ESTIMATE OF POROSITY IN RESERVOIR ROCKS OF THE RESENDE FORMATION USING 3D HIGH-RESOLUTION X-RAY COMPUTED MICROTOMOGRAPHY

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Abstract *In this work it was studied the core plugs from the Resende formation that were collected in Porto Real, Rio de Janeiro. This formation is characterized by sandstones and fine conglomerates with associated fine siliciclastic sediments and the paleoenviroment is interpreted as a braided fluvial system. There are not many information about petrophysical characteristics of this formation. In this way, in order to get new informations non destructive tests were done with estimate porosity. Porosity is one of principles characteristics to be analyzed, because it represents the direct capacity of storage fluids in the rocks. By definition, porosity is the ratio of pore volume to the total bulk volume of the formation, expressed in percentage, being able to be absolute or effective. Through the convecional petrology it is possible to estimate the absolute porosity using a Ultra poro-perm based in pressure variation. However, the X ray computed microtomography (μ-CT) is a useful tool for the study of inner characteriscts of geological samples. This is only non-destructive technique with small resolution (~ microns order) that provide 3D image of the object.Thus, in order to improve the porosity estimate, it was analyzed using convecional petrophysics and μ-CT twelve samples taken at different depths of the well called GPR3. The results obtained by the correlation techniques show that the μ-CT is reliable technique. Through the images and data it was possible to quantify the porosity and view the size and shape of porous.*

Keywords*: porosity, X ray computed microtomografy, Ultra poro-perm, non-destructive*

1. INTRODUCTION

X-ray microtomography (μ-CT) is a nondestructive technique that allows 3D visualization of the internal structure of objects, determined mainly by variations in density and atomic composition. This technique was originally developed by medical applications, and due to its widespread use and application, μ-CT also has been a useful tool in geology studies. In accordance with M.Van Geet *et al* (1999), many studies have demonstrated the power of μ-CT with respect to classical petrography in geological research**.** The μ-CT can be used for quantitative and qualitative analysis of inner characteristic of geological materials (Mees F. *et al*, 2003). The 3D characterization of porous medium from the core plug evaluation leads to petrophysical properties such as porosity, pore distribution and permeability.

Most of all oil and gas produced comes from accumulations in the pore spaces of reservoir rocks. The amount of oil or gas contained in a unit volume of the reservoir is the product of its porosity and the hydrocarbon saturation. Therefore, porosity is a very important petrophysical parameter of rocks (Schlumberger, 1991). Porosity is the pore volume per unit volume of formation. It is the fraction of the total volume of a sample that is occupied by pores or voids.

In this work it was studied core plugs from the well of *Resende Formation* which were collected in *Porto Real*, *Rio de Janeiro*. This formation is characterized by sandstones and fine conglomerates with associated fine siliciclastic sediments and the paleoenviroment is interpreted as a braided fluvial system. Direct measures of porosity for sediment geological characterization of Resende basin have been few used, for this reason, the aim of this work was to estimate porosity from the analysis of data obtained by conventional petrophysics using a gas Ultra poro-perm and X-ray computed microtomography. Therefore, improving information about petrophysical characteristics of GPR3 well and Resende Formation.

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2. THEORY

The petrophysical analysis present in this work refers to core withdrawn of only one well called by GPR3, with 50 m of depth, situated in Resende basin. This basin belongs to part of the taphrogenic bases set called The Continental Rift of Southeastern Brazil (Ricommini, 1989) which joins the geological evolution of the Serra do Mar and the Cenozoic part of the Santos basin, in the continental margin of the Brazilian southeastern region. The well GPR3 is located in an outcrop at "Ponte dos Arcos" in the Resende basin (Ramos, 2003), in Porto Real, Rio de Janeiro State with coordinates UTM 765,140 NS and 7,681,984 EW. Fig.1

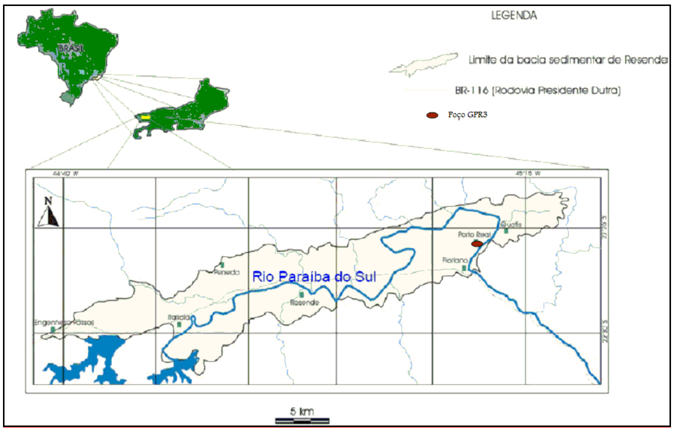


Figure 1: The range of the Resende basin, in the middle course of the Paraíba do Sul river and the well GPR3 location in the city of Porto Real (Ramos, 2003)

The Resende basin is located in the middle course of the Paraíba do Sul river and covers the cities Engenheiro Passos, Barra Mansa, Porto Real, Resende, Itatiaia and Quatis in southeastern Brazil. Geographically, the area is found between the parallels 22°22' and 22°35' latitude S and 44°12' and 44°40' longitude W. The well GPR3 was witnessed with material recovery estimate of around 66%. The witnessing is the process of obtaining samples of rock in the subsurface, called core plugs, with minimal changes in the properties of natural rock.

The measures were taken in the Ultra poro-perm of the *Core Laboratories Inc*. equipment owned by Petrophysics Laboratories in the Geology Institute/UFRJ and in the X-ray computed microtomography *Skyscan 1172* owned by Embrapa Agricultural Instrumentation located in São Carlos / SP.

2.1. Ultra poro-perm

To obtain the total porosity it was employed measuring methods by pressure changes in an adjoining chamber, using Ultra-Poro-Perm's ® 500 equipment by *Core Laboratories Inc*. This equipment was designed to consolidated sediments (rocks).The Ultra poro-perm measures the volume of grains or pores of the core sample, through the principle of expanding gas.

A known volume of gas is isothermally expanded into an unknown porous volume. After the expansion, the result of pressure is measured and this value depends on the unknown pore volume, which is obtained using the law of Boyle (Vidal, 2006):

$$p_i V_i = p_f V_f \qquad (1)$$

The Ultra poro-perm has a gas chamber of constant volume V_1, where the nitrogen gas is injected and stored at a pressure p_1 fig.2. The gas chamber is connected to the compression chamber of the sample volume V Eq.(2). When the compression of the sample chamber contains a volume V_A , it can not contain more than $V - V_A$ of the gas volume. When the valve that connects the gas chamber with the compression chamber is opened, and the nitrogen gas is isothermically released into the sample, there is a change in volume ΔV and a new pressure p_2 is measured.

$$p_1 V_1 = p_2 (V_1 + \Delta V) \qquad (2)$$

Where $\Delta V = V - V_A$, ΔV is the volume of gas in the sample, or in other words, the volume of pore space in the sample in cm^3. Therefore, the porosity of the sample is calculated by Eq.(3):

$$\Phi = \frac{\Delta V}{V} \tag{3}$$

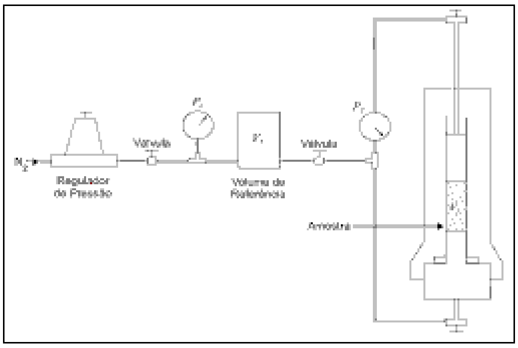


Figure 2: Scheme of Ultra poro-perm operation.

