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Laboratory Studies to Understand the Controls on Flow and Transport for CO_2 Storage

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Challenges for Geologic Carbon Storage

- The subsurface is complex and was not designed by engineers
- Natural heterogeneity at all scales affects CO_2 flow and trapping processes
- This challenges our ability to exploit the available pore space efficiently and to reduce uncertainties around storage estimates

Key requirements for efficient and safe exploitation of the storage complex:

- Understanding CO_2 migration at multiple scales
- Understanding subseismic geologic heterogeneity and its impact on trapping
- Understanding of when and how caprocks fail

ELEGANCY addresses these challenges by combining laboratory- and pilot-scale studies

Key achievements

Development of advanced experimentation for the study of key processes in geologic CO_2 sequestration, including transport in reservoir and seal rocks

1. Relative permeability and capillary trapping in sandstones and heterogeneous carbonate rocks

2. Assessment of fracture properties evolution under brine flow to quantify self-healing potential of caprocks (jointly with ETH Zurich, Switzerland)

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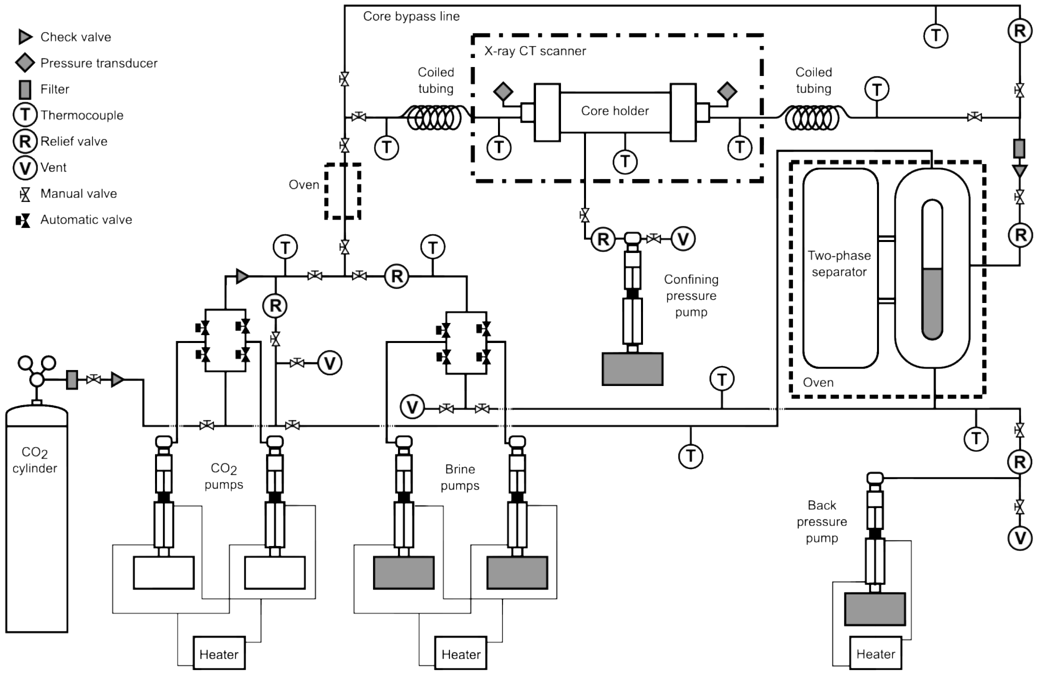
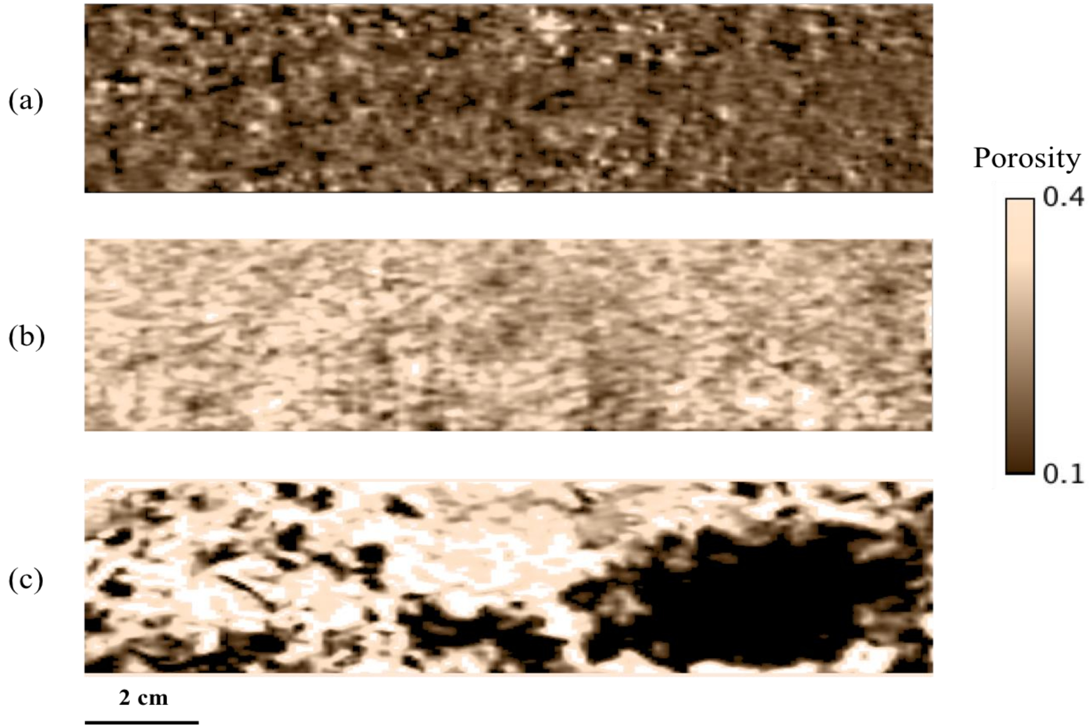
Relative permeability and trapping are key for flow modeling, but carbonate reservoirs are heterogeneous



