Comparison of Porosity using Conventional and Nuclear Magnetic Resonance Well Logs in the Gato do Mato Prospect, Santos Basin

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Abstract

There are many regions that have limited studies on porosity, either due to lack of economic interest or acreage availability. This study aims to compare different methods for calculating porosity in the Gato do Mato Prospect, Santos Basin to help comprehend the porosity of the reservoirs in the region. The results were obtained using well data provided by the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP). The workflow consisted of data loading, quality control, composite well log assembly, porosity calculation, and results comparison. Two wells from the northern region of Gato do Mato were used, 1-SHEL-26-RJS and 3-SHEL-27-RJS, with the first showing predominance of cemented carbonates and porosity slightly below 15% throughout the well, while the second showed an increase in porosity compared to the first one and a disconnection in the middle of the hydrocarbon column. Overall, the results of the study demonstrate the importance of integrating different data sources for improved reservoir analysis, and aim to make a clear contribution to economic feasibility studies of the Gato do Mato Prospect region – a region still considered an area under exploratory evaluation.

Introduction

The study of well porosities is crucial for exploration because it helps determine the amount of oil or gas that can be extracted from a reservoir, and if the well has favorable conditions for the oil migration. Porosity refers to the percentage of open spaces or voids in a rock that can hold fluid such as oil, gas, or water. Rocks with high porosity generally have more space available to hold hydrocarbons, which means they can produce more oil or gas. Understanding porosity is also important in determining the permeability of the rock, or how easily fluids can flow through it. This information is essential for designing the drilling and production strategies needed to extract oil and gas from a reservoir efficiently and cost-effectively.

This research aimed to perform a porosity comparison in carbonate reservoirs in the Gato do Mato prospect, which is a promising area in the Santos Basin. The methodology involved calculating the porosities of each well using equations commonly used to obtain the porosity by density and sonic, as well as utilizing the NMR logs, specifically the effective porosity. The interpretation of calculated data allowed for the identification of interesting conditions for oil migration. In addition, the porosity values provided a better understanding of the reservoirs and their potential for hydrocarbon production.

As a result, the findings from this study have important implications for future exploration and production activities in the region. Specifically, the results can be used to guide the development of more effective exploration strategies and improve the efficiency of oil and gas production in the Gato do Mato prospect. Overall, the study highlights the importance of understanding the porosity of carbonate reservoirs in the Santos Basin and suggests that careful analysis of porosity data can provide valuable insights into the potential for hydrocarbon production in the region.

Regional Geology

The Santos Basin is the largest offshore basin in the region and produced 74.7% of Brazil's oil and 73.5% of its natural gas in 2022 (ANP, 2023). It is located on the Brazilian coast, bounded to the north by the Campos Basin and to the south by the Pelotas Basin. The basin has a complex architecture due to polyphasic tectonic and magmatic events. Its southern limit allowed for evaporitic deposition to the north, while marine conditions predominated in the Pelotas Basin to the south (Gambôa *et al.*, 2008; Mohriak, 2004). The Santos Basin's pre-salt is the subject of many studies as it has the largest evaporitic reservoirs, and its tectono-stratigraphic evolution helps to understand its importance. The basin was divided into rift, post-rift, and drift stages (Moreira *et al.*, 2007).

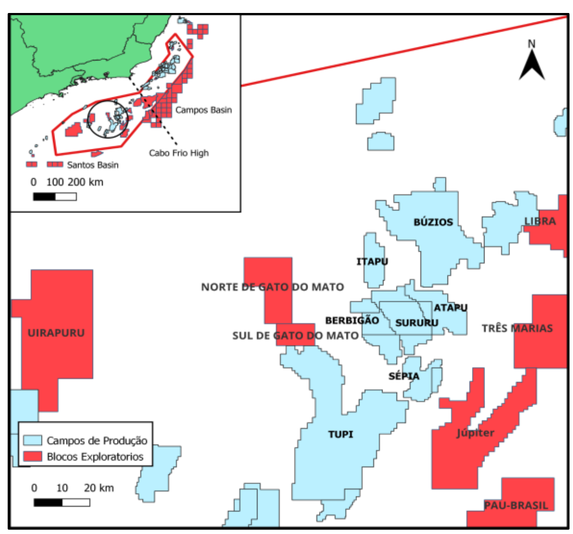

Figure 1 – Localization map of the Gato do Mato Prospect, within Santos Basin, Brazil.

During the rift phase, basaltic flows coincided with the initial stretching of the crust. In the final rift phase, conglomerates and sandstones were deposited in nearby areas, while black shales with high organic content were deposited in deeper areas of the basin. The Itapema Formation, with bioclastic carbonate in proximal areas and black shale layers in distal areas, was formed after the Piçarras Formation. The Barra Vela Formation, a succession of biogenic and abiogenic carbonates with distinct textures (Farias *et al.*, 2019), covers the Itapema Formation and was deposited in an alkaline and hypersaline lacustrine environment during the SAG phase.

Local Geology

The Gato do Mato Prospect is located at the Outer High of the Santos Basin (Gomes *et al.,* 2012) (Figure 1), an area within the pre-salt polygon that contains some of the largest oil and gas reserves in the world. The strategic location of Gato do Mato makes it an area of great interest for oil and gas companies, who are looking to eventually turn the area into a field for oil production. Recent studies have identified the presence of *SF1* facies (Mounded) in the Gato do Mato ridge, which suggests that the area is a complex of high-energy reefs (Minzoni *et al.*, 2021). The structural high partitioning in the prospect area played a key role in the formation of the Barra Velha Formation's carbonate reservoirs.

