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Nuclear Waste Services

Visualising gas flow in the laboratory

EURAD Summer School

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Acknowledgements: R. Cuss, J. Harrington, C. Graham at the British Geological Survey)

All laboratory results and images courtesy of the British Geological Survey

Contents

- Why do we need to understand gas flow for nuclear waste disposal?
- How is gas produced in a repository?
- What methods can we use to investigate this in the laboratory?
- Recent results from the EURAD GAS study
- Main results and knowledge gaps for the future

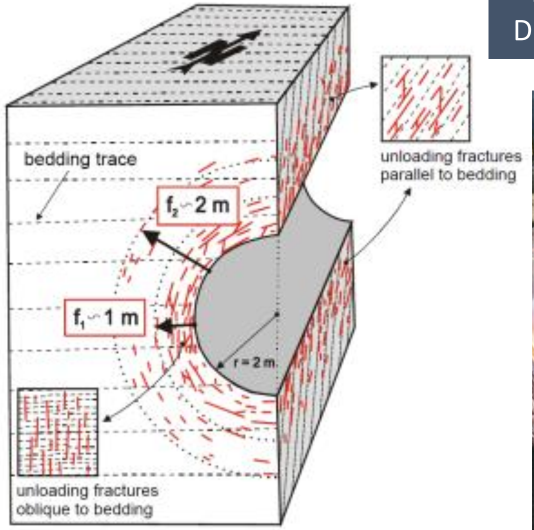
Experimental results were all measured and recorded at the British Geological Survey. Work was predominantly carried out as part of the EURAD GAS project, with work being partially funded by NWS and other European WMO's (EC project number 847593)

Gas generation in a GDF

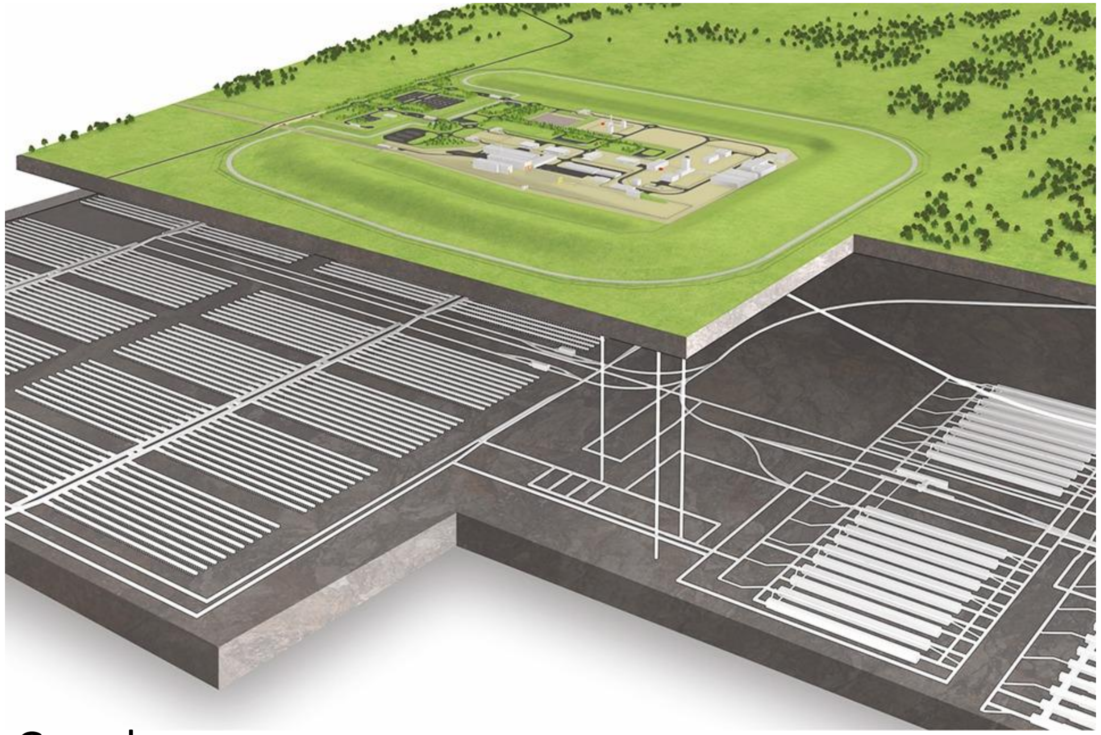
- In a repository for **heat emitting** radioactive waste gas will be generated through a number of processes including:
  - **Corrosion** of metals (H_2)
  - Radioactive **decay of the waste** (Rn…)
  - **Radiolysis** of water (H_2)
- If production exceeds diffusion capacity a discrete gas phase forms.
- Gas will accumulate until its pressure becomes sufficiently large to enter the engineered barrier or host rock
- Understanding gas generation and migration (**in clay-based systems**) is a key issue in the assessment of **repository performance**

- Also relevant to **shale gas**, **hydrocarbon migration**, **carbon capture storage** and **landfill design**…

Induced Engineering Damage Zone fractures



From: Bossart *et al.* (2002)



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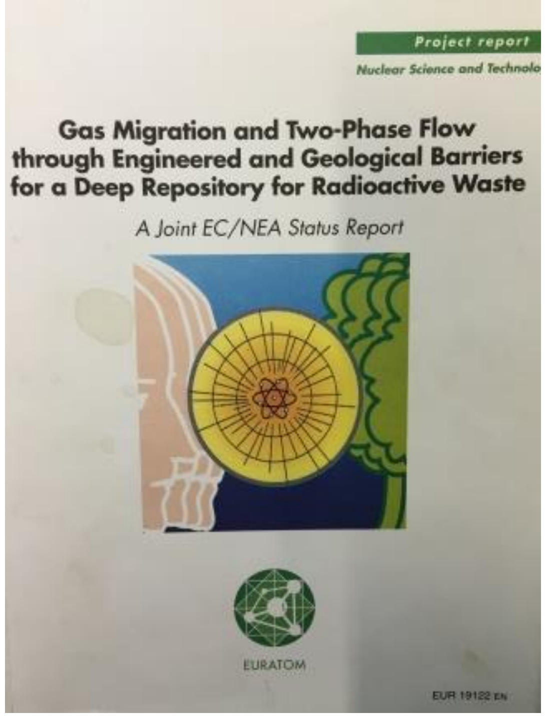
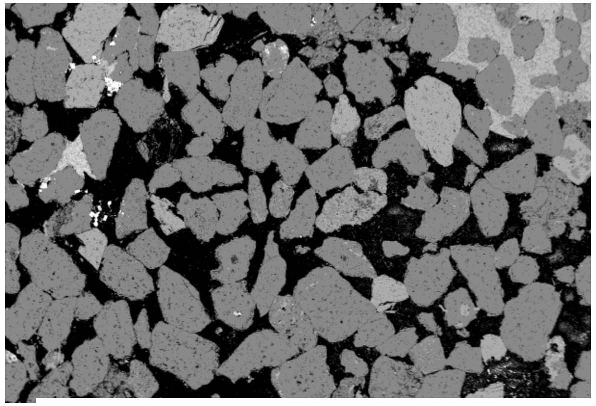
Introduction to low permeability materials

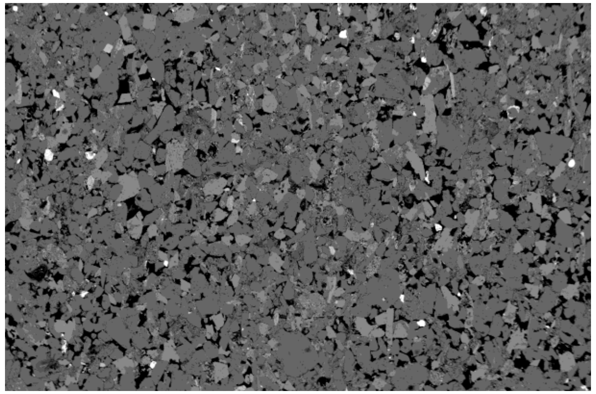
"*There are few problems in geoscience more complex than the quantitative prediction of gas migration fluxes through an argillaceous rock formation*" (Rodwell et al. 1999)