Steady state coreflooding and X-ray imaging

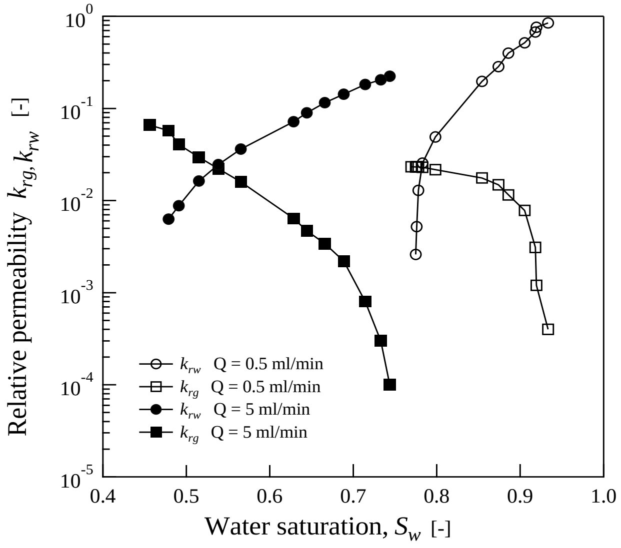


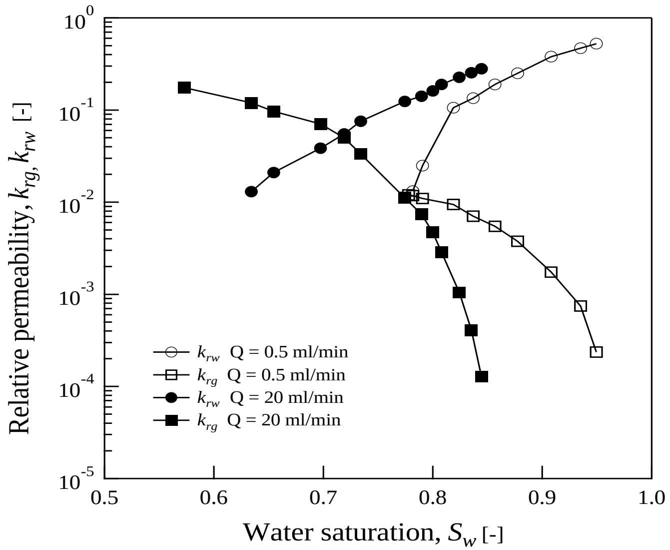
Three carbonate rocks with different degrees of heterogeneity

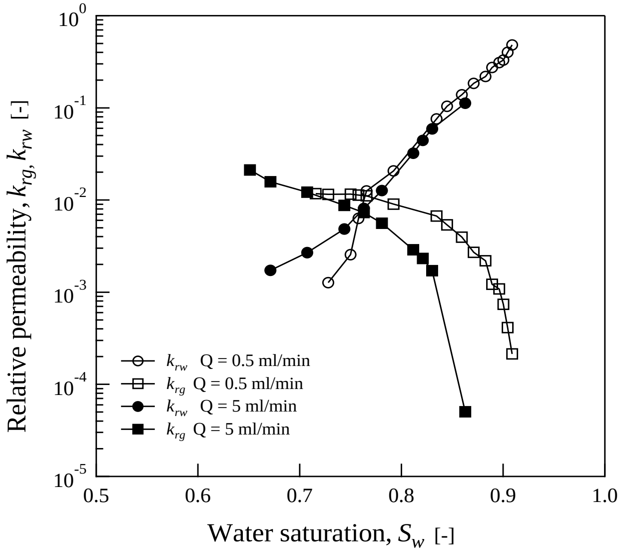
Heterogeneity leads to flow rate dependence of relative permeability, and impacts on trapping

