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Fracture propagation during fluid injection experiments in shale at elevated confining pressures.

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The use of hydraulic fracturing to recover shale-gas has focused attention upon the fundamental fracture properties of gas-bearing shales. Fracture propagation trajectories in these materials depend on the interaction between the anisotropic mechanical properties of the shale and the anisotropic in-situ stress field. However, there is a general paucity of available experimental data on their anisotropic mechanical, physical and fluid-flow properties, especially at elevated confining pressures.

Here we report the results of laboratory-scale fluid injection experiments, for Whitby mudstone and Mancos shale (an interbedded silt and mudstone), as well as Pennant sandstone (a tight sandstone with permeability similar to shales), which is used an isotropic baseline and tight-gas sandstone analogue. Our injection experiments involved the pressurisation of a blind-ending central hole in an initially dry cylindrical sample. Pressurisation was conducted under constant volume-rate control, using silicone oils of various viscosities.

The dependence of breakdown pressure on confining pressure was seen to be dependent on the rock strength, with the significantly stronger Pennant sandstone exhibiting much lower confining-pressure dependence of breakdown pressure than the weaker shales. In most experiments, a small drop in the injection pressure record was observed at what is taken to be fracture initiation, and in the Pennant sandstone this was accompanied by a small burst of acoustic energy. Breakdown was found to be rapid and uncontrollable after initiation if injection is continued, but can be limited to a slower (but still uncontrolled) rate by ceasing the injection of fluid after the breakdown initiation in experiments where it could be identified. A simplified 2-dimensional model for explaining these observations is presented in terms of the stress intensities at the tip of a pressurised crack.

Additionally, we present a suite of supporting mechanical, flow and elastic measurements. Mechanical experiments include standard triaxial tests, pressure-dependent permeability experiments and fracture toughness determined using the double-torsion test. Elastic characterisation was determined through ultrasonic velocities determined using a cross-correlation method.