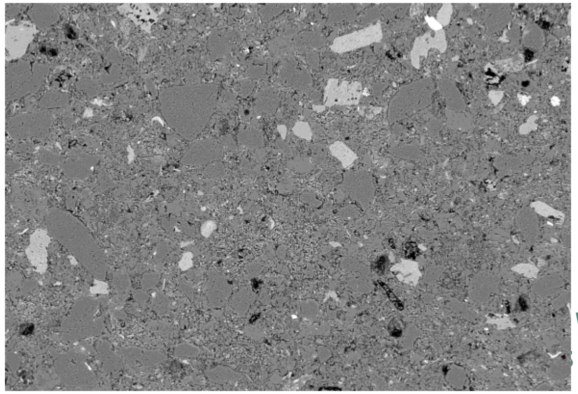
A number of key features distinguish clay-rich media from other rock-types such as:

- sub-microscopic dimensions of the interparticle spaces
- very large specific surface of the mineral phases
- strong physico-chemical interactions between water molecules and surfaces
- very low permeability
- generally low tensile strength
- deformable matrix
- very pronounced coupling between the hydraulic and mechanical response



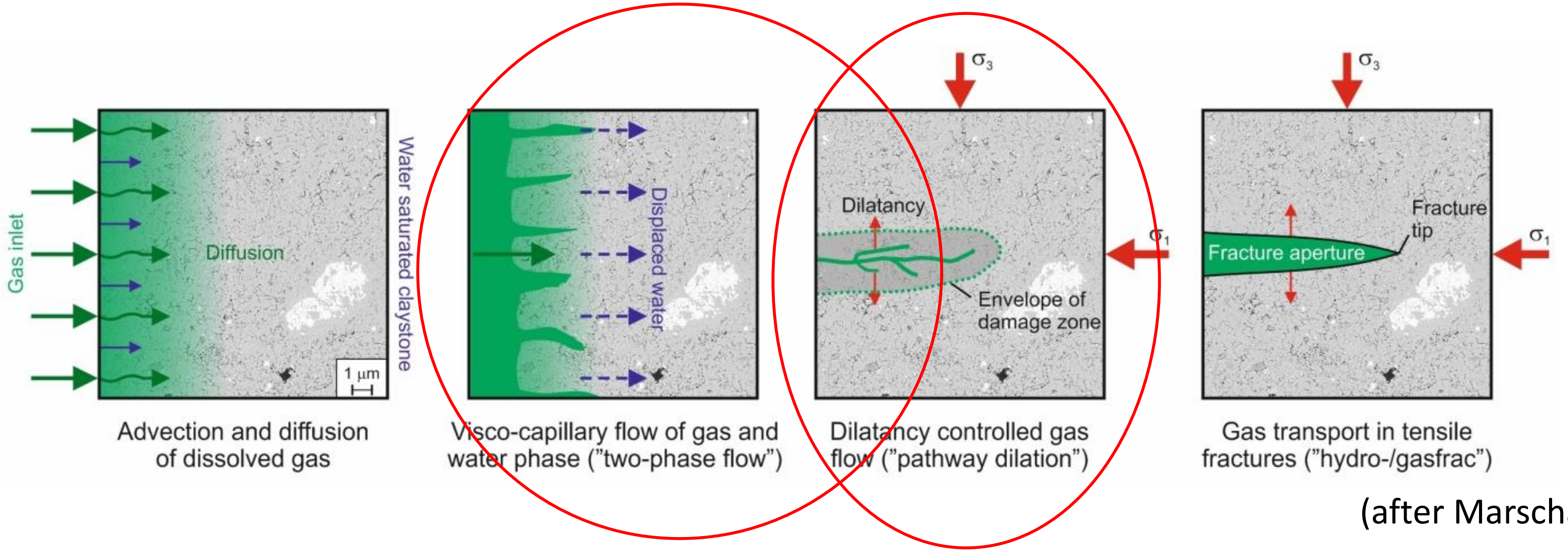

Sherwood sandstone


Siltstone


Permian Marl

How does gas flow?

Movement of gas will occur by the combined processes diffusion and bulk advection.



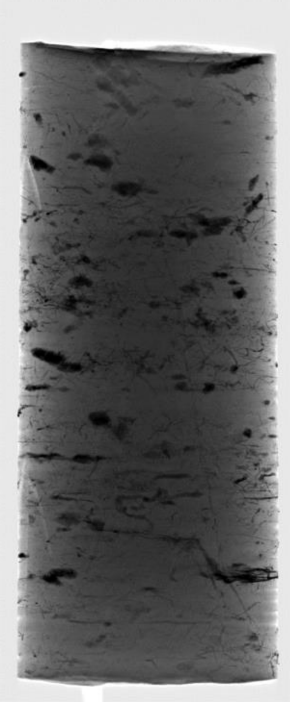
(after Marschall et al. 2005)

EURAD GAS aiming to look at controls on gas flow in these low permeability materials.

- Mineralogy
- Stress state
- Orientation
- Influence of Engineering Damaged Zone

Importance of workflow and sample quality

- Preservation of samples is an important part of testing on mudrocks
- Laboratory testing should be carried out as close to *in situ* conditions as possible.
- Sample preservation, preparation and storage techniques are especially important for low permeability materials.
- Laboratory workflow should be conscious of this at all times
- Pre and post test quantification of properties, e.g. geotechnical and petrological, are vital to give sample and data context



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Things to consider?

Aims & hypothesis

- What specific questions are we aiming to answer?
- Do we have a conceptual model to prove or disprove?

Apparatus

- What apparatus is available?
- Does this suit the questions we want to answer?
- Do any modifications need to be done?

Workflow (pre and post test)

- Sample preservation, preparation, characterisation, installation and post test analysis.

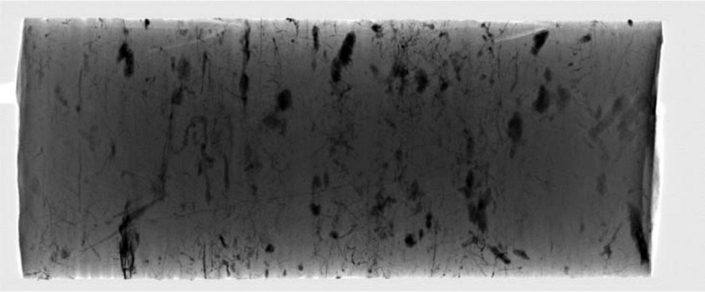
Boundary conditions

- What are the boundary conditions we want to test under? E.g. pressure, temperature, salinity, pH
- Are these suitable to the question we want to answer?
- Do we have the apparatus for these conditions?

