Multiscale Pore-Network Model of Carbonate Reservoirs: Experimental Validation and Wettability Analysis

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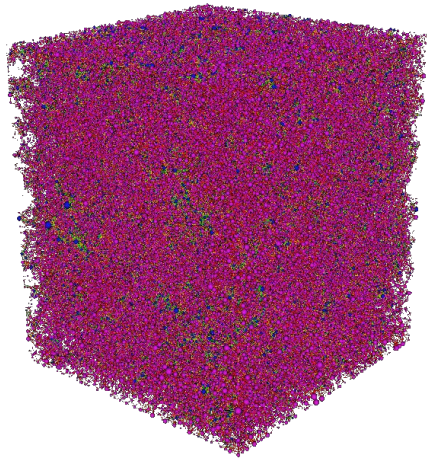
Context and Objectives

Context

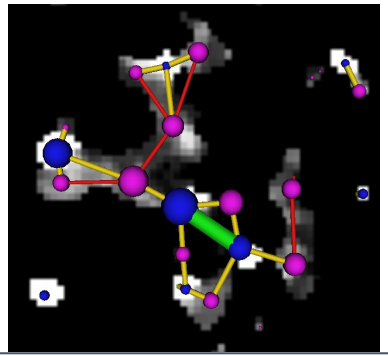
- Research and Development of the free, open-source Digital Rock Software Geoslicer, in partnership with Petrobras.

Objectives

- Run Two phase flow simulations on 20 carbonate rock Micro computer tomography samples using multiscale Pore Network Models.
- Evaluate the effects of contact angle and surface wettability on the relative permeability curve



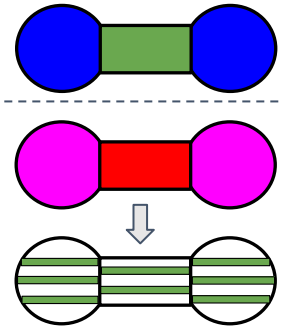
Overview of PNM method



Extracted from porosity map:

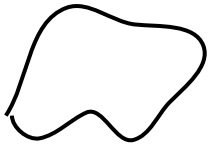
Resolved porosity
(100% voxel void)

Unresolved porosity
(< 100% voxel void)



Resolved porosity:
Simulated as per Valvatne model

Unresolved porosity:
Converted to a bundle of capillary tubes, which are then solved by the Valvatne model



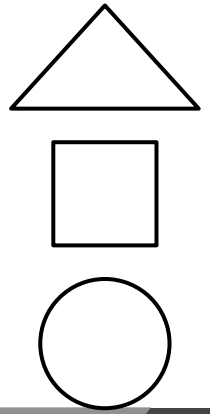
Porous transversal section (arbitrary form)

Shape factor:
$G = A/P^2$
In which:
A - Area
P - Perimeter

G <= sqrt(3)/36
Triangle (k=3/5)

sqrt(3)/36 < G < 0.07
Square (k=0.5623)

G >= 0.07
Circle (k = 1/2)



Valvatne, Per H., and Martin J. Blunt. "Predictive pore-scale modeling of two-phase flow in mixed wet media." Water Resources Research 40, no. 7 (2004).

Challenges

Scientific Challenges

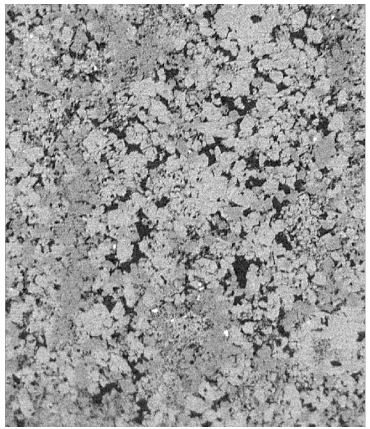
- Image preprocessing, segmentation, pore separation and porosity calculation
- Subresolution porosity capillary geometry definition
- Determination of contact angles of pores and throats for the simulation