2.2. μ-CT

The X-ray microtomography is a non-destructive imaging technique. This is the unique system that allows us to visualize and measure complete three-dimensional object structures without sample preparation or chemical fixation. The μ-CT measures the material density variations in the sample extend through the attenuation of X- ray beam transmitted.

$$I = I_o \exp(-\mu x) \tag{4}$$

The simplest common elements of μ-CT are an X ray source, an imaginary object through which the X-rays pass, and a detector that measure the extent to which the X ray signal has been attenuated by the object eq.(4), fig.3. In this technique the X-ray source and the detector are fixed. During the acquisition the object will rotate over 180 or 360 degrees with a fixed rotation step. At each angular position a transmission image will be acquired. The cone beam acquisition will save all these projection images as 16 bit TIFF files on the disk. After image capture, the same is reconstructed using a reconstruction algorithm. When the reconstruction finishes, the 3D image can be generate.

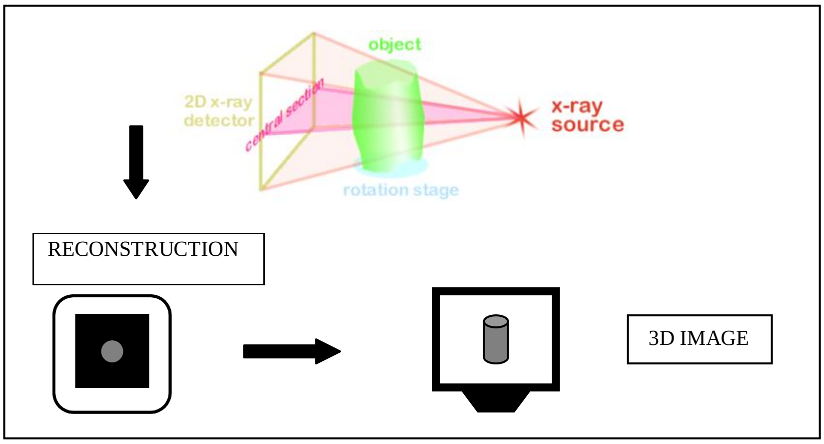


Figure 3: An illustration of the acquisition and reconstruction processes with cross-section to image in μ-CT.

2.3. METODOLOGY

The porosity estimate started with the selection of twelve cores taken at different depths of the GPR3 well. The cores were prepared in a 1 inc shape cylinder for measurements in Ultra poro-perm. The μ-CT does not need sample preparation.

2.3.1. μ-CT

All the samples were scanned employing a Skyscan 1172 μ-CT scanner, fig.4, using a tungsten anode and operating at 100 kV an 100 mA (spot size < 5μm). The samples were analyzed using filter Al+Cu and a 10 Mp CCD camera. Total rotation angle was 360^o with rotation step size angle of $0{,}40^o$. A total of 961 μ-CT slices were obtained with spatial resolution of the 14.9 μm.

Usually, the porosity estimate is performed using the image treatment software CtanR The bidimesional image goes by a treatment where the region of interest (ROI) in the rocks is appointed. The image is binarised in grayscale and it is done the determination of the optimal threshold. The porosity is estimate from the 3D analysis of binary image. It is the proportion of the volume of interest occupied by binarised porous sample.

