Hydrogen displacement and trapping during storage in porous reservoirs

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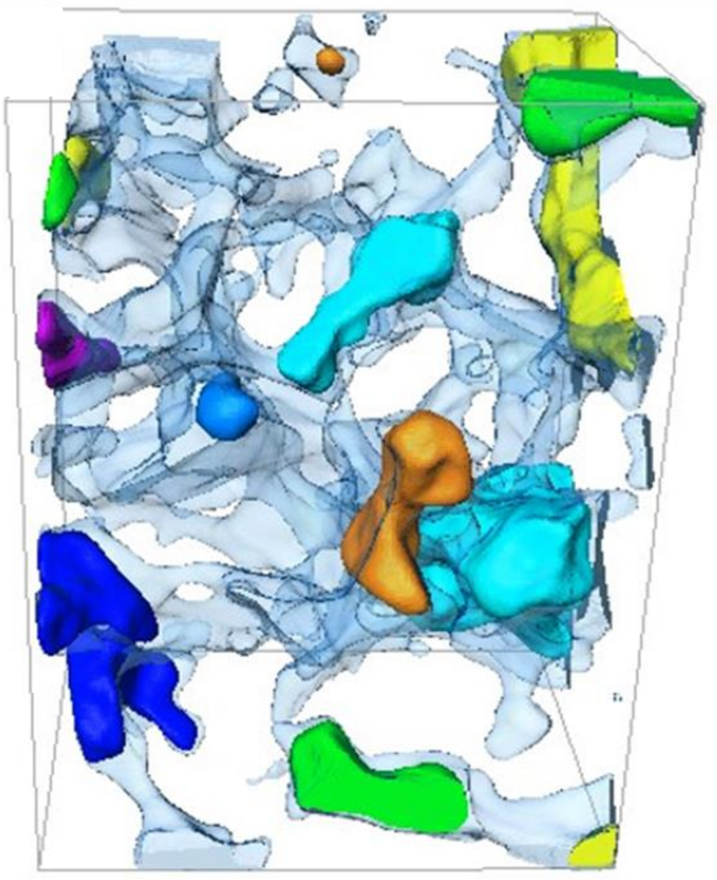

With input from the entire subsurface hydrogen team at Edinburgh Geosciences including Niklas Heinemann, Eike Thaysen, Saeid Abadi, Ciaran Hemming, Andrew Kilpatrick, Tim Armitage, Andrew Cavanagh, John Low, Lubica Slabon, Mark Wilkinson, Ian Butler, Stuart Haszeldine, David Stevenson, Ali Hassanpouryouzband, Hannah Bryant, Solmaz Abedi, Ismail Saricam, Behjat Kari, Marianna Skupinska ...

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Experimental investigations into hydrogen displacement and trapping

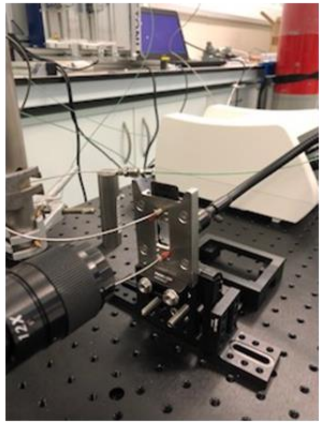
Undertaken a suite of experiments to evaluate hydrogen flow, displacement and trapping.

- 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 diameter cores and 10mm long)

5mm ϕ X-Ray hydrogen flow cell

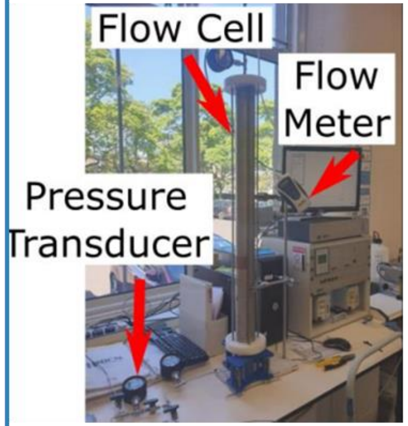
5mm ϕ X-Ray hydrogen flow cell

Hydrogen multiphase flow micromodel

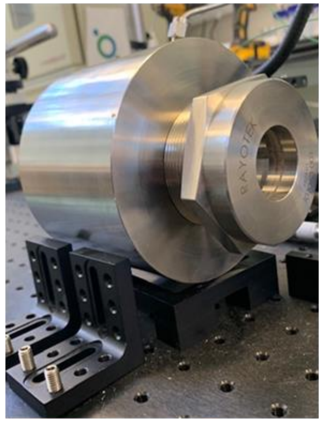


Multiphase high P/T 38mm ϕ Hydrogen flow cell

1m long, 38m ϕ Hydrogen flow cell



Hydrogen high P/T visual cell



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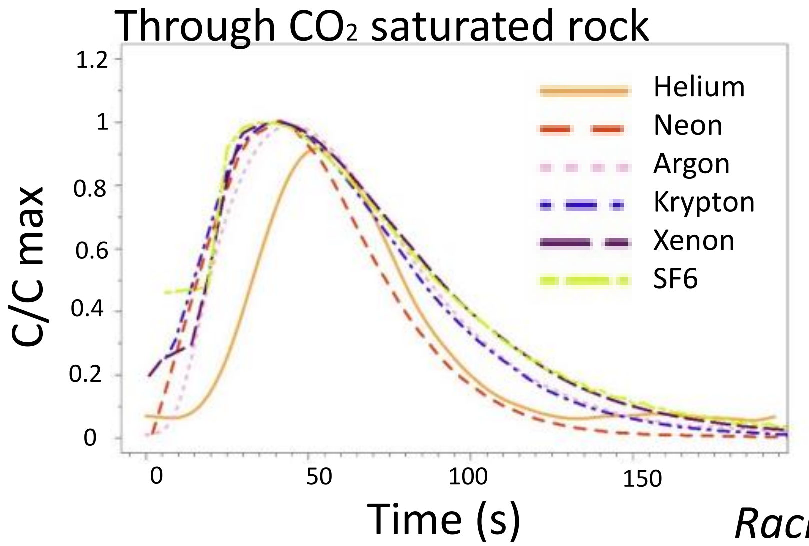
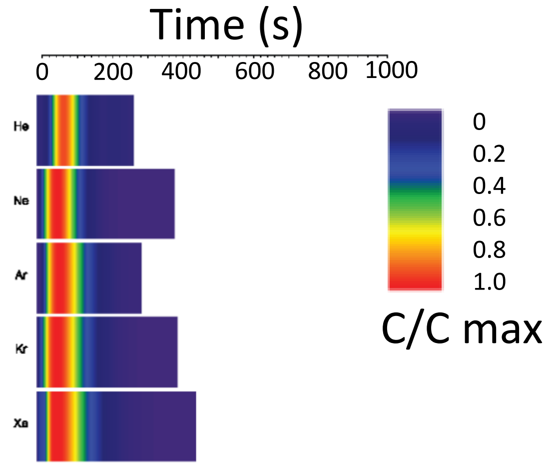
Hydrogen pulse flow through dry rock

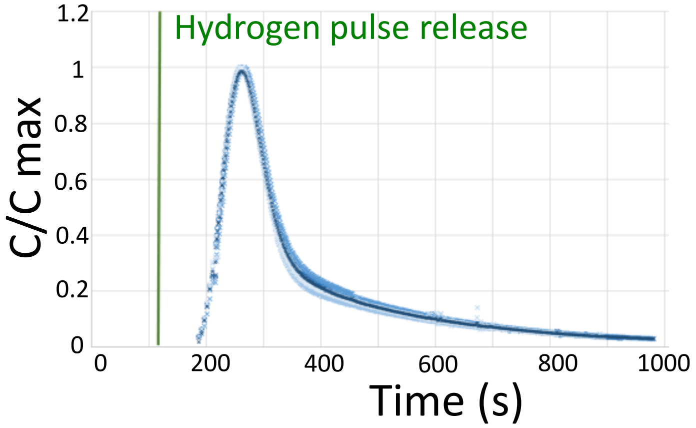
- Hydrogen:
  - ✓ Tight curve = advection dominated.
  - ✓ Delayed arrival
- Suggests that hydrogen flow accesses many pores, moving as a semi-uniform front.

