Rock typing of coquinas from the Morro do Chaves Formation.

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Abstract

Accurate determination of rock types is essential for the characterization of a reservoir. Rock typing can be an arduous task due to high variation in the pore geometry and a lack of correlation between pore body and pore throat sizes, among other factors. In this work, rock types were determined from permeability bands in coquinas of the Morro do Chaves Formation in Brazil, considered to be close analogues of some Pre-salt reservoirs. The rocks were described using thin sections, while their similarities were confirmed using nuclear magnetic resonance. Results indicated characteristic patterns in terms of their T_2 distributions. Samples within the same rock type showed similar distribution curves, with the advantage of allowing direct measurements without more complex analyses to characterize the rock types.

Introduction

Rock typing is a critical factor in reservoir characterization by driving the accuracy of reservoir simulations. The identification of petrophysical rock types is especially difficult because of their highly variable pore geometry, a lack of correlation between pore body and pore throat size, and thus between porosity and permeability. It also causes difficulty in establishing a link between small scale pore properties and large scale reservoir properties. Establishing a link between a petrophysical view of the reservoir and the geologic view is hence not trivial. (Skalinski, et al. 2009).

When a reservoir is composed of carbonate rocks, this determination is even more important. Due to their mineralogy, carbonate rocks are more susceptible to diagenetic processes, leading to far more variations in porosity and permeability (Martins et al, 2018).

This study uses coquina rock samples from the Morro do Chaves Formation at the Sergipe-Alagoas Basin in Northeast Brazil. Rocks in this formation are composed of bioclastics, the majority of which are lacustrine bi-valves, modified by transport and diagenesis, resulting in complex pore systems (Hoerlle et al., 2018). The Morro do Chaves Formation can be considered to be a reasonable analogue of some Pre-salt carbonate formations in the Santos and Campos basins, offshore Brazil, and are similar in age, ranging from Late Barremian to early Aptian (Borghi et al, 2013).

As reported by Corbett et al. (2016), coquinas from the Morro do Chaves Formation have a diagenetic history that can result in dramatic changes in permeability with only slight changes in porosity. This requires the development of a new rock typing approach that simplifies the estimation of flow properties from petrophysical observations.

To aid in the petrophysical characterization of the samples, nuclear magnetic resonance (NMR) techniques were used due to its great power in the investigation of the physical properties of the materials. Often used in the petroleum industry, NMR characterizes reservoirs through laboratory measurements, in addition to using well logging tools (Rios et al., 2010).

An NMR signal is acquired by aligning the spins of ^{1}H, contained in the saturating fluid of the samples and induced by a constant magnetic field (B_0). An oscillating magnetic field (B_1) is then applied, perpendicular to B_0, in order to unbalance the system. After suspension of the B_1 field, the spins return to their equilibrium position; this return is called nuclear magnetic relaxation, being modelled by exponential decays (Hoerlle et al., 2018). These decays are reversed through mathematical calculations (Laplace inverse transforms) to generate distributions curves. According to Coates (1999), these distributions can be related to size distributions of porosity, the total porosity of the sample and the type of fluid saturating the sample. If only one type of fluid is present, the decay rates directly indicate the pore size since T_2 is determined by the amount of spin interactions with the pore wall. Therefore, signals with long T_2 signals can be assigned to large pores, while short T_2 signals are indicative of small pores (Westphal et al., 2005).

In this work we determine the rock types based on clusters developed from permeability bands. NMR techniques are also applied to confirm similarities between the groups through the T_2 distribution patterns (Rios et al., 2010). Thin sections were used to aid the classification of rocks, together with descriptions of the pore types and their two-dimensional arrangements.

Method

In this research project, 16 coquina core samples were obtained from the 2-SMC-02-AL well bore (9° 45'29.05" S / 36° 9'10.65" W) at the CIMPOR Mine, a former Atol Quarry owned by Intercement, in São Miguel de Alagoas (AL). The samples, measuring 1 inch in diameter and 1.5 inch in length, were first cleaned to remove the fluids and any impurities present in the pore systems. For this we used Soxhlet extraction with toluene to remove hydrocarbons and methanol to extract the salts. After cleaning, the samples were oven dried at 80 ºC for 12 hours.

