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The influence of Effective Stress and Pore Fluid Pressure on Brittle Creep in Water-Saturated Darley Dale Sandstone

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The characterization of time-dependent brittle deformation is fundamental to understanding the long-term evolution and dynamics of the Earth's upper crust. The chemical influence of water promotes time-dependent deformation through such mechanisms as stress corrosion cracking that allows rocks to deform at stresses far below their short-term failure strength and at very low strain rates. Even under a constant applied stress, such crack growth is highly non-linear and accelerates towards dynamic failure over extended periods of time.

Here we report results from a study of time-dependent brittle creep in water-saturated samples of Darley Dale sandstone (initial porosity of 13%) under triaxial stress conditions and at room temperature. Throughout this study, stress-stepping experiments were performed to allow the influence of variation in effective stress and pore fluid (water) pressure to be studied in detail. Sample variability during conventional creep experiments requires that many experiments must be performed to yield a concise result. However, our study shows that stress-stepping experiments provide a means to overcome this problem, and the results compare favourably with those derived from conventional experiments. Crack damage evolution was monitored throughout all of our experiments by measuring the damage proxies of axial strain, volume change and output of acoustic emission energy over creep strain rates in the range 10^{-6} to 10^{-9} s^{-1}.

The influence of effective stress was investigated in experiments with a constant pore fluid pressure of 20 MPa and confining pressures of 30, 50 and 70 MPa. Creep strain rates were calculated for each stress-step from the resultant steady-state creep phase. In addition to the purely mechanical influence of water, governed by the effective stress law, which results in a shift in the creep strain rate curves against differential stress, our results also demonstrate that the chemically-driven process of stress corrosion cracking appears to be inhibited at higher effective stresses. This results in an increase in the gradient of the creep strain rate curves with increasing effective stress. We suggest that the most likely cause of this change is a decrease in water mobility due to a reduction in crack aperture and an increase in water viscosity at higher pressure. By contrast, our data suggest that creep strain rate remains unchanged when pore fluid pressure was raised from 20 and 40 MPa while maintaining a constant effective stress of 30 MPa. Finally, we show that the creep behaviour of Darley Dale sandstone can be equally well described by either exponential or power law forms of the creep law, over the range of strain rates measured.