FACULTY OF SCIENCES

DEPARTMENT OF GEOLOGY
RESEARCH GROUP PPROGRESS

PREDICTING AND MEASURING PORE-SCALE CAPILLARY PRESSURES ASSOCIATED WITH MENISCUS MOVEMENTS DURING SLOW IMBIBITION

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InterPore2022

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PROGRESS
Pore-scale Processes in Geomaterials

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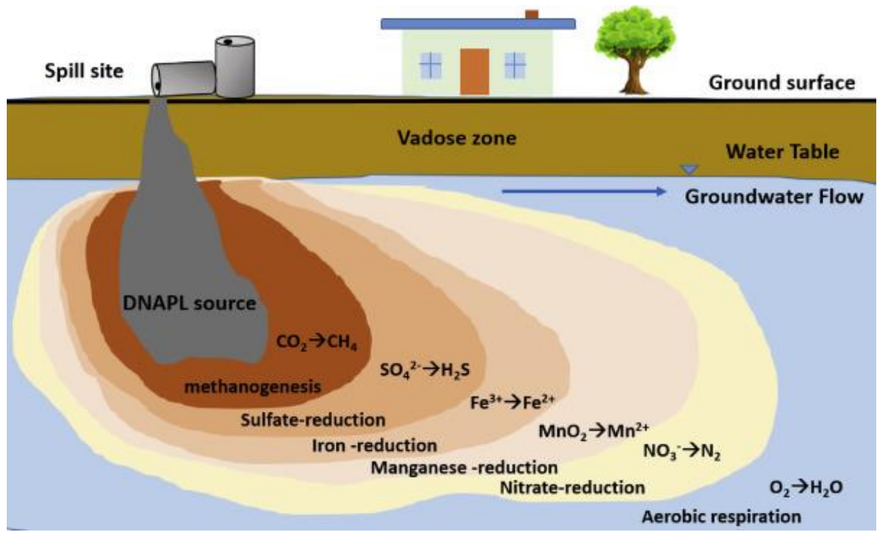
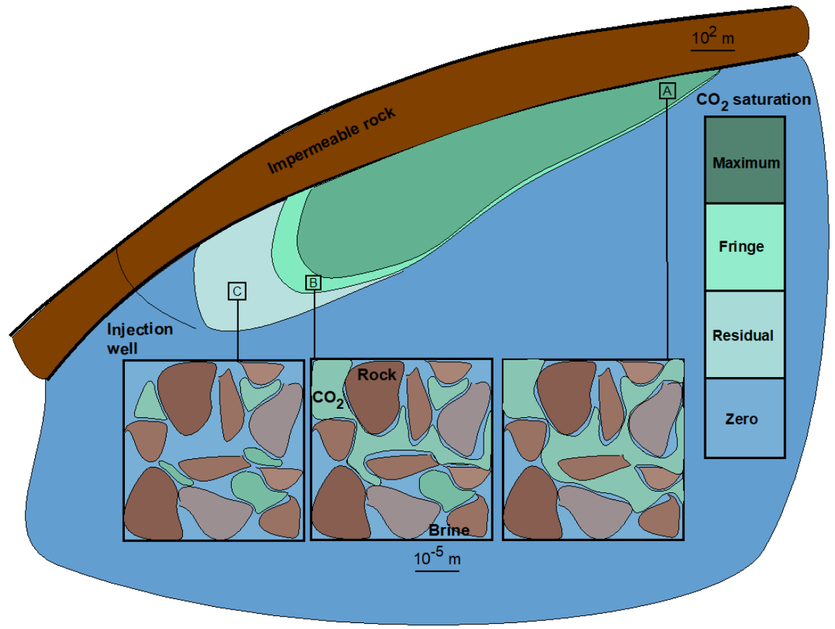
UGCT

InterPore

Multiphase flow is important

- Contaminant transport & remediation
- Subsurface energy storage
- CCS





Krevor et al. et al., 2015

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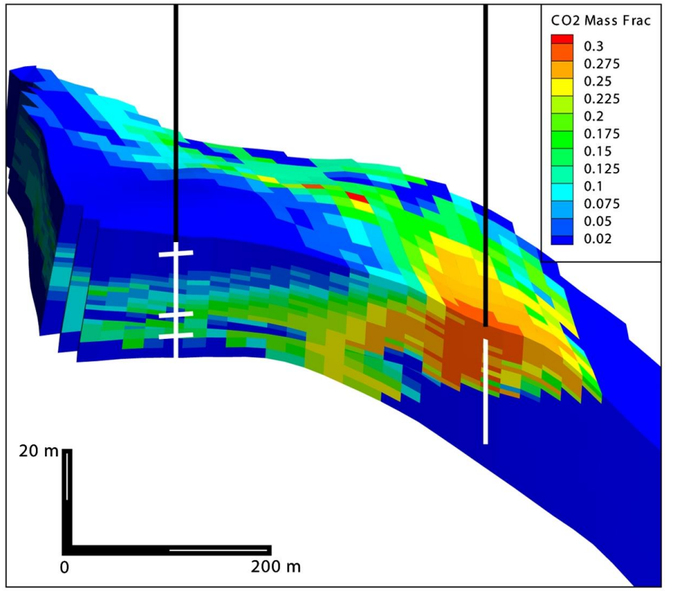
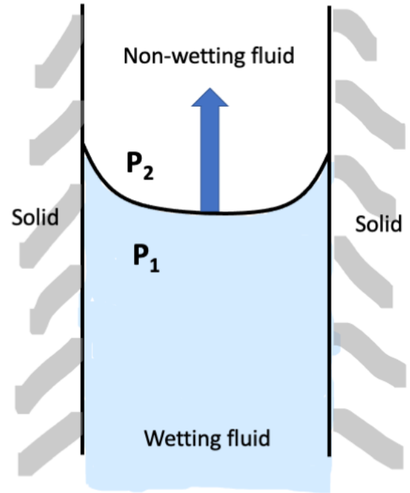
Importance of capillary pressure

