Geophysical Research Abstracts,
Vol. 11, EGU2009-1783, 2009
EGU General Assembly 2009

Effect of fluid infiltration on brittle failure of rocks under true triaxial stress

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Conventional triaxial tests (in which $\sigma_1 > \sigma_2 = \sigma_3$)suggest that the process of brittle failure in rock begins with microcracking upon dilatancy onset, followed by localization along an eventual shear band, ending in faulting or brittle failure. True triaxial tests ($\sigma_1 > \sigma_2 > \sigma_3$) reveal additional details of the mechanical behavior not otherwise observed. I summarize here true triaxial testing programs carried out on rectangular prismatic specimens from cores extracted during drilling of three deep scientific boreholes: KTB (amphibolite), San Andreas Fault Observatory at Depth (SAFOD-granodiorite), and Taiwan Chelungpu-fault Drilling Project (TCDP-siltstone). The three rocks have in common a very low permeability, but differ in other mechanical properties. Dry rectangular prismatic specimens were subjected to constant σ_2 and σ_3 and a monotonically raising σ_1 to failure. All three rocks exhibited similar failure mechanism, in which induced or reopened microcracks are primarily aligned with the $\sigma_1 - \sigma_2$ plane, and the developed fault is steeply inclined in the σ_3 direction. For the same least principal stress σ_3 (applied by confining fluid pressure), rock resistance to faulting increases substantially as σ_2 is elevated over the conventional $\sigma_2 = \sigma_3$. Thus, the common Mohr-type criteria, which ignore the effect of σ_2, usually underestimate rock strength. Moreover, contrary to Mohr prediction, fracture plane slope for the same σ_3 steepens as σ_2 rises above the base value ($\sigma_2 = \sigma_3$). SEM examinations of cross sections cut along the $\sigma_2 - \sigma_3$ plane reveal not only that the strike of the main fracture is subparallel to σ_2 direction, but that fracture aperture narrows as the level of σ_2 magnitude increases, since more of the microcracks align themselves with the $\sigma_1 - \sigma_2$ plane.

The same rocks were also tested with the σ_3 faces unjacketed, thus exposing them to the pressurized fluid. This configuration simulates conditions prevailing around a borehole wall, where fluid pressure acting directly on the exposed rock is also the least principal stress. In contrast to dry rock, unjacketed specimens in all three rocks tested develop clusters of through-going fractures adjacent and subparallel to specimen σ_3 faces, bringing about premature failure. The closely spaced fractures resemble exfoliation in flat granitic outcrops. They are also similar to breakout-forming multiple extensile cracks that develop parallel to borehole walls in regions of high stress concentration. The type of failure is analogous to Brace's (1964) finding in conventional triaxial extension tests in which $\sigma_1 = \sigma_2$ were applied radially to unjacketed cylindrical specimens by confining fluid pressure. Our interpretation, similar to Brace's, is that upon dilatancy onset some of the new or reopened microcracks adjacent to the specimen unjacketed faces are intruded and extended by the confining fluid to become long and often through-going open tensile fractures, bringing about rock failure at levels considerably lower from those of jacketed specimens. A simple two-dimensional model explains why microcracks grow as soon as they are fluid-filled, causing compressive failure just after dilatancy onset.