After drying, routine core analyses (RCALs) were perform for measuring poroperm properties We used UltraPore-300 for the gas porosity and UltraPerm-600 for the gas permeability (both from Core Laboratories) at a confining pressure of 500 psi. The measurements were performed by Solintec, a local core analysis company. After measuring porosity and permeability, the cores were saturated with brine containing 30,000 ppm KCL. Afterwards, the NMR T_2 distributions were measured at the Laboratory for Applications of NMR and Petrophysics at Fluminense Federal University (UFF-LAR) using GeoSpec2, a 2MHz lab NMR machine made by Oxford Instruments.

Results

The main results from the core analysis (RCA) are shown in Table 1. The results were used to construct the porosity-versus-permeability cross-plot shown in Figure 1. Notice the variations in porosity from 4.1 % to 18.8 % and the wide range in permeability from 0.045 to 556 mD. The NMR porosity compared well with gas porosimetry results, which indicates that the samples were fully saturated with brine.

Table 1 – RCAL and NMR types information.

Sample codes	ϕ_{gas} (%)	K_{gas} (mD)	ϕ_{NMR} (%)	T_{2LM} (ms)	Rock types
146.25	4.10	0.045	4.40	11.507	RT1
148.00	6.09	0.162	6.20	83.046	RT1
169.45	7.74	0.166	8.00	17.659	RT1
88.00	8.70	5.21	9.00	133.049	RT2
122.45	12.23	5.65	12.10	75.427	RT2
173.50	10.79	5.77	11.00	102.516	RT2
176.85	9.84	1.73	9.100	98.663	RT2
126.05	11.54	13.01	11.20	225.055	RT3
128.05	12.08	22.10	13.00	145.096	RT3
154.20	16.59	77.17	16.20	390.126	RT3
184.95	11.06	63.65	11.20	285.174	RT3
83.05	18.59	556.36	17.70	484.410	RT4
100.70	16.26	227.73	15.90	458.550	RT4
189.40	15.10	273.66	15.20	463.135	RT4
102.55	18.81	174.08	18.10	310.927	RT5
162.50	17.52	121.98	17.60	311.066	RT5

The porosity-permeability scatter plot in Figure 1 was also useful for identifying the 5 main rock types shown as colour coded clusters, with rock types 1-4 showing a trend of increasing permeability with porosity, while rock type 5 indicates a lower permeability than rock type 4, but a higher porosity.

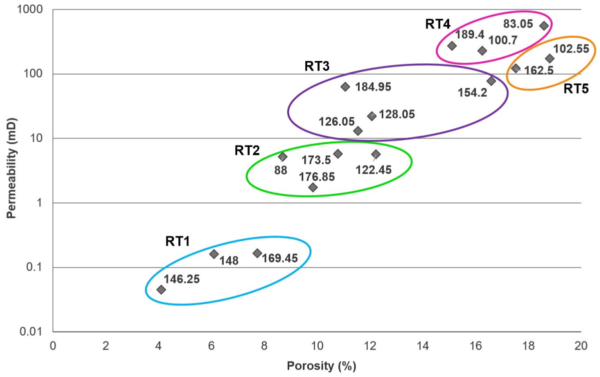

Figure 1 – Cross-plot showing porosity versus permeability for different rock types.

As indicated in Figure 1, the samples were separated into rock types (RT) according to permeability bands. The RT1 samples had lower permeabilities, from 0.045 to 0.166 mD; the RT2 samples varied from 1.73 to 5.77 mD; the RT3 samples varied from 13.01 to 77.17 mD; the RT4 samples from 227.73 to 649.91 mD; while the RT5 has permeabilities varying in value from 121.98 to 232.93 mD.

The similarity among the samples of each group was confirmed based on the shape of the T_2 distributions and their logarithmic mean values T_{2LM} (Table 1). The classification of pores was based on qualitative partitioning of the T_2 distributions as used by Silva et al. (2015). The heterogeneity of the samples is well evidenced by the variation of the pore families within the set, thus reinforcing the T_2 partitioning ideas presented by Silva (2015): T_2 up to 1 ms is considered to be micropores; between 1 and 10 ms is a transition region between micro and mesopores; from 10 to 100 ms consists of mesopores; from 100 to 1000 ms is a transition zone between meso and macropores, and over 1000 ms are macropores. Figures 2a, 3a, 4a, 5a and 6a show the distributions of T_2 for rock types RT1, RT2, RT3, RT4 and RT5, respectively.

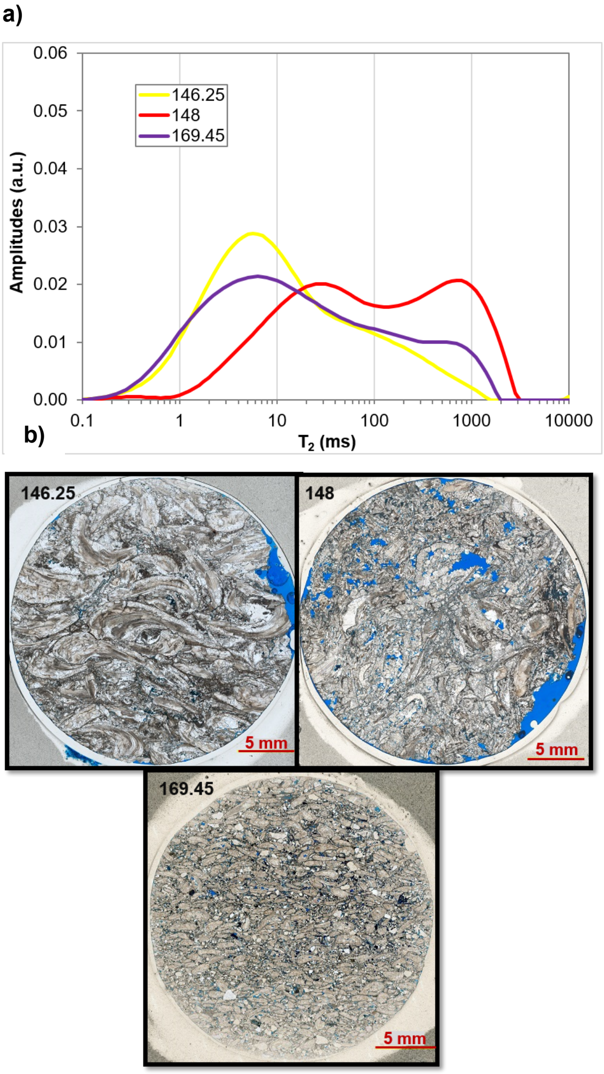

Figure 2 - a) T_2 distribution and b) thin sections of the RT1 samples.

In Figure 2a variations in pore sizes can be observed according to their transverse relaxation times. The set presents bimodal samples, with pores that vary between micro- and macro-pores according to the partitioning used by Silva et al. (2015). The distributions have low amplitudes corresponding to low porosities and low permeabilities. T_{2LM} range from 11 to 83 ms, with porosities between 4.1 and 7.79% and permeabilities between 0.045 and 0.166 mD.

Figure 2b, shows thin sections of RT1. The rocks were classified as calcarenites composed of whole and fragmented shells, which are densely packed, with predominance of moldic and intraparticle pores. Note the scarcity of pores in the images, especially of sample 146.25, due to intense cementation resulting in a porous system that is more closed.