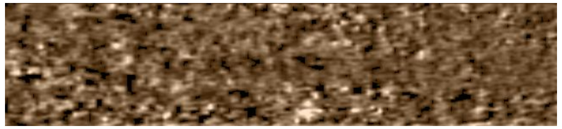
The impact depends on the heterogeneity and properties used in flow modelling must incorporate the impacts

This makes characterisation difficult – we must characterise more, and in more detail









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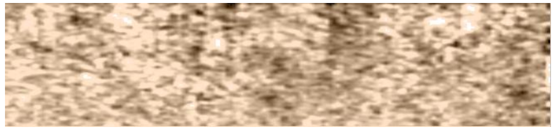

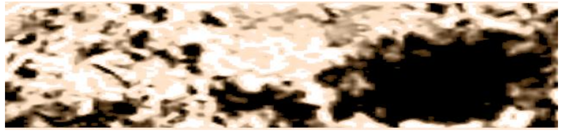

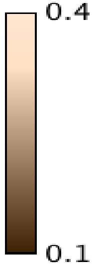

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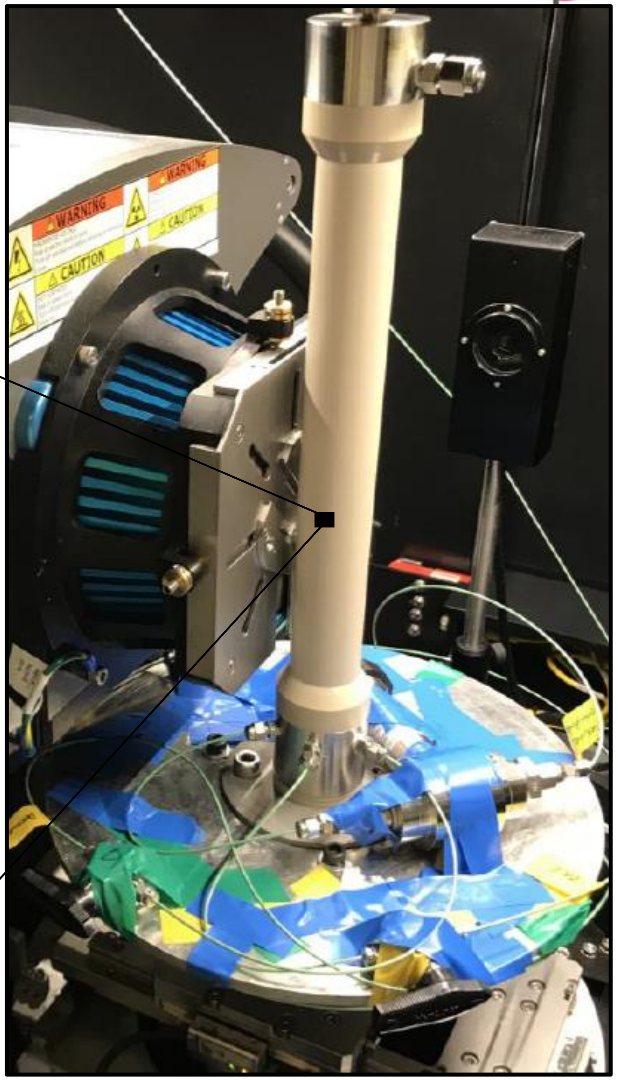
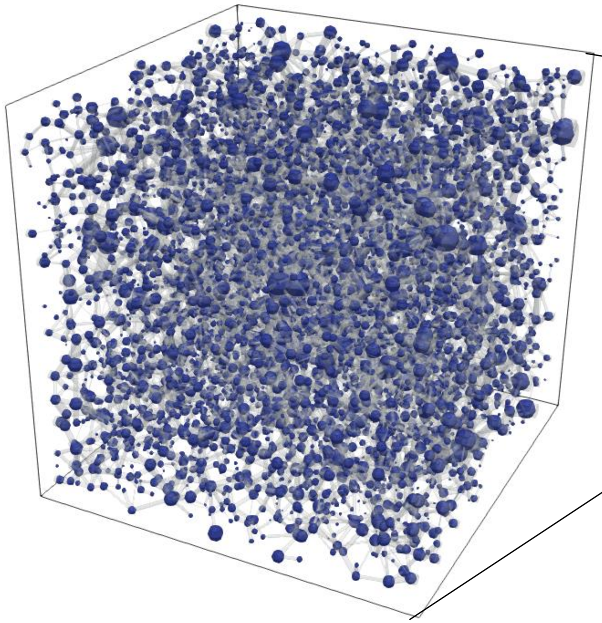
A digital approach to characterising heterogeneity

X-ray micro-computed tomography could allow more characterisation, faster, but was unvalidated

