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Physical-mechanical analysis of carbonatic rocks in the potiguar basin, Rio Grande Do Norte, Brazil

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ABSTRACT: The carbonate rock outcrops of Potiguar Basin are essential for the oil industry, because it is considered an analogue to the reservoir of Pre-salt sequence. This paper shows physical and mechanical characterization of carbonate rocks of Jandaíra Formation, Potiguar Basin, including in-situ Schmidt hammer tests, porosity and density determination, and ultrasonic velocity measurements. Ten samples of carbonate rocks were collected, distributed between moderately and slightly fractured outcrops, in some cases being close to subhorizontal fractures, which coincide with the planes of greater carbonate dissolution where small caves develop. The samples collected from moderately fractured outcrops have density varying between 2.1 and 2.24 g/cm3, with average porosity of 20%, uniaxial compressive strength (UCS) ranging from 18.5 to 47 MPa, according to the values obtained with Schmidt hammer, velocity of ultrasonic waves between 2979 and 3385 m/s, and dynamic Young modulus of 12.47 – 21.24 GPa. The samples collected from little fractured outcrops have specific mass varying between 2.37 and 2.63 g/cm3, average porosity around 9.6%, UCS between 71-113 MPa, ultrasonic wave velocity between 4012-4841 m/s, and dynamic Young modulus between 33.75 – 52.96 GPa. In general, the samples show a a pattern of behavior in which samples collected from low-fractured outcrops are less porous, have higher specific masses, greater unconfined compression strength, and higher wave propagation speeds, when compared to the samples from moderately fractured outcrops.

KEYWORDS: Carbonate rocks, outcrops, Potiguar Basin

1 INTRODUCTION.

The Potiguar Basin is located in the states of Rio Grande do Norte and Ceará, the Northeast Region of Brazil. This basin has an emerged area of approximately 26700 km², and a submerged area of approximately 195400 km². The Basin is of great interest to the oil industry, because there are exploration of hydrocarbons in its extension since 1949 (ANP, 2015), and the carbonate rocks found in its outcrops are considered analogous to ones composing Pre-salt reservoirs.

The present paper addresses Jandaíra Formation (Apodi Group), a carbonate formation characterized predominantly by shallow and agitated marine carbonates (Tibana & Terra, 1981), which shows karst features, and a large number of caves. According to Carneiro et al. 2015, the karst dissolution in the Jandaíra Formation has a strong structural control and can occur in tectonic features such as faults where there is a concentration of fractures.

The study in question aims to analyze the physical and mechanical changes that occur in the carbonates of the Jandaíra Formation when located in very or slightly fractured outcrops, or when the sample is near sub-horizontal fractures which coincide with the plane of carbonate dissolution concentration. Ten plugs of carbonate rocks were collected in a fieldwork. In these samples, physical tests were performed to obtain specific mass and porosity, mechanical tests using the Schmidt Hammer, point load test, and wave propagation velocity tests.

The analyzes show a pattern of behavior where the samples collected in the little fractured outcrops present a higher mechanical resistance than those collected in the little fractured outcrops. However, two samples were out of the observed pattern, this is probably justified by the proximity to a fracture plane, where the carbonate dissolution is concentrated.

2 MATERIALS AND METHODS

2.1 *Geological-Geotechnical Characterization*

The geological characterization was accomplished by fieldwork in Felipe Guerra, more precisely, in the region of Cachoeira do Roncador, to recognize the geological context of the place. Some specific samples were studied in more detail, and the description of the minerals and structures present in the rock was made. Analyzes on a macroscopic scale were performed using the Carl Zeiss magnifying glass.

2.2 *Physical Characterization*

For physical indices characterization ISRM suggested method was used (ISRM, 1979b). The following parameters were obtained: dry density, density of solid constituents, void ratio, and porosity.

2.3 *Mechanical Characterization*

For mechanical analysis, in situ measurements were made using Proceq SilverSchmidt L type hammer with impact energy of 0.735 Nm according to the ISRM standard (revised version by Aydin, 2009). And, in some specific points, the point load test for irregular blocks following the ISRM standard (ISRM, 1985).

2.4 Ultrasonic Wave Propagation

Wave velocities were measured in the unconfined state by ultrasound pulse propagation using NER Autolab system module (Aydin, 2013). The equipment consists of transmitter and receiver caps, an oscilloscope and a data acquisition system. Honey was used as a couplant. The velocities of P (Vp) and S (Vs) waves were measured, and dynamic Young's modulus and Poisson's ratio were then calculated.

