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Multiphase Flow in Carbonate Porous Media

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General Abstract

What would it be like if you were to walk inside the porous media in a carbonate rock sample ?...

Although we have not grown this tiny, we visualize it as being represented by pore bodies and connections between them called pore throats. We can materialize this idea through a network composed of nodes (pores bodies) and bonds (pore throats) with appropriate characteristics that allow us to perform flow calculations.

Abstract

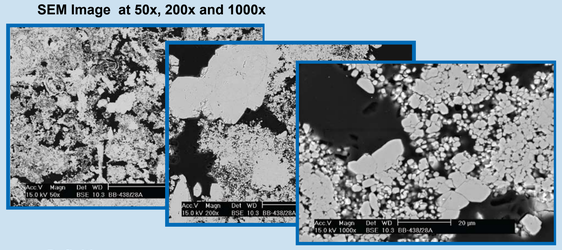
Porous-media characteristics (grain sizes and shapes, their packing and cementation) are closely related to the rock texture. High resolution 2D SEM images are able to capture the textural characteristics at different scales of magnification. We have observed that for SEM images of the same rock section the porosity function changes with increasing magnification, indicating different textual behaviour due to additional micro-porosity becoming visible. Based on studying the image magnification basic concept and applying them to a synthetic rock image we propose a method of identifying Macro- and micro-porosity. The approach is to define a Macro-Porosity at the largest scale and, similarly a micro-porosity at further smaller scales. First, a binarization threshold analysis is carried out allowing us to identify the Macro- and micro-porosity on the SEM images. We use this information to derive spatial correlation statistics for reconstructing a 3D digital rock sample.This is followed by a network extraction from the 3D digital rock samples to calculate petrophysical rock functions. We compare the simulated results (Pc function) against mercury injection capillary pressure measurements to validate the model. We take the network model from there to predict two phase relative permebilities (Krw and Kro functions).

Motivation

Carbonate rocks present a complex porous structure in which the study of the flow at the pore scale is essential to understanding the poor oil recoveries at the large scale of an oil field.

1 - Multiscale Thresholding Behaviour

SEM Image at 50x, 200x and 1000x

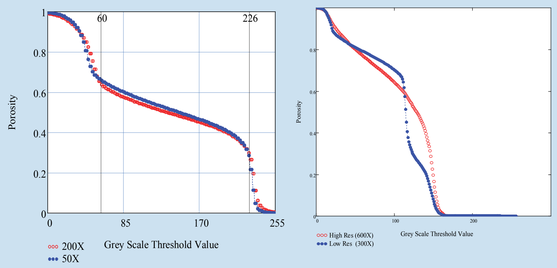


Definitions

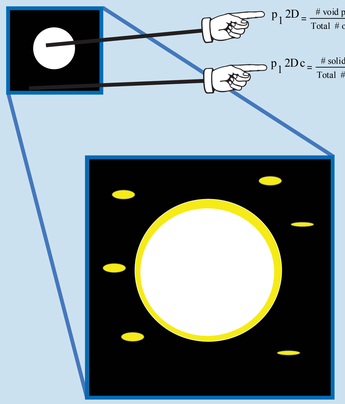
$$\text{solid} < \text{grey scale threshold} \leq \text{void}$$

$$\text{Porosity (threshold)} = \frac{\#\text{ pixels} \geq \text{grey scale threshold}}{\text{Total \# of Pixels}}$$

2D Image Porosity function.



2 - Fundamental Approach (The most simplified Porous Media)



$p_1\,2D = \frac{\#\text{ void pixels}}{\text{Total \# of Pixels}}$ Macro-Porosity in 2D

$p_1\,2Dc = \frac{\#\text{ solid pixels}}{\text{Total \# of Pixels}}$

$p_2\,2D^*$ } Yellow and white

$p_2\,2D^*c$ } Black

$p_2\,2D^* = [p_2\,2D + (p_1\,2D \wedge p_2\,2DM)]$ E1

$p_2\,2D^* = [p_2\,2D + (p_1\,2D)]$ E2

$p_2\,2D^* = [p_2\,2D + (p_1\,2D)]$ E3

$p_2\,2D = p_2\,2D^* - p_1\,2D$ E4 (2D micro-Porosity)

