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Dilatancy hardening and water weakening in sandstones

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Understanding the role of pore fluids on mechanical properties of rocks is an essential precursor to understanding a range of problems in numerous fields of applied research such as geothermal energy provision, groundwater withdrawal, mining or slope stability. Earthquake occurrence is also related to the mechanical and chemical interaction between rocks of various types and pore fluids at different states of saturation, be it in short-term (failure) or in long-term (healing) processes. Apparently, the presence or absence of clay minerals plays a central role in the water sensitivity of strength. Yet, it is still unresolved whether this relation results dominantly from their effect on local hydraulic properties (drainage) or on pore water chemistry (dissolution, subcritical crack growth). To distinguish between these two underlying mechanisms we performed triaxial deformation experiments at different strain rates on three types of sandstones (Wilkeson sst, Fontainebleau sst, Ruhr sst) varying in porosity, permeability, saturation treatment (minutes to months), and mineralogical composition. The latter was derived from petrographic analyses on thin sections and X-ray diffraction. The applied strain rates range from 10^{-7} to 10^{-3} s^{-1} covering the critical strain rates for internal drainage calculated from the determined hydraulic properties of the three sandstone types. Tests were performed at room temperature and an effective pressure of 20 MPa, i.e., dry samples were tested at a confining pressure of 20 MPa while saturated samples were tested at 50 MPa confining pressure and 30 MPa pore pressure. Under these conditions all samples exhibit brittle failure and hence dilatancy hardening occurs when deformation proceeds too fast for maintaining internal drainage. Axial ultrasound velocities and amplitudes of P-waves, as well as acoustic emissions were measured simultaneously during triaxial deformation to investigate the effect of transient drainage states on wave propagation and to monitor the onset of microcracking, respectively. The results of our study contribute to the understanding of (i) dilatancy hardening in sandstones by comparing tests of dry and saturated samples at different strain rates, (ii) the interaction between pore fluid and rock sample by linking failure strengths of dry and saturated samples at corresponding effective stresses, (iii) the role of clay minerals in deformation processes and their mechanical and chemical contribution to water weakening, and (iv) the chances to monitor states of transient damage in the underground, e.g., during failure mechanisms in rupture zones.