3 RESULTS AND DISCUSSION

3.1 *Geological-Geotechnical Characterization*

The study area is part of the Jandaíra Formation, located on Cachoeira do Roncador region in Felipe Guerra (RN). The predominant rocks in the region are carbonates, in several points it is possible to observe centimeter geodes with calcite precipitation. During the fieldwork, it was observed that the outcrops had subvertical fractures with a predominantly NW-SE direction, and subhorizontal fractures. Sub-horizontal fractures sometimes coincide with planes of greater carbonate dissolution, these planes may be filled by a carbonate tuff or have small caves. The studied region was separated into two domains that differ according to the degree of fracturing (Figure 1). The blue domain represents the slightly fractured outcrops, and the orange domain represents the rocky wall of the waterfall, moderately to very fractured. The regions with low fractures are approximately flat levels separated by the rocky wall of Cachoeira do Roncador.

Figure 1. Studied region map (base from: Google Earth).

The rock wall is approximately 10 meters high, moderately to highly fractured, and the outcrop rocks vary from little to very altered (Figure 2). Subvertical fractures are mostly closed, and may or may not be persistent along the wall. Horizontal fractures accompany the bedding of the rock, and sometimes have small caves showing a plane of greater dissolution of carbonate. These fractures are usually open, can be filled, and are persistent in the outcrop. In the most fractured regions of the rock wall, the fracture frequency is estimated to be 10-12 per meter.


Figure 2. Rock wall moderately to very fractured.

On the flat plateaus there are little fractured outcrops, where the rocks vary from little to slightly altered. The fractures found there have similar characteristics to those of the rock wall, however, it is estimated that their frequency is lower, with approximately 3-5 fractures per meter.

The three samples studied in greater detail were collected at the upper level (CR-19-009, CR-19-010, CR-19-011) around a sub-horizontal fracture where there is evidence that there was a greater concentration of dissolution of the carbonate rock, with sample 009 being the closest, and samples 10 and 11 are at approximately the same distance.

According to the macroscopic analysis of the sample CR-19-009, the rock is moderately altered, with many brown colored calcite crystals from the alteration (Figure 3). The crystals have a length of about 0.2-0.5 mm. The pores have a diameter up to 1 mm and generally they are rounded. It was possible to observe microfractures in the sample, and there is precipitation of calcite on the face of a fracture.


Figure 3. Sample CR-19-009 with alteration features.

In CR-19-010 macroscopic analysis, it can be seen that it is little altered, and has millimeter-sized microfractures, usually closed and not filled (Figure 4). The calcite crystals provide length ranging from 0.2-0.5 mm, and there are rounded pores up to 1 mm diameter throughout the sample. In this sample, observed a rounded feature filled with clay that appears to represent an alteration of some differentiated grain (Figure 5).


Figure 4. Microfracture in CR-19-010 sample.


Figure 5. Rounded feature filled with white clay in CR-19-010.

The CR-19-011 sample is similar to CR-19-010 sample, it also shows millimeter-sized microfractures, the largest of which is centimeter. The calcite crystals are approximately 0.2 mm long and rounded pores up to 0.5 mm long (Figure 6).

Figure 6. Rounded pore in CR-19-011 sample.

3.2 *Physical Characterization*

According to the results of the physical characterization, with the exception of the sample CR-19-009, the other samples present a pattern as shown in Table 1. The samples located in the moderately to very fractured outcrop (rock wall) show specific masses lower than the samples of the little fractured outcrops. The porosity is higher in the rock wall than in the little fractured outcrops. The porosity of the plugs collected in the rock wall it is considered high, and that of the little fractured outcrops is medium to low.

However, the sample CR-19-009, located in one of the little fractured outcrops, has physical properties that appear to be between the two patterns, and even closer to the properties of the samples collected in the rock wall, because it has a lower specific weight than the others located in its outcrop and high porosity. For this reason, this sample was called a nonstandard sample.

Table 1. Physical properties of specimens.

Moderately to Very Fractured Outcrop	Specific Weight (kN/cm3)	Porosity (%)
CR-19-001	20.8	21.9
CR-19-002	21.5	19.5
CR-19-004	21.8	18.4
CR-19-005	21.9	19.1
CR-19-006	21.4	21.8
Little Fractured Outcrop	**Specific Weight (kN/cm3)**	**Porosity (%)**
CR-19-009 (nonstandart sample)	23.2	18.2
CR-19-010	24,0	12.8
CR-19-011	25.8	4.4
CR-19-024	25.18	6.7
CR-19-025	25.2	6.07

3.3 *Mechanical Characterization*

The mechanical characterization was performed with the Schmidt hammer and point load tests where it was possible to collect samples. It can be seen that among the different types of outcrops, the little fractured outcrops present a greater resistance to simple compression (Table 2). The uniaxial resistance to Schmidt hammer is low to median in outcrops moderately to very fractured, and high in outcrops that are slightly fractured.

The point load tests were done only on samples collected from low-fractured outcrops, and it is noted that among the results, the CR-19-009 sample presents a significantly lower mechanical resistance than the other tested samples (Table 2). The strength to uniaxial compression from point load test in point CR-19-009, and median to high in the other outcrop points.

Table 2. Mechanical properties of specimens.

