Petrophysical, mineralogical and elastic property characterization of Halocene carbonates from Salgada lagoon, Brazil

Nathaly L. Archilha*[1], Roseane M. Missagia[2], Marco A. R. de Ceia[2] and Irineu A. Lima Neto[1].
[1] Doutorando/PPGERE/LENEP/UENF
[2] Universidade Estadual do Norte Fluminense/LENEP

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Abstract

Approximately 60% of oil and 40% of gas world reserves are in carbonate reservoirs. These reservoirs are heterogeneous with a textural variety and typically fractured, leading to low recovery factors and also complex relationships between rock properties and geophysical data. Studies of these reservoirs have become very important in Brazil after 2005, when Petrobras announced a large carbonate reserve in the pre-salt region of Santos basin. The reservoir characterization requests a better understanding of the relationship between geology, petrophysical and acoustic properties. In this work, we made a petrophysical, mineralogical and elastic property characterization of Halocene carbonates from Salgada lagoon, RJ, Brazil. Measurements of X-ray diffraction (XRD) showed that the mineral composition is different in each of the three facies of this carbonate, but it is always a mixture of high-magnesian calcite (HMC), aragonite and quartz. The thin section observation revealed the presence of skeletal material, quartz grains and regions that suggest recrystallization. Mercury intrusion porometry (MIP) revealed porosities between 14 and 26%, and microporosity in all carbonate facies. The hysteresis loop between the intrusion and extrusion curves is large, indicating that the pore shielding effect is significant for the MIP analysis. The velocity and the bulk density were estimated from mineralogical and petrophysical information and compared with empirical equations. The velocity versus porosity and density versus velocity crossplots showed that this rock has a behavior close to a limestone.

Introduction

Stromatolites are lithified and biosedimentary structures that grow through layers of sediments trapped by the carbonates' precipitation (Altermann & Kazmierezak, 2003). The specific carbonate studied on this work was obtained from the Salgada lagoon outcrop, a hypersaline lagoon with an area of ~16 km2, located on the municipality of Campos dos Goytacazes, on the coast of Rio de Janeiro state, Brazil (Figure 1). The great similarity of this stromatolite with some Brazilian pre-salt reservoirs, as shown in Figure 2, leads such interest on studying it.

These carbonate reservoirs consist on a mixture of three dominant precipitations, related to three carbonate factories: T, M and C (Schlager, 2005). The elements' occurrence and distribution of these factories (fractures, pore types and mineralogy, for example) are closely related to the petrophysical properties of the rock (Dürrast & Siegesmund, 1999). The rock porosity and bulk density are the main factors that influence the seismic velocities (Rafavich et al., 1984). Therefore, characterizing carbonate reservoirs by studying the rock mineralogy, petrophysical and acoustic response provides a fundamental understanding of reservoirs petrophysical response to geological features and its dynamic changes.

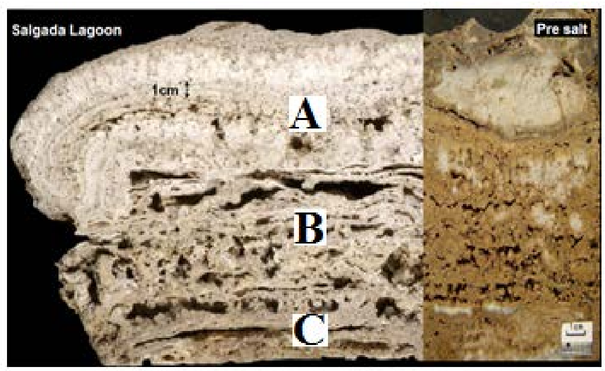

Figure 2: Comparison between a sample from the Salgada lagoon (left) and a core sample from the pre-salt of Santos basin (right). Sections A, B and C indicate the three similar regions studied: A – stromatolite, B – thrombolite and C – travertine (classification proposed by Lemos, 1995). Figure adapted from Estrella (2008) apud Papaterra (2010).

Methods

A fast detector X-ray diffractometer was used to determine the mineral composition of all samples. The step angle used was 0.02° and the scanning rate was 0.6 s/step, allowing the refinement of the crystalline structure by the Rietveld method (Rietveld, 1969). This data refinement determined the mineralogical quantitative.

Petrographic thin sections were observed with an optical microscope, using magnifies from 25 to 1000 times.

A mercury porosimeter was used to estimate the sample porosity, grain and pore size distribution, besides to study the hysteresis loop between the intrusion and extrusion curves.