Workflow

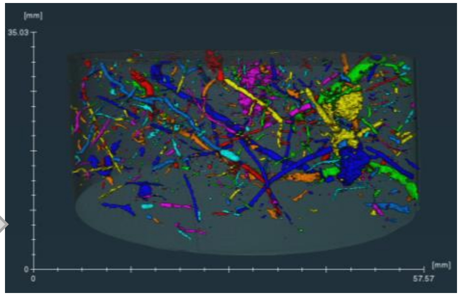
Pre-test

- Sample preparation
- Sample characterisation
- Calibration/leak testing of apparatus



CT image of core barrel for sample selection

Sample manufacture by machine lathing



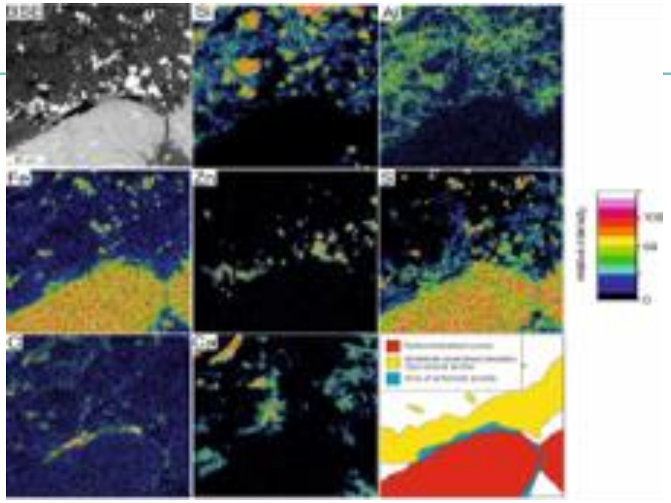
CT image of sample

Test

- E.g. gas injection test with a clear aim and boundary conditions

Post-test

- Careful dismantling of apparatus
- Sample characterisation



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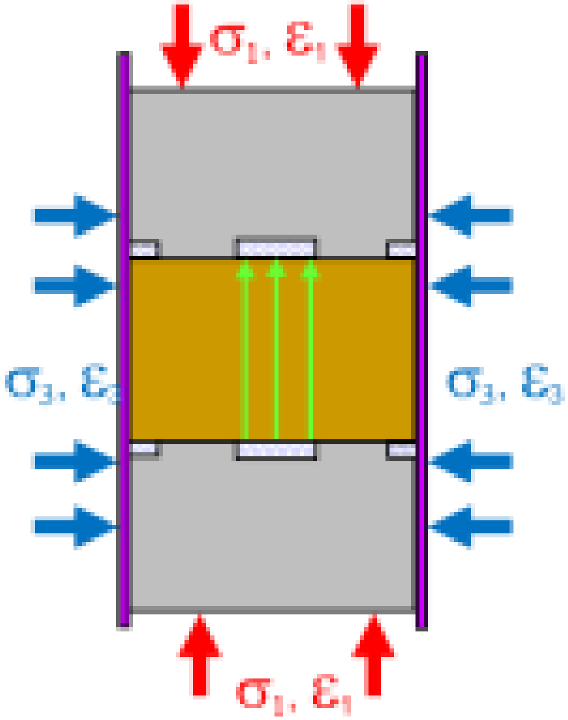
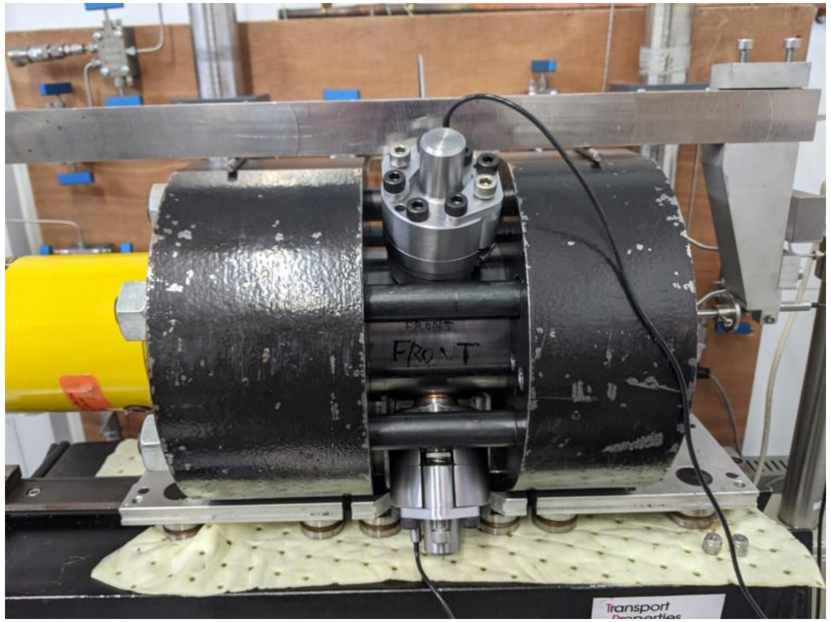
Triaxial apparatus





- Axial stress
- Confining stress
- Injection and Backpressure system
- 3 Radial sensors
- Axial sensors

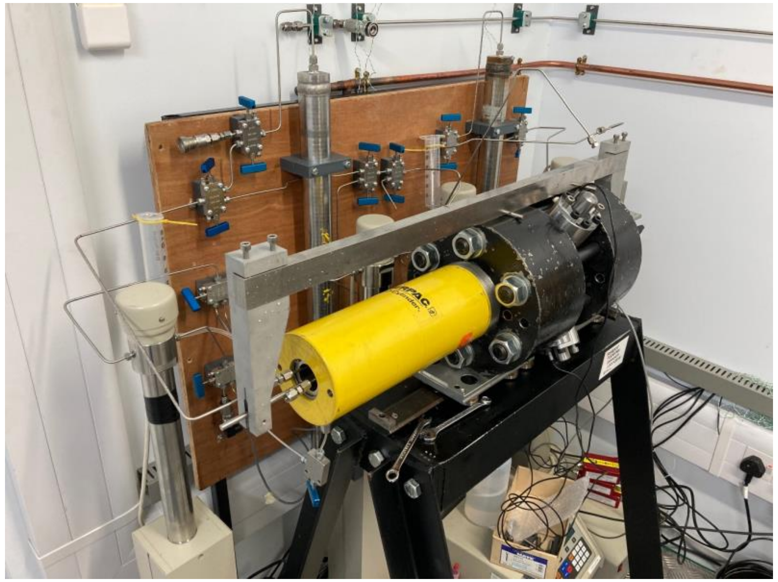
Testing carried out at *in situ* pressure conditions

Within EURAD programme tests carried out on Boom Clay, Opalinus Clay and Callovo-Oxfordian Claystone

Triaxial gas injection tests

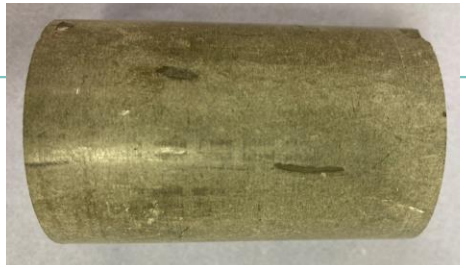
Rationale

- Displacement versus dilatant gas flow (natural material)
    - undertake a series of triaxial measurements examining the mechanisms governing gas flow through intact samples of Boom Clay and Cox
    - Tests performed parallel and perpendicular to bedding
- Experiments consist of a baseline hydraulic test followed by gas injection at one end of the sample



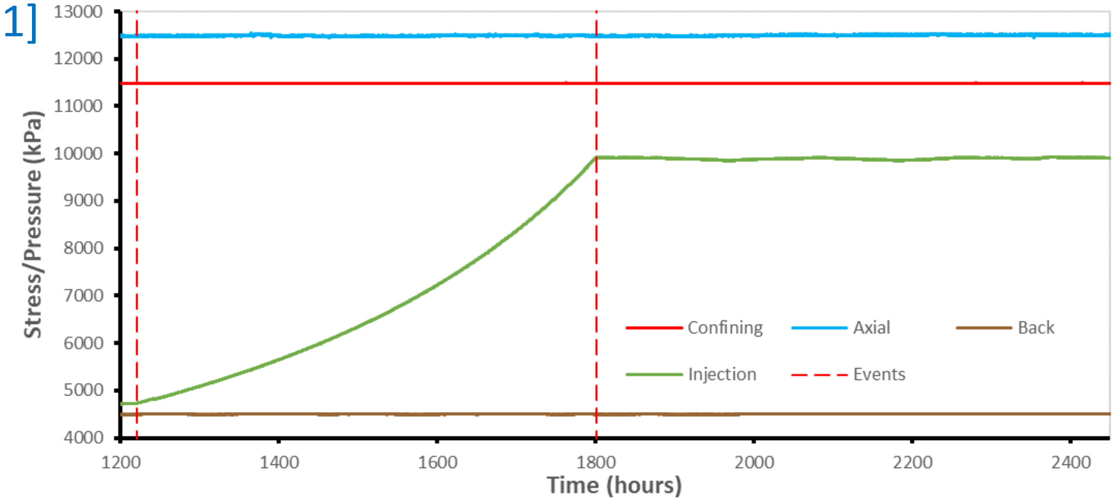
Test	Apparatus	Rock type	Stages	Boundary	Direction
1	Triax	COx	HY, GE, PP	In situ	//
2	Triax	Boom Clay	HY, GE, PP	In situ	⊥
3	Triax	Boom Clay	HY, GE, PP	Low/high confining	⊥
4	Triax	COx	HY, GE, PP	Low/high confining	//

Gas test 1 COx // (sample 21-043)

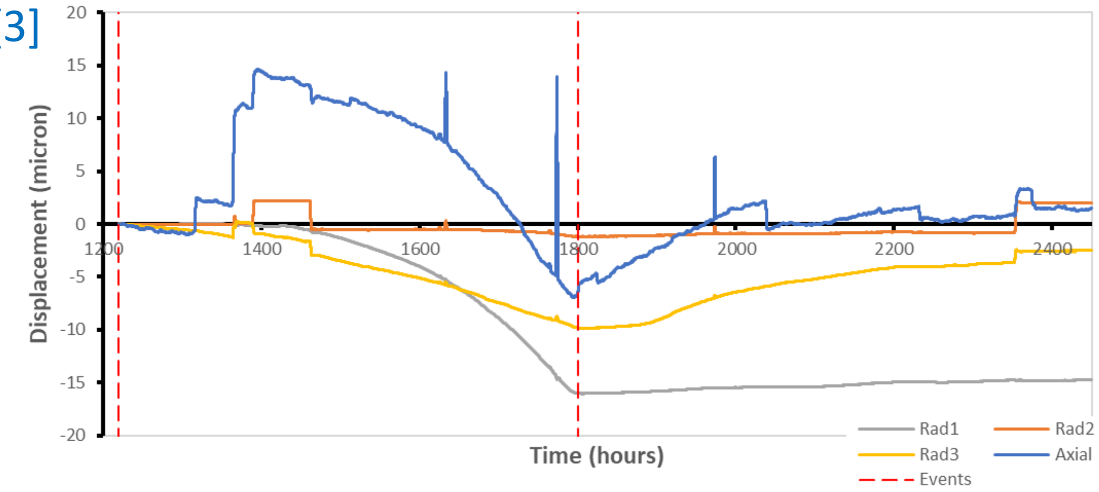


- A simple two-step gas injection ramp performed [1]
- During ramp 1 a small outflow seen as water was expelled from the injection filter [2]
- During first gas ramp the sample showed dilation from swelling [3]

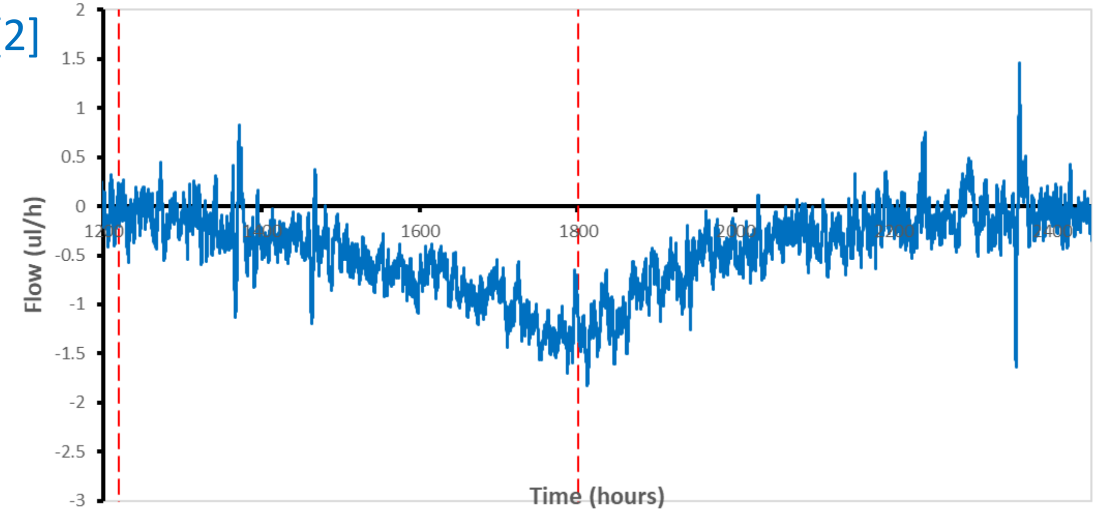
[1]



[3]



[2]



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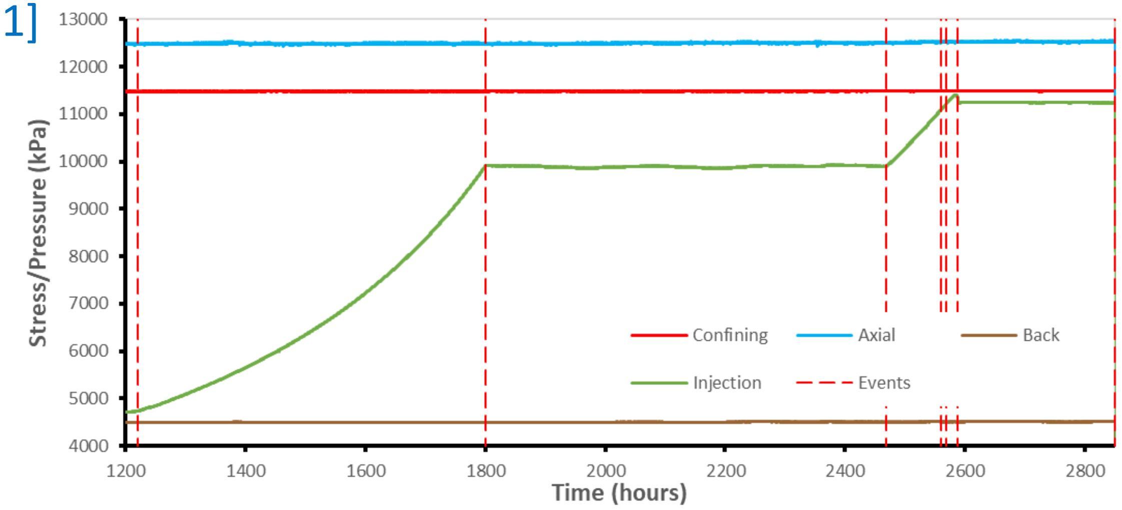
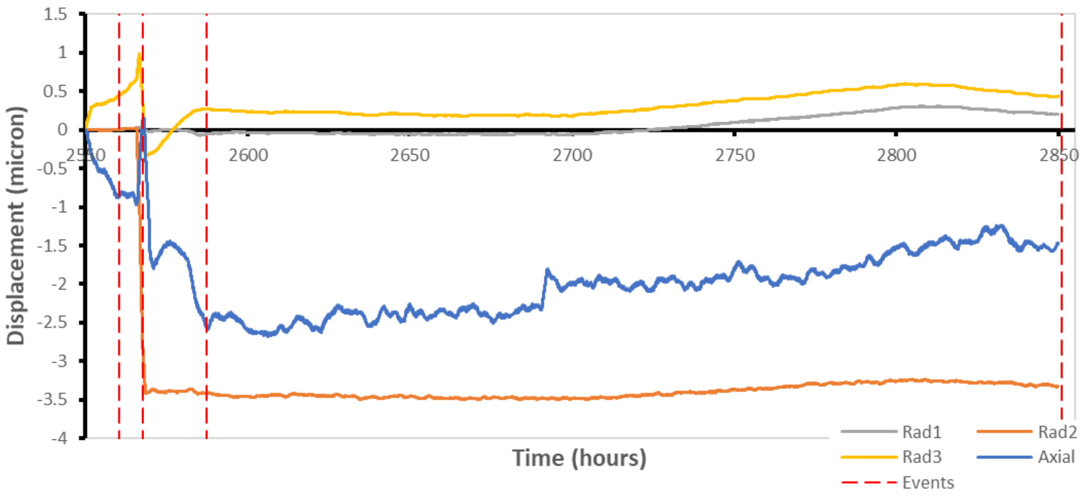
Gas test 1 COx // (sample 21-043)