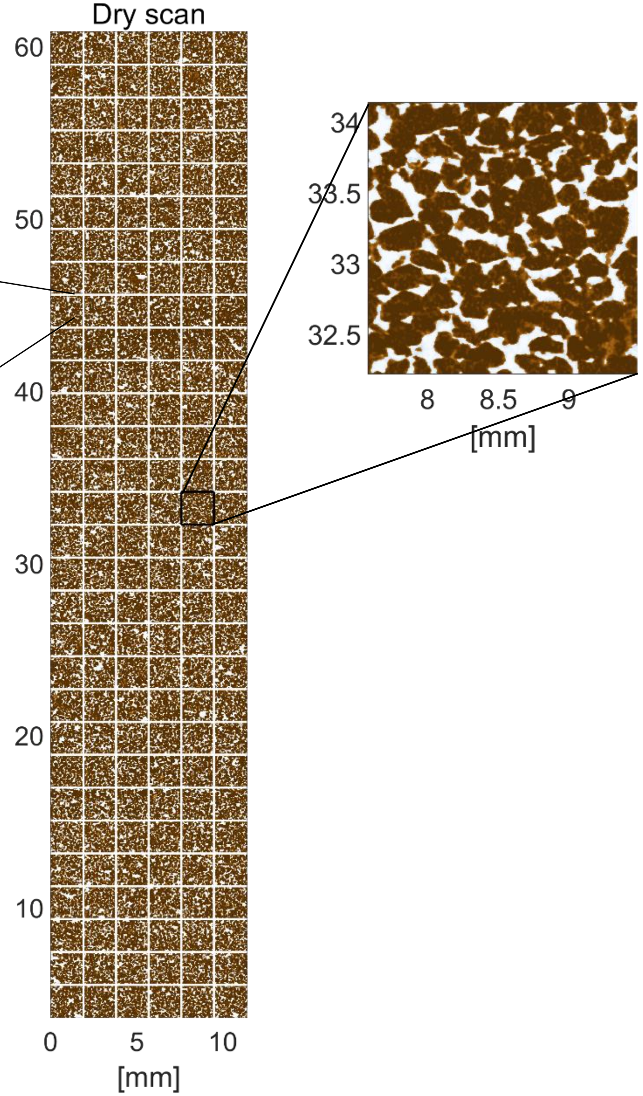


Digital Workflow to Characterise Heterogeneity

Pore network model



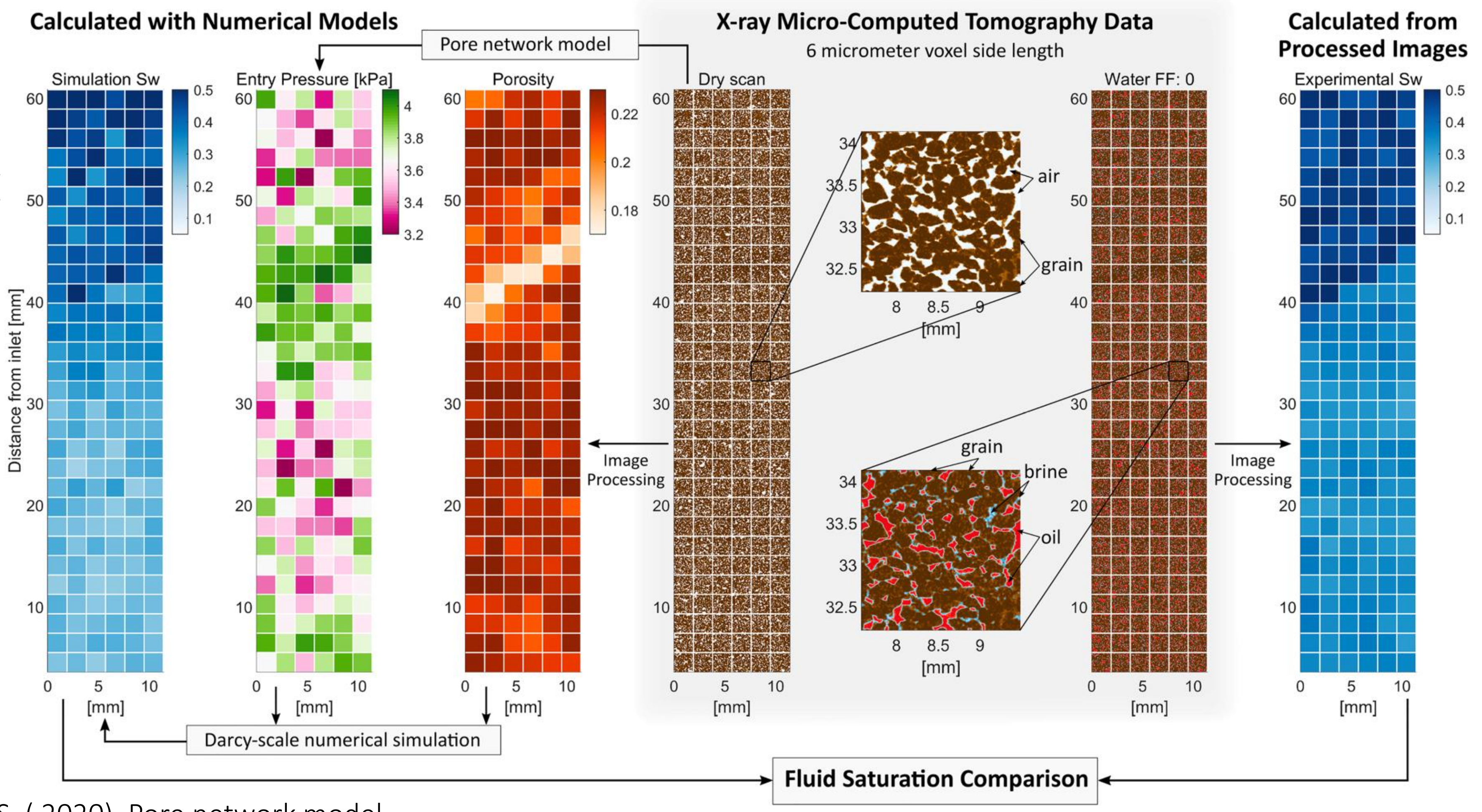
[*Pnflow* pore network model codes based on Valvatne and Blunt, 2004]