The slowness (p) and the bulk density (ρ) of the rock were calculated by Equation 1, where g is any bulk property. The bulk velocity of each region was determined by the inverse of slowness, see Schön (2011).

$$g = \sum_{i=1}^{n} V_i g_i \quad \text{and} \quad \sum_{i=1}^{n} V_i = 1 \qquad (1)$$

These experimental data were compared with empirical Equations 2 – 3, obtained from experimental data, some water-saturated, others water-saturated as calculated from dry rock data using Gassmann´s equations, with effective pressure varying from 10 to 50 MPa (Mavko et al., 2009).

Limestone: $$\rho = 1.513 + 0.202 V_p \qquad (2)$$
$$V_p = 5.624 - 6.65\phi$$

Chalk: $$\rho = 1.045 + 0.373 V_p \qquad (3)$$
$$V_p = 5.059\phi^2 - 8.505\phi + 5.128$$

Dolomite: $$\rho = 1.843 + 0.137 V_p \qquad (4)$$
$$V_p = 6.606 - 9.380\phi$$

Experimental Results

Figure 3 shows X-ray diffractograms for the three studied regions. After that, it was possible to carry out a quantitative mineralogical determination by the Rietveld method (Table 1). The magnesium occupancy was estimated and it revealed that all samples are composed by HMC, since the occurrence of $MgCO_3$ is between 11 and 18 mol%, quartz and aragonite.

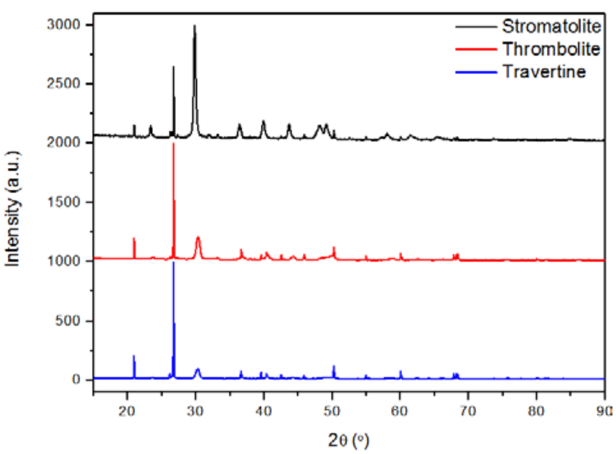

Figure 3: X-ray diffractogram for samples A, B and C.

Sample	Magnesian calcite (wt%)	Quartz (wt%)	Aragonite (wt%)
A	85.4	9.7	4.9
B	62.6	30.5	6.9
C	44.5	53.5	1.9

Table 1: Mineralogical characterization by Rietveld method of regions A, B and C.

Thin section observations (Figure 4), show skeletal material (a), different pores types (a, b, c), quartz grains (d) and some region that suggest recrystallization (d - golden region).

Through mineralogy and porosity, it was possible to determine the rock´s bulk velocity and density (both water saturated), and the results are shown in Table 2. It was necessary to normalize the minerals fractions for obeying Equation 1. These data were compared with empirical equations (Mavko et al, 2009) – see Figure 5.

Table 3 shows results of three samples from each microfacie that were submitted to MIP, for better statistic. Figures 6 – 8 show the hysteresis loop between the intrusion and extrusion curves and also the volume of mercury intruded as a function of pore throat diameter.

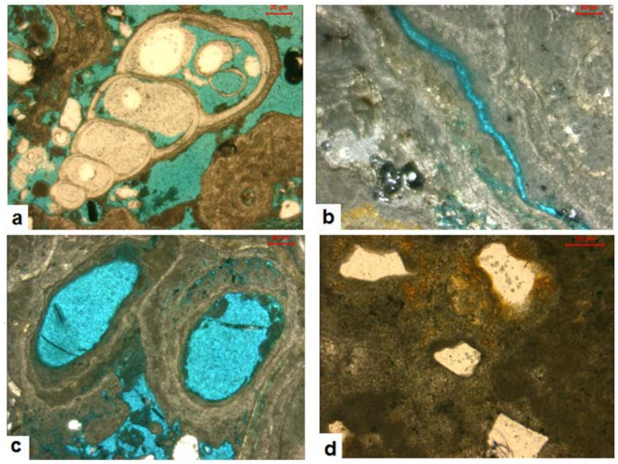

Figure 4: Thin sections from different regions of the rock.