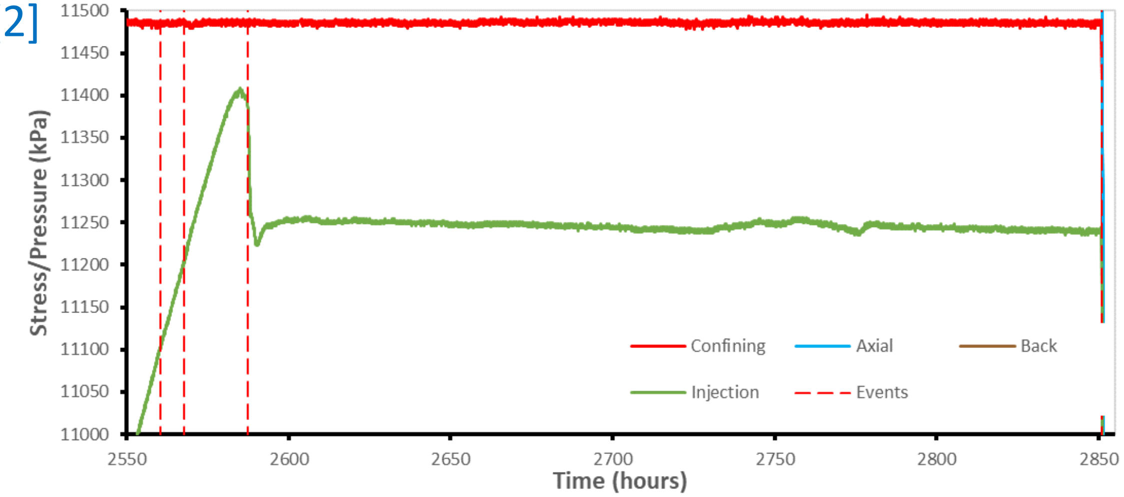
[1]



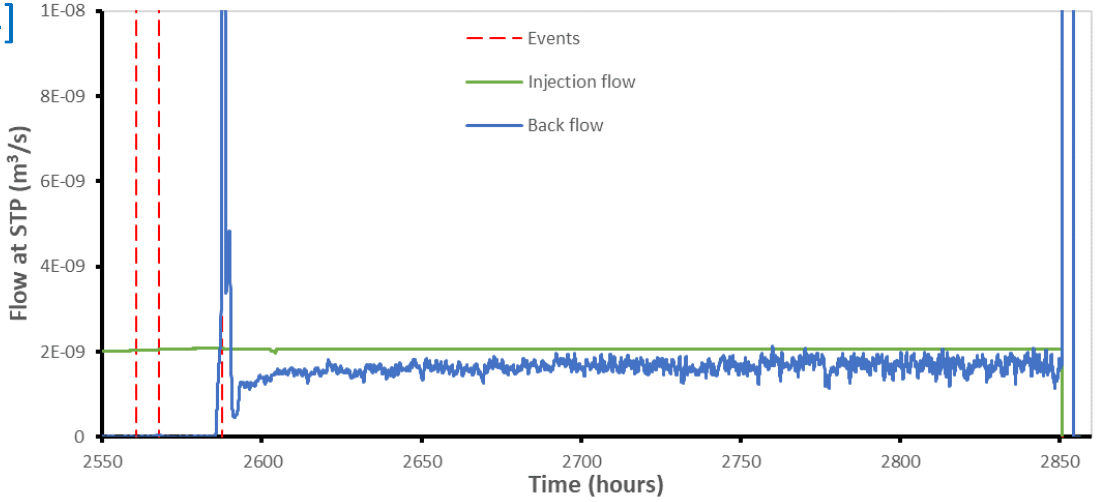
[3]



[2]



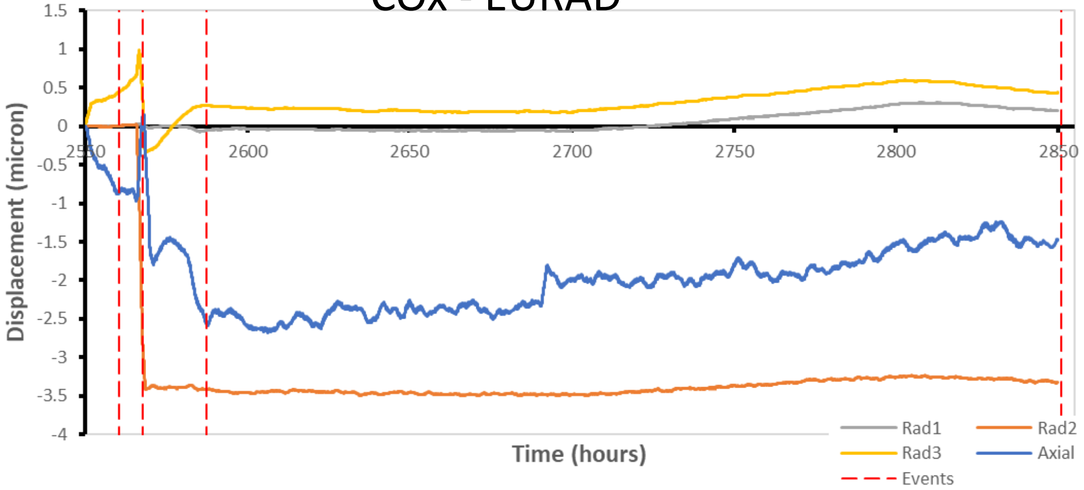
[4]



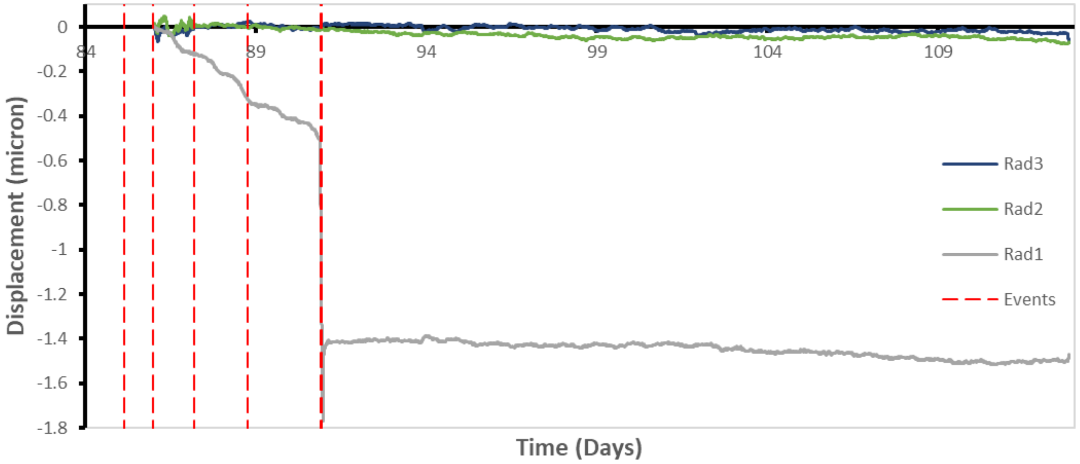
Similar gas outflow results seen in Boom Clay and Opalinus Claystone

