Geophysical Research Abstracts
Vol. 21, EGU2019-5105, 2019
EGU General Assembly 2019

Time and Temperature Dependent Creep in Tournemire Shale

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We conducted a series of triaxial creep experiments on shale specimens coming from Tournemire, France, using the stress-stepping method up to failure, at a confining pressure of 80 MPa, on two orientations (parallel and perpendicular to bedding), and at temperatures of 26 and 75 °C. In these week-long experiments, stress, strains, and P wave ultrasonic velocities were recorded (quasi-) continuously. The strength at creep failure of Tournemire shale was ∼70% higher than the peak strength measured during constant strain rate (∼107/s) experiments, and failure was reached at larger strains. An overall transition from P wave velocity increase at moderate differential stress to P wave velocity decrease closer to brittle failure was also observed. At a smaller timescale, P wave velocities initially decreased and then increased gradually during each step of creep deformation. The magnitude of these variations showed important (i) stress, (ii) orientation, and (iii) temperature dependences: larger increase was observed for P wave propagating along the main compressive stress orientation, larger decrease for P wave propagating perpendicular to it, and a changing behavior enhanced at a higher temperature. Scanning electron microscopy performed postmortem revealed evidence of time-dependent pressure solution, localized compaction, crack growth, and sealing/healing. Our data reveal that shale deformation is highly stress sensitive only in a narrowstress domain where stress corrosion cracking-induced brittle dilatant creep deformation is dominant. At stresses below, pressure solution compaction creep dominates the deformation and shales compact, consolidate, and heal. This has important implications for the mechanics of shallow fault zones and accretionary prisms.