- Macroscopic Pc
  - Important field-scale model input
  - Controlled by local Pc
- Invasion Pc
  - Lowest equilibrium Pc (imbibition)
  - Controls fluid displacement
- Quasi-static PNM
  - Common modelling approach
  - Large size domains
  - Interpretable



Jenkins et al., 2012

local Pc < equilibrium Pc



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Validation using local Pc can expose causes of error

- Models align poorly with reality
- Validations using fluid distributions and Pc curves don't explain why (Bakke and Øren, 1997; Valvatne and Blunt, 2004; Berg et al., 2016)
- Aim:
  - Validation workflow for quasi-static PNMs using local Pc
  - Pin down leading causes of errors in these models

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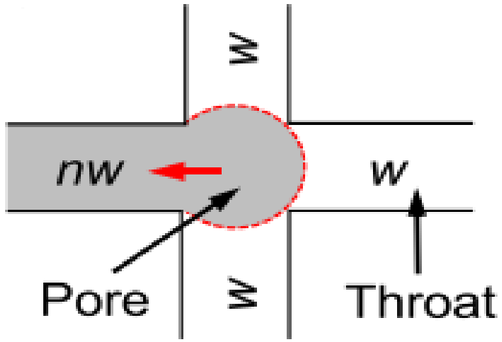
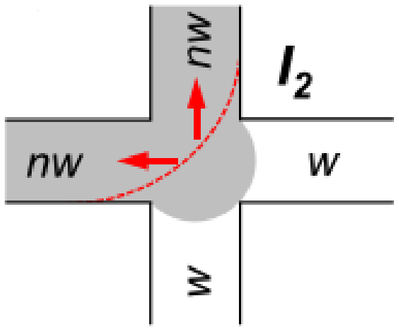
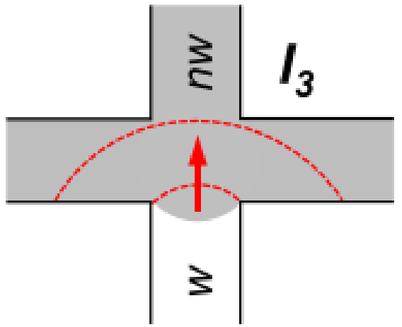
Imbibition displacements

