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In situ real-time multi-scale quantification of flow pathways during three-phase flow through porous media

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Quantifying and understanding the behaviour of reactive and non-reactive flow in geological materials is a key requirement for many geological, environmental and engineering research problems: from hydrocarbon extraction, to ground water modelling and engineering geological disposal solutions. However, validation and refinement of existing numerical models and simulation methods for heterogeneous geomaterials requires experimental data at different spatial and temporal scales, data that is largely lacking.
Here we present qualitative and quantitative analysis of unsaturated and saturated flow derived from in situ 3D X-ray and neutron tomography data. We showcase newly developed methodologies that enable the capture of the dynamics of flow in 4D (3D + time), and show how to combine data across spatial and temporal scales. By integrating neutron, laboratory and synchrotron X-ray tomography we show how it is possible to track and quantify the flow fronts, concentration changes, the dynamic evolution of the porosity network, contact angles and local phase distributions with micron scale resolution; and how the dynamics of these behaviours can be captured from individual 3D images with acquisition times ranging from 0.6 seconds to 20 minutes.
By using the 4D in situ methods we present, it is now possible to generate accurate micro- and macro-scale models of flow behaviours, thereby allowing validation and iteration of multi-scale modelling approaches for complex mass transport problems.