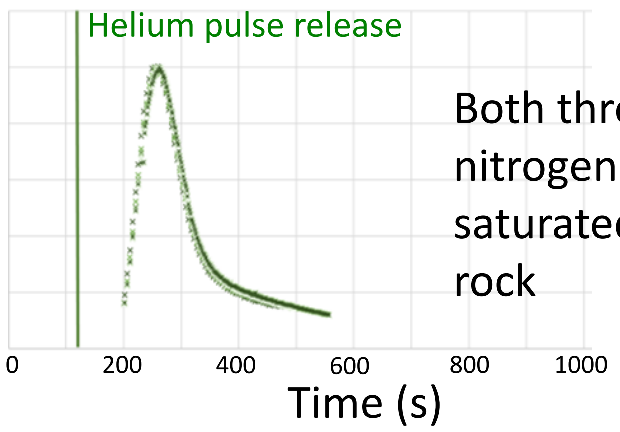
- Advection = breakthrough time / velocity
- Diffusion / dispersion = spreading of the curve





Rachel Kilgallon UoE PhD Thesis, 2016





Both through nitrogen saturated rock

Chris McMahon UoE MSc. Thesis, 2019

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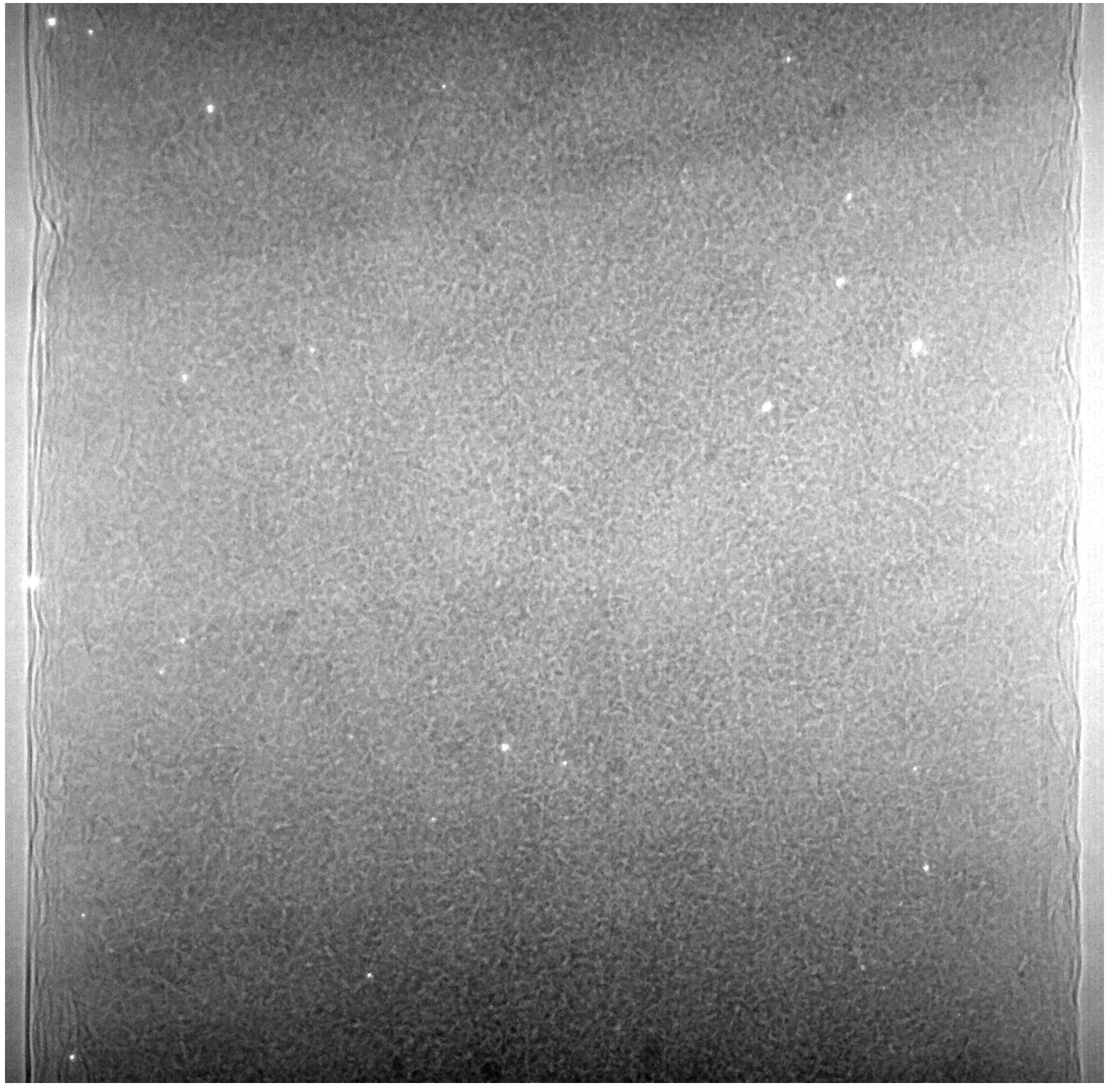
Hydrogen flow through brine saturated porous rock

- 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



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Hydrogen behaves as a non-wetting fluid

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

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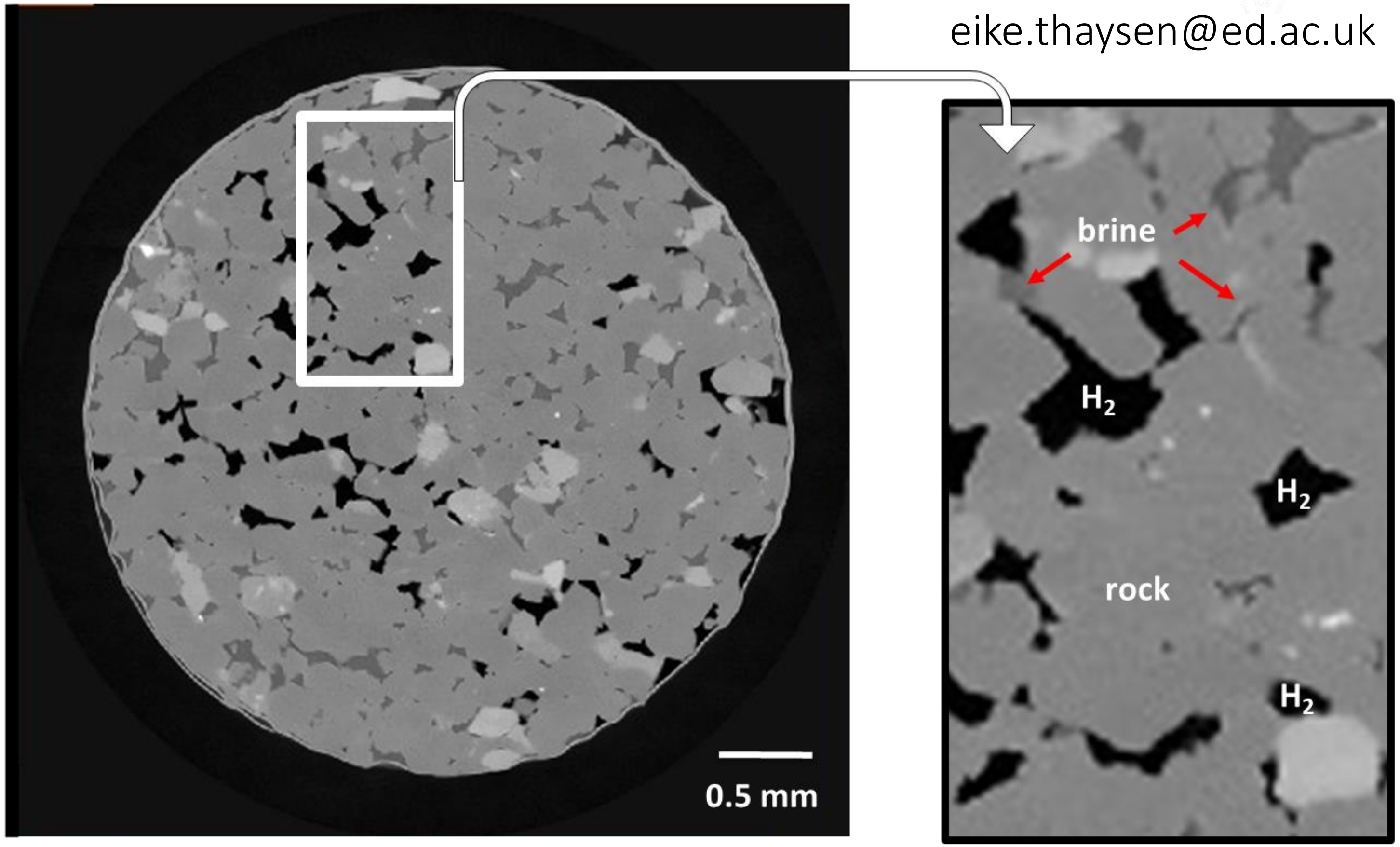

https://doi.org/10.1016/j.ijhydene.2022.10.153

- 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:
  - 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.