– Piston-like displacements in pores

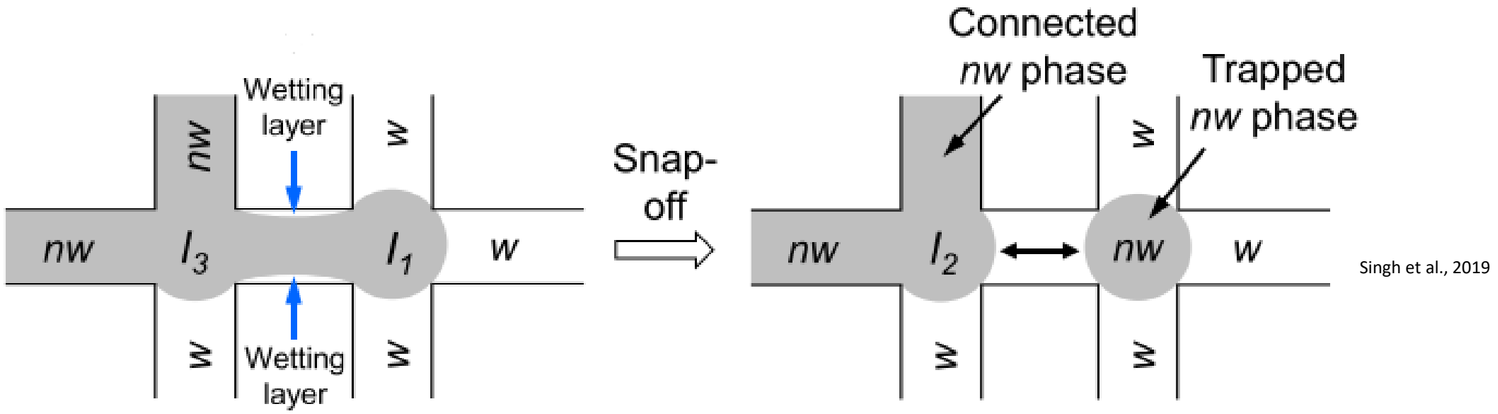


– Cooperative pore-fillings





– Snap-off



Singh et al., 2019

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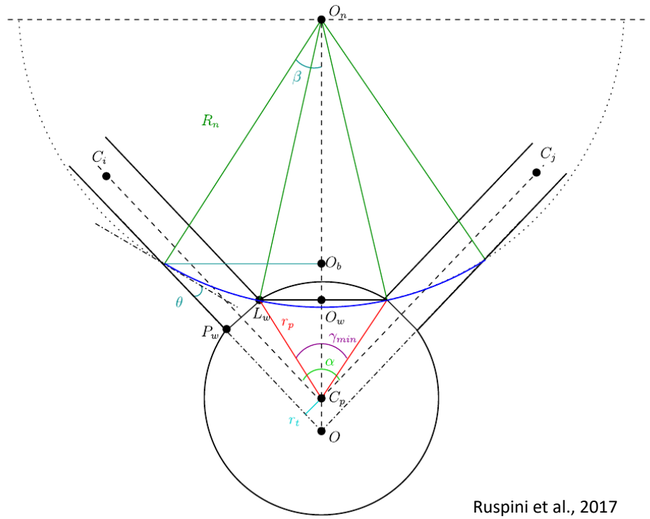
Standard quasi-static Pc models

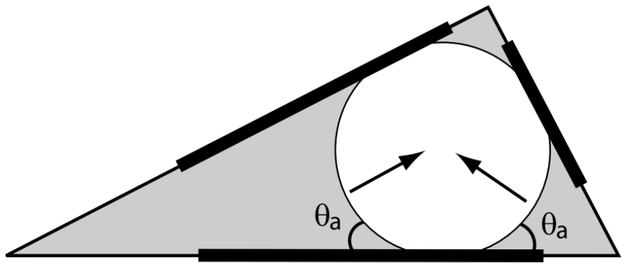
- Piston-like displacements:
  - Young-Laplace equation (for displacements in pores)

$$Pc = \frac{2\sigma \cos\theta}{r}$$



Ruspini et al., 2017

- Cooperative pore fillings:
  - Trigonometric model
- Snap-off:
  - Model assuming triangular throats



Valvatne and Blunt, 2004

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What we did

- Analyzed time-resolved dataset of imbibition (Schlüter et al, 2016)
- Used Pc models to estimate invasion Pc, using:
  - Extracted PNM
  - Locally measured contact angles (Mascini et al., 2020)
- Determined curvature-based local Pc
  - From extracted menisci (Li et al., 2018; Mascini et al., 2020)
- Used local Pc to validate invasion Pc models

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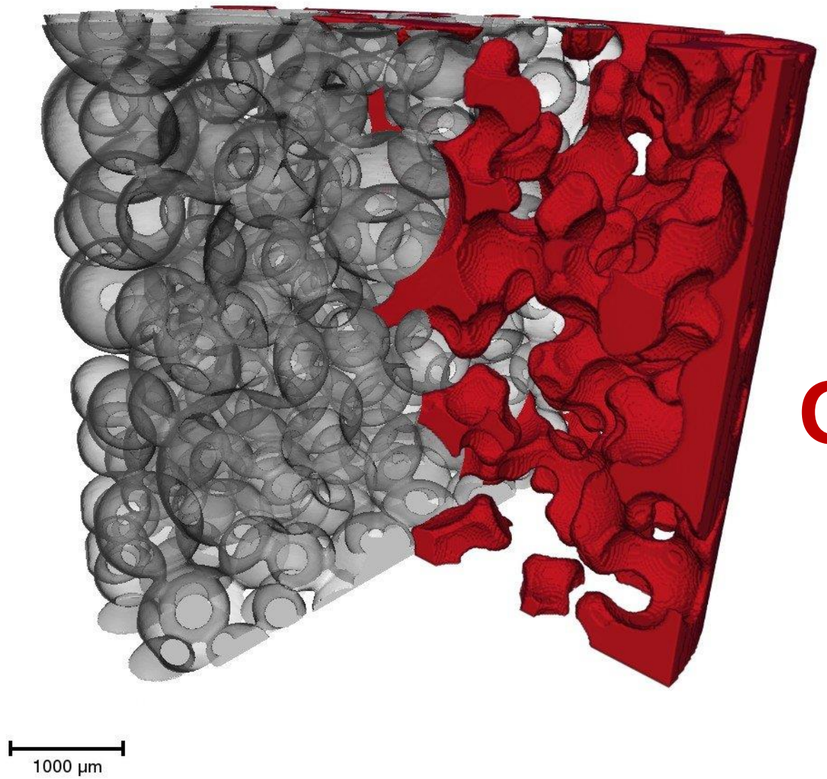
Experimental data

- Imbibition in sintered glass bead pack (Schlüter et al., 2016)
- CsCl-brine & n-dodecane
- Capillary dominated flow ($Ca = 10^{-8}$)
- 52 scans (113 s between scans)



