Impact of hydrogen trapping in underground porous formations on recovery efficiencies during inter seasonal storage injection and withdrawal cycles

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Motivation

- Uncertainty surrounding hydrogen recovery efficiencies and residual trapping losses over multiple hydrogen storage cycles.
  - Is residual trapping cumulative with each injection and withdrawal cycle?
  - How much hydrogen could be residually trapped during storage operations?
  - Is this trapping influenced by the geometry of the pore network and heterogeneities?

HyStorPor

Experimental investigations into hydrogen displacement and trapping

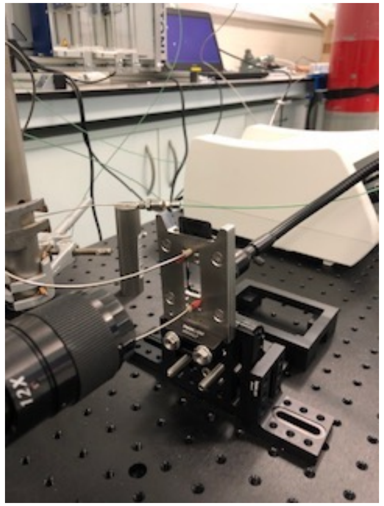
Undertaken a suite of experiments to evaluate hydrogen flow, displacement and trapping.

- Xray CT imaging, using in house and Diamond facilities
  - 5mm diameter and 47mm long cores.
- Glass micromodels & visual cells
- Core flooding
  - Hassler cell (38mm diameter core and ~70cm long) for in-situ storage conditions
  - Bespoke 1m long core flow cell (38mm dimater cores and 10mm long)

5mm ϕ X-Ray hydrogen flow cell

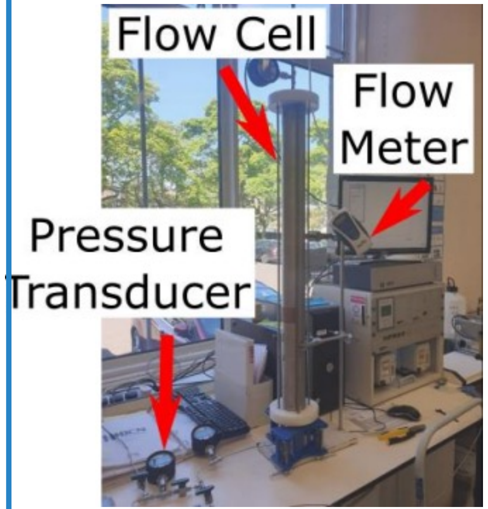
5mm ϕ X-Ray hydrogen flow cell

Hydrogen multiphase flow micromodel

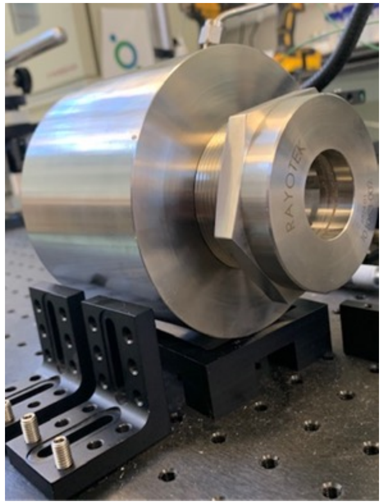


Multiphase high P/T 38mm ϕ Hydrogen flow cell

1m long, 38m ϕ Hydrogen flow cell

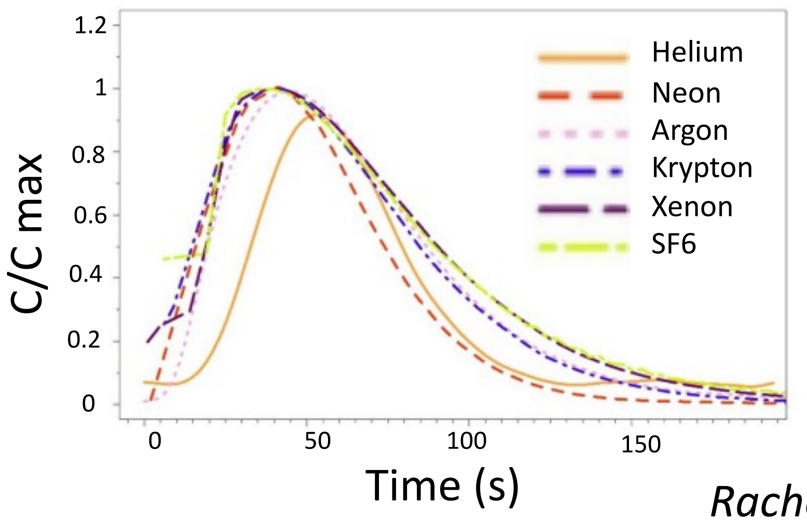


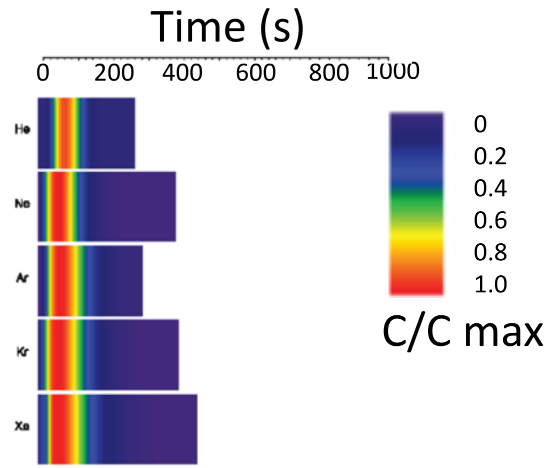
Hydrogen high P/T visual cell



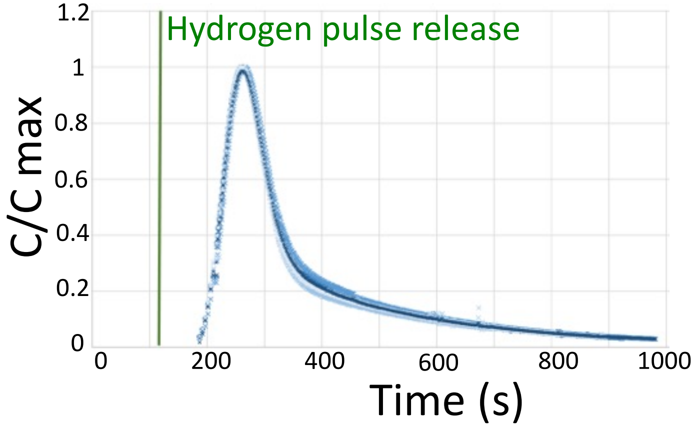
Hydrogen pulse flow through dry CO_2 saturated rock

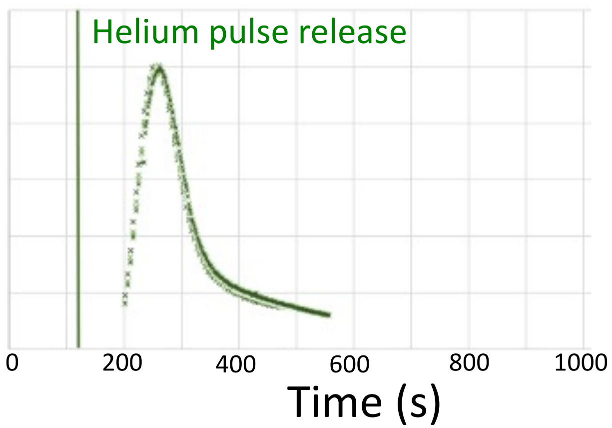
- Hydrogen:
  - ✓ Tight curve = advection dominated.
  - ✓ Delayed arrival
- Suggests that hydrogen flow accesses many pores, moving as a semi-uniform front.





