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Brittle and compaction creep in porous sandstone

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Strain localisation in the Earth's crust occurs at all scales, from the fracture of grains at the microscale to crustal-scale faulting. Over the last fifty years, laboratory rock deformation studies have exposed the variety of deformation mechanisms and failure modes of rock. Broadly speaking, rock failure can be described as either dilatant (brittle) or compactive. While dilatant failure in porous sandstones is manifest as shear fracturing, their failure in the compactant regime can be characterised by either distributed cataclastic flow or the formation of localised compaction bands. To better understand the time-dependency of strain localisation (shear fracturing and compaction band growth), we performed triaxial deformation experiments on water-saturated Bleurswiller sandstone (porosity = 24%) under a constant stress (creep) in the dilatant and compactive regimes, with particular focus on time-dependent compaction band formation in the compactive regime. Our experiments show that inelastic strain accumulates at a constant stress in the brittle and compactive regimes leading to the development of shear fractures and compaction bands, respectively. While creep in the dilatant regime is characterised by an increase in porosity and, ultimately, an acceleration in axial strain to shear failure (as observed in previous studies), compaction creep is characterised by a reduction in porosity and a gradual deceleration in axial strain. The overall deceleration in axial strain, AE activity, and porosity change during creep compaction is punctuated by excursions interpreted as the formation of compaction bands. The growth rate of compaction bands formed during creep is lower as the applied differential stress, and hence background creep strain rate, is decreased, although the inelastic strain required for a compaction band remains constant over strain rates spanning several orders of magnitude. We find that, despite the large differences in strain rate and growth rate (from both creep and constant strain rate experiments), the characteristics (geometry, thickness) of a compaction band remain essentially the same. Several lines of evidence, notably the similarity between the differential stress dependence of creep strain rate in the dilatant and compactive regimes, suggest that, as for dilatant creep, compactant creep is driven by subcritical stress corrosion cracking. We highlight the attendant implications for time-dependent porosity loss, subsidence, and permeability reduction in sandstone reservoirs.