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Impact of mechanical damage on fluid flow in mudstones: matrix versus fracture permeability of deformed Whitby Mudstone (UK)

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Considering fluid flow in mudstones, such as shale gas flowing from the matrix to a production well, we should account for the dual permeability of the medium considering a higher permeable fracture network together with a tight matrix. In the context of fluid production, it is key to be able to quantify the impact of (induced) mechanical damage on permeability, aimed at improving flow, as a function of the state of stress and bedding orientation.
We conducted a series of experiments to investigate permeability change in response to deformation and damage. We used cylindrical 1 inch diameter samples of Whitby Mudstone (UK) as an analogue for typical mudstones and shales used for shale gas production. Bulk sample permeability of the Whitby Mudstone was measured perpendicular, parallel, and at an angle to the bedding before and after deformation of the material, induced at a confining pressure of 30MPa using a direct shear setup. For intact material, matrix permeability perpendicular to the bedding was consistently one to two orders of magnitude lower than the permeability parallel to the bedding, on the order of 10-19 to 10-22 m2 and 10-18 to 10-20 m2 at confining pressures of 3-30 MPa, respectively. The matrix permeability was 10-19 m2 at 3 MPa confining pressure when measured oblique to the bedding, but dropped below the detection limit (i.e. < 10-23 m2) at higher confinement. All samples showed a 2-5 orders of magnitude increase in permeability at low confining pressure (3 MPa) after deformation of the shales. At high confining pressure (30 MPa), permeability increased 4-5 orders of magnitude for the sample oblique to bedding, and half an order of magnitude for the sample perpendicular to the bedding, permeability measured parallel to the bedding was similar before and after deformation.
X-ray micro-tomography analysis of the samples after deformation showed that fractures preferentially developed parallel to bedding, with a well-developed fracture network connecting top and bottom of that particular sample. Such a fracture network was also visible, but less extensive, in the oblique-to-bedding sample. The sample taken bedding-perpendicular lacked a distinctly visible connecting fracture network, although permeability was enhanced after deformation. This suggests that on a (much) smaller scale, fractures must have developed in the form of a damage zone which still resulted in increased permeability of the matrix, as opposed to fracture flow dominating permeability. Additional Scanning Electron Microscopy will be performed on the deformed samples to elucidate the potential and extent of damage in mudstones and the impact this has on permeability.