Multi-scale, image-based pore network models to simulate two-phase flow in heterogeneous rocks

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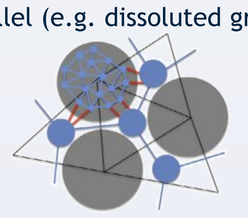
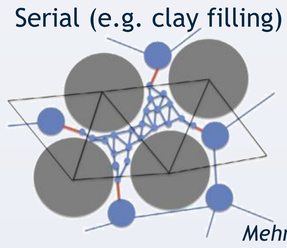
Problem

- **Rocks** with a wide range of pore length scales often do not adhere to classical transport relations (e.g. Archy's law, Brooks-Corey relationship).
- **Microporosity** influences their behaviour.
- **Coupling** of the microporosity and the macroporosity is crucial.
- Trying to capture this coupling in a model is **computationally difficult**.

Parallel (e.g. dissoluted grains)



Serial (e.g. clay filling)

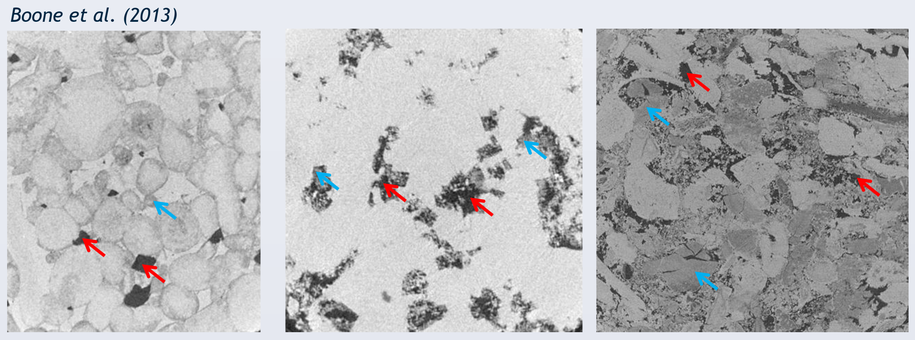


Mehmani & Prodanovic (2014)

Approach

1. Start from **micro-CT** scan:

Boone et al. (2013)



Macropores | Microporous regions

2. Perform **segmentation** into 3 phases:

Pore voxels | Microporous voxels | Solid voxels

3. Extract maximal ball **pore network model (PNM)** from pore space (Dong & Blunt, 2009)

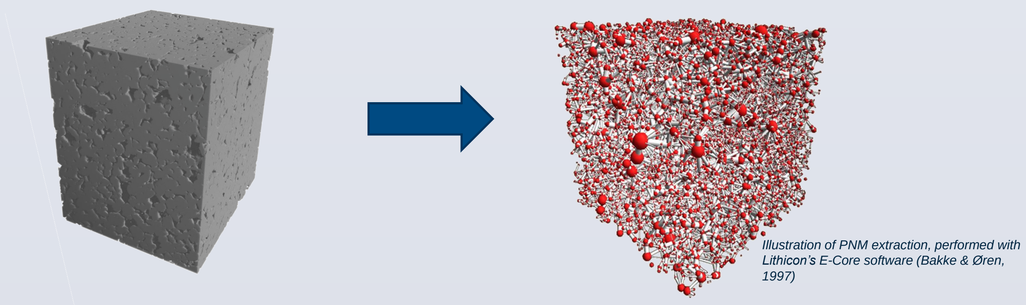
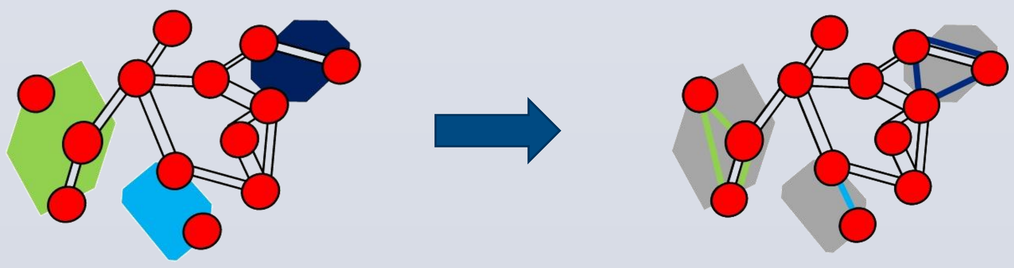


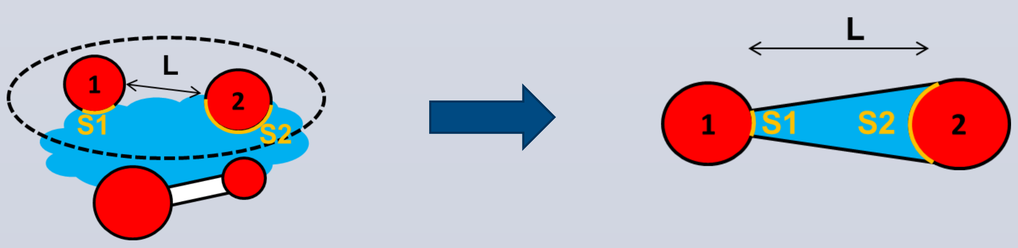
Illustration of PNM extraction, performed with Lithicon's E-Core software (Bakke & Øren, 1997)

4. Cluster microporous voxels into **connected regions** and add the **appropriate connectivity** between neighbouring macropores in the PNM



4. Treat the **microporosity** as a **continuous porous medium** and assign continuum properties to it (e.g. porosity, Pc-curve, relative permeabilities,…)

5. Approximate microporous pathways geometrically as **truncated cones** by measuring contact surface areas and lengths **locally on the micro-CT**



