9º CONGRESSO BRASILEIRO DE PESQUISA E DESENVOLVIMENTO EM PETRÓLEO E GÁS

TÍTULO DO TRABALHO:

ANALYSIS OF PETROPHYSIC CHARACTERIZATION OF CARBONATE ROCKS BY X-RAY MICROTOMOGRAPHY

AUTORES:

Carolina Pessanha Gonçalves; Roseane Marchezi Misságia (D.Sc.); Marco Antônio Rodrigues de Ceia (D.Sc.); Irineu A. Lima Neto (D.Sc)

INSTITUIÇÃO:

Modelagem Integrada de Reservatório – Laboratório de Engenharia e Exploração de Petróleo – Universidade Estadual do Norte Fluminense Darcy Ribeiro

ANALYSIS OF PETROPHYSIC CHARACTERIZATION OF CARBONATE ROCKS BY X-RAY MICROTOMOGRAPHY

Abstract

Carbonate reservoirs have been largely researched worldwide, since they hold a significant proportion of the world's oil reserves. Carbonates can exhibit highly varying properties within small sections of the reservoir, which poses significant challenges to data acquisition, petrophysical evaluation and reservoir description. In order to better characterize the reservoir, a detailed understanding of the fluids saturation, pore-size distribution, permeability, rock texture, reservoir rock type, and natural fracture systems at different scales is necessary. The analysis of 3D images obtained by X-ray microtomography can be applied to differentiate the pore space from a matrix material and quantify pore structure properties, allowing the application of statistic models for physical properties behavioral prediction. This study aims to expand the knowledge on digital image analysis using X-ray microtomographic scans of carbonate rocks, establishing the acquisition and processing workflow that will achieve better results. The set of samples selected to be scanned by microCT comprises of 13 Albian carbonates from Campos Basin. The data acquisition was performed at the Brazilian Synchrotron Light Laboratory, Campinas, SP. The processing step included reconstruction and segmentation of the data volume. With the segmented volume in hands, the next step was to compute and quantify the porous space of the samples, using the PoreShape GeoLab routines of the software Geodict 2015. The pore properties computed were: total pore area, dominant size, gamma, porosity, aspect ratio, among others. This data will be analyzed and compared with the results published by ARCHILHA et al. (2016), in order to infer if different resolutions and processing techniques cause significant differences in the results of microCT scanning.

Introduction

A significant proportion of the world's oil reserves are found in carbonate reservoirs. It is estimated that more than 60% of the world's oil and 40% of the world's gas reserves are held in carbonate rocks. The Middle East, for example, is dominated by carbonate fields, with around 70% of oil and 90% of gas reserves held within these reservoirs. In Brazil, reserves contained in carbonate reservoirs are increasing in importance, especially due to discoveries in the Pre and Post-salt provinces (SPADINI, 2008; SHEPHERD, 2009; BURCHETTE, 2012).

Carbonates can exhibit highly varying properties (e.g., porosity, permeability, flow mechanisms) within small sections of the reservoir, making them difficult to characterize. The primary pore system includes interparticle porosity that co-exists with a highly variable secondary system of dissolution voids and fractures. As a result, carbonate reservoirs are heterogeneous from pore to reservoir scales and this variability poses significant challenges to data acquisition, petrophysical evaluation and reservoir description. In order to better characterize the reservoir, a detailed understanding of the fluids saturation, pore-size distribution, permeability, rock texture, reservoir rock type, and natural fracture systems at different scales is necessary (ANSELMETTI et al., 1998; EBERLI et al., 2003; BUST et al., 2009).

The Digital Image Analysis (DIA) method has been greatly applied to evaluate mineral content and pore systems, and can be used to differentiate the pore space from a matrix material and quantify pore structure properties, such as size, shape, grain distribution, cementation and permeability (LIMA NETO, 2015).

Nevertheless, resolution limitations can be a problem, under or superestimating properties values. Three-dimensional images obtained by X-ray microtomography can be applied to determine these parameters and also to visualize the pore and matrix structures with greater resolution, improving the understanding of the porous space and its geometric properties.