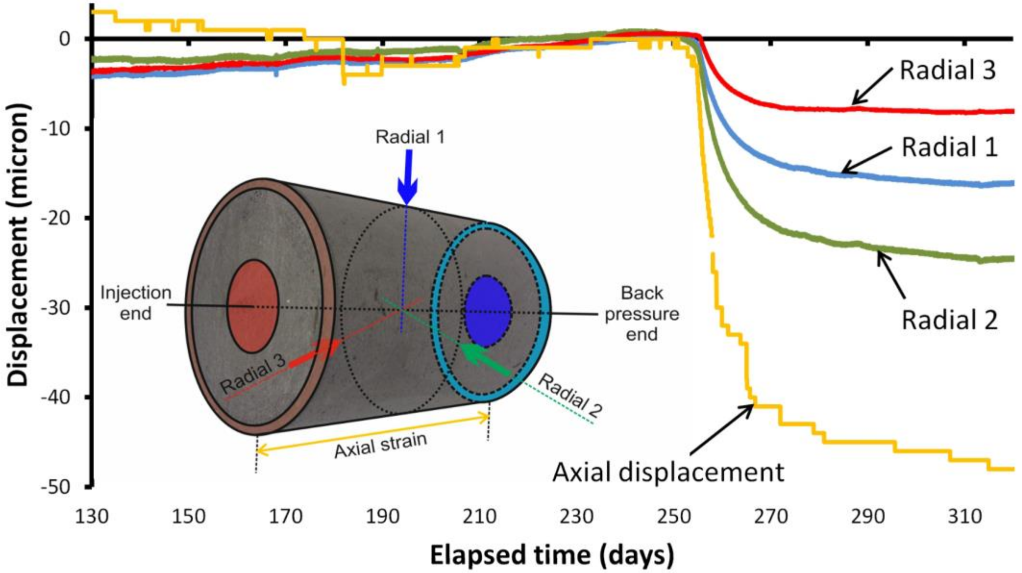
Comparison to previous results

COx - EURAD

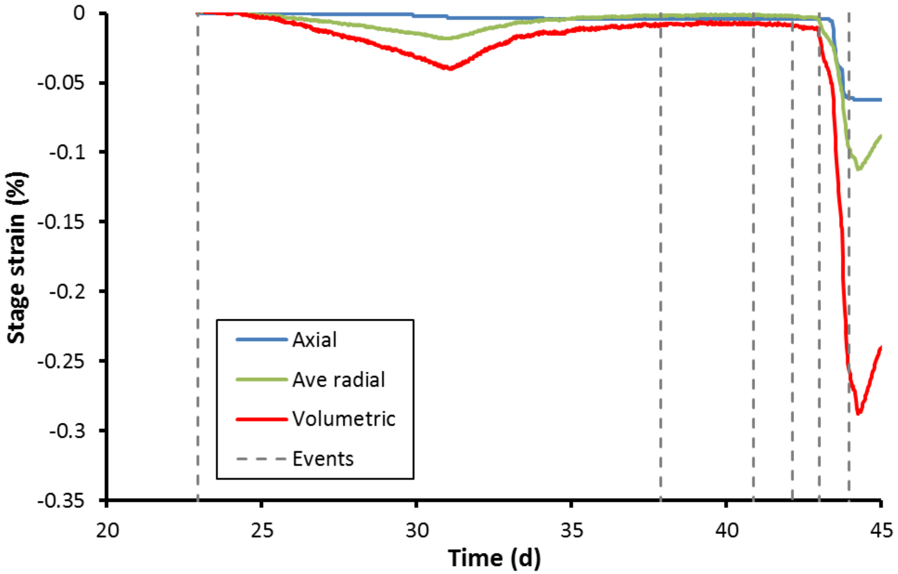


Boom Clay - EURAD





COx - FORGE



Boom Clay - OPERA

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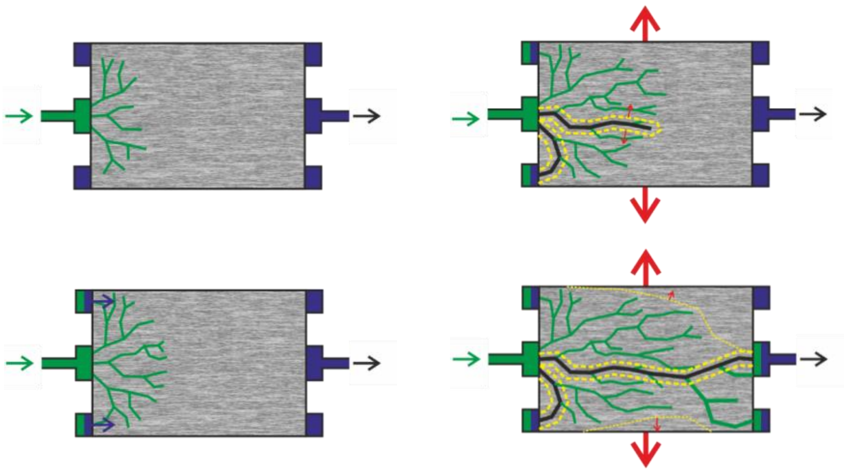
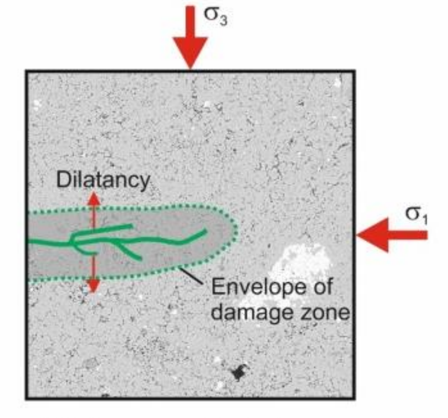
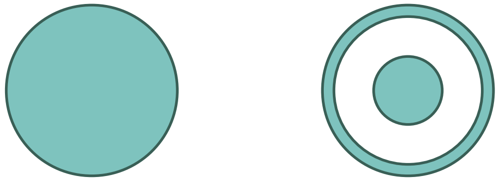
What do these results mean?

- As gas enters and moves through the sample we see very small amounts of strain until a rapid gas breakthrough event occurs. Strain does not occur evenly throughout the sample, suggesting dilation flow.
- In previous tests, using a smaller injection filter, this breakthrough event occurred over a much longer time.





Dilatancy controlled gas flow ("pathway dilation")

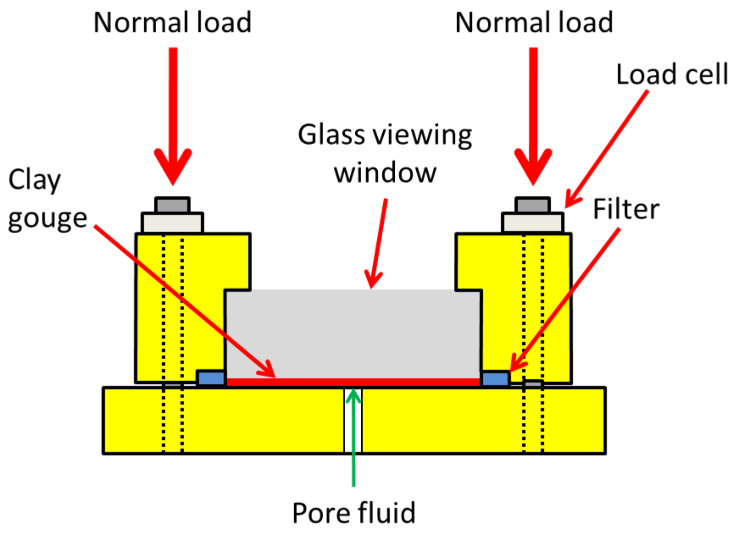


- Test geometry different. Are the current tests exploiting damage on the outside of the sample
- Sidewall flow test conducted as part of GT. Saw dilation << 1 µm

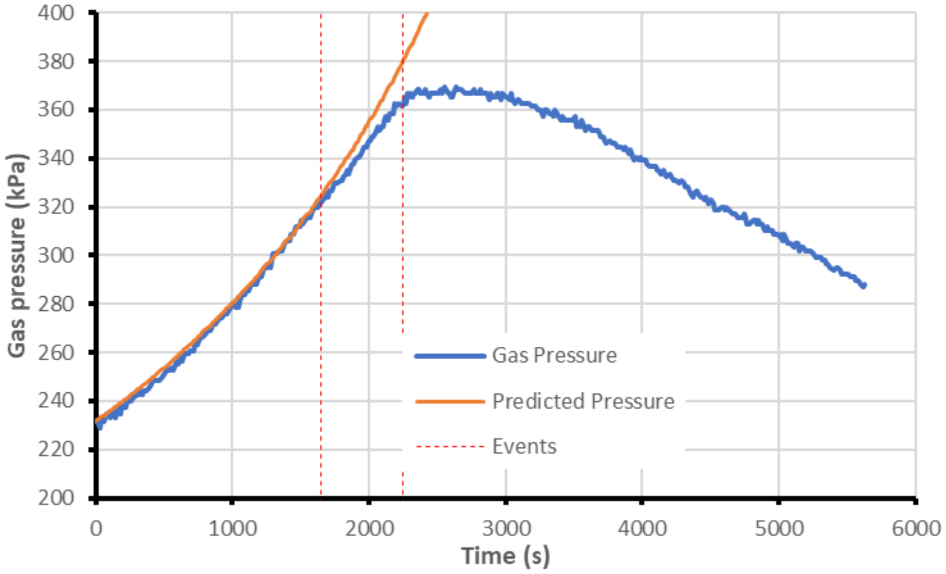
How can we visualise this process in the laboratory?

