic Depths: Recent Results from the SAFOD Experiment

by
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ABSTRACT

The San Andreas Fault Observatory at Depth (SAFOD) was drilled into the San Andreas Fault Zone to study the physics of faulting and earthquake generation and determine the composition, physical properties, and mechanical behavior of an active, plate-bounding fault at depth. SAFOD is located 10 km NW of Parkfield, California, and penetrates a section of the fault that is moving through a combination of repeating microearthquakes and fault creep. During Phases 1 and 2 in the summers of 2004 and 2005, SAFOD was drilled vertically to a depth of 1.5 km and then deviated across the San Andreas Fault Zone to vertical depth of 3.1 km. During Phase 3 of SAFOD in the summer of 2007, cores were acquired from holes branching off the main hole to directly sample the country rock as well as actively deforming traces of the fault.

Geophysical logs define the San Andreas Fault Zone to be relatively broad (~250 m), containing several discrete zones only 2-3 m wide that exhibit very low P- and S-wave velocities and low resistivity. Two of these zones have progressively deformed the cemented casing at measured depths of 3194 m and 3301 m (corresponding to vertical depths of 2.6 - 2.7 km), indicating that they are actively creeping shear zones. The 3194 m casing deformation zone lies ~100 m above a cluster of repeating M2 earthquakes that form the southwestern boundary of the active fault zone. There are no indications of anomalous pore pressure in the deforming fault core. Rather, the fault separates distinct hydrologic regimes, with elevated pore pressure and anomalous geochemical signatures on the northeast side of the fault.

Stress and temperature measurements in the SAFOD main hole (and co-located vertical pilot hole) confirm previous inferences that the San Andreas Fault is a relatively weak fault in an otherwise strong crust. The direction of the maximum horizontal principal stress rotates with increasing depth to maintain a high angle to the fault, even up to the active shear zones. Hydraulic fracturing stress measurements indicate an increase in the magnitude of the least principal stress in the vicinity of the active fault at depth, as theoretically predicted. There is no thermal evidence of frictionally-generated heat on the San Andreas Fault.

During Phase 3 we obtained core from just outside the geologically defined San Andreas Fault Zone and from the active deformation zones at 3194 and 3301 m. The cores obtained from these deformation zones exhibit a variety of features indicating pronounced strain localization and probably marked weakening. These include highly sheared shales and siltstones, cataclasites, veined serpentinite and chert bodies, and foliated, cohesionless serpentine-bearing fault gouge. The occurrence of serpentinite is particularly significant, because serpentine and related minerals are widely regarded to be important in controlling frictional strength and the stability of sliding. The Phase 3 core samples will be extensively tested in the laboratory to study the composition, deformation mechanisms, physical properties and rheological behavior of the fault rocks. In the summer of 2008, an array of seismometers, accelerometers, tiltmeters and fluid pressure sensors will be deployed in the cased borehole in the immediate vicinity of the repeating M2 earthquakes to test hypotheses related to earthquake rupture initiation and propagation and the possible role of fluid pressure in controlling fault strength and earthquake periodicity.

BIOGRAPHY

Stephen Hickman is a senior research geophysicist with the U.S. Geological Survey's Earthquake Hazards Team in Menlo Park, California. He received a PhD in solid earth geophysics from the Massachusetts Institute of Technology in 1989. His research includes borehole studies of stress, faulting and fluid flow in seismically active areas and laboratory studies of the chemical effects of pore fluids on the mechanical behavior of fault rocks. He has led or participated in numerous scientific drilling projects in the United States and abroad, including studies of the relationship between stress and fracture permeability in fault-hosted geothermal fields at Dixie Valley, Nevada, and Coso, California. He is currently co-principal investigator (with Mark Zoback and William Ellsworth) on the San Andreas Fault Observatory at Depth and is Chair of the Science Advisory Group for the International Continental Scientific Drilling Program.