Contribution ID: **469** Type: **Poster Presentation**

Nano-scale imaging and modelling of gas transport in clay-rich mudstones

Thursday, 25 May 2023 10:45 (1h 30m)

Hydrogen is considered to be a sustainable and clean energy carrier that holds significant potential to replace fossil fuels and hence enable an energy transition to meet the net-zero target set in the Paris Agreement in 2015. Large-scale underground hydrogen storage (UHS) in geological formations such as salt caverns, porous aquifers and depleted hydrogen reservoirs, can provide the predicted required scale of storage and is currently an area of focus. The sealing ability of mudstone caprocks, including marl, shale, argillite, claystone and mudstone, is a primary consideration for safe and secure storage of hydrogen, especially in the case of porous rock hydrogen storage. Additionally, an understanding of hydrogen-sealing capacity of mudstones is also important in the development of safety cases in the deep geological disposal of nuclear waste. In these systems, hydrogen gas may form due to the anoxic corrosion and degradation of steel canisters used in the underground radioactive waste repositories, resulting in the accumulation of pressure leading to rock deformation, gas migration and potential gas and other solute leakage. In both applications, therefore, hydrogen gas transport behaviour in clay nanopores is an essential parameter to understand in assessing the long-term behaviour of mudstone caprocks and seals.
Current transport models characterizing the geological transportation of subsurface fluids are not sufficient to understand the complex transport pathways and mechanisms in clay-rich rocks at nanoscale, owing to the lack of nano-scale quantitative measurement and images of the gas transport phenomenon. With recognition that 3D micro-scale X-ray computed tomography (Micro-CT) and Focused Ion Beam Scanning Electron Microscopy (FIB-SEM) commonly used for pore network modelling are insufficient to describe the clay-rich mudstones of nanometric pore sizes, Transmission Electron Microscope (TEM) can be adapted to provide microstructural information for its high magnification. This research will thus implement TEM microscopy to image the fluid's physical interactions and chemical reactions with clay-rich mudstones. Progressively, while experimental investigations of gas transport behaviours are deemed challenging in replicating the actual porous structures at a magnitude of tens of nanometres typical for clay-rich mudstones, molecular modelling with accurate established force fields describing the system's inter- and intramolecular relations in nanometre pore-scales could provide a representation of the physio-chemical coupled processes in the gas-rock system by implementing TEM imaging results as inputs.

Core samples extracted from the Lias clay formation deposited in Eastern England are adapted for common caprock representations in this study, where preliminary Scanning Electron Microscopy (SEM) tomography unveiled the microstructural pore morphologies while Energy Dispersive Spectroscopy (EDS) analyses identified numerous mineral compositions, allowing nano-scale clay specimen selection within the rock matrix. With the combination of FIB-SEM milling preparation and static TEM imaging, clay lattice fringes and pore topography were obtained for quantitative characterizations aiding future hydrogen gas transport examinations in clay-rich mudstones at nano-scale. This research thus aims to provide unique quantifications and images, hence compare with and correlate the findings to the macroscopic imaging and modelling to provide further insights for current model improvements, contributing to the new era of our energy future.

Participation

In-Person

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Session Classification: Poster

Track Classification: (MS01) Porous Media for a Green World: Energy & Climate