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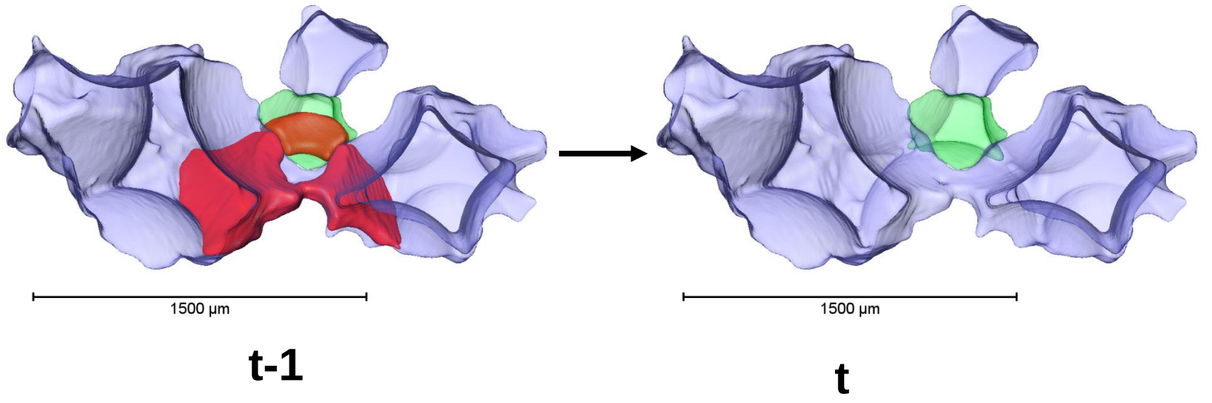
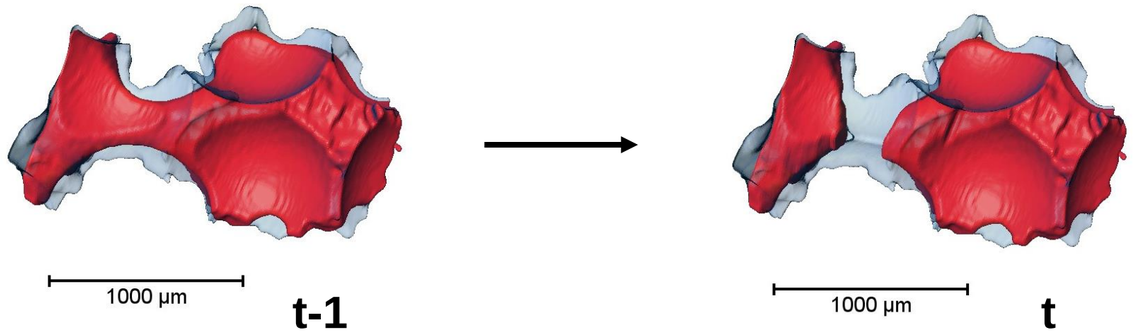
Identifying fluid displacements

- Piston-like displacements & cooperative pore fillings:
  - Pores changed occupancy



- Snap-offs
  - Throats changed occupancy but adjoining pores did not



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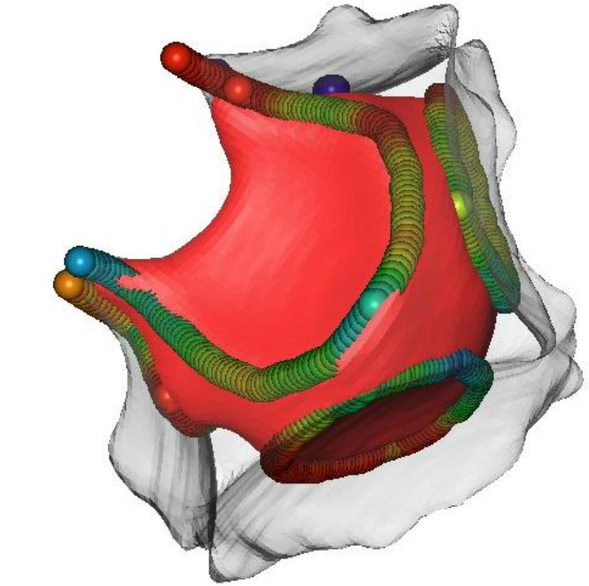
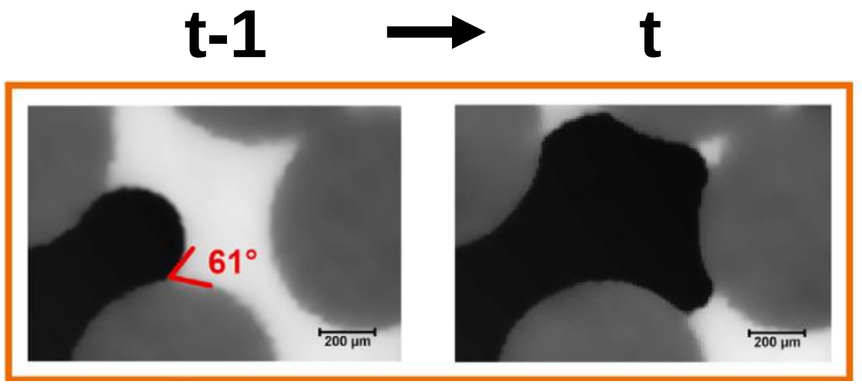
Locally measured contact angles