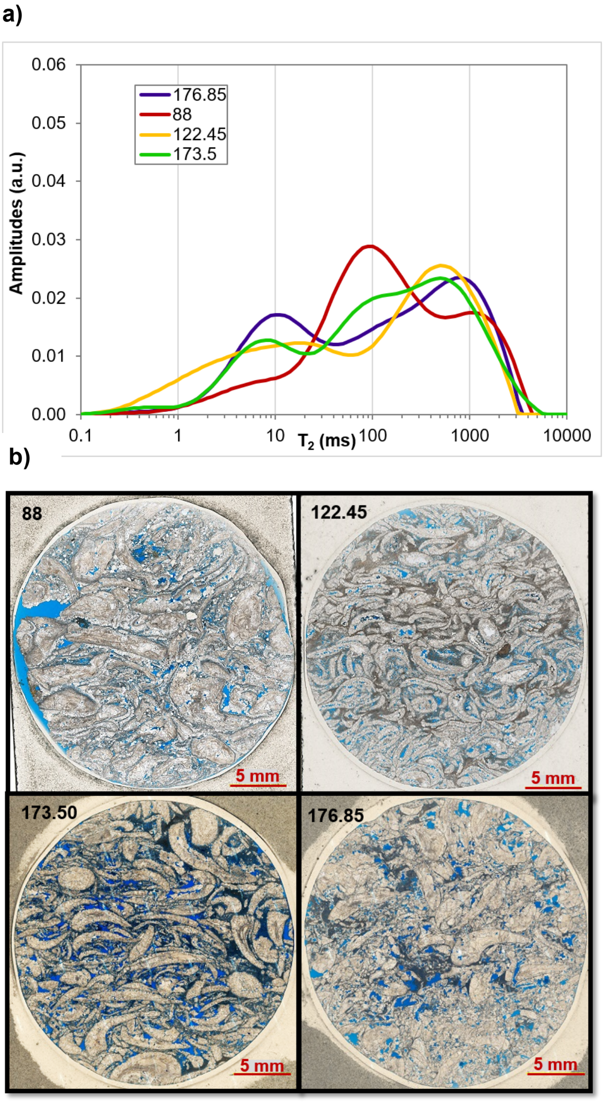

Figure 3 – a) T_2 distributions and b) thin sections of the RT2 samples.

Figure 3a shows curves of the samples belonging to RT2. The set consists of bimodal samples, with the pore size varying between micro-and macro-pores, and with T_{2LM} between 75 and 133 ms, porosity between 8.70 and 12.23 % and permeability from 1.73 to 5.77 mD. Although the samples of RT1 and RT2 presented bimodal distributions with large variations in their pore size, it is worth mentioning that RT2 has a higher average T_2, which is consistent with the increase in permeability.

In the descriptions of the thin sections (Fig. 3b) we observed that the samples are classified as calcarenites and calcirudites composed of whole and fragmented shells, densely to loosely packed. The pores, for the most part, are interparticle, intraparticle and vugs. The pore system of these samples ws different as compared to RT2, with a higher presence of visible pores. Due to compaction, these samples presented low connectivity, thus impacting the permeability.

