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Imaging cross fault multiphase flow using time resolved high pressure-temperature synchrotron fluid tomography: implications for the geological storage of carbon dioxide within sandstone saline aquifers

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Applied shear stresses within high porosity granular rocks result in characteristic deformation responses (rigid grain reorganisation, dilation, isovolumetric strain, grain fracturing and/or crushing) emanating from elevated stress concentrations at grain contacts. The strain localisation features produced by these processes are generically termed as microfaults (also shear bands), which occur as narrow tabular regions of disaggregated, rotated and/or crushed grains. Because the textural priors that favour microfault formation make their host rocks (esp. porous sandstones) conducive to the storage of geo-fluids, such structures are often abundant features within hydrocarbon reservoirs, aquifers and potential sites of CO_2 storage (i.e. sandstone saline aquifers). The porosity collapse which accompanies microfault formation typically results in localised permeability reduction, often encompassing several orders of magnitude. Given that permeability is the key physical parameter that governs fluid circulation in the upper crust, this petrophysical degradation implicates microfaults as being flow impeding structures which may act as major baffles and/or barriers to fluid flow within the subsurface. Such features therefore have the potential to negatively impact upon hydrocarbon production or CO_2 injection, making their petrophysical characterisation of considerable interest.

Despite their significance, little is known about the pore-scale processes involved in fluid trapping and transfer within microfaults, particularly in the presence of multiphase flow analogous to oil accumulation, production and CO_2 injection. With respect to the geological storage of CO_2 within sandstone saline aquifers it has been proposed that even fault rocks with relatively low phyllosilicate content or minimal quartz cementation may act as major baffles or barriers to migrating CO_2 plume. Alternatively, as ubiquitous intra-reservoir heterogeneities, micro-faults also have the potential to enhance capillary trapping of CO_2, and may indeed be equitable features for the immobilisation of large volumes of CO_2. However, previous investigations using static microstructural analysis or bulk petrophysical measurements have been incapable of capturing the fundamental pore scale fluid processes at work in such systems. As a consequence, considerable ambiguity remains over the role of microfaults in determining the eventual fate of CO_2 injected into sandstone saline aquifers.

With this in mind, the present work seeks to investigate the influence of microfaults over the injection of supercritical CO_2 within sandstone saline aquifers. By employing high temperature-elevated pressure fluid tomography, we are able to directly image at pore scale $scCO_2$-brine primary drainage within a sandstone micro-core (Orange Quarry, Bassin de Sud-est, France) intersected by a single cataclastic fault. The time series data reveals that intra-fault capillary heterogeneity plays an important role in the breaching of microfaults by the non-wetting phase (i.e. $scCO_2$). Such low entry pressure regions facilitate bypass of the fault, suggesting that the capacity of microfaults within clean sandstones to act as major baffles or barriers to a buoyantly migrating CO_2 plume may have been previously overestimated.