Rachel Kilgallon UoE PhD Thesis, 2016





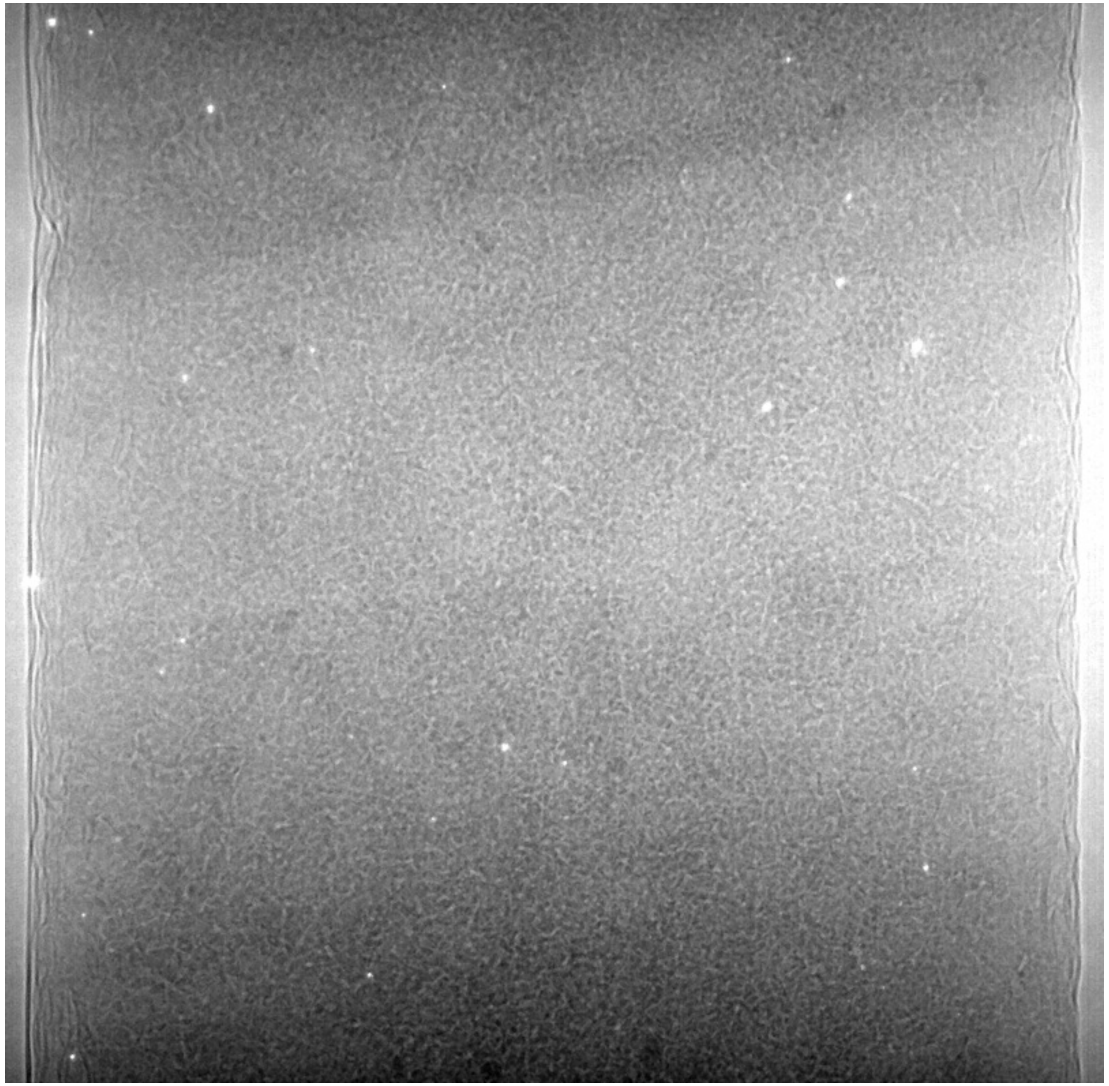
Chris McMahon UoE MSc. Thesis, 2019

- Advection = breakthrough time / velocity
- Diffusion / dispersion = spreading of the curve

HyStorPor

Hydrogen flow through brine saturated porous rock

- Visualisation of hydrogen entering a brine saturated rock.
- Undertaken at Diamond Light Source
  - Clashach sandstone.
  - 5 μl/min hydrogen flow rate
  - 5 MPa injection pressure
  - 10 MPa confining pressure