$$\Phi = 1 - \frac{BV}{TV} \quad (5)$$

Where BV is the volume of the rock matrix and TV is the total volume of the core

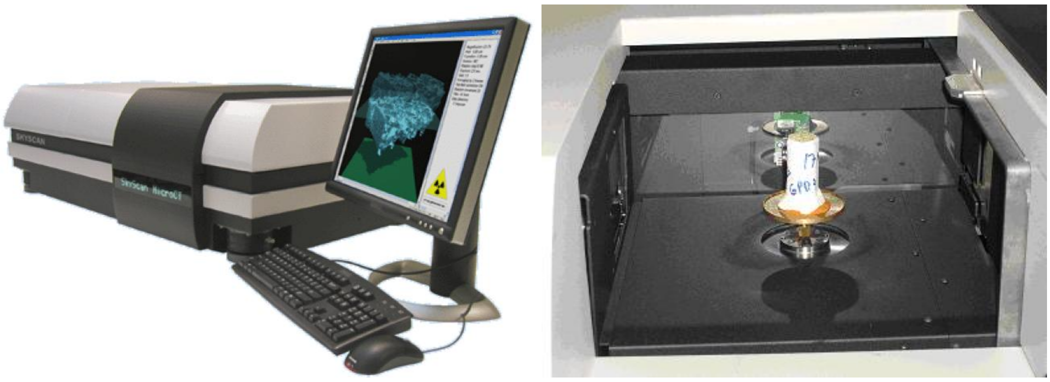


Figure 4: X-ray computed microtomography, Skyscan 1172

2.3.2. Ultra poro-perm

During the porosity measurement the core must be submitted to a minimum pressure of 400 psi. The minimum pressure is required, because the space between the core sample and the wall of the rubber cylinder must be eliminated. This procedure avoids the gas passing throughout this region and restricts it only inside the core sample.

2.4. RESULTS AND DISCUSSION

The μ-CT appears to be a useful tool in the determination of petrophysical parameters, like porosity. The results obtained by conventional petrologic using an Ultra poro-perm, qualify the μ-CT as a reliable technique for inner structure characterization fig.5. Both techniques showed results in accordance with the main factors which influence porosity, such as arrangement and shape of the rock grains and grain size distribution. The quantitative analyze of image obtained by μ-CT allows us to estimate the porosity of the cores using all of tridimensional structure without necessity of sample preparation and destruction.

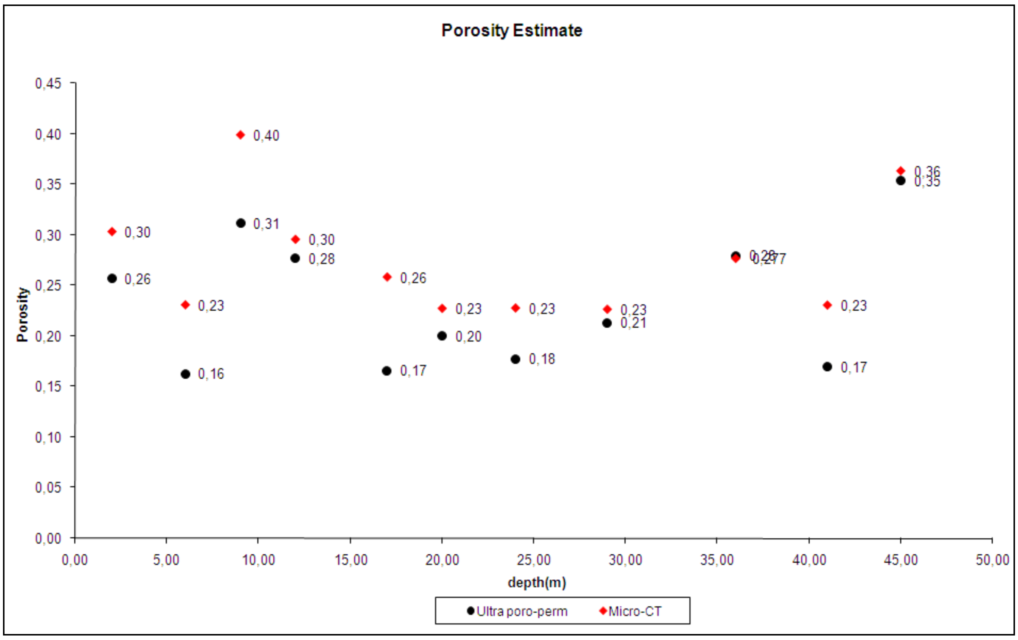
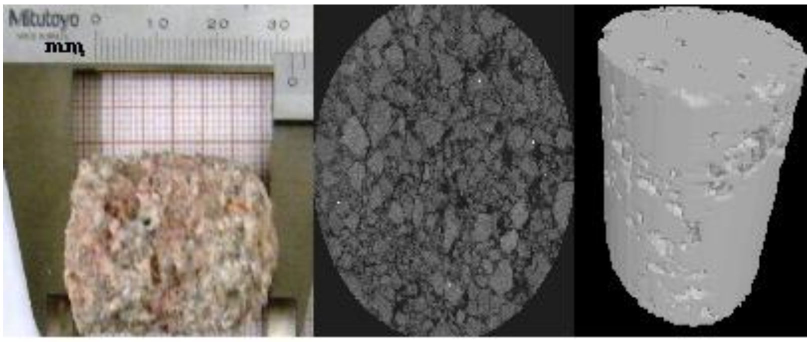