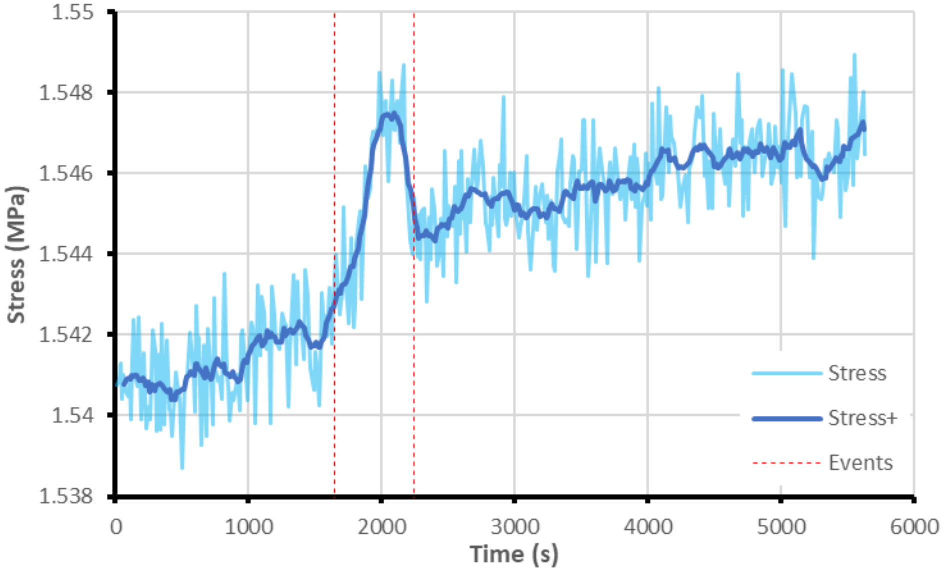
Visualising gas flow

- Apparatus constructed with 50mm thick, 150mm diameter UV fused silica glass window.
- Normal load applied via steel platens and torque on screws, up to 3 MPa.
- Capable of gas injection pressure ranging from 0.5-15 MPa, controlled by 260D Teledyne Isco syringe pump.
- Pump flow rate can range from 1 µl/min to 107 ml/min
- Helium, Hydrogen, CO_2, Nitrogen, Compressed air & water capability for injection
- Time-lapse macro photography.