1. Segment dry images and calculate local porosity
2. Use pore network model to characterize capillary ***entry*** pressure in each subdomain

Digital Workflow Opens the Door to Practical Characterisation

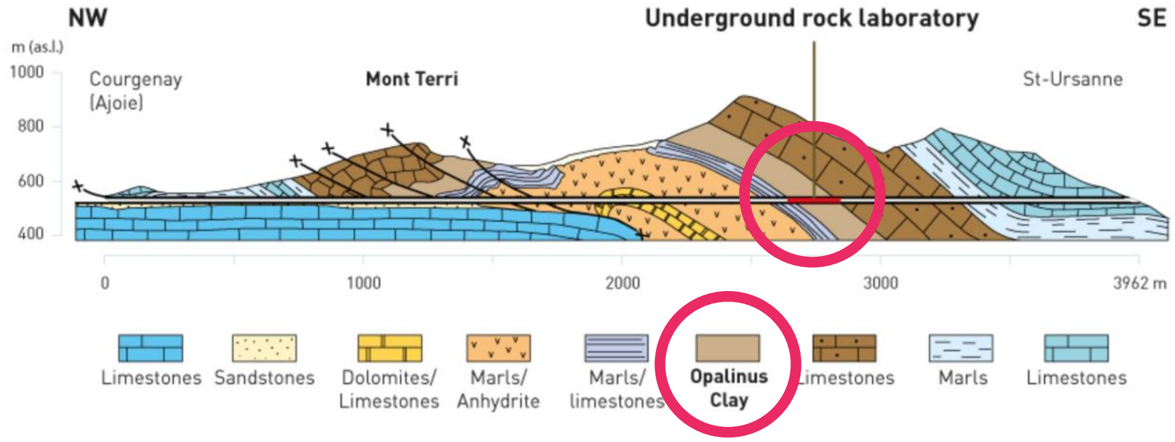
- Validated predictions against observations
- Workflow can be applied rapidly to a large number of samples



Zahasky, C., Jackson, S. J., Lin, Q., & Krevor, S. (2020). Pore network model predictions of Darcy-scale multiphase flow heterogeneity validated by experiments. Water Resources Research, 56, e2019WR026708. https://doi.org/10.1029/2019WR026708

When and how does a caprock fail?

Decameter scale field experiment at the Mont Terri Underground Laboratory (CH)



https://www.mont-terri.ch

- Opalinus clay has important water retention properties – up to 5-9%wt.[1]
- Volumetric behaviour observed when the rock is subjected to wetting/re-saturation

Opalinus clay: analogue for a clay-rich (40 – 80%wt.) caprock above CO_2 sequestration reservoirs

Behaviour under confinement?
Effects on fracture transmissivity?
Self–healing potential?