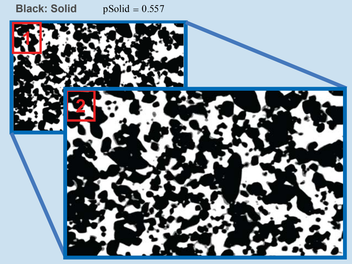
3 - Synthetic Rock Sample (Fundamental Approach Validation)

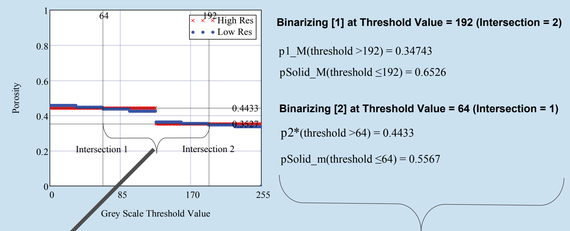
Starting Values

White : Macro Pore $p1 = 0.353$

Grey : Micro Pore $p2 = 0.091$

Black: Solid $pSolid = 0.557$





Binarizing [1] at Threshold Value = 192 (Intersection = 2)

$p1\_M(\text{threshold} > 192) = 0.34743$

$pSolid\_M(\text{threshold} \leq 192) = 0.6526$

Binarizing [2] at Threshold Value = 64 (Intersection = 1)

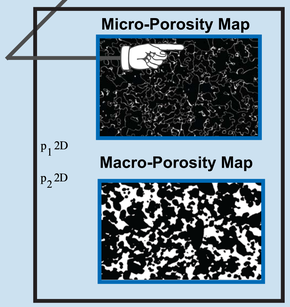
$p2^*(\text{threshold} > 64) = 0.4433$

$pSolid\_m(\text{threshold} \leq 64) = 0.5567$

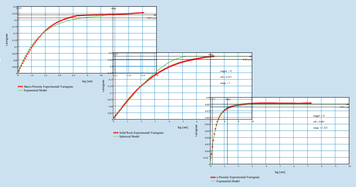
Using E4 $p_2\,2D = p_2\,2D^* - p_1\,2D$

$p2^* - p1\_M = 0.096$

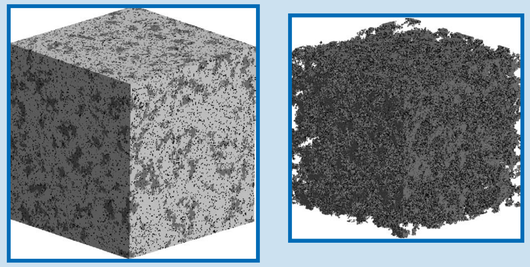
Matching the starting values



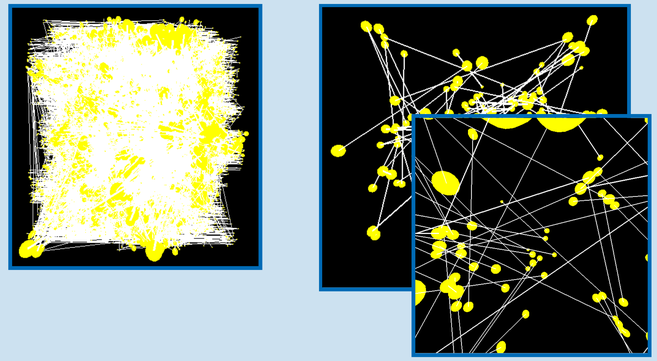
Derive Porous Space Statistics Input for 3D reconstruction



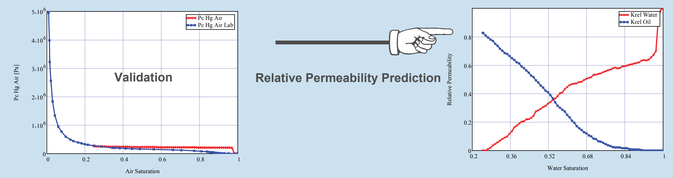
4 - Reconstruction of the Porous Structure



5 - Extracted network capturing the topology of the reconstructed porous structure.



6 - Transport Properties (Capillary Pressure and Relative Permeability)



7 - Conclusions

The thresholding analysis appears to demostrostrate a promising methodology to characterize systematically the Macro and micro-porosity in carbonate rocks.

8 - Ongoing Work

Validation of the approach in carbonate reservoir dataset.

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