Outcrop Moderately to Very Fractured	Uniaxial Compression Strength (Schmidt Hammer) - MPa	Uniaxial Compression Strength (Point Load Test) - MPa
CR-19-001	47	-
CR-19-002	30	-
CR-19-004	20.5	-
CR-19-005	17.5	-
CR-19-006	18.5	-
Outcrops Little Fractured	**Uniaxial Compression Strenght (Schmidt Hammer) - MPa**	**Uniaxial Compression Strenght (Point Load Test) - MPa**
CR- 19 - 009 (nonstandart sample)	71	17.96
CR-19-010	89	36.61
CR-19-011	-	64.28
CR-19-024	113	-
CR-19-025	74	45.17

When looking at the graphs in Figures 17 and 18, it is noted that the mechanical strength increases with the increase in dry specific weight and the decrease in porosity. Sample 009 is the one with the lowest mechanical resistance, the lowest specific weight and the highest porosity, followed by the sample 10, and finally, the sample 11, which has the highest mechanical resistance, the highest specific weight, and the lowest porosity.

Apparently, the degree of change in sample 009 is the most evident difference in the analysis that may have influenced the characteristics of the rock so that it behaves anomalously in relation to the other surrounding samples. This more expressive degree of alteration, which affects the physical and mechanical characteristics of this rock, may be related to its proximity to a fracture where a greater degree of carbonate dissolution is concentrated.

3.3 *Ultrasonic wave measurements*

The compressional wave velocities of the samples varied between 2700 and 4800 m/s, whereas shear wave velocities were found to be between 1300 and 2800 m/s. As expected, with increasing porosity, there was a decrease in ultrasonic velocities. The relation between Vp, Vs and rock porosity showed a linear trend as it can be seen in Figure 9. The calculated Young modulus values varied from 7 to 50 GPa. This data dispersion can be attributed to different weathering degrees and the presence of vugs in some of the samples.

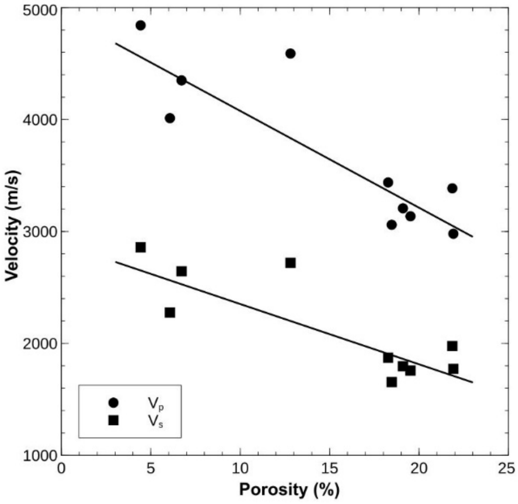

Figure 9. Relations between compressional and shear wave velocities and sample porosity.

A number of authors have presented empirical and theoretical correlations between P and S wave velocities (Pickett,1963; Greenberg & Castanga, 1992). Some of these correlations obtained for limestones and dolomitic rocks are plotted in Figure 10 in relation to the data found in present study. A relatively close resemblance between predicted and observed trends can be noted.

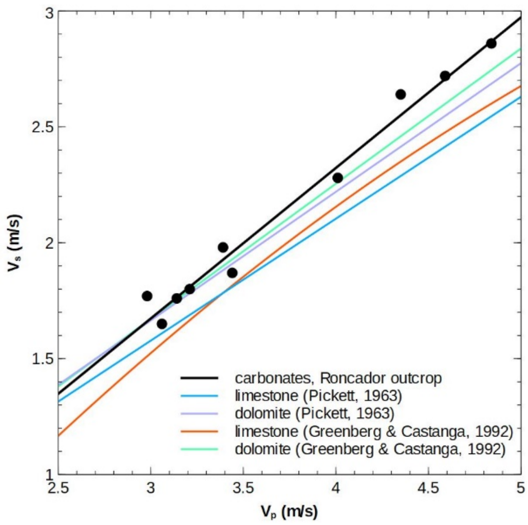

Figure 10. P and S wave velocity correlations found in this study as compared to literature data.

4 CONCLUSIONS

It is concluded that the often fractures in outcrops can influence a portion of the intact rock in some ways, such as the degree of alteration and the formation of microfractures. These changes directly influence physical and mechanical characteristics of rocks. In general, the samples exhibit a pattern of behavior in which those collected in the low-fractured outcrops are less porous, have higher specific masses, greater unconfined compression strength, and higher wave propagation velocities than the samples collected in the moderately to very fractured regions.

The sample with nonstandard behavior, CR-19-009, may have presented discrepancy due to its greater degree of alteration. Its physical characteristics may also have been influenced by its proximity to the region of greater carbonate dissolution.

The results obtained using ultrasonic wave measurements showed expected behavior, despite a wide dispersion due to different weathering degrees, and the presence of vugs and fractures.

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