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In-situ synchrotron X-ray tomography of fluid injection experiments

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A suite of laboratory-scale fluid injection experiments were conducted on 20mm diameter shale samples at elevated confining pressures between 20 and 50 MPa. Experiments were conducted on Bowland, Haynesville, Kimmeridge, Mancos and Whitby shales, as well as Solnhofen limestone. An Aluminium pressure vessel was specially developed to perform these fluid injection experiments with in-situ X-Ray Tomography on the I12 beamline at Diamond Light Source, UK. Tomographs with a voxel edge-length of 17µm were generated in this way and have been used to correlate fractures to the layering in the materials.

Here, the breakdown pressures of the various rock samples were seen to increase linearly with confining pressure as has been seen in previous studies, with little difference between sample materials. However, here, two distinct linear trends are interpreted, offset by around 10MPa. The tomographs demonstrate that the higher of these two trends corresponds to the development of new fractures, while the lower trend corresponds to reopening in samples featuring populations of existing fractures.

Tomographs were recorded throughout the application of the confining pressure, and subsequently, the injection of fluid into the central boreholes in the samples. These tomographic images have been used to investigate the closure of existing fractures during the application of the confining pressure, as well as the development of new fractures induced by the fluid pressure. In general, the primary fracture opened up parallel to the borehole, independent of the orientation to bedding. However, borehole-perpendicular primary fractures were observed in some of the more laminated shales, and secondary, bedding-parallel, fractures were induced in many samples with the borehole perpendicular to bedding.

Post-experiment SEM images of the regions around the main fractures demonstrate substantial differences in the characteristics of the damaged region around the main fracture body between materials. In Haynesville shale, the damaged zone appears to mostly contain reactivated microfractures lying parallel to bedding, while in the more homogenous Bowland shale, this small-scale damage has a wider range of orientations.