Technological Challenges

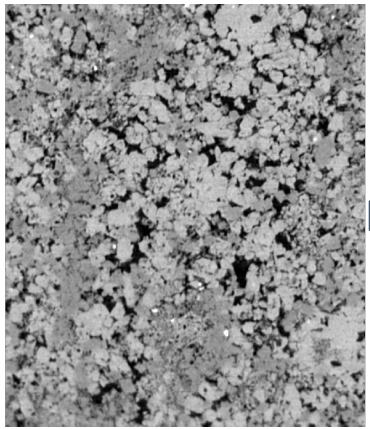
- Computational cost of extraction and sensitivity simulation

Image processing

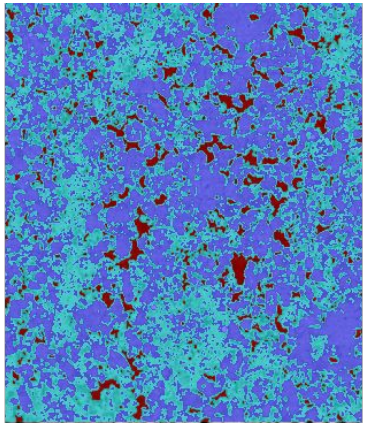
Original image



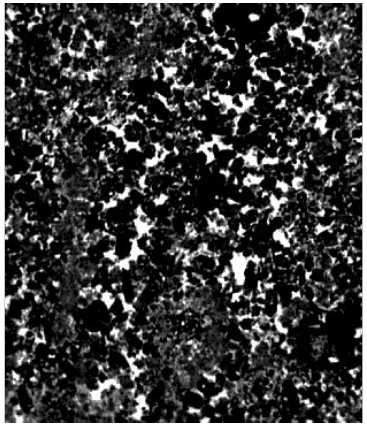
Gradient Anisotropic Diffusion



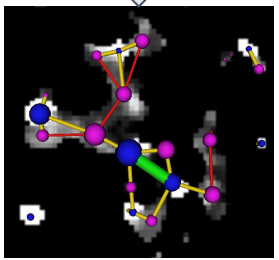
Phase segmentation



Porosity map calculation

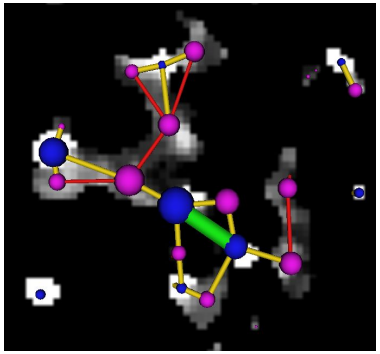


Network extraction



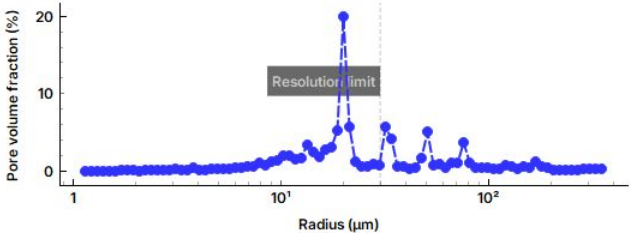
The process from x-ray attenuation image to porosity map is critical, since there are subjective parameters that directly impact the extracted network

Subscale porosity models

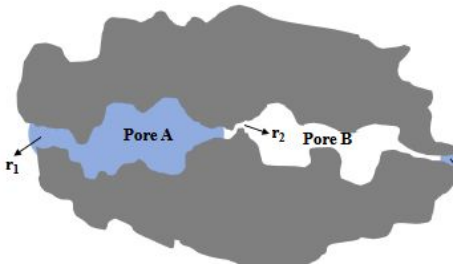


Resolved porosity: Properties extracted from measuring of the image

Unresolved porosity: Radii must be evaluated from other sources, such as MICP and higher resolution images



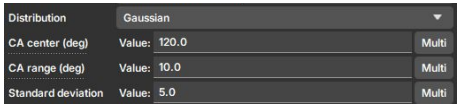
Mercury Injection Capillary Pressure is a readily available method, however the data is subject to ink-bottle effect



Gu, Z.; Wang, S.; Guo, P.; Zhao, W. Utilizing Differences in Mercury Injection Capillary Pressure and Nuclear Magnetic Resonance Pore Size Distributions for Enhanced Rock Quality Evaluation: A Winland-Style Approach with Physical Meaning. *Appl. Sci.* **2024**, *14*, 1881. https://doi.org/10.3390/app14051881