diamond

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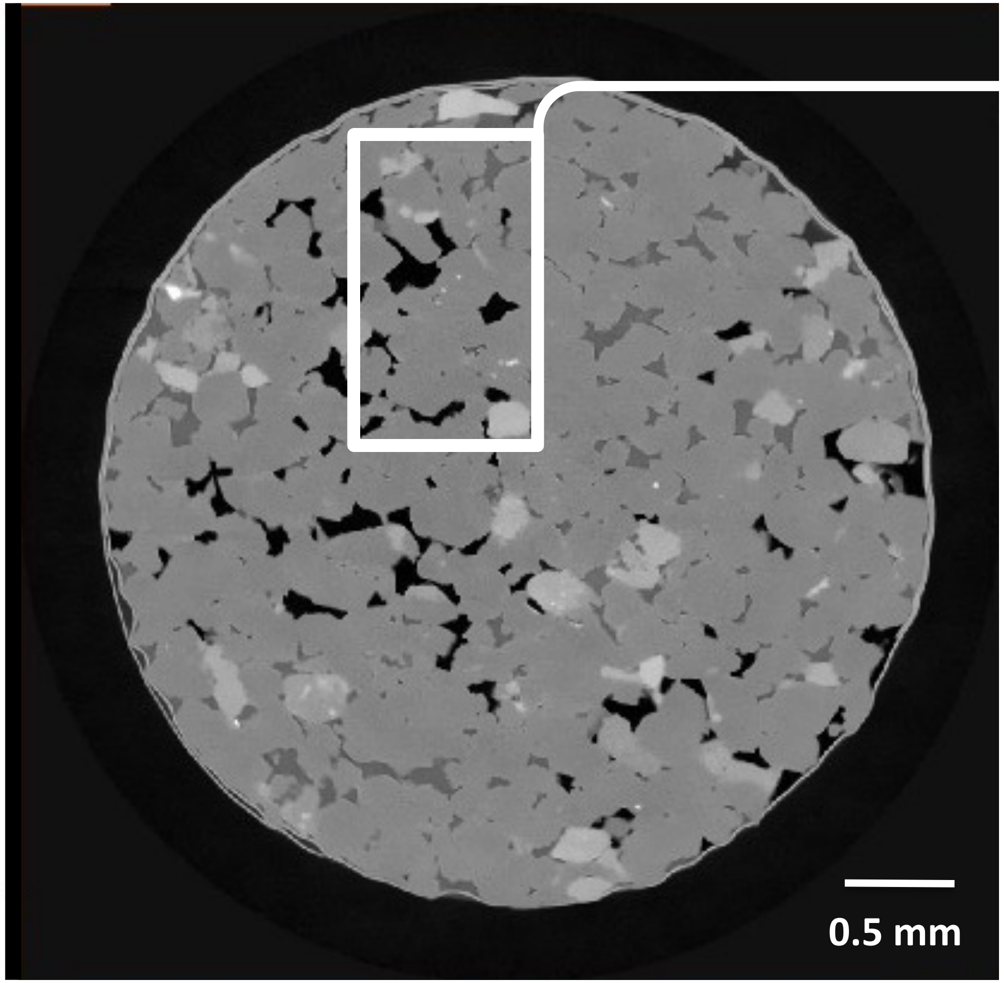
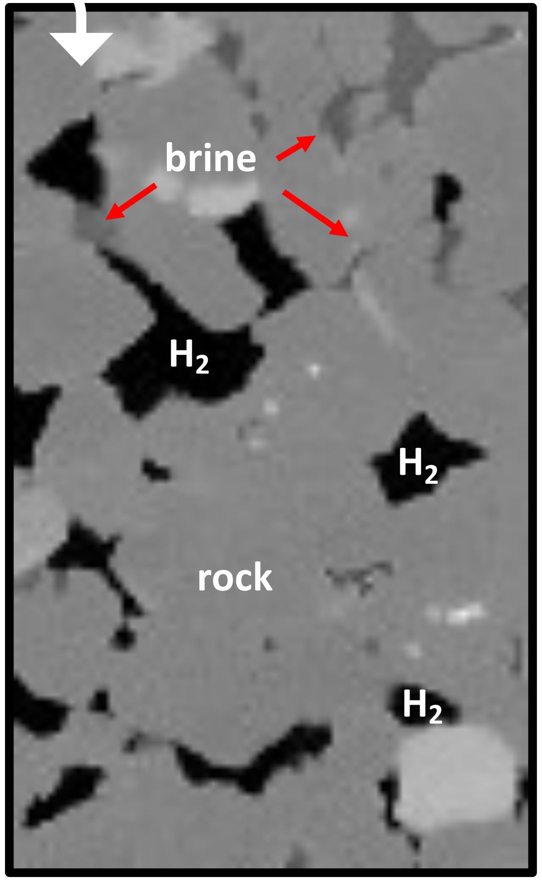
H_2 behaves as a non-wetting phase

Clashach sandstone after injection of 10 PV of brine (0.5 M Caesium Chloride) followed by 10 PV Hydrogen





- Hydrogen (black) fills the centre of the pores
- Residual brine (dark grey) remains in corners, pore throats and as thin films around grains (paler greys)
- **hydrogen behaves as a non-wetting phase in our experiments (good news):**
  - A non-wetting gas does not readily adhere to or spread across the rock surface it encounters.
  - Non-wetting gases have low interfacial tension with liquids, making them highly mobile in porous media.
  - The non-wetting nature of the gas helps reduce residual trapping.
  - Behaves in a similar manner to methane and other gases so existing software will not need adapted.