Figure 5: Porosity values of GPR3 well estimate by µ-CT and Ultra poro-perm:

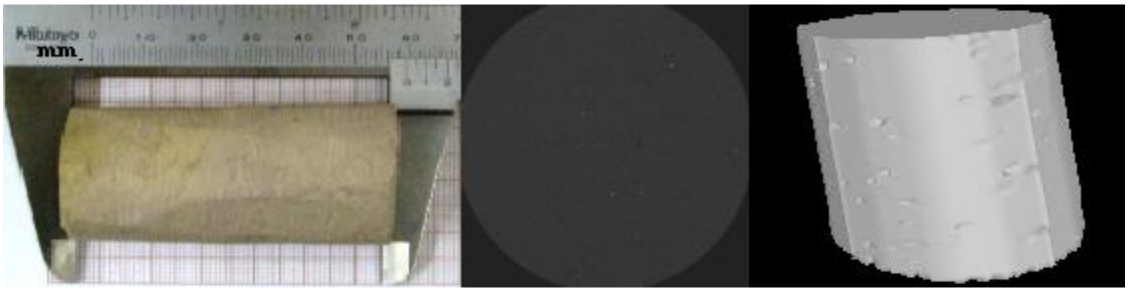
The 3D porosity is estimate from the ratio between black voxels and total image voxels. The image treatment software CTanR provides confidence limits of 95% of the image voxels meadium. So, the porosity values found have 95% of credibility.

Observing the cores, for example, at 2 m of depth the well comprises from conglomerates of fine sandstone consisting of sediments sandstone very coarse-grained, supported by clastos and very badly selected, fig.6. Also there was, at 6 m of depth, very thin sandstone to thin silty with rounded grain, poorly selected and present some coarse grains, fig.7. Based on the lithologic description and 3D visualization of the pore volume generated by µ-CT is possible to notice that the cores with grains more angular and with lower sphericity showed higher porosity estimate. This fact was confirmed by conventional petrologic using Ultra poro-perm. These results confirm the potential of the µ-CT technique with respect to analyze geologic material.



(a) (b) (c)

Figure 6: (a) The core at 2 m of depth. (b) One slice of 2-D µ-CT visualization (c) 3-D µ-CT image with 14.9 µm of voxel resolution



(a) (b) (c)

Figure 7: (a) The core at 6 m of depth. (b) One slice of 2-D μ-CT visualization (c) 3-D μ-CT image with 14.9 μm of voxel resolution

2.5. CONCLUSIONS

The μ-CT technique is a useful tool in qualitative and quantitative analyses of geological materials. The great advantage of this technique is the bidimensional and tridimensional visualization of the size and shape of porous presents in the rock without material damages. The μ-CT is the only non-destructive technique of inner characteristics analysis that can be applied of geologic material, the correlation with conventional petrologic showed that the results obtained are reliable and effective.

3. ACKNOWLEDGEMENTS

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5. RESPONSIBLE NOTICE

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