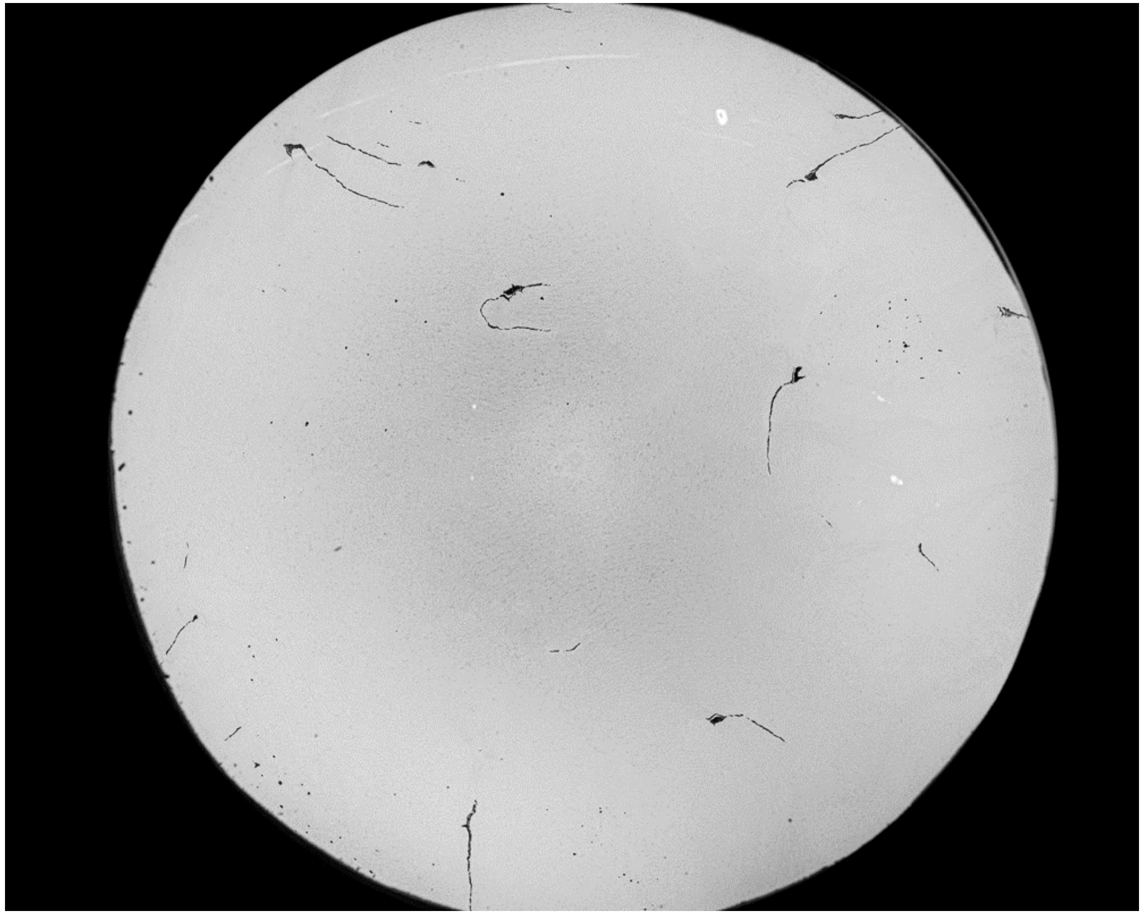
Callovo-Oxfordian

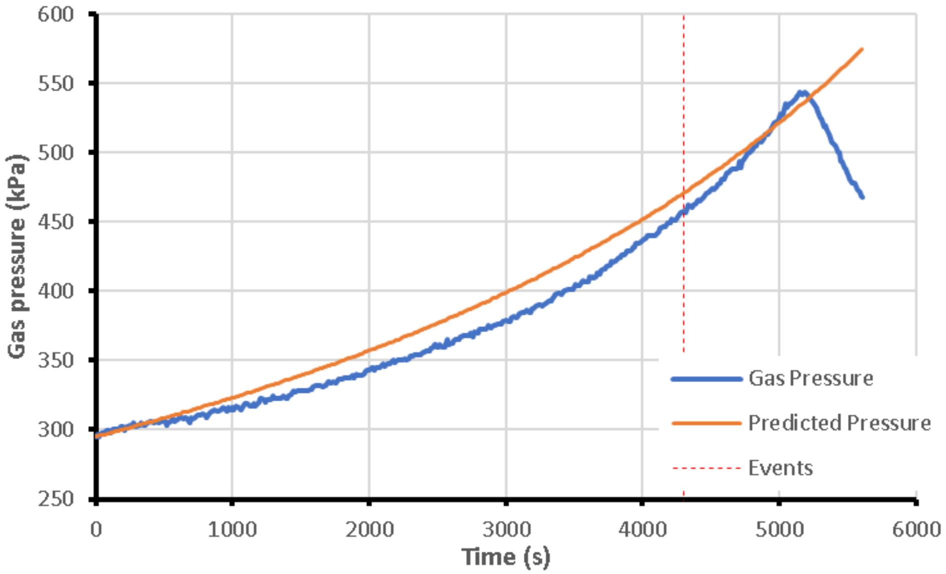


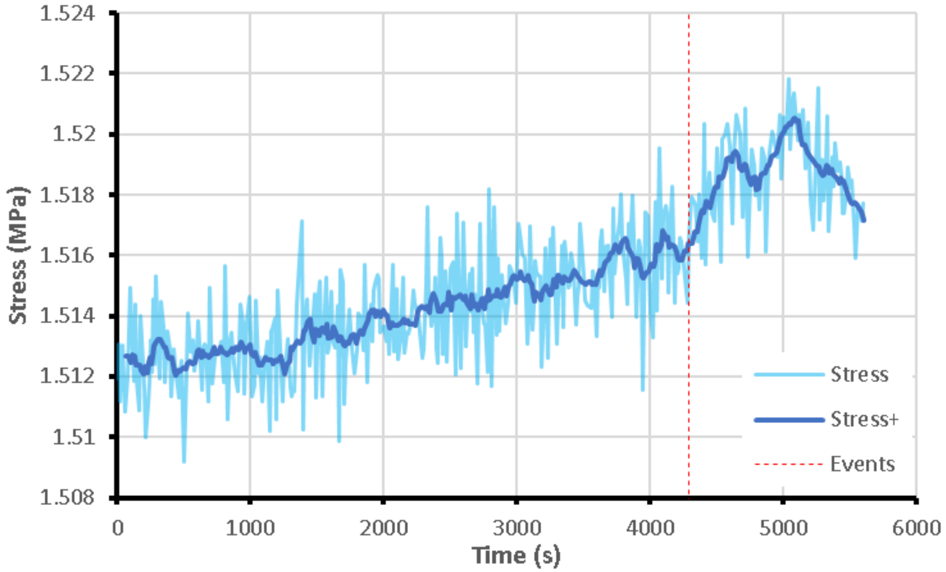


- 675s video

Evidence of Self-sealing – COx

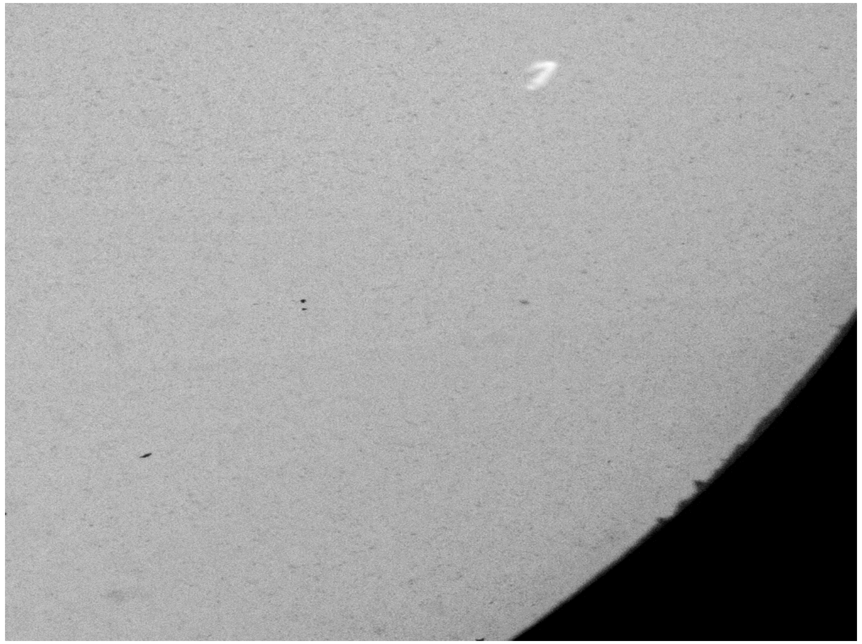


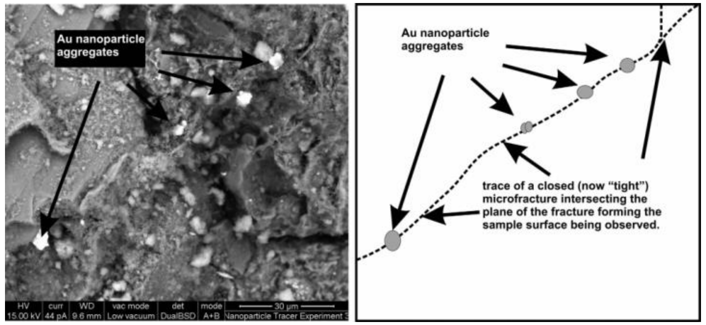




Gas flow via dilation pathways

- Pathways appear to be stochastic and do not always take advantage of what appear to be natural weaknesses in the analogue samples
- Clear deformation of local surrounding matrix
- Do not always appear to exploit apparent weaknesses in the matrix, e.g. pre-existing features
- Branching of pathways, searching for route of least resistance
- Only visible in analogue samples. Previous work has examined other ways of visualising these features
- How would these features be modelled?



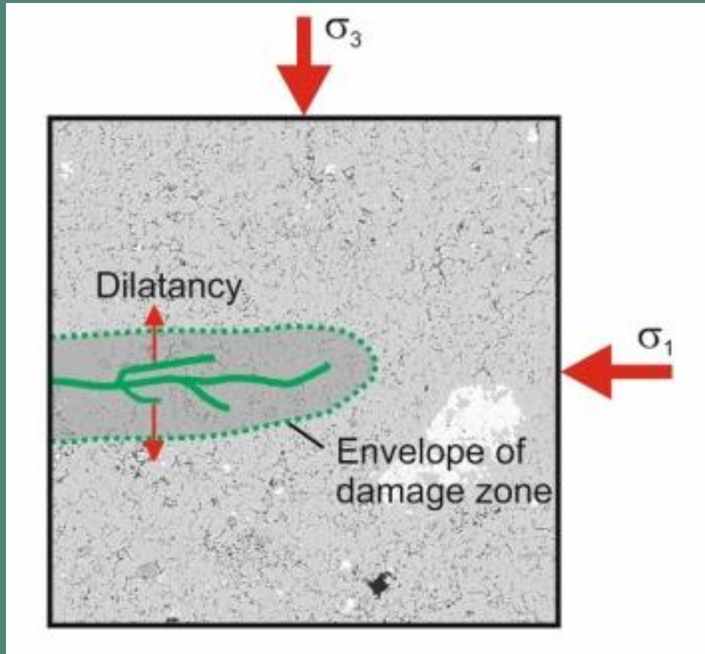


- Nano particle injection provided definitive proof of dilatant flow in BC
- Gas permeability is a dependent variable related to the number and geometry of pressure-induced pathways

Conclusions and lessons learnt

- In these clay-rich, low permeability materials gas flows via dilation pathways (where advection flow is occurring)
- Complex to model stochastic nature and small scale of pathways – research needed to understand controls
- What controls the pathway route?
- How do these processes upscale to field scale?

- Combination of methods often needed to build evidence base for claims
- Tests on both intact and analogue materials can be important
- Need to be aware of impact of test arrangement on results
- Detailed and constantly developed workflows allow results to be put into context and details on physical processes to be understood



Dilatancy controlled gas flow (”pathway dilation”)

Overlapping research areas

- Carbon Capture and Storage
- Compressed Air Energy Storage / Hydrogen Storage
- Engineering geology

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Any questions?

Acknowledgements: Jon Harrington, Rob Cuss, Caroline Graham, Katherine Daniels and NWS AS+R team