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Residual hydrogen saturation is influenced by pore fluid pressure

(all at **20µL/min flow** and confining pressure of 8 MPa)

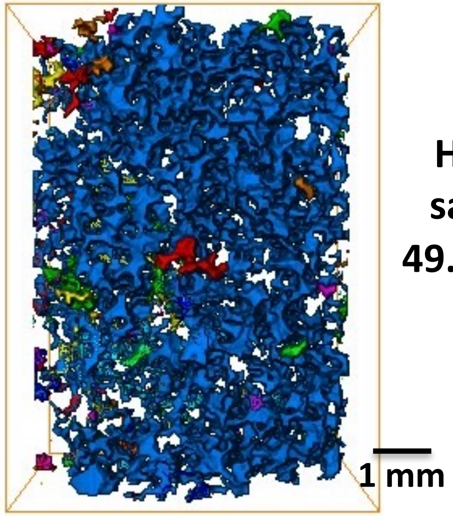
H_2 saturation after drainage (hydrogen injection H_2 displaces H_2O)

Each colour reflects a single cluster of connected hydrogen filled pores:

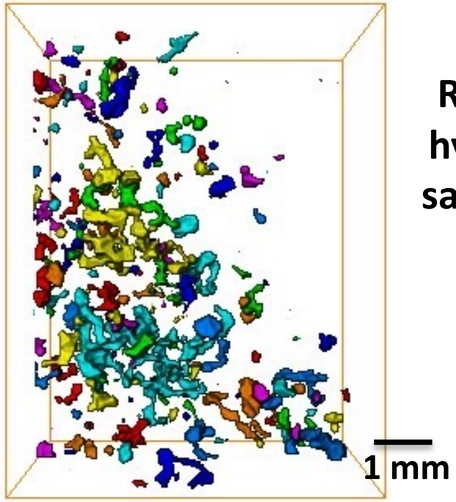
- images dominated by a single colour = well-connected hydrogen gas within the pore network
- images with many colours = poorly connected hydrogen gas within the pore network (perhaps residually trapped)

Residual H_2 saturation after imbibition (hydrogen production H_2O displaces H_2)