The tectonic changes in Gato do Mato are like those seen in other pre-salt areas, emphasizing the significance of this field for comprehending regional geology. The identification of these features can aid oil and gas companies in their exploration and production efforts in the area.

Method

In this study, data from two wells that were drilled in the Gato do Mato Prospect were utilized (1-SHEL-26-RJS and 3-SHEL-27-RJS). The primary aim was to calculate and subsequently compare the porosities of the Barra Velha Fm, a pre-salt reservoir.

In pursuit of this objective, the density (RHOB/RHOZ), sonic (DT), and neutron (NPHI) logs, commonly referred to as conventional well logs, were employed. Additionally, the Effective Porosity (CMRP_3MS) log was also used for the comparative analysis. It should be emphasized that porosity estimates obtained from conventional well logs may be subject to overestimation or underestimation caused by various factors, such as the mineralogical composition of the matrix and other materials present within the rock.

In order to compute porosity values based on density logs, the calculation involves incorporating density values for both the matrix (ρ_{ma}) and fluid (ρ_{fl}) (as obtained from the well folder) as well as the formation density within the study region (ρ_b) (obtained from the well log). The mathematical expression utilized for this computation is Equation 1:

$$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}}$$

Equation 1 – Calculating porosity by density

The computation of porosity derived from sonic well logs can be achieved using the time average Wyllie equation, as presented by Wyllie *et al*. (1958). The equation is expressed in Equation 2:

$$\phi_s = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_{fl} - \Delta t_{ma}}$$

Equation 2 – Calculating porosity by sonic using Wyllie et al.'s equation.

To determine porosity from the neutron well log, the neutron log's zero value is typically used, aligning with the density log's zero value within a range of 1.95-2.95 g/cm3. Assuming a carbonate matrix, porosity can be calculated by adding 6% for each line of the scale. Sandstone and dolomite matrices require adjustments to this calculation, with 4% and 6% added and subtracted, respectively. It is worth noting that factors such as borehole roughness, mud salinity, pressure, mineralogy, and temperature must be considered as they can impact the accuracy of the direct reading of porosity from the well log, and also a more accurate interpretation of porosity is only possible with image well logs, as they allow for a clearer interpretation of whether the porosity reading is being affected by vuggy porosity, caves, fractures, faults, etc.

Results

In the first well, 1-SHEL-26-RJS, porosity curves were plotted on a logarithmic scale ranging from 0.3 to 0, revealing the predominance of cemented carbonates that are not suitable for hydrocarbon reservoirs. In the shale region, high porosity is identified by all conventional logs, although the NMR log is unable to detect it due to the structural complexity and heterogeneity of this type of sedimentary rock (Figure 2). It is noteworthy that the end of the log, there is an increase in porosity that follows the compositional changes observed in the well.

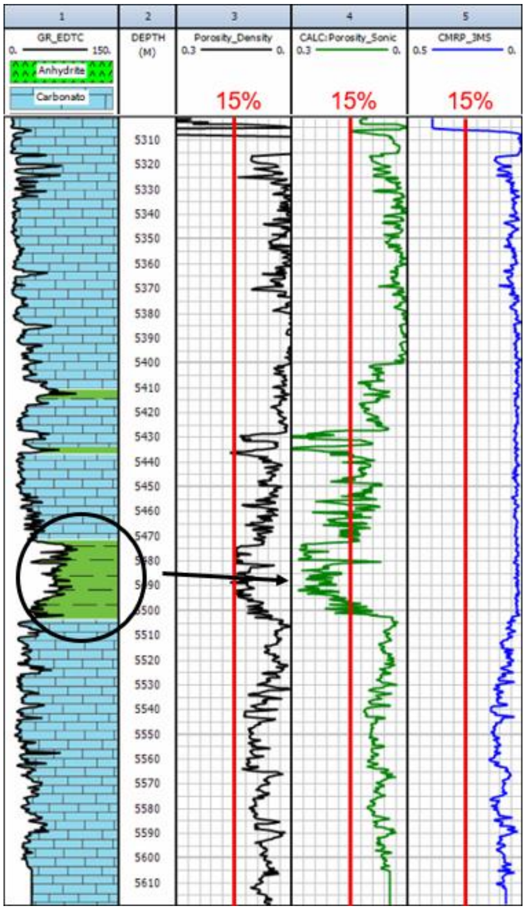

Figure 2 – Logs assembled with density porosity curves (black – Track 3), sonic porosity (green –Track 4), and NMR effective porosity (blue – Track 5), in addition to lithology with gamma ray (Track 1) and depth (Track 2).

The neutron curve confirms porosity slightly below 15% throughout the well (Figure 3). Also, combining neutron and density curves is useful for identifying lithologies.

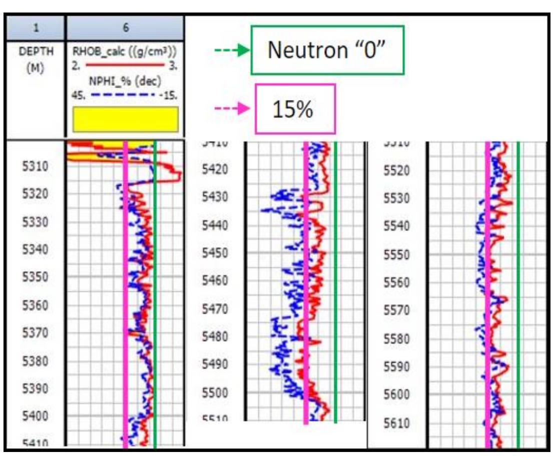

Figure 3 - Density-neutron log, with a green dