Microporosity analysis from petrographic thin-sections and elastic modulus estimative through DEM model in outcrop carbonate rocks

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Abstract

Carbonate reservoirs present a complex pore system characterized by their heterogeneity. It affects directly the rock's elastic properties. The external pressure's variation may cause pore volume reductions and affect the propagation velocity of elastics waves in sedimentary rocks. Thus, this paper aims to study the velocity variation of compressional and shear waves and the porosity in carbonate rock samples. By the data analysis from a number of samples, it intends to empirical models (Differential effective medium model – DEM) that relate variations in elastic velocity with changes in porosity.

Introduction

Carbonate rocks are important hydrocarbon reserves with complex textures and petrophysical properties (porosity and permeability) resulting mainly from diagenetic processes. It is estimated that such rocks make up more than 60% of the world's oil reserves. Therefore, the knowledge of these rocks as mechanical properties becomes fundamental criteria for operation performances related to the petroleum industry (Assefa et al., 2011). The rocks properties change when undergo external confinement pressure. In general, acoustic velocities tend to increase and porosity tends to decrease. Therefore, confining pressure is an important parameter to be considered in the mechanical properties of rocks study. Rock characterization presents relevant information to describe the reservoir behavior forecast and allow us to simulate production scenarios, contributing to mitigate production problems (LIMA NETO et al., 2011).

This paper aims to estimate the elastic modulus through inclusion models, such as Differential effective medium model (DEM), and geometrical properties of the pore space of the carbonate samples from petrographic thin-section analysis where it is possible to estimate the pore aspect ratio and other parameters.

Method and Theory

Thin-section Analysis

In order to determine the pore aspect ratio of samples, it is necessary to perform a petrographic analysis through thin-section with an optical microscope aid. This technique also allows the rock porosity estimation and it is made from a thin-section in the sample that is impregnated with a resin of coloration normally in blue (Figueiredo et. al, 2014; Richa et. al., 2006).

Figure 1 shows the thin-sections analyzed for the samples AC-001, DP-001, EY-002, SD-002, ILS-001 and EW-002 (left to right, respectively).

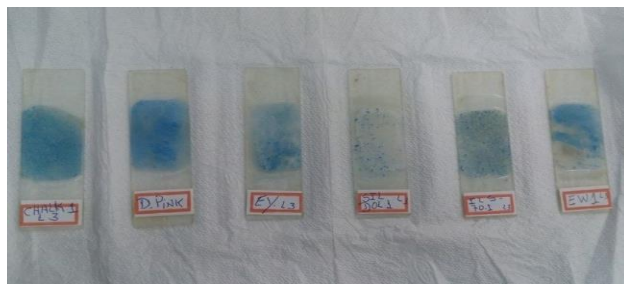

Figure 1: *Thin-sections of carbonate samples*.

Using an optical microscope of polarized light and a coupled camera, it was possible to capture the images for analysis.

Figure 2: *Microscope with coupled camera used to capture digital images.*

The softwares used for image analysis were IrfanView and ImageJ in Fiji version (figure 3). IrfanView was used to change 32-bits palette images in 8-bits through jPor plugin (highlighted in red in figure 3). ImageJ (version Fiji) was used to digital image analysis.

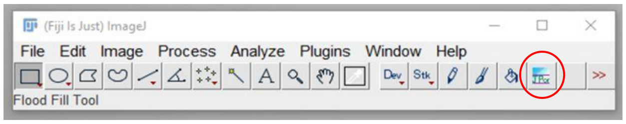

Figure 3: *ImageJ software screenshot and jPOR plugin.*

In threshold step (figure 4-6), the blue colored pores are identified and automatically highlighted in red, which makes possible to estimate the porosity and the geometrical characteristics, as the pore aspect ratio of each sample.