This study aims to expand the knowledge on digital image analysis using X-ray microtomographic scans of carbonate rocks, in order to improve the acquisition and processing workflow that will achieve better results. The understanding of porous space and its controlling geometric attributes is of high relevance for predicting influential physical properties on carbonate rocks. Three-dimensional evaluation of rock microstructures is important for a better understanding of physical phenomena and for rock characterization on the micro-scale, and allows the application of statistic models for physical properties behavioral prediction.

Methodology

The suite of rock samples selected to be scanned by microCT was a set with 13 Albian carbonates from two neighboring wells from Campos Basin, cored at the reservoir interval (Figure 1). Previous studies performed several laboratory measurements of these samples, such as X-ray diffraction, petrographic thin section analysis, gas porosity and gas permeability (ARCHILHA et al., 2013, 2015, 2016; LIMA NETO et al., 2014). The list of samples and their descriptions are summarized in Table 1.

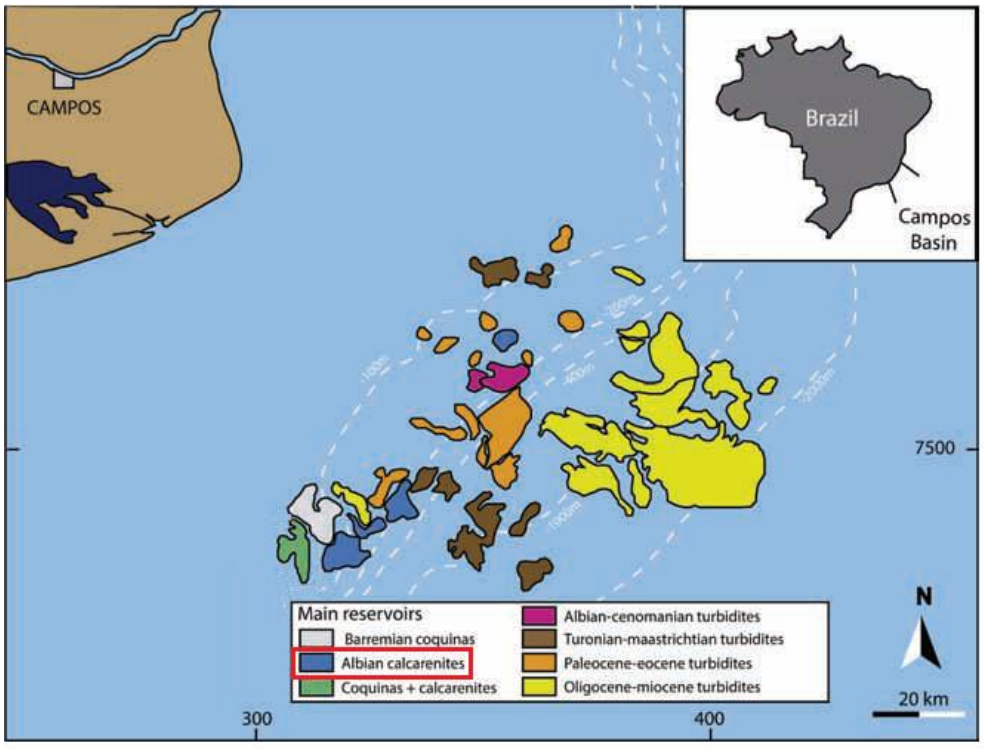

Figure 1 – Location map of Campos Basin, identifying its main reservoirs and the studied area (OKUBO, et al., 2015)

Table 1 – List of Albian Carbonate samples used in the research and their petrophysical measurements

Samples	Texture Characterization	X-Ray Diffraction Calcite (wt%)	Gas Porosity (%)	Gas Permeability (mD)	Vp (km/s)
W1-01	Mudstone	97,1	34,68	4,93	2,37
W1-02	Oolitic grainstone	99,7	23,03	8,95	3,11
W1-03	Oolitic grainstone	95,2	25,71	221,50	2,97

W1-04	Oolitic grainstone	97,0	22,07	32,15	2,79
W1-05	Oolitic grainstone	96,5	22,27	13,50	3,19
W1-06	Oolitic grainstone	95,6	28,89	602,30	2,26
W1-07	Oolitic grainstone	95,5	28,51	126,60	2,10
W1-08	Oolitic grainstone	97,0	22,88	9,78	2,84
W2-01	Mudstone	97,4	12,35	~	3,82
W2-02	Cimented grainstone	99,8	16,32	0,24	4,11
W2-03	Cimented grainstone	99,4	21,94	2,02	3,00
W2-04	Cimented grainstone	99,1	17,98	0,42	~
W2-05	Cimented grainstone	100,0	22,11	1,02	2,86

The methodology applied in this study is divided in the following steps: Acquisiton; Processing; Analysis and Interpretation.

The data acquisition for this study was performed in Campinas, SP, at the Brazilian Synchrotron Light Laboratory (LNLS) at CNPEM (Brazilian Research Center in Materials and Energy area), using the IMX (X-ray Imaging) beamline. The magnification on the equipment was 5X and the pixel size was 1.64 µm, and the sample size was of approximately 2 mm x 2 mm x 5 mm.

The processing step included reconstruction and segmentation of the data volume, which was done after scanning the rock samples. After the reconstruction, a volume of interest was cropped from the 3D image, avoiding rings originated from border scattering.

The segmentation of the volume consists in separating pores from rock matrix. The segmentation was performed using an automatic procedure for threshold analysis available in the software GeoDict 2015, which applies the Otsu method, and then supported by a visual validation.

With the segmented volume in hands, the next step was to compute and quantify the porous space of the samples. This process was achieved using the PoreShape GeoLab routines of the software Geodict 2015, with modifications made by Irineu A. Lima Neto. The pore properties computed were: total pore area, dominant size, gamma, porosity, aspect ratio, among others.

Preliminary Results

As this research is still under way, the analysis and interpretation of the processed data is not completed yet. The preliminary results are presented in Table 2, which shows some of the pore properties computed for each sample.

Table 2 – Preliminary results of the pore properties computed for the Carbonate samples

Samples	Porosity (%)	DomSize (microns)	Specific Surface Area (mm^{-1})	Mean Aspect Ratio
W1-01	28,47	64,30	95,51	0,63
W1-02	5,77	65,61	97,23	0,61
W1-03	47,79	66,74	65,07	0,63
W1-04	22,96	74,49	78,043	0,58
W1-05	14,73	64,90	99,92	0,59
W1-06	16,64	73,91	82,79	0,55
W1-07	16,49	69,46	90,29	0,56
W1-08	20,04	66,57	84,37	0,61

W2-01	31,58	62,62	101,70	0,63
W2-02	22,75	63,82	100,16	0,60
W2-03	32,54	66,14	93,94	0,60
W2-04	21,73	63,36	101,43	0,59
W2-05	16,84	67,09	91,55	0,60

The next step is to complete the interpretation of the pore properties obtained in the processing phase. The results published by ARCHILHA et al. (2016) of the microCT scans of this set of samples performed at the University of Manchester's equipment (XRadia MicroXCT) will be applied in this research as comparative parameters, in order to infer if different resolutions and processing techniques cause significant differences in the results of microCT scanning.

Additionally, this research aim to analyze local and global parameters of the porous space, as well as their influence on other properties, such as dispersion and attenuation of elastic waves. Local and global parameters of the porous space can be obtained from a 3D image. Global parameters are related to the whole pore space properties, such as micro- and macro-porosity, specific surface area and tortuosity. Local parameters, on the other hand, are associated with properties of a single pore. These are mostly related to the specific properties of the pore, such as geometry, aspect ratio and roundness.