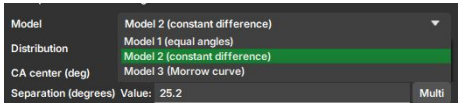
Contact angle simulation assigning

1)

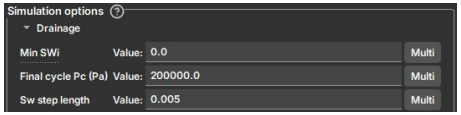


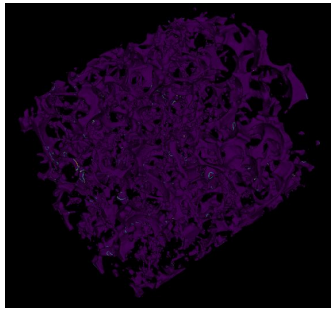
2)

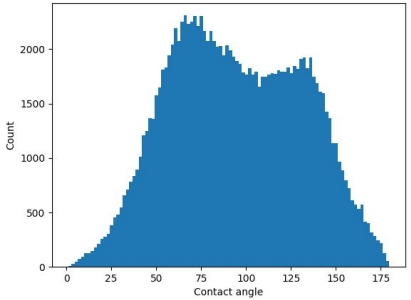
3)



4)







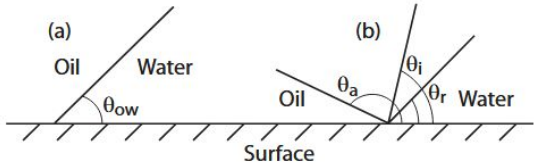


Image Source: H. Valvatne, "Predictive Pore-Scale Modelling of Multiphase Flow", PhD thesis, November (2003)

1 and 2 - Is the rock water-wet or oil-wet? How strongly? Does it have one or two distributions? Do the contact angle correlate with some property of pore radius or surface material or roughness? Does microporosity have the same wettability as resolved porosity?

3 - How does advancing and receding angles relate to intrinsic angles?

4 - How far and how dynamic should the simulation be?

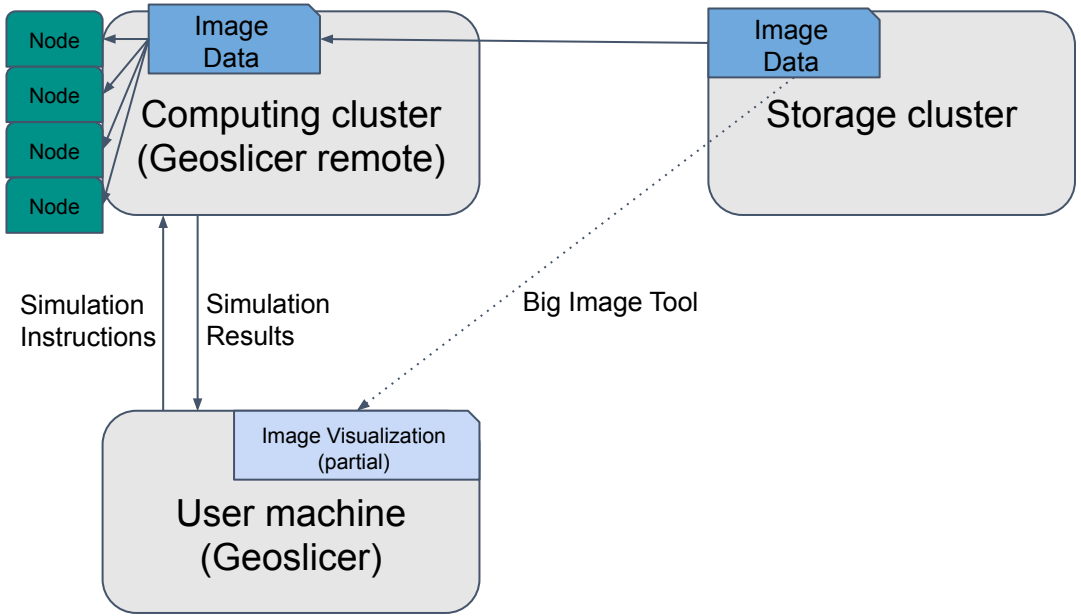
We can simulate all this, but what are the “right” parameters?