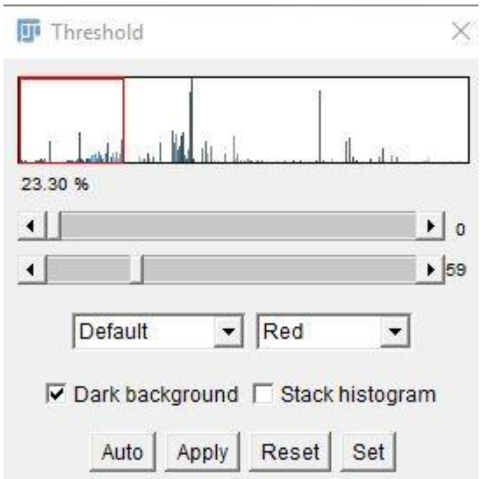

Figure 4: *Threshold (ImageJ).*

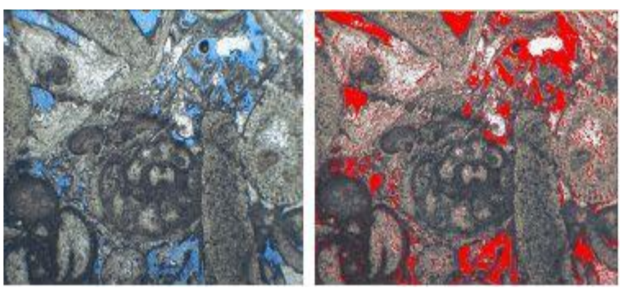

Figure 5: *Porosity in blue color of the sample ILS-001.*

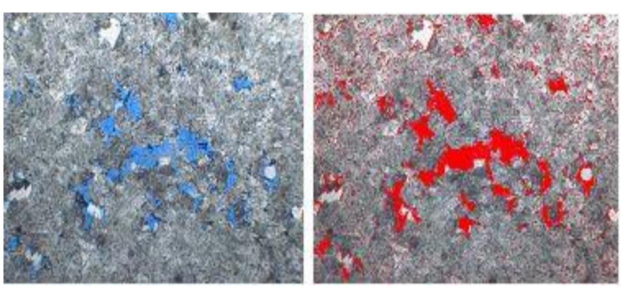

Figure 6: *Porosity in blue color of sample SD-001.*

Binarization (figure 7) consists of segmenting an image into regions of pores and matrix. The geometric parameters quantification (such as the rock's pore sizes distribution) will depend on the correct definition of these regions. Such regions are represented by black (pores) and white (matrix) pixels.

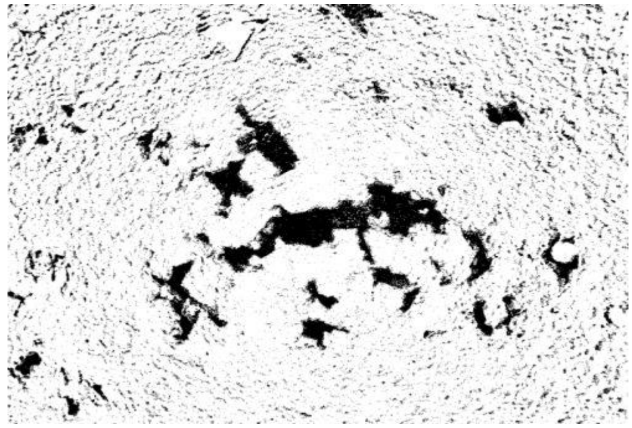

Figure 7: *Binarization of sample SD-001.*

Therefore, figure 8 shows the sequence used for this image analysis methodology.

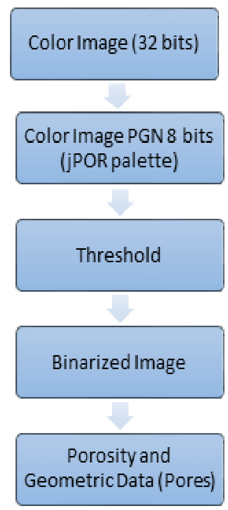

Figure 8: *Sequence of the digital images analysis methodology.*

Microporosity was predicted by applying the Equation 1:

$$\phi_{micro} = \phi_{gas} - \phi_{image} \qquad (1)$$

Helium-gas porosity is measured in laboratory by represents the bulk porosity of sample. Image porosity is achieved through digital image analysis method, representing only macro-mesopores. The difference between these parameters provides microporosity.

Differential effective medium model

DEM (differential effective medium) is a model that assumes isolated pores embedded in a host material that remains continuous at all porosities. The DEM consider and simulates the porosities in a composite medium of two phases by incrementally adding small amounts of pores (phase 2) into a matrix (phase 1) until the total porosity (ϕ) is attained (Berryman, 1992):

$$(1-y)\frac{d}{dy}[K^*(y)] = (K_2 - K^*)P^{(*2)}(y) \quad (2)$$

$$(1-y)\frac{d}{dy}[\mu^*(y)] = (\mu_2 - \mu^*)Q^{(*2)}(y) \quad (3)$$

with initial conditions $K^*(0) = K_1$ and $\mu^*(0) = \mu_1$, where K_1 and μ_1 are the bulk and shear moduli of the intial host material (phase 1), K_2 and μ_2 are the bulk and shear moduli of the incrementally added inclusions (phase 2), and y is the concentration of phase 2. For fluid inclusions and voids, y equals the porosity. The terms P and Q are geometric factors given by Berryman (1980) andMavko et al. (2009).

Estimation of the microporosity aspect ratio

The goal of this study is to determine the most reliable aspect ratio for microporosity that, combined with macro-mesopores, allows the carbonate rocks complex pore system characterization, by using elastic properties and petrophysical measurements.

This methodology follows that established by Lima Neto et al. (2014) to forecast the microporosity inclusion aspect ratio and characterize pore geometry parameters and complexities related to the elastic properties of carbonates.

Results

The samples to be used in this paper are carbonates from outcrops of different regions of the United States.

Table 1 provides the density and the bulk and shear moduli of the samples.

Table 1: *Petrophysical properties of the samples*.

Samples	Density (g/cc)	Bulk Density (g/cc)	K (GPa)	K_{ma} (GPa)	K_{min} (GPa)	G (GPa)	G_{ma} (GPa)	G_{min} (GPa)
AC-001	2,707	2,001	12,792	70,29	76,59	8,382	30,19	31,92
DP-001	2,709	1,983	15,773	70,56	76,70	10,026	30,34	32,02
EY-002	2,711	2,067	22,424	70,79	76,82	9,638	30,36	32,02
EW-002	2,710	2,400	31,615	70,65	76,73	17,153	30,33	32,00
IL3-001	2,715	2,297	24,928	70,68	76,63	14,746	30,35	32,08
SD-002	2,870	2,403	37,320	80,23	94,90	23,049	48,77	45,00

Table 2 lists the helium gas porosity results of the samples.

Table 2: *Helium gas porosity results.*

Samples	Gas Porosity (%)	Image Porosity (%)
AC-001	26,11	18,67
DP-001	26,83	23,97
EY-002	23,29	19,92
EW-002	11,45	10,03
IL3-001	15,40	14,37
SD-002	16,28	13,06

With the data set from petrographic thin-sections study, it was possible to know some details regarding the samples' aspect ratios.

Figures 9 and 10 show a mean (average) and median macro-mesopore aspect ratio of samples SD-002 and ILS-001, respectively.

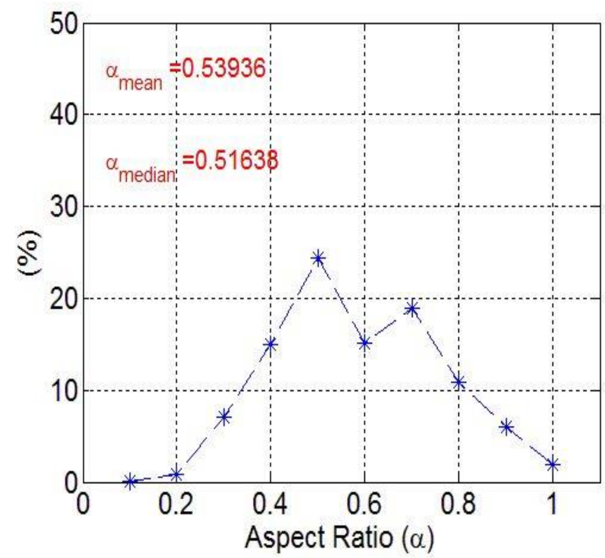

Figure 9: *Mean (average) and median macro-mesopore aspect ratio for of sample SD-002.*

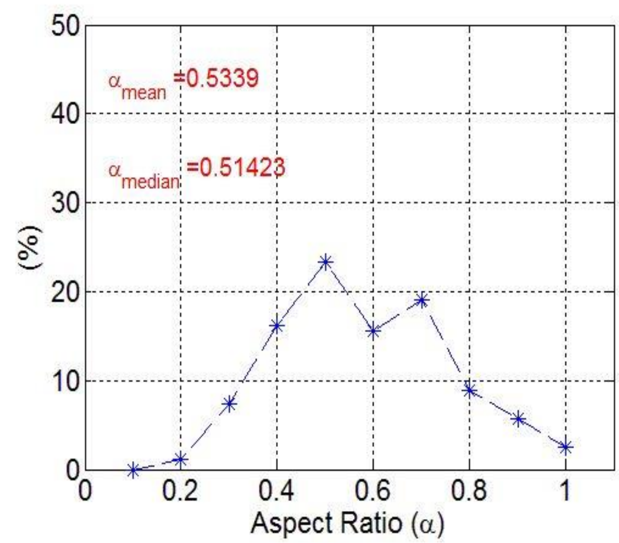

Figure 10: *Mean (average) and median macro-mesopore aspect ratio for of sample ILS-001.*

Figures 11 and 12 illustrate the relationship between aspect ratio, cumulative porosity and pore size diameter, where the darke blue color tones indicate a smaller porosity accumulation. These still shows the relationship of the pore size diameter with gamma (γ).

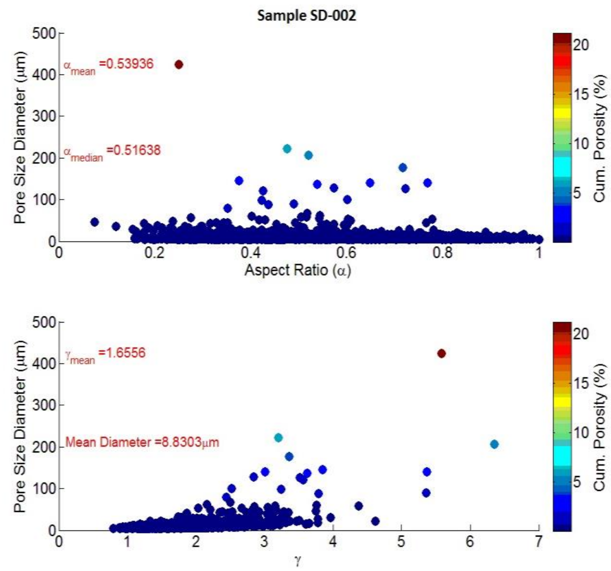

***Figure 11:** Relationship between aspect ratio, cumulative porosity, pore size diameter and gamma (γ) of sample SD-002.*

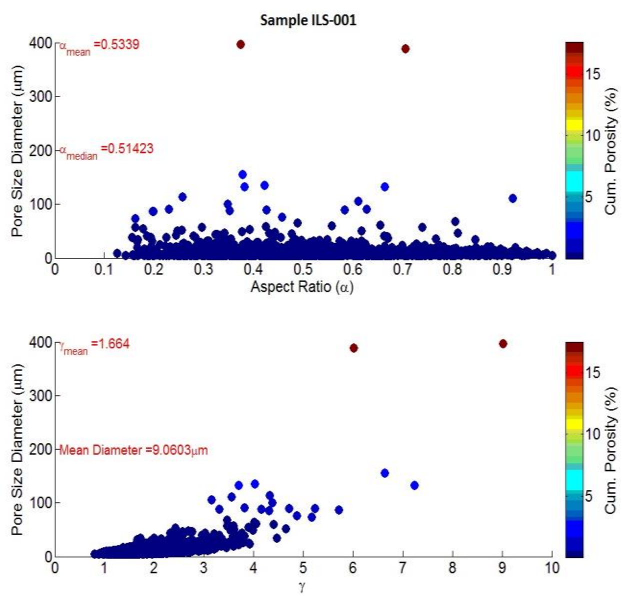

***Figure 12:** Relationship between aspect ratio, cumulative porosity, pore size diameter and gamma (γ) of sample ILS-001.*

With macro-mesopore aspect ratio data, microporosity aspect ratio was estimated through a DEM model, also obtaining compressional wave velocity Vp_{dem} and shear wave velocity Vs_{dem}.

The main goal of this study is to preview microporosity parameters using velocity-porosity relation, image analysis and DEM model. These parameters are microporosity aspect ratio and complex pore geometries characterization with elastic properties of the carbonates.