Conclusions

Since carbonate rocks are the main oil and gas reservoirs worldwide, studying and understanding its complexities is of great importance for the petroleum industry. Three-dimensional images obtained by X-ray microtomography can be applied to determine pore parameters and also to visualize the pore and matrix structures with greater resolution, improving the understanding of the porous space and its geometric properties. The understanding of porous space and its controlling geometric attributes is of high relevance for predicting influential physical properties on carbonate rocks. As this research is still under way, the analysis and interpretation of the processed data is not completed yet. The next step is to compare the pore properties computed in this study with the results published ARCHILHA et al. (2016). Furthermore, we intend to analyze local and global parameters of the porous space, as well as their influence on other properties, such as dispersion and attenuation of elastic waves.

Acknowledgments

The authors would like to thank UENF/LENEP, PRH-ANP-20, PRH-PETROBRAS-226, LNLS/CNPEM and PETROBRAS for the facilities provided to perform this work.

References

ANSELMETTI, F.S., LUTHI, S., EBERLI, G.P. Quantitative characterization of carbonate pore systems by digital image analysis. AAPG Bulletin, v. 82, p. 1815 – 1836, 1998.

ARCHILHA, N., MISSÁGIA, R.,CEIA, M.,LIMA NETO, I., CASTRO, L., SOUZA, F. Petrophysical, mineralogical and P-wave velocity characterization of Albian carbonates from Campos Basin, Brazil. SEG Technical Program Expanded Abstracts, p. 2989– 2993, 2013.

ARCHILHA, N.L., MISSÁGIA, R.M., HOLLIS, C., CEIA, M.A.R., MCDONALD, S.A., LIMA NETO, I.A., EASTWOOD, D.S., LEE, P. 3D experimental investigation of velocity-

permeability controlling factors in carbonates rocks. SEG Technical Program Expanded Abstracts, p. 3000 – 3004, 2015.

ARCHILHA, N.L., MISSÁGIA, R.M., HOLLIS, C., CEIA, M.A.R., MCDONALD, S.A., LIMA NETO, I.A. Permeability and acoustic velocity controlling factors determined from x-ray tomography images of carbonate rocks. AAPG Bulletin, 100, n. 8, 1289-1309, 2016.

BURCHETTE, T.P. Carbonate rocks and petroleum reservoirs: a geological perspective from the industry. Geological Society, London, Special Publications, 370:17-37, 2012.

BUST, V.K., OLETU, J.U., WORTHINGTON, P.F. The challenges for carbonate petrophysics in petroleum resource estimation. SPE Reservoir Evaluation & Engineering, v. 14, n. 01, p. 25-34, 2011.

EBERLI, G.P., BAECHLE ,G.T., ANSELMETTI, F.S., INCZE, M.L., DONG, W., TURA, A., SPARKMAN, G. Factors controlling elastic properties in carbonate sediments and rocks. The Leading Edge, v. 22, p. 654 – 660, 2003.

LIMA NETO, I., MISSÁGIA, R.M., CEIA, M.A.R., ARCHILHA, N.L., OLIVEIRA, L. Carbonate pore system evaluation using the velocity-porosity–pressure relationship, digital image analysis, and differential effective medium theory. Elsevier, Journal of Applied Geophysics, 110, 23-33, 2014.

LIMA NETO, I. A. Carbonate pore system evaluation under texture control for prediction of microporosity aspect ratio and shear wave velocity. Tese de doutorado –Laboratório de Engenharia e Exploração de Petróleo, Universidade Estadual do Norte Fluminense Darcy Ribeiro, Macaé, Rio de Janeiro, 2015.

OKUBO, J., LYKAWKA, R., WARREN, L.V., FAVORETO, J., DIAS-BRITO, D. Depositional, diagenetic and stratigraphic aspects of Macaé Group carbonates (Albian): example from an oilfield from Campos Basin. Braz. J. Geol., São Paulo , v. 45, n. 2, p. 243-258, June 2015 .

SHEPHERD, M. Carbonate reservoirs. In: M. Shepherd: Oil field production geology: AAPG Memoir 91, p. 301-309, 2009.

SPADINI, A. Carbonate Reservoirs in Brazilian sedimentary basins. In: 19th World Petroleum Congress. World Petroleum Congress, 2008.