Comparing empirical equations (Mavko et al, 2009), with velocity versus porosity and density versus velocity crossplots, it was determined that this rock has a behavior close to a limestone, as shown in Figure 5. All the empirical equations were obtained from measurements of rocks under pressure, which close the pores and increase the velocity. Thereby, it is possible to explaining the fact that all estimated velocities are lower than the expected from limestone's empirical equations.

Conclusions

The mineralogical result shows that stromatolite (A) and thrombolite (B) are composed mainly by high magnesian calcite (HMC), as the concentration of $MgCO_3$ is higher than 4 mol% in both samples, with small amounts of quartz and aragonite, but the travertine (C) is composed mainly by quartz, with plenty occurrence of HMC and some aragonite. Due to the presence of the quartz cemented by calcite, this microfacie was probably a phase of marine influence, as described by Iespa (2008).

Aragonite presented as skeletal materials and some quartz grains were observed over the thin sections using optical microscopy and confirmed by XRD. The blue regions (Figure 4) show pores of different sizes and shapes, some of them suggesting the presence of channels (Figure 4b), characteristic of carbonate rocks.

MIP experimental results along with thin sections observations revealed the heterogeneity of the samples: the average porosity varies between 14 and 26%, with a standard deviation that reaches 6% and the average grain and pore size values (Table 2) show the expressive variation between minimum and maximum values, ranging from 10^{-9}m to 10^{-6}m. In Figures 6 – 8, it is important to note that there is a dominant peak between 0.1 and 10 µm, but it can also be observed that all samples exhibit pores smaller than 7 nm, however it was not possible to analyze due to experimental limitation. The hysteresis loop between intrusion and extrusion curves is large (Figures 6 – 8), indicating that the pore shielding effect is significant in MIP analysis, and it also should cause an underestimation of the porosity (Yao & Liu, 2012).

The pore type is a fundamental information for rock physics models that will be implemented in future works to estimate P and S wave velocities. These velocities will be compared to the results of this work and also to a third method, the experimental rock physics system.

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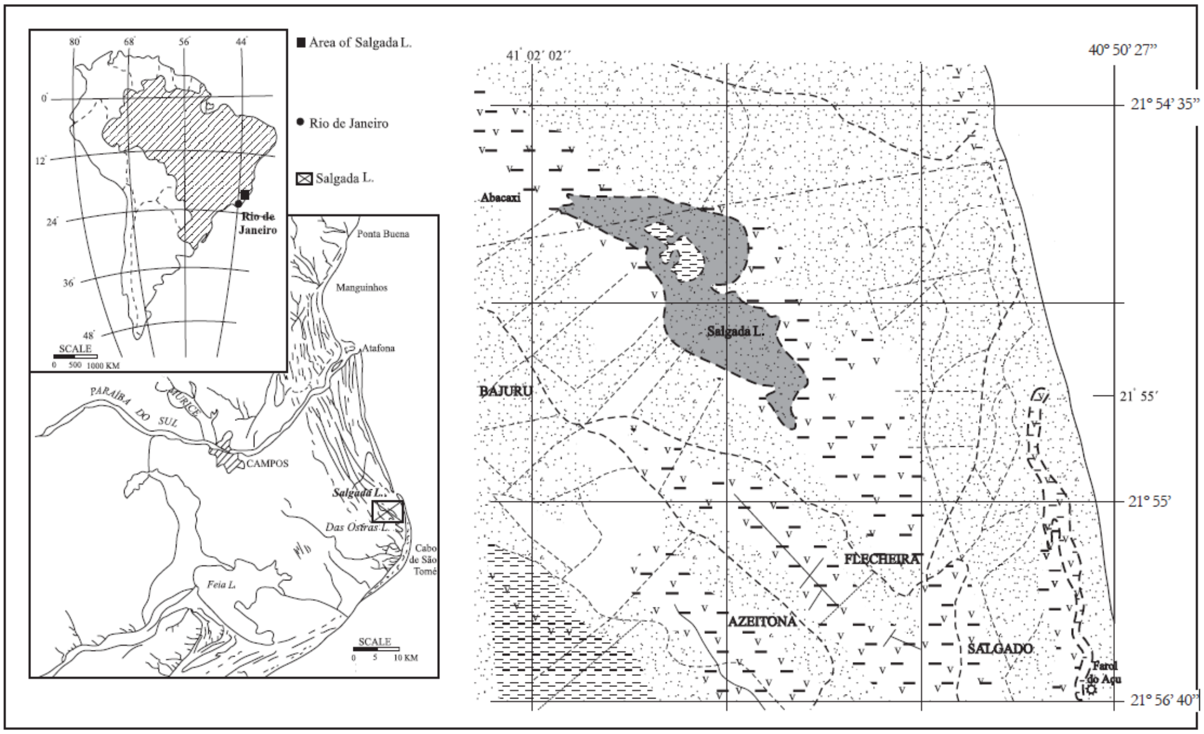