- Wettability is variable
- Need contact angles which are local in space and time
- Local geometric contact angles (Mascini et al., 2020)
  - Uses automated algorithm (AlRatrout et al., 2017)
  - Better accounts for contact angle hinging





Mascini et al., 2020

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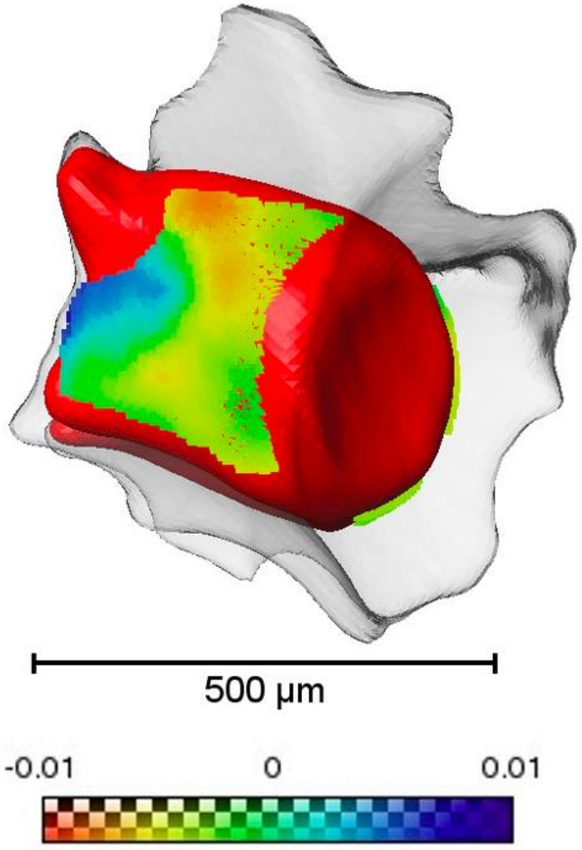
Curvature-based Pc

- Curvature measurements
  - Fluid menisci extracted
  - Curvature per displacement

- Curvature-based Pc
  - Young Laplace



$$P_{c,thr} = 2\sigma\kappa_{thr}$$

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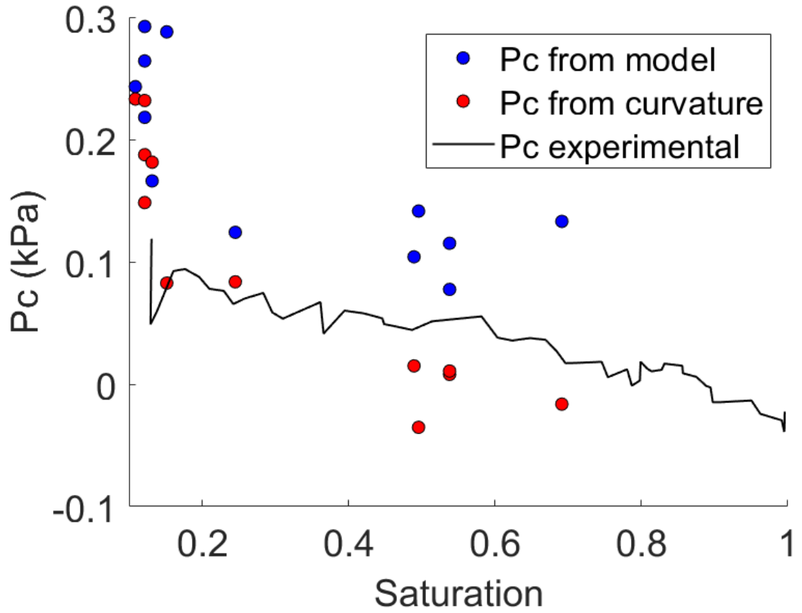
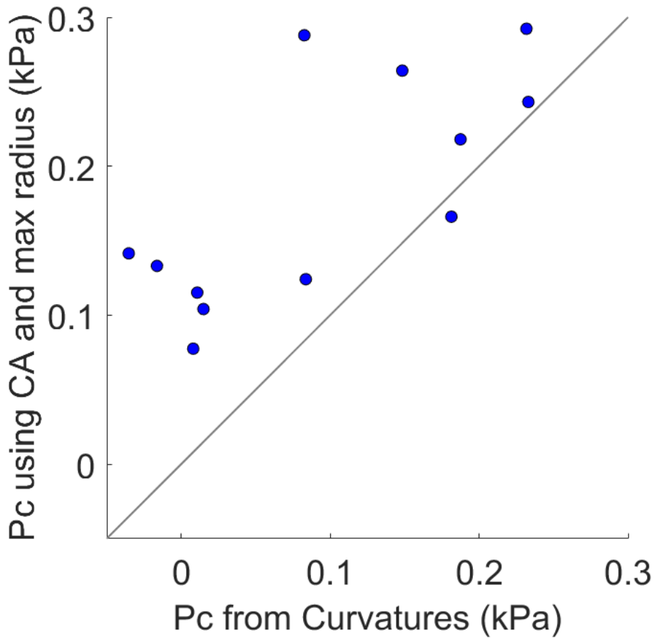
Piston-like displacements