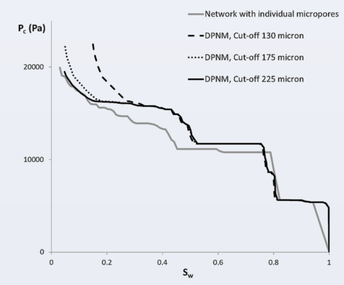
6. Compute **two-phase flow properties** of the **coupled** system (Pc-curve, K, Kr-curve, FF, RI-curve)
   - Solver is extension on Valvatne & Blunt (2004)
   - Also includes non-wetting phase percolation through microporosity

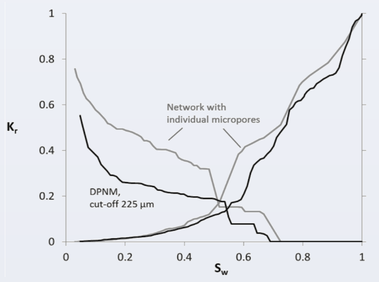
Results

1. Artificial network

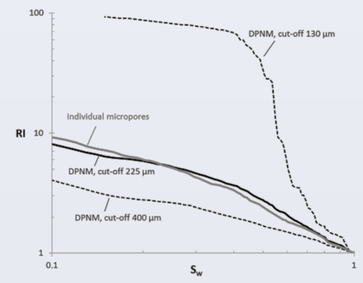
Can the model replicate the behaviour of a PNM where microporosity is taken into account as individual small pores, instead of as a continuous porous medium ?

- Mehmani & Prodanovic (2014): artificial network in which 50 % of **macropores were "clogged"** and replaced with microporosity
- Generate equivalent network with our method and compare results:



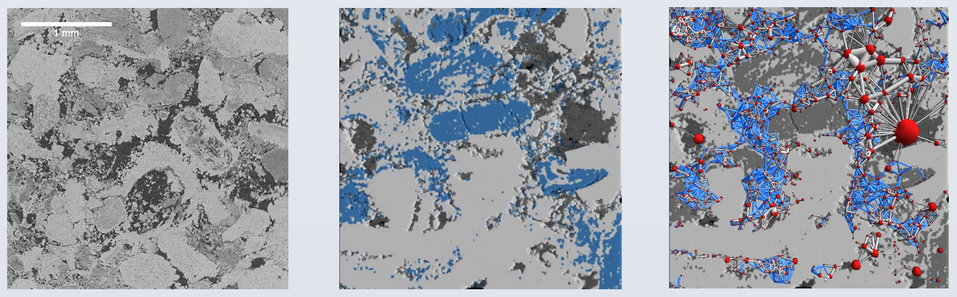


Network		*K (mD)*	*FF*	*Number of network elements*
DPNM, cut-off:	130 µm	238	103.6	9662
	225 µm	531	22.2	13307
	400 µm	1069	7.6	29004
PNM w/ individ. micropores		**245**	**49.0**	363749
Microporous parent PNM		553	6.5	

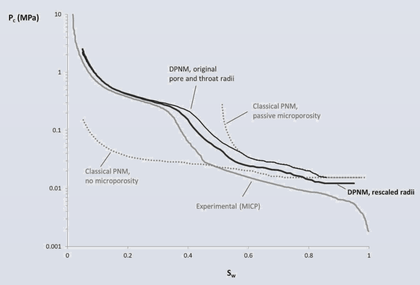


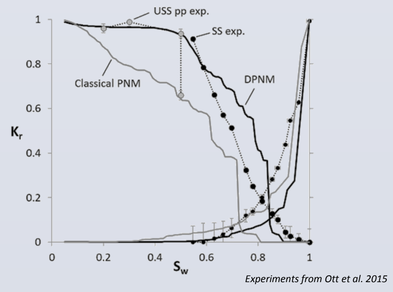
- Challenge: user-defined **cut-off length** for microporous connections needed, can this parameter be eliminated?

2. Micro-CT-based network of Estaillades limestone



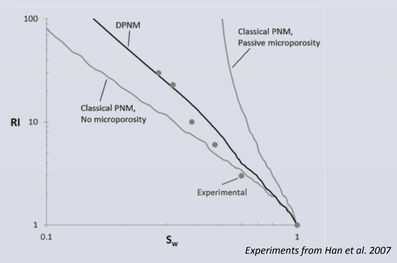
- Input parameters for microporosity from MIP experiment and literature
- Radii in the PNM were adjusted to fit MIP experiment / permeability





Experiments from Ott et al. 2015

Transport property	*ϕ (%)*	*K (mD)*	*FF*
Experimental[1]	25	273 ± 16	24 ± 0.24
Classical PNM, radii x 1.25	13.9	281	36.8
DPNM, cut-off length 67.5 µm	25.5	290	18.1



Experiments from Han et al. 2007

Conclusions

- Our image-based DPNM takes microporosity into account in drainage simulations, allows simulations where macroporosity does not percolate
- Theoretically, behaviour of a network with individual micropores can be replicated
- Multiphase flow behaviour of Estaillades can be replicated, but:
  - Microporosity input parameters are hard to assess
  - Remaining user-defined cut-off length parameter
  - Further development necessary for predictive modeling

More info: Bultreys et al. "*Multi-scale, micro-computed tomography-based pore network models to simulate drainage in heterogeneous rocks*", Adv Water Resour 2015;78:36–49.

Acknowledgments & references

M.J. Blunt, A.Q. Raeini, A. Mehmani, M. Prodanovic, G. De Schutter and IWT are greatly acknowledged!

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