2 MPa Pore Fluid Pressure

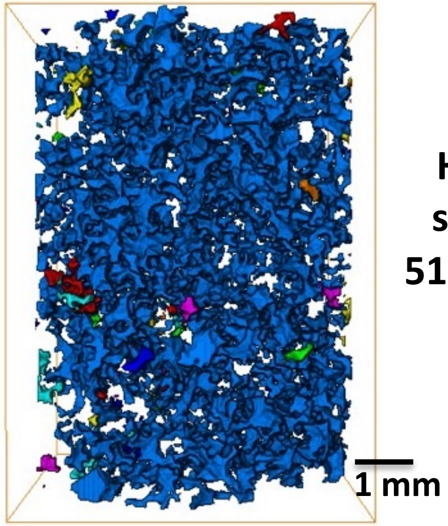


Hydrogen saturation 49.8 ±0.01%

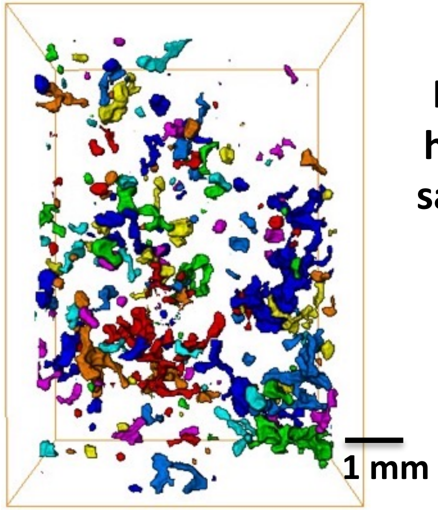


Residual hydrogen saturation 10.0%

5 MPa Pore Fluid Pressure

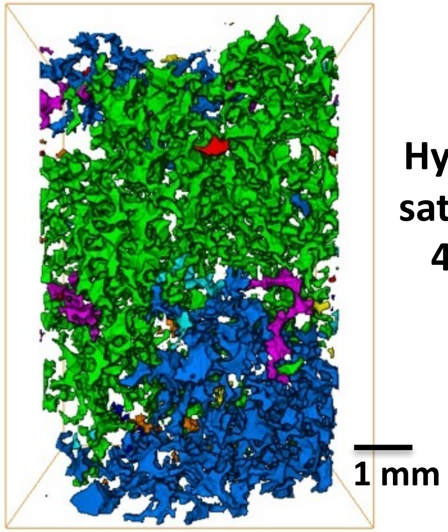


Hydrogen saturation 51.7 ±0.66%

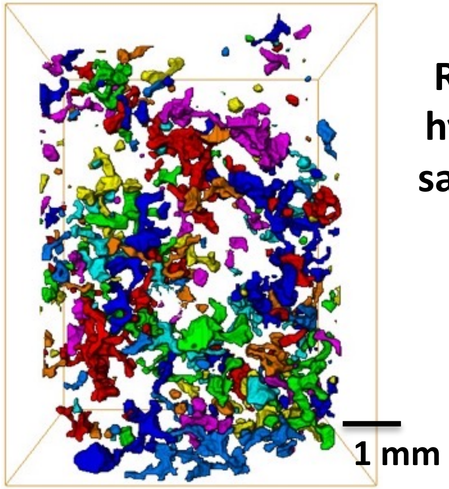


Residual hydrogen saturation 11.5%

7 MPa Pore Fluid Pressure



Hydrogen saturation 49.5 %



Residual hydrogen saturation 21.4 %

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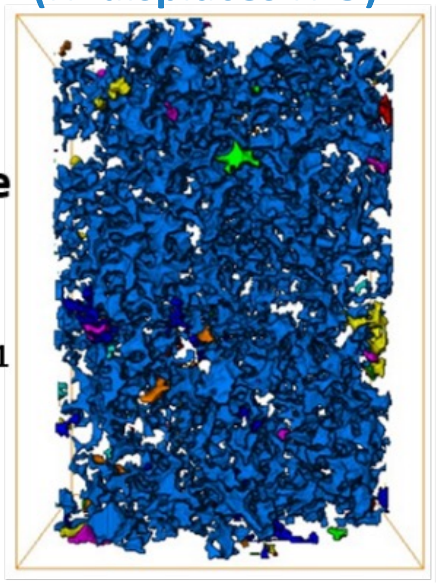
Influence of multiple cycles of drainage and imbibition on residual trapping

- Cyclic hydrogen injection into 5mm diameter Clashach sandstone cores at 5 MPa and 80 µl/min
- Demonstrated negligible differences in hydrogen saturation and hydrogen connectivity after primary drainage and imbibition as compared to after secondary drainage and imbibition.
- Good news as suggests that the initial trapping losses will not get worse in subsequent cycles.

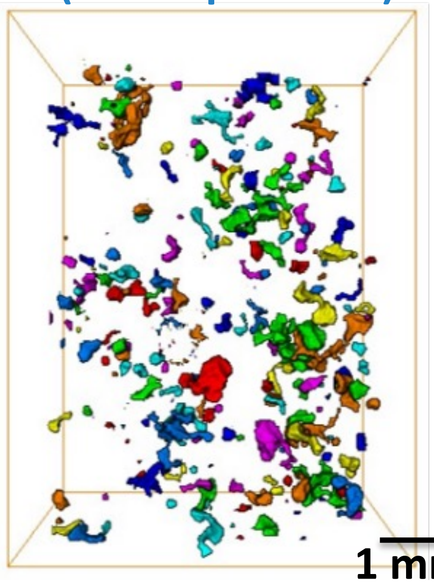
1st cycle 5 MPa, 80 µl min^{-1}

Primary Drainage (H_2 displaces H_2O)



Hydrogen Saturation: 47.9%

Secondary Imbibition ($H_2 0$ displaces H_2)