- Causes of mismatch:
  - Erroneous classification
  - Over-segmentation of pore space
  - Maximum inscribed sphere radius
  - Dynamic effects





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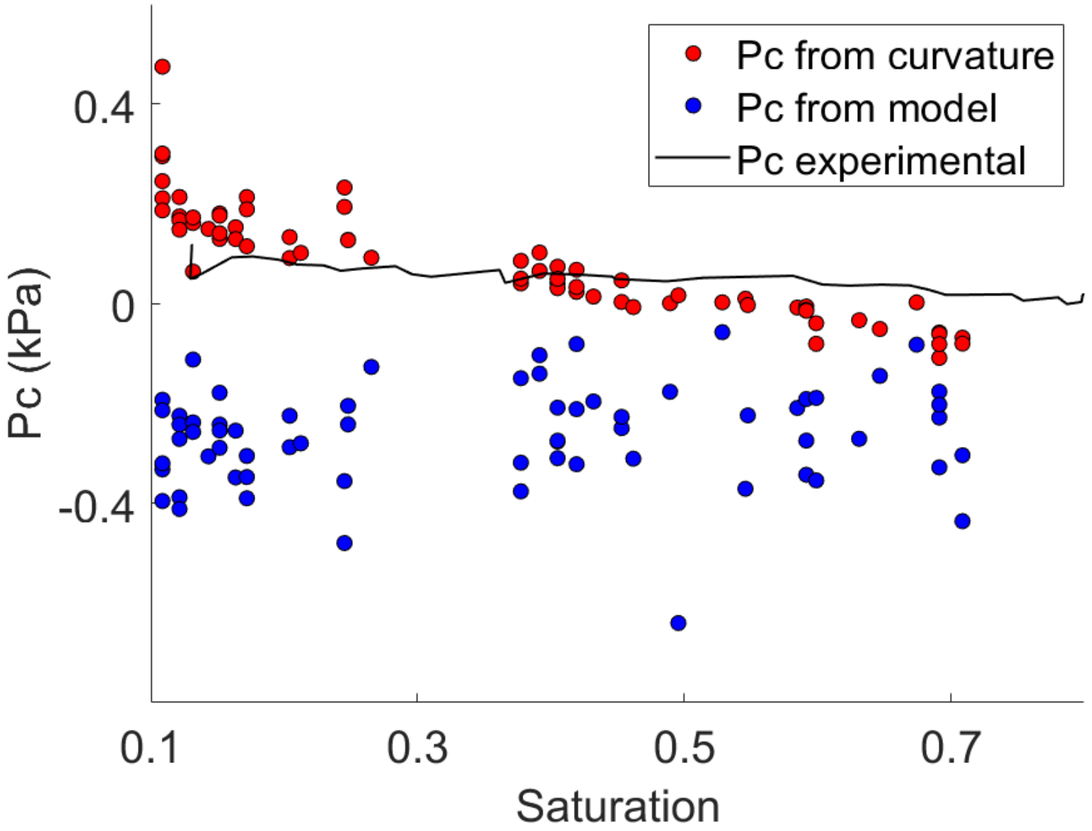
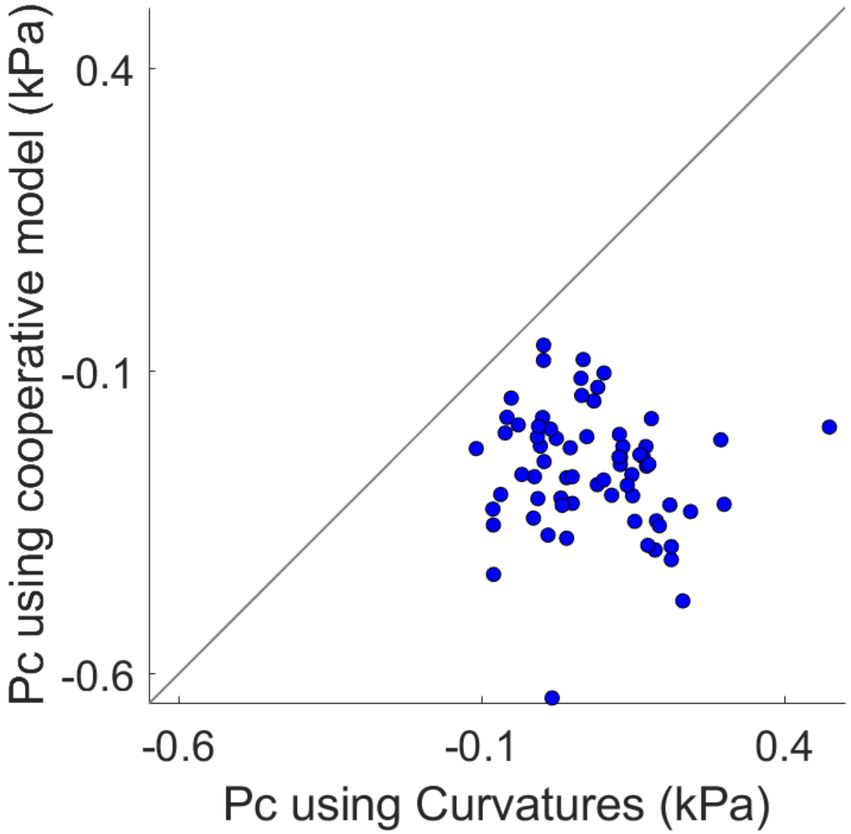
Cooperative pore fillings

– 68 displacements could be matched to model





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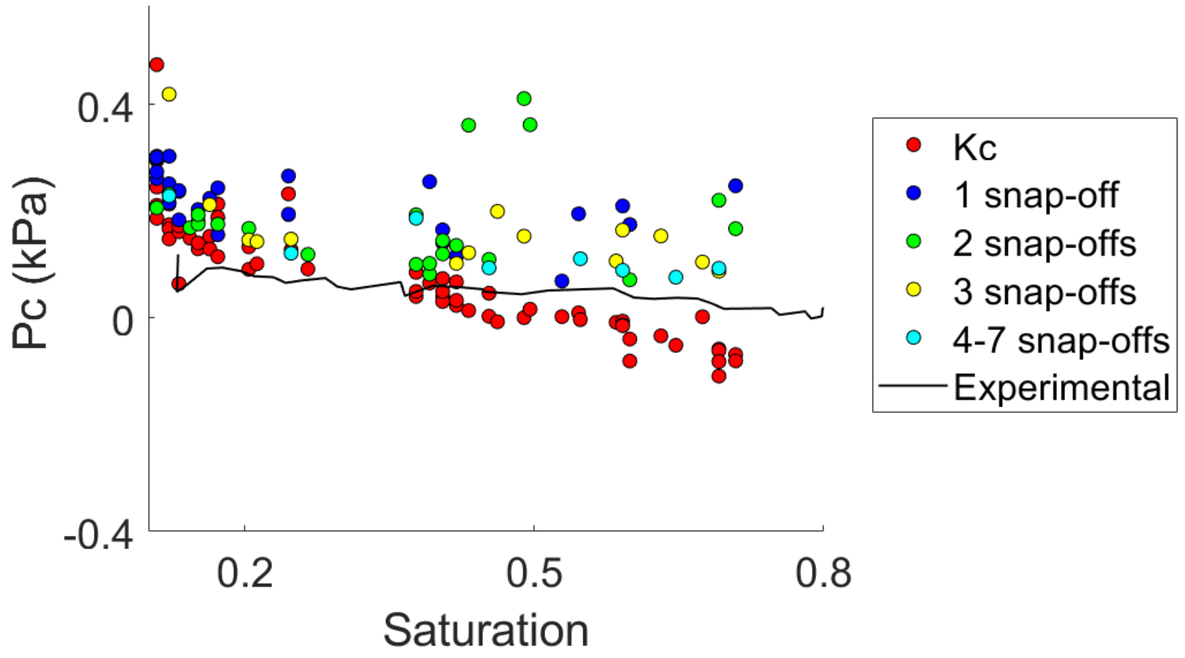
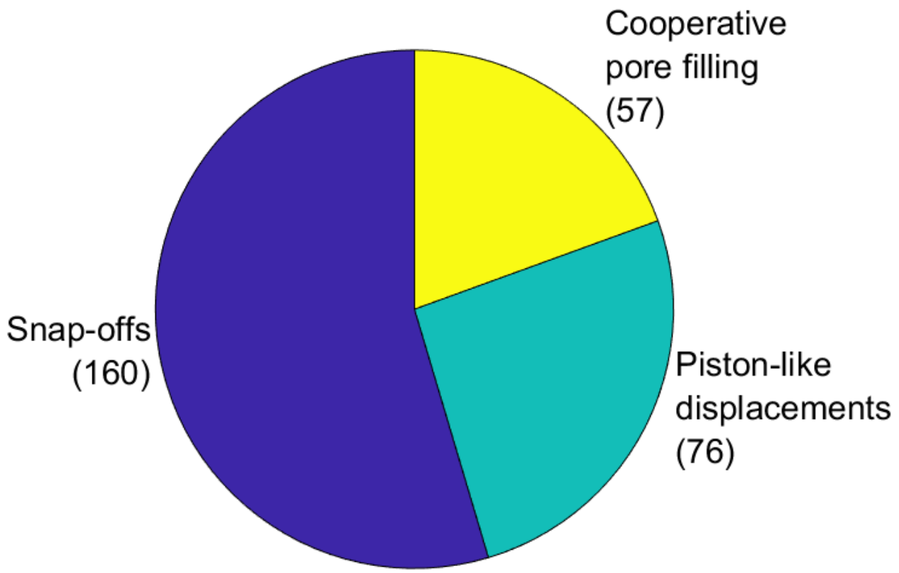
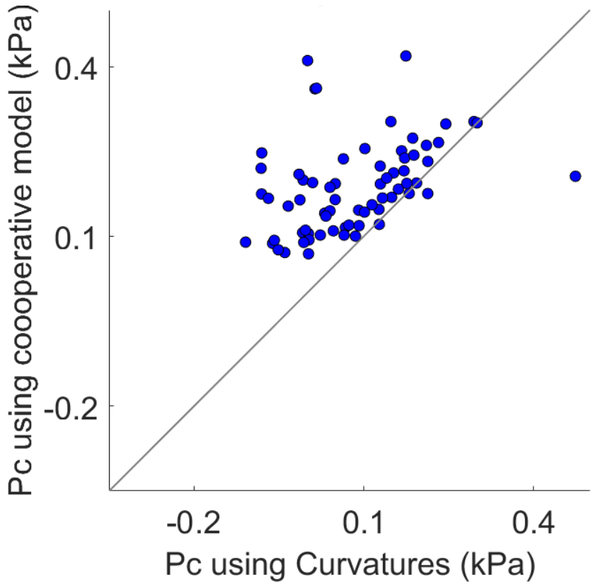
Cooperative pore fillings

– Recalculated after snap-offs







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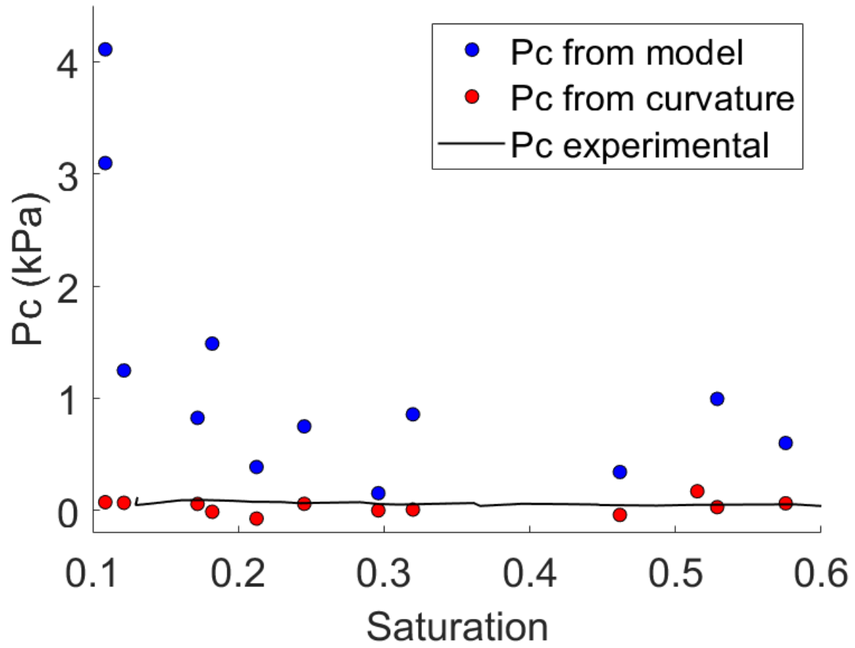
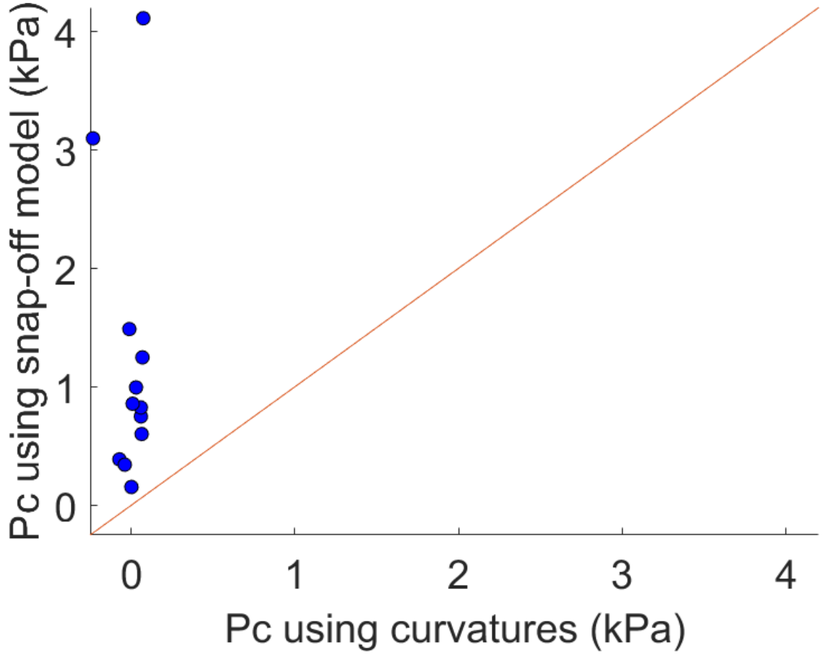
Snap-offs

- 13 identified by image analysis





- Causes of uncertainty:
  - Low temporal resolution
  - Lack of capillary equilibrium

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Conclusions and future outlook

- Workflow for validating imbibition models using local Pc
- Model predicted Pc values followed same trends as curvature-based values
- Causes of uncertainty:
  - Network extraction methods
  - Dynamic effects
  - Limited resolutions
- Improve pore network extraction methods & resolutions

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Thank you!

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