Influence of multiple cycles of drainage and imbibition on residual trapping

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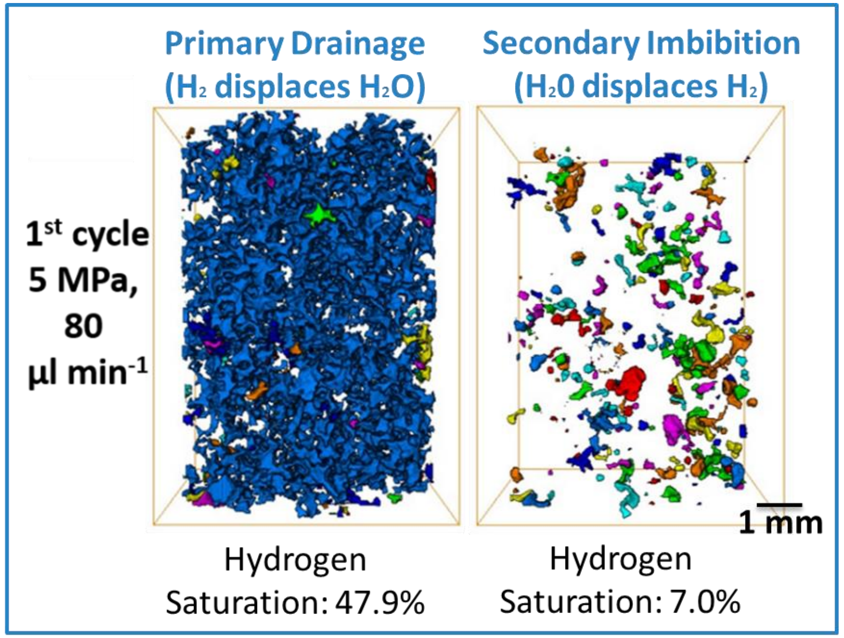
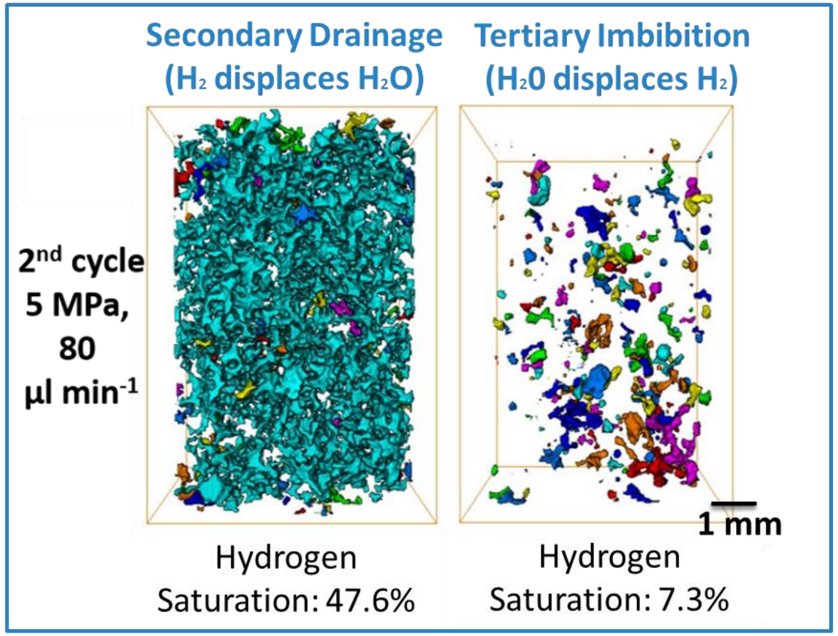
- Cyclic hydrogen injection into 5mm diameter Clashach sandstone cores at 5 MPa and 80 µl/min
- Demonstrated negligible differences in hydrogen saturation and hydrogen connectivity after primary drainage and imbibition as compared to after secondary drainage and imbibition.

✓ Suggests that the initial trapping losses will not get worse in subsequent cycles.





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Cyclic Flow – residual trapping