Figure 1: Location map of Salgada lagoon, Rio de Janeiro, Brazil, adapted from Srivastava, (2002).

Sample	Max. pore diameter (µm)	Min. pore diameter (µm)	Max. grain diameter (µm)	Min. grain diameter (µm)	Average porosity (%)	Velocity (m/s)	Bulk density (g/cm³)
A	8.9(6)	7.3(2)E-3	62 (5)	30 (1)	26 (6)	3585.8	2.27
B	8(1)	7.3(2)E-3	53 (9)	30 (1)	14 (2)	4346.8	2.46
C	8(2)	7.5(8)E-3	54 (9)	30 (1)	14 (3)	4333.4	2.45

Table 2: MIP results and bulk properties estimation for samples A, B and C.

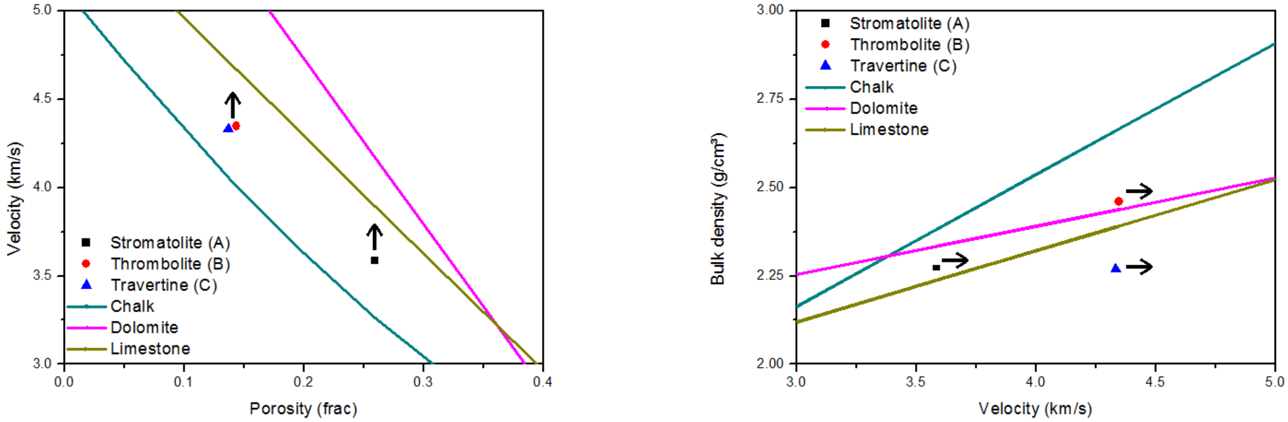

Figure 5: Velocity x Porosity Crossplot (left) and Density x Velocity Crossplot (right). The arrows indicate the increasing velocity due to pressure increases.

