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An exploration of the rate-dependent rupture of granites in compression and tension

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The rupture of geomaterials is integral to multiple areas of geoscience and engineering, and is of particular importance to subsurface engineering projects that address decarbonisation, such as geothermal energy extraction and carbon capture and storage. Laboratory experimentation has led to the development of numerous, elegant micro-mechanical solutions that detail the accumulation of damage during deformation. Yet few studies have constrained the impact of deformation rate (which spans 10's of orders of magnitude in nature and during subsurface stimulation) on material strength, rupture architecture and associated geophysical signals.

Here, we perform a suite of uniaxial compressive strength (UCS) and Brazilian disc tests with acoustic emission monitoring at 4 deformation rates (0.0004, 0.004, 0.04 and 0.4 mms^{-1}) using a dense (1% porosity), low permeability ($7 \times 10^{-19} \text{ m}^2$ at 10 MPa effective pressure) medium-fine grained monzogranite. Rates chosen equate to strain rates (for UCS) and diametric equivalent strain rates (Brazil tests) span 10^{-5} to 10^{-1} , encompassing and expanding upon standard conditions for reporting of material strength. We find that materials undergo apparent strengthening under increasing deformation rate in both compression and tension. UCS is increased by ~45 % and Brazilian tensile strength by ~35 % across the rates tested. Young's Modulus also shows an apparent increase of ~17 % across the rates tested. In UCS, increasing rate results in increasingly localised rupture and increasingly efficient grain size reduction along the fracture plane, suggesting that the rate of rupture impacts development of permeable pathways and hence fracture conductivity in deformed media.

Acoustic emission monitoring shows that ruptures developed in compression and tension follow different characteristic rates of acceleration, driven by the initiation, propagation and coalescence of fractures which differs under the two regimes. Moreover, b-value, calculated for the frequency-amplitude distribution of AEs is shown to be higher in tension than in compression. As a function of rate in both compression and tension, we find a higher prevalence of higher energy AE events with increasing deformation rates, which also serves to reduce b-value. This demonstrates that the predictability of failure events is dependent on stress regime (tensile/ compressive) and deformation rate, which impacts our ability to accurately forecast behaviour; however monitoring

and predictive strategies largely fail to account for these controls. One of the most robust strategies for monitoring changes in material response to deformation may thus be tracking b -value with fixed sampling windows. A better understanding of the signals that accompany rate-dependent deformation will aid in the interpretation of seismicity both in natural phenomena and during geoenery applications.