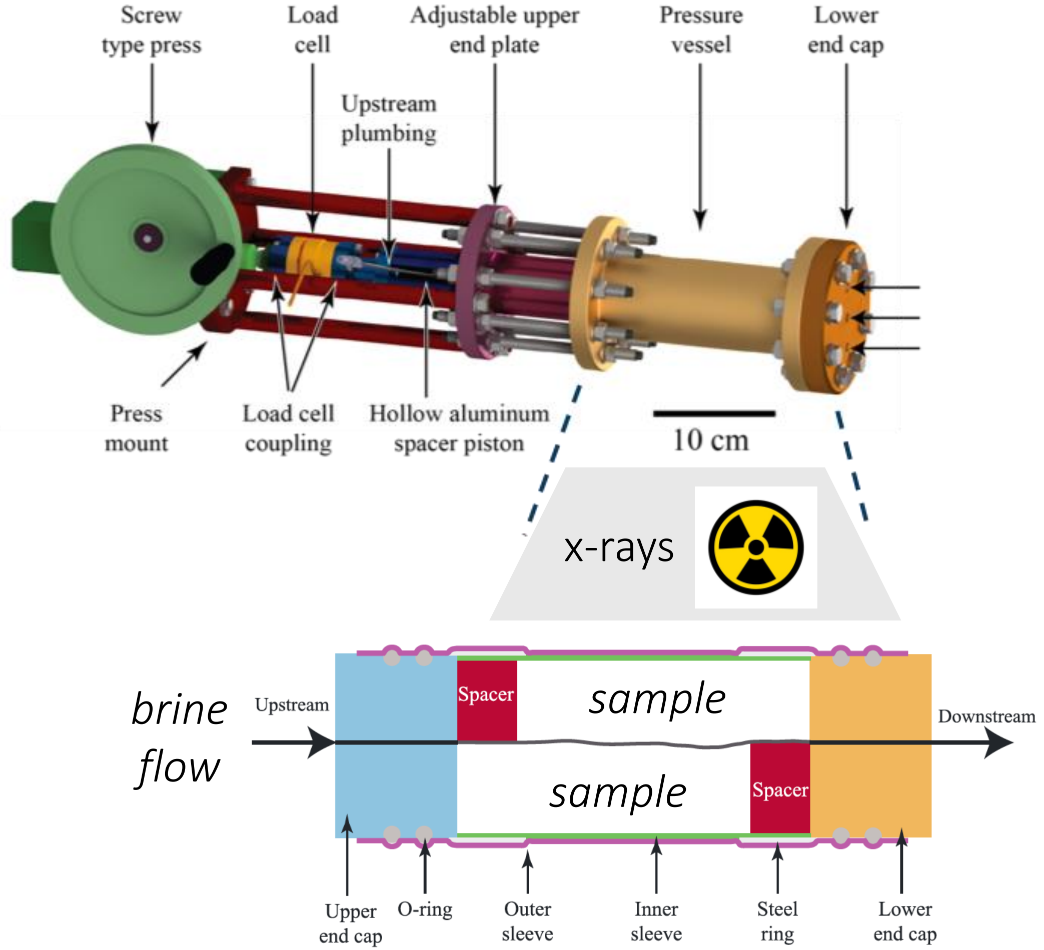
[1] P. Bossart and M. Thury. Mont terri rock laboratory. project, programme 1996-2007 and results. Technical Report 3, Reports of the Swiss geological Survey, 2008.

Chemo-mechanical coupling in fractured shale

To study caprock behaviour at representative conditions

Experimental approach: direct-shear experiments with simultaneous fluid injection and imaging by X-ray Computed Tomography on a fractured sample under pressure

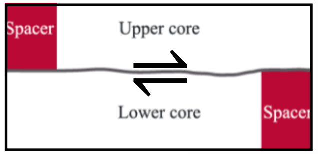
- New X-ray transparent direct shearing core-holder [1]
- Spatial mapping of the fracture aperture field and its evolution in time
- Quantification of fracture transmissivity