Solution: Sensitivity analysis.

Technical Challenges

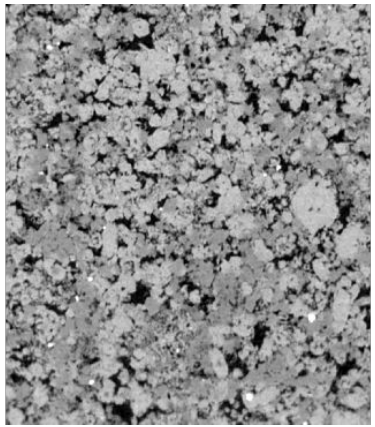
Optimization, parallelization and GPU implementation of algorithms for euclidean distance transform (PyEdt) and improvement of PMEAL network extraction in Porespy

HPC Environment

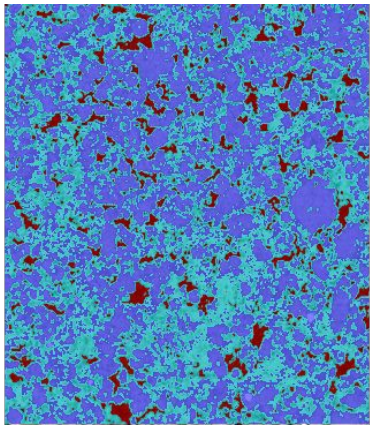


Experimental Results

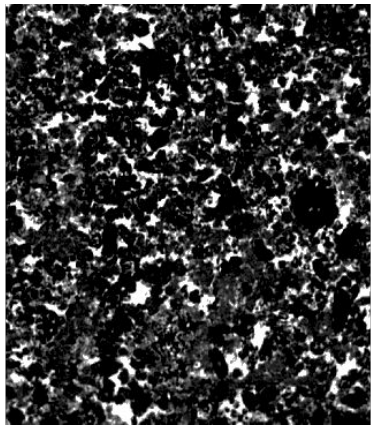
Calibration process and Sample group



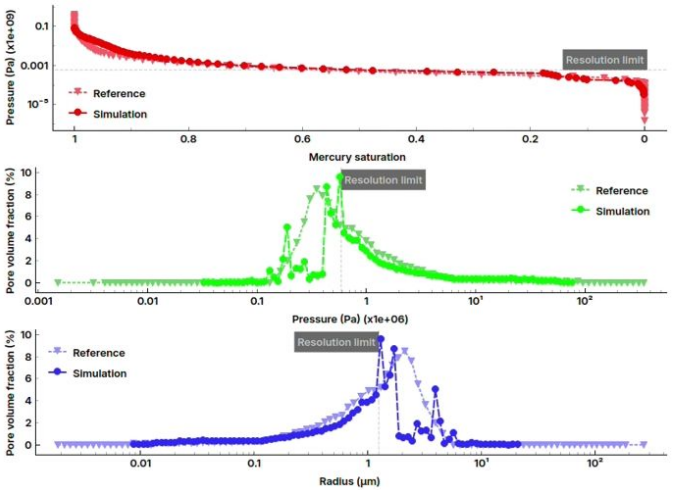
MicroCT



Segmentation



Porosity Map

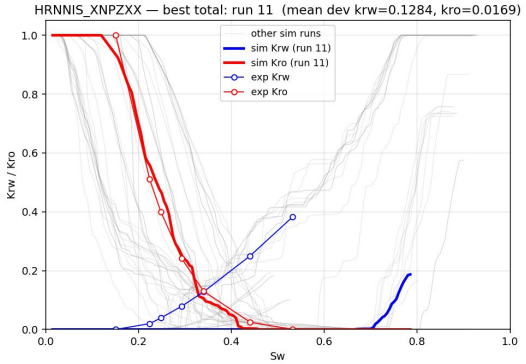


The samples group contained 20 carbonate rock images. Six of those samples were manually evaluated, with segmentation, porosity map and watershed parameters being modified until micp simulation, porosity and absolute permeability were well adjusted. Those parameters were then used to run the automated sequence on all samples.