Figures 13 and 14 show crossplots between $Vp_{measured}$ versus Vp_{dem}, and $Vs_{measured}$ versus Vs_{dem}, respectively, exhibiting their adjustment coefficient (R). Where R is calculated by equation 4.

$$R = \frac{1 - |Vmeasured - Vdem|}{Vmeasured} \qquad (4)$$

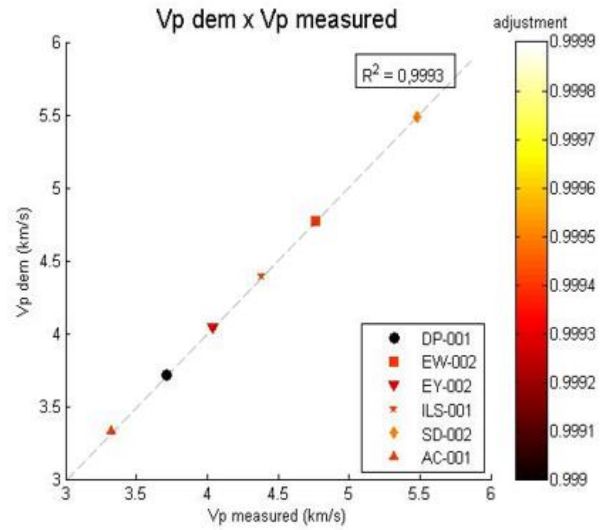

***Figure 13:** Crossplot between P-wave velocity determined from acoustic measurements and estimated using DEM. A Reference line is also plotted indicating where both results where expect to coincide.*

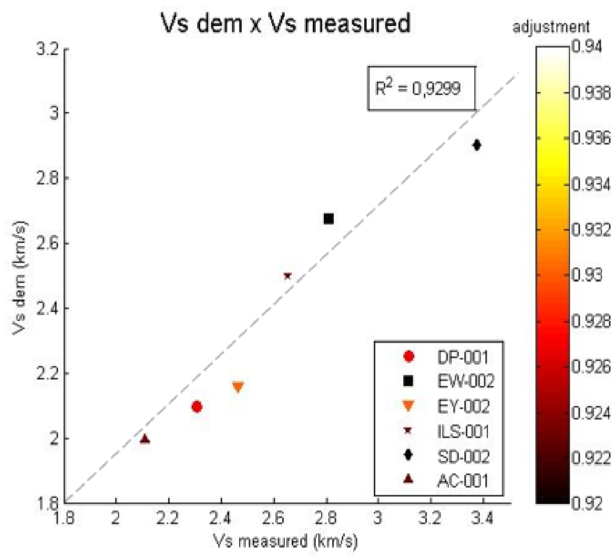

***Figure 14:** Crossplot between S-wave velocity determined from acoustic measurements and estimated using DEM.*

Figure 15 provides microporosity aspect ratio from image analysis parameters, velocity and porosity data.

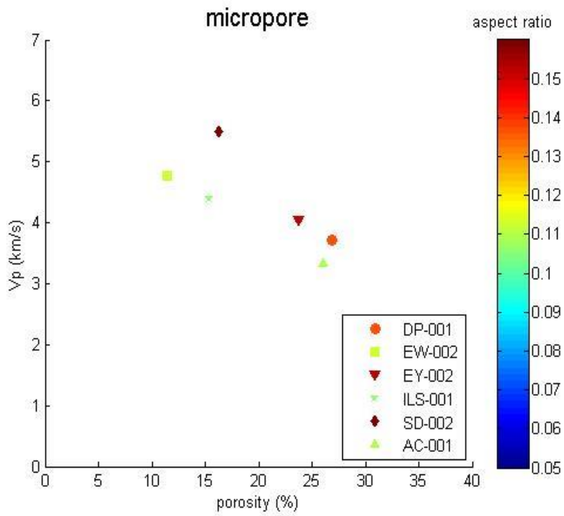

Figure 15: *Microporosity aspect ratio.*

The results show that macro-mesopore inclusion contributes for stiffer rocks and high velocity waves. Microporosity inclusion contributes for softer rocks and low velocity waves.

Conclusions

Velocity and porosity data considered were measured in laboratorial analysis. Through the analysis of optical microscopic digital images obtained from petrographic thin-sections, it was possible to estimate the macro-mesoporo aspect ratio, image porosity, and other parameters, as gamma (γ), pore size diameter and cumulative porosity.

Applying DEM model to these data, was estimated microporosity aspect ratio inclusion, and also velocities Vp_{dem} and Vs_{dem}.

Microporosity was obtained from the difference between thelium-gas porosity and image porosity, making possible to calculate microporosity aspect ratio inclusion.

Finally, velocities obtained from the DEM model and from the acoustic measurements were compared, showing a good adjustment.

Acknowledgments

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