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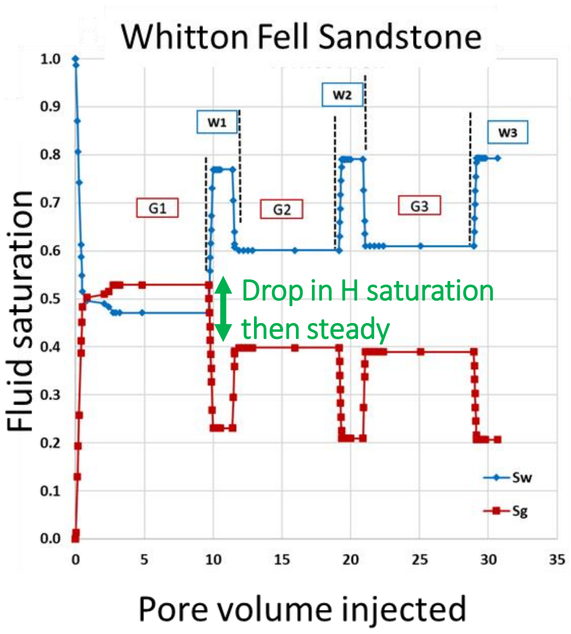
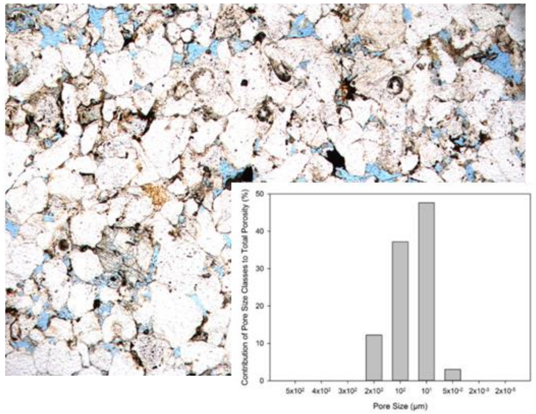
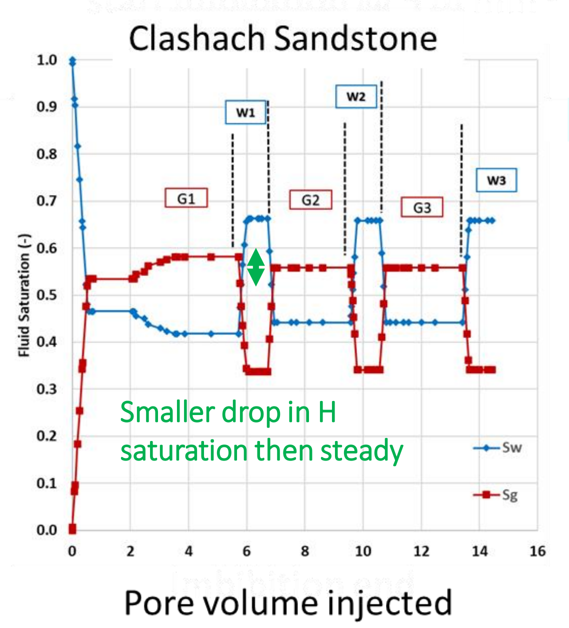
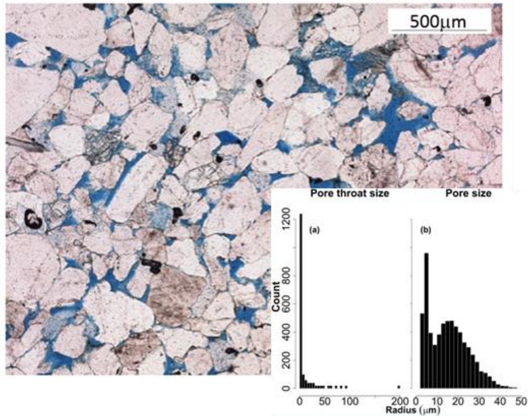
- 3 injection and production cycles of hydrogen and water undertaken on 38mm diameter core samples.
- We see a change in hydrogen saturation from the first to second cycles, but in subsequent cycles hydrogen saturation remains steady.
    - ✓ Confirms trapping losses will not get worse in subsequent injection/production cycles.
- There are differences in the initial trapping saturations between different rock types indicating a dependency of the residual trapping on rock type/pore network
    - ✓ Site selection based on optimal pore network 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 et al, Hydrogen flow through porous media, 2021, https://ui.adsabs.harvard.edu/abs/2021AGUFMSY33B..02T/abstract

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- EU H2020 and Clean hydrogen partnership HyUsPRe "Hydrogen storage in underground reservoirs" project. Grant Agreement 101006632.
- EU Marie Curie Post Doctoral Network: SHINE "Safe underground Hydrogen storage IN porous subsurface rEservoirs" Grant Agreement 101073271 and UKRI EPSRC Grant EP/X026957/1
- Scottish Government Emerging Energy technology Fund "StorageUpscale" project
- Net Zero Technology Centre and CGG "Geological controls on efficient hydrogen storage operations: Investigating depleted gas field reservoirs for future low carbon energy storage" project.
- Net Zero Technology Centre and SGN funded "Hydrogen Storage in Porous Rock, Demonstrator Feasibility Study, Balgonie Fife".
- SGN funded "Balgonie hydrogen storage" project
- SGN funded "Hydrogen Storage Database" project

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