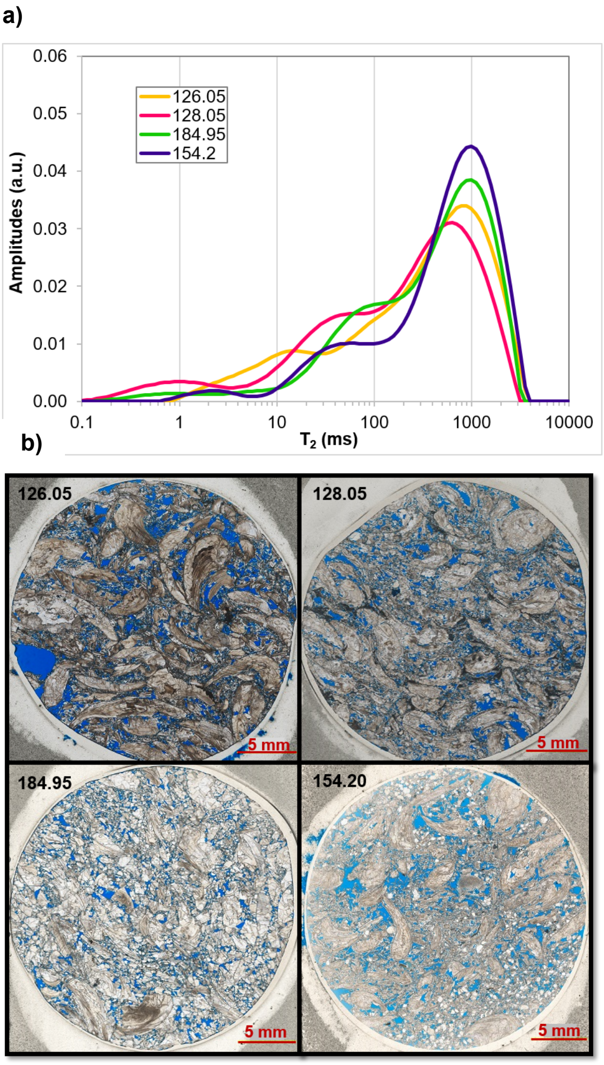

Figure 4 – a) T_2 distribution curves and b) thin sections of the RT3 samples.

In Figure 4a, the T_2 distribution of the RT3 samples are composed of pores varying from micro- to macro-pores. They have T_{2LM} values between 225 and 390 ms, porosities between 11.60 and 16.59 % and permeabilities between 13.01 and 77.17 mD. Again, an increase in T_{2LM} values correlates with an increase in permeability.

The thin sections of this rock type (Fig.4b) were described as calcirudites and calcarenites, composed of whole and fragmented shells, densely packed. Most of the pores were classified as intraparticular, moldic and intercrystalline. Higher amounts of pores were visible and more connected, consistent with an increase in permeability as compared with RT1 and RT2.

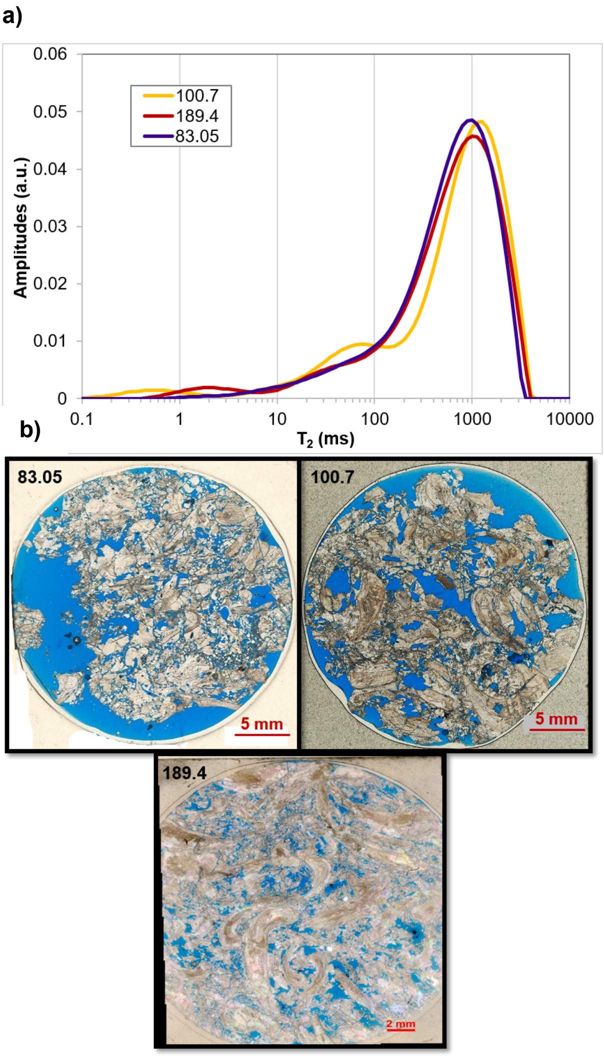

Figure 5 – a) T_2 distributions and b) thin sections of the RT4 samples.

Distributions of the RT4 samples are shown in Figure 5a. Note the predominance of pores above the hybrid region of meso- and macro-pores, with no presence of micropores. They have higher T_{2LM} values, ranging from 458 to 484 ms, porosities ranging from 15.1 to 18.59%, and relatively high permeabilities, from 227.73 to 556.36 mD.