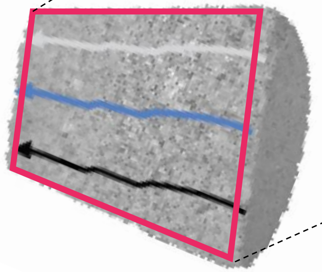


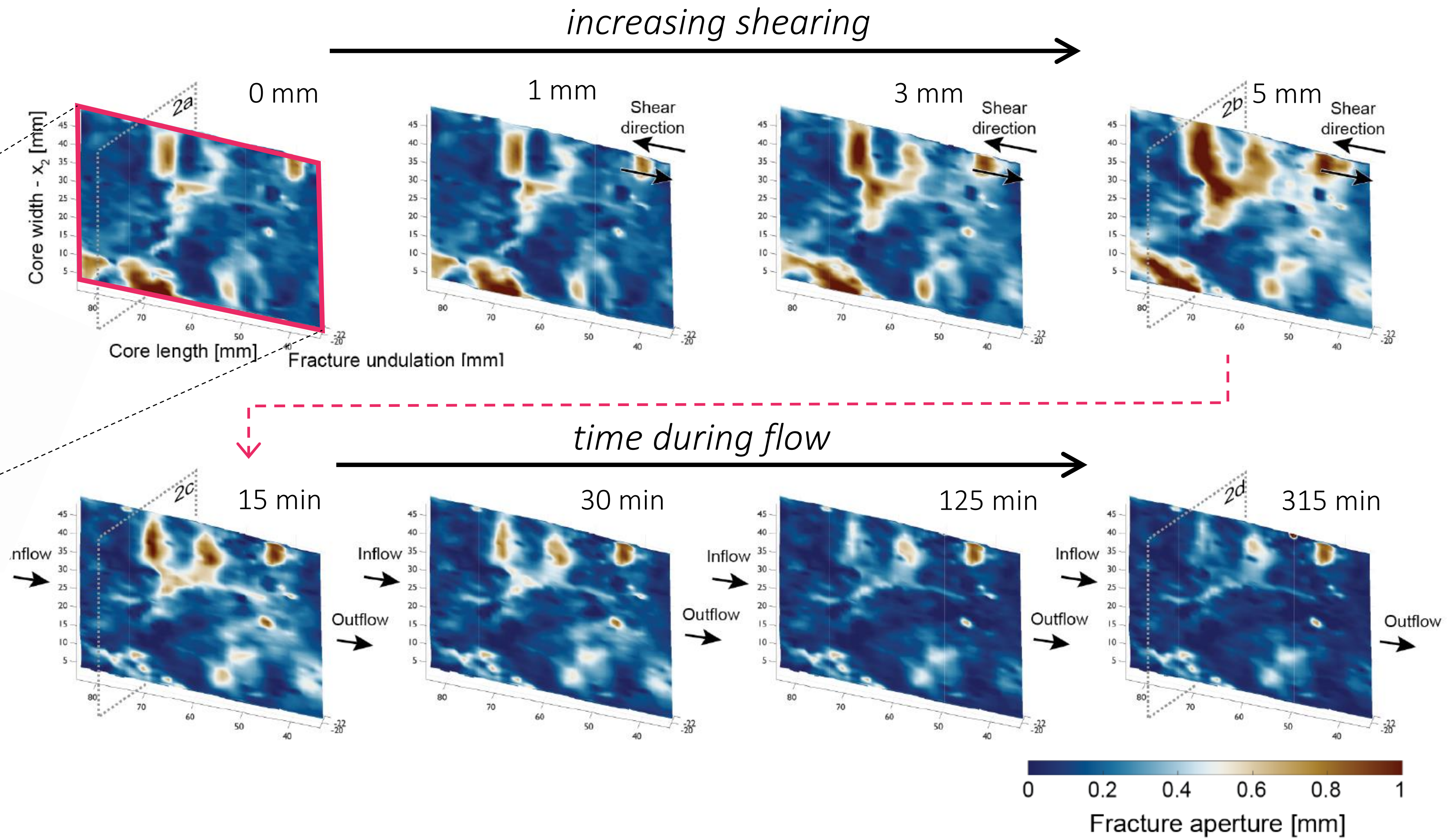
[1] Wenning et al (2019) *Journal of Geophysical Research: Solid Earth*, 124(7): 7320-7340

Direct imaging of fracture evolution during shearing and brine flow in Opalinus clay

Fracture evolution during direct shearing (no flow)





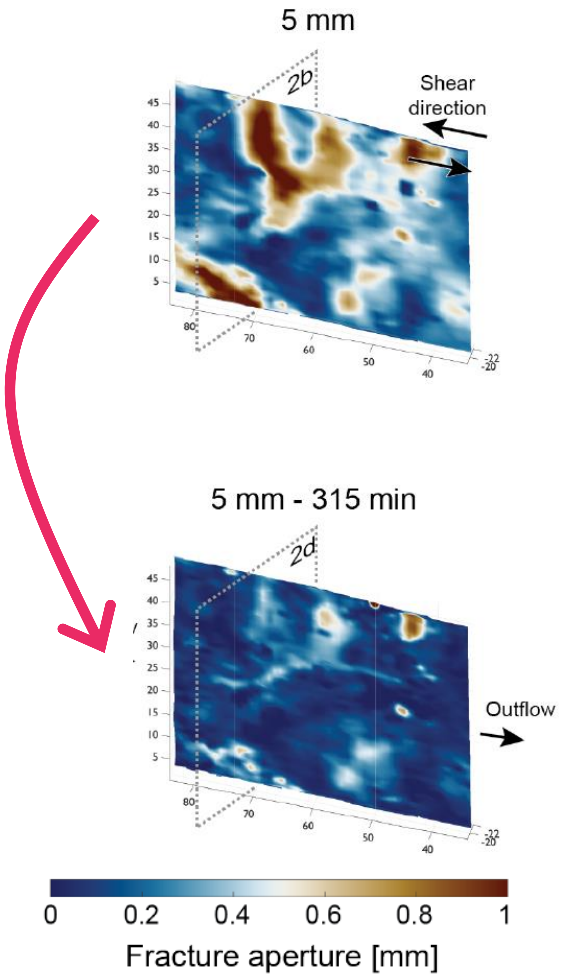


Fracture evolution upon re-wetting (flow)