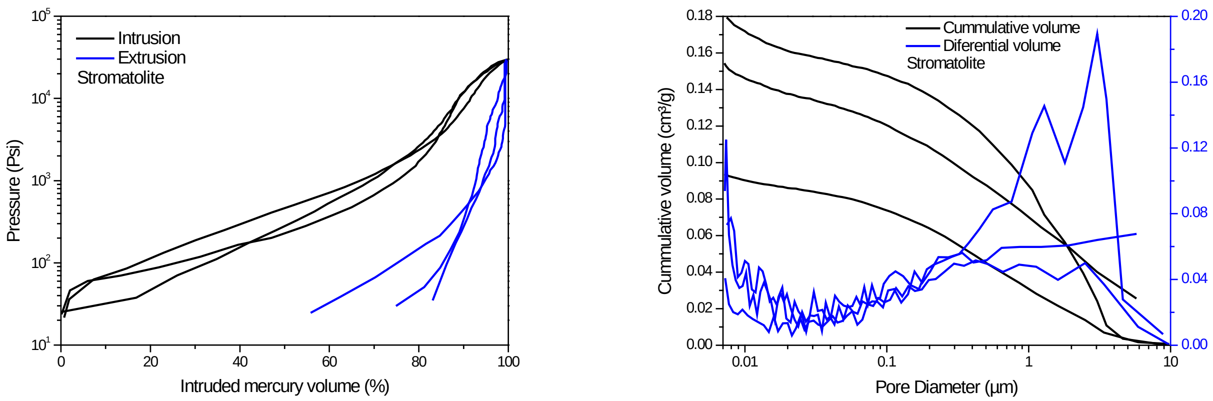

Figure 6: Hysteresis loop between the intrusion and extrusion curves (left) and volume of mercury intruded as a functions of pore throat diameter (right) for stromatolite samples.

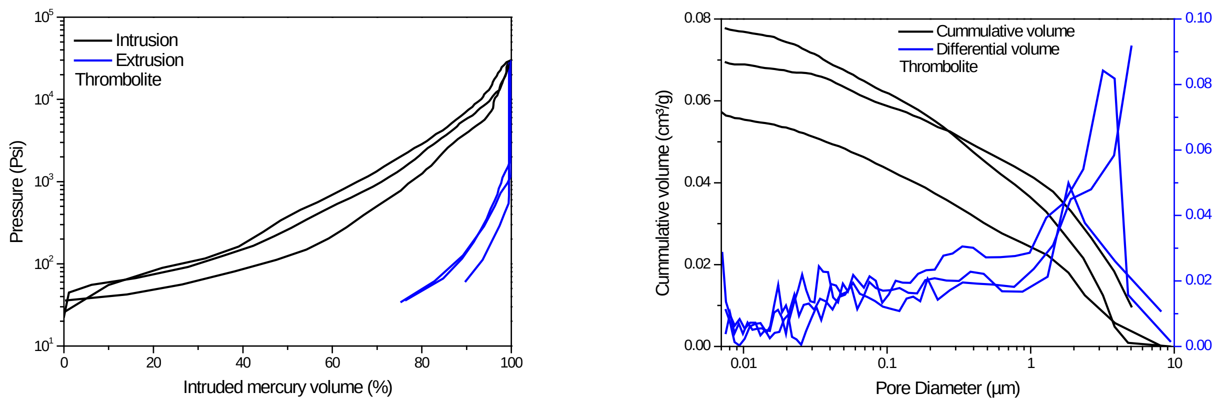

Figure 7: Hysteresis loop between the intrusion and extrusion curves (left) and volume of mercury intruded as a functions of pore throat diameter (right) for trombolite samples.

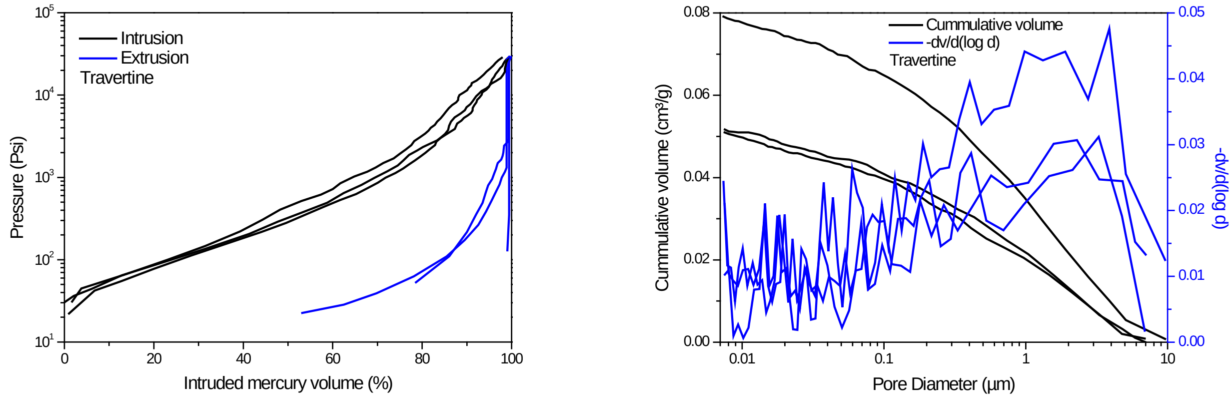

Figure 8: Hysteresis loop between the intrusion and extrusion curves (left) and volume of mercury intruded as a functions of pore throat diameter (right) for travertine samples.

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