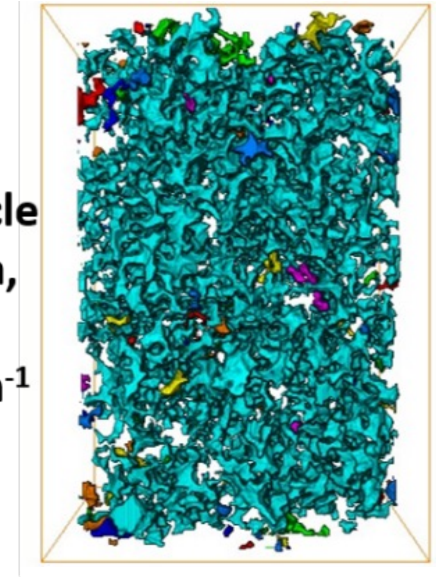
1 mm

Hydrogen Saturation: 7.0%

Experiment undertaken at higher flow rate than previous experiments shown (20 µl/min) Which could explain the slight reduction in residual hydrogen saturations after imbibition (from 11.5% to 7%)

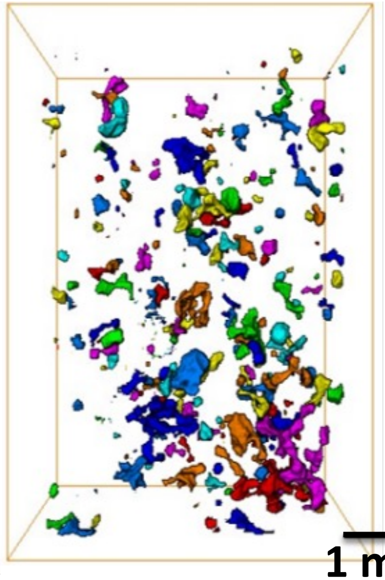
2nd cycle 5 MPa, 80 µl min^{-1}

Secondary Drainage (H_2 displaces H_2O)



Hydrogen Saturation: 47.6%

Tertiary Imbibition ($H_2 0$ displaces H_2)



