# Milton Dobrin Memorial Lecture

# Scientific Drilling into the San Andreas Fault

**February 6, 2006**

**Dr. Mark D. Zoback**
Stanford University

5:30pm (followed by a reception)
University Hilton
University of Houston

This talk will provide an overview of drilling, sampling and down-hole measurement activities associated with the first two phases of the *San Andreas Fault Observatory at Depth* (SAFOD). The SAFOD is located at the transition between the creeping and locked sections of the fault, 9 km NW of Parkfield, CA, approximately half way between San Francisco and Los Angeles. A 2.1 km deep vertical pilot hole was drilled at the site in 2002. The SAFOD main borehole was drilled vertically to a depth of 1.5 km and then deviated at an average angle of 55 deg to vertical, passing beneath the surface trace of the San Andreas fault at a depth of 3.2 km. Repeating micro-earthquakes on the San Andreas define the main active fault trace at depth, as well as a secondary active fault about 250 m to the SW (i.e., closer to SAFOD).

The hole was rotary drilled; comprehensive cuttings were obtained and a real-time analysis of gases in the drilling mud was carried out. Spot cores were obtained at three depths (at casing set points) in the shallow granite and deeper sedimentary rocks penetrated by the hole, augmented by over fifty side-wall cores. Continuous coring of the San Andreas Fault Zone will be carried out in Phase 3 of the project in the summer of 2007. In addition to sampling mud gas, discrete fluid and gas samples were obtained at several depths for geochemical analysis. Real-time geophysical measurements were made while drilling through most of the San Andreas Fault Zone, and a suite of “open hole” geophysical measurements were also made over essentially the entire depth of the hole.

The geophysical logs define the San Andreas Fault zone to be relatively broad (~250 m) with discrete shear zones where the localized deformation is taking place. Direct and indirect indicators of fluid pressure indicate no anomalous pore pressure in the core of the fault zone. Rather, the fault zone appears to separate distinct hydrologic regimes, with elevated pore pressure and anomalous geomechanical signatures on the north east side of the fault. Both direct and indirect stress measurements indicate that the San Andreas fault is a relatively weak fault in an otherwise strong crust, confirming three decades of inferences about fault strength from heat flow and stress orientation measurements. Construction of the multi-component SAFOD observatory is well underway, with a seismometer and tiltmeter operating at 1 km depth in the pilot hole and a fiber-optic laser strainmeter cemented behind casing in the main hole.

**Mark Zoback** is the Benjamin M. Page Professor of Earth Sciences and Professor of Geophysics at Stanford University. From 1975 to 1984, he was a research geophysicist at the U.S. Geological Survey and, from 1981-1984, Chief of the Branch of Tectonophysics. He has been a Professor of Geophysics at Stanford since 1984. His principal research interests are related to the forces that act within the earth's crust and their role to processes affecting plate tectonics, earthquakes and oil and gas reservoirs. He has authored, or co-authored, approximately 250 technical publications, is editor of several books and holder of three patents. He is currently one of the Principal Investigators of the San Andreas Fault Observatory at Depth (SAFOD) project that involves a complex suite of experiments and construction of a geophysical observatory during within the active fault zone at 3 km depth.