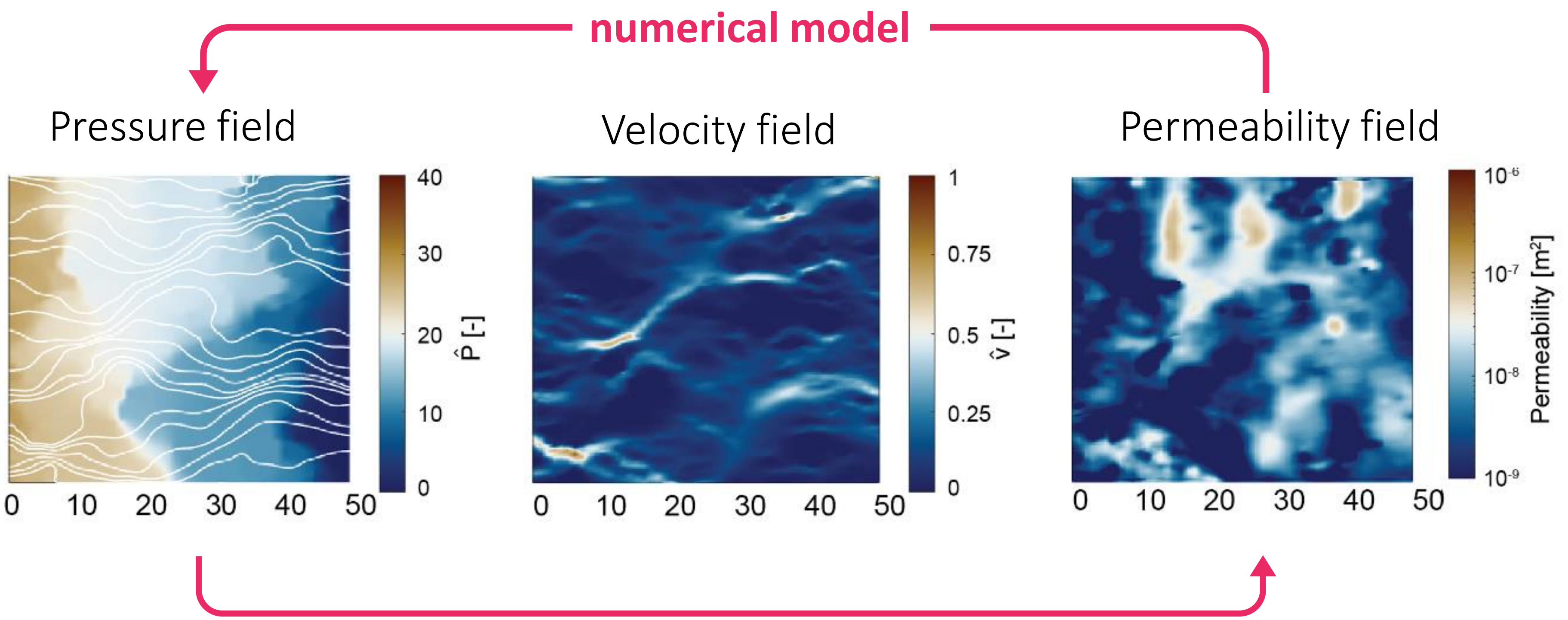
Direct imaging of fracture evolution during shearing and brine flow in Opalinus clay

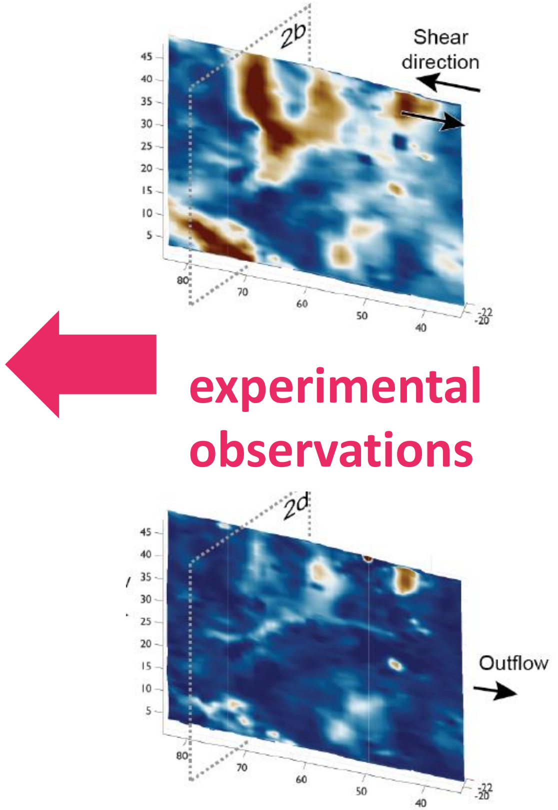
Key observations

- Shearing opens fractures and induces a highly heterogeneous permeability field
- Brine sorption induces swelling leading to fracture closure; this was not observed in a control experiment with decane
- Hydraulic permeability decreases by up to two orders of magnitude during brine injection (self–healing)
- Deformation is induced even at locations not reached by the injected fluid (bulk expansion under constant radial stress)



Integrated workflow to study the transport of chemically reacting fluids through caprocks





Inform the development of monitoring technologies in a relevant environment (clay-rich seal rock)

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Acknowledgements

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