1 mm

Hydrogen Saturation: 7.3%

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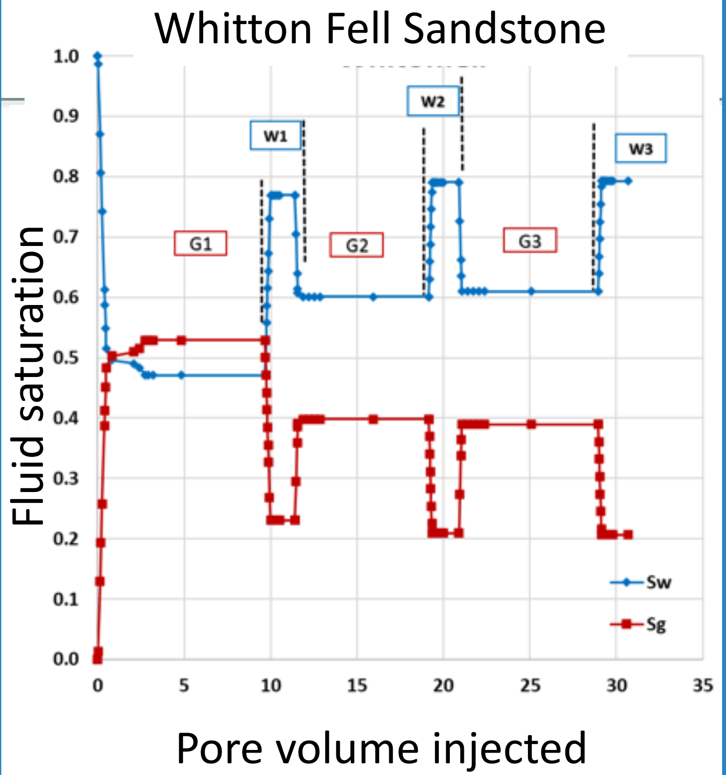
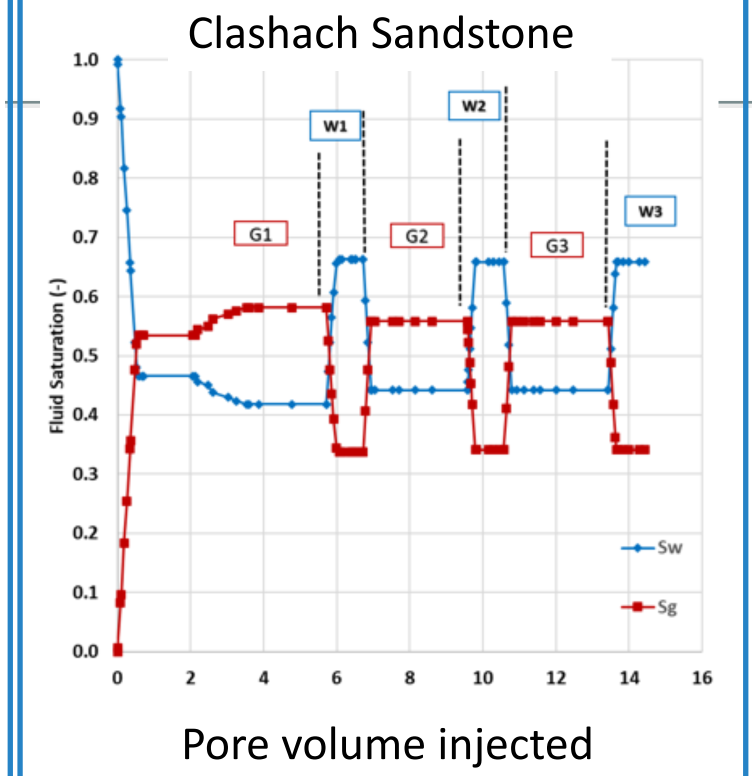
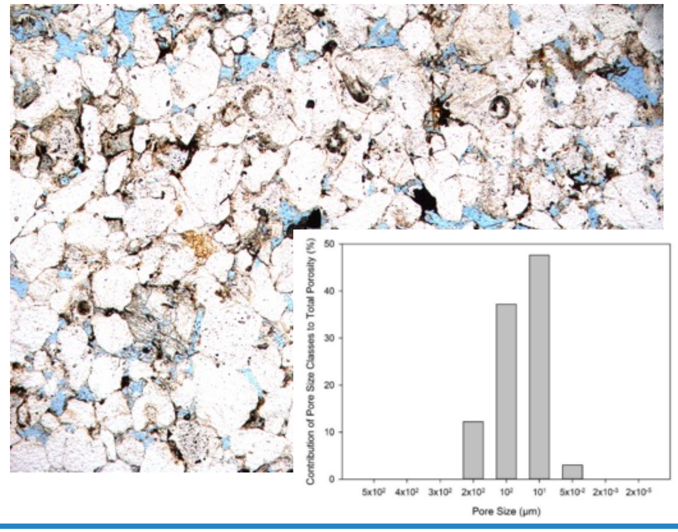
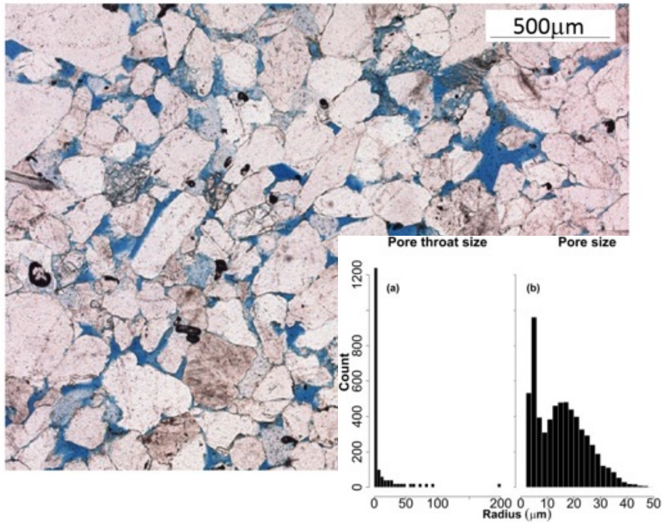
Cyclic Flow – residual trapping

- 3 drainage and imbibition cycles of hydrogen and water undertaken in the multiphase flow rig on 38mm diameter core samples.
- In both samples we see a change in hydrogen saturation from the first to second cycles, **but in subsequent cycles hydrogen saturation remains steady.**
  - **Good news as confirms trapping losses will not get worse in subsequent cycles.**
- There are significant differences in the initial trapping saturations between the two rock types indicating a **dependency of the residual trapping on rock type/pore network = site selection to minimise the initial loss to residual trapping**









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Thank you

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Related Publications:

- Thaysen et al, Pore-scale imaging of hydrogen displacement and trapping in porous media, 2023, https://doi.org/10.1016/j.ijhydene.2022.10.153
- Thaysen et al, Hydrogen recovery from porous media decreases with brine injection pressure and increases with brine flow rate, 2022, EGU22-2458, https://doi.org/10.5194/egusphere-egu22-2458
- Thaysen at al, Hydrogen flow through porous media, 2021, https://ui.adsabs.harvard.edu/abs/2021AGUFMSY33B..02T/abstract

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