The samples (Fig. 5b) were classified as calcirudites and calcarenites composed of whole and fragmented shells, densely packed. The pores were represented by vugs and a majority of intraparticles. It is evident that the significant increase of visible pores, especially the pore throats (which are larger than those of RT1, RT2 and RT3) results in higher permeabilities, as is the case for sample 83.05 having a permeability of 556.36 mD.

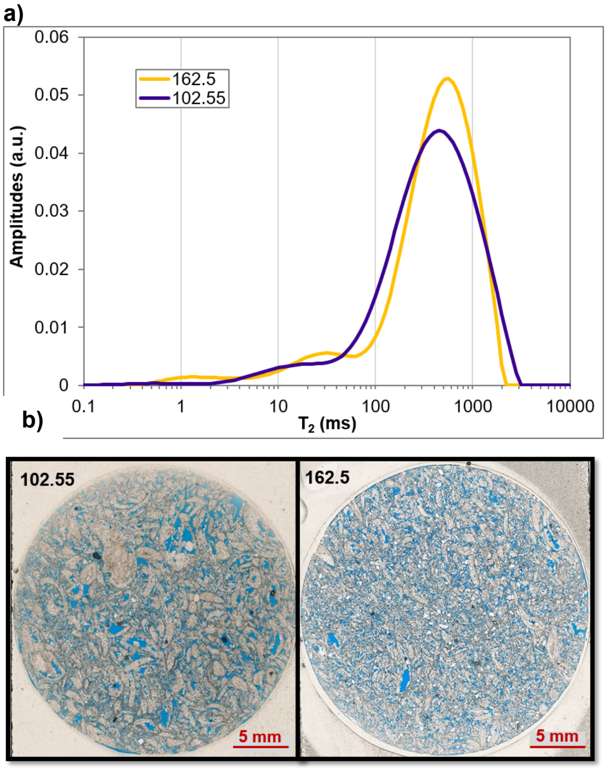

Figure 6 – a) T_2 distribution and b) thin sections of the RT5 samples.

As can be seen in Figure 6a, the RT5 samples showed T_2 distribution in the meso- and macro-pore range, while no microporosities were observed. Samples 102.55 and 162.5 had T_{2LM} values of 310.9 and 311.06 ms, respectively; porosities of 18.81 and 17.52%, respectively; and permeability values of 174.08 and 121.95 mD, respectively. Samples of this rock type were separated from RT4 due to the decrease of T_{2LM} and the decrease of the permeability, following the pattern found for the division of the clusters.

The samples of this group (Fig. 6b) were classified as calcirrudite and calcarenite composed of whole and fragmented shells, densely packed. The pores of these samples were for the most part classified as intraparticular and moldic. Figure 6b shows the differences in pore morphology of groups RT4 and RT5: pore sizes as well as their shapes can be observed. They show smaller sizes than RT4 samples (Fig. 5) and greater packaging, in addition to narrower pore throats, leading to a slight decrease in permeability. These results confirm that the samples do not have the same petrophysical characteristics, and hence that the RT4 samples must be separated.

Conclusions

This research concerned rock typing of samples taken from a core drilled at the Morro do Chaves Formation. Using routine core analysis data, a porosity versus permeability cross-plot was constructed and the clusters were elaborated based on the permeability bands.

The rocks were described by analysing thin sections, which showed the preservation of shells, packaging and different type of pores. Since the samples showed large heterogeneities, the recognition of similarities between them became complex, being insufficient for their separation into different groups. However, the identification of the pores and their connections was advantageous, such as in the case of the RT4 samples, which had narrower pores as compared to RT5, resulting in lower permeabilities.

The similarities between the samples within a specific rock type were confirmed by NMR measurements. By observing curves of the T_2 relaxation times, which reflect the distributions of the pore size families, it was possible to observe similar curve shapes. Based on the assumption that logarithmic mean relaxation times are associated with mean pore size, we observed that the T_{2LM} increase is directly related to permeability increased.

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