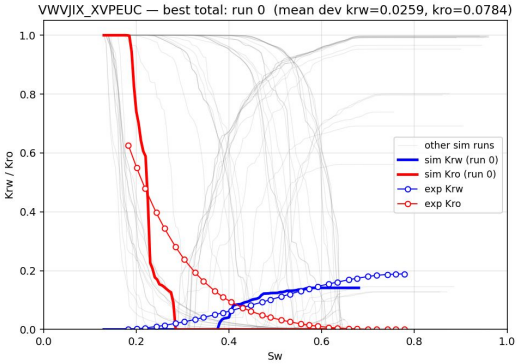
Of the 20 samples, 2 didn't have all the required experimental results, and another 2 had the simulation process corrupted, ending in 16 valid samples.

	Porosity (%)	Permeability (mD)
Experimental	19.8	18.9
Simulation	19.72	10.8 (z) 8.2 (y) 8.8 (x)

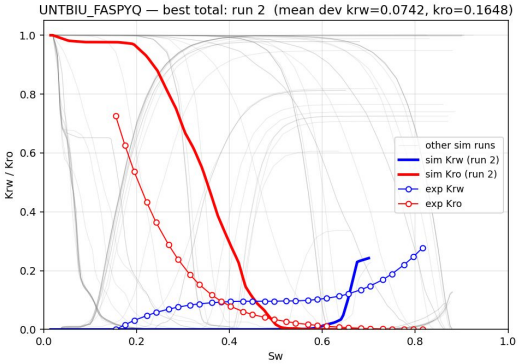
Sensitivity Test Result



Kro curve fits very well (dev = 0.0169), Krw doesn't (dev = 0.1284)

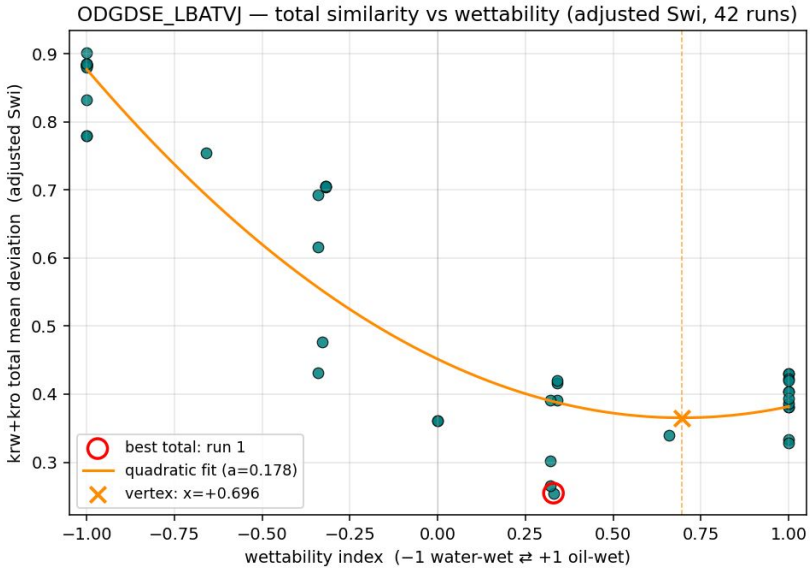


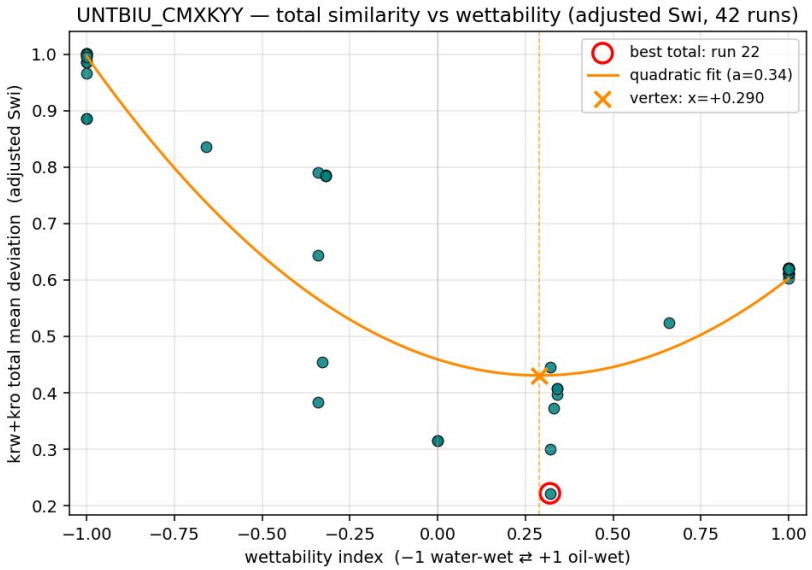
Krw curve has some similarity (dev = 0.0259), Kro is very different (dev = 0.104)



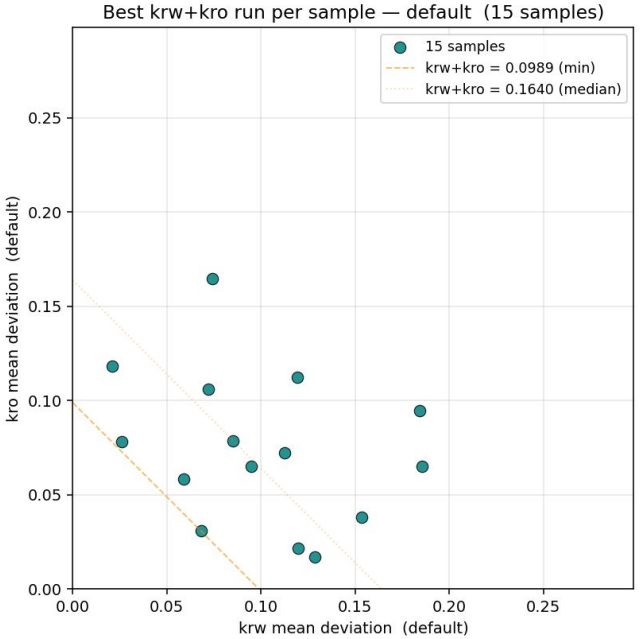
Neither curve fits well, Kro dev = 0.2838, Krw dev = 0.073

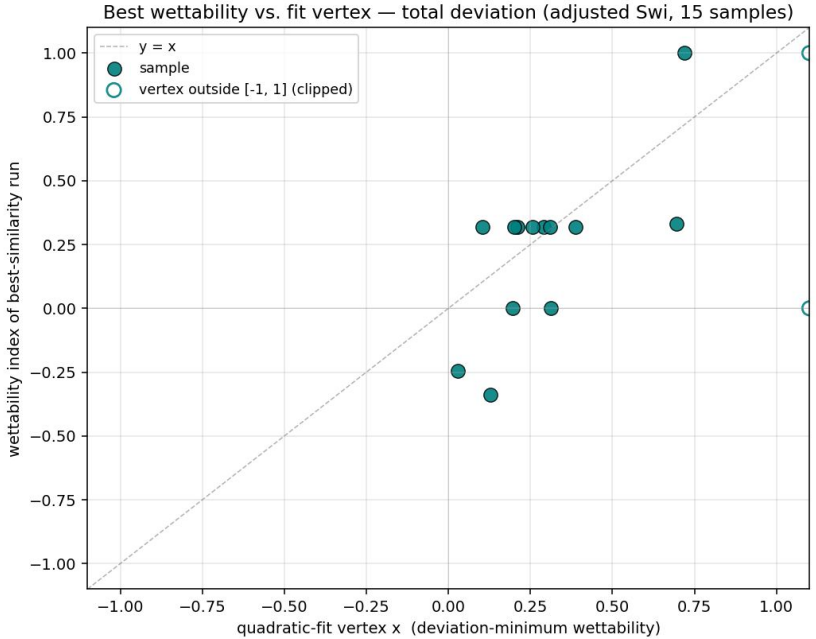
Curve similarity and Wettability Index





Curve fitting analysis





Conclusion and next steps

Conclusion:

- Technical improvements allow remote processing of large multiscale images.
- It is possible to correlate the krel simulations with wettability parameters.

Next steps:

- Define accurate contact angle assignment from the sample wettability
- Improve Krw simulation
- Further analysis of the imbibition process to adjust the initial imbibition point

Thank you!

Contact email: rafael.arenhart@ltrace.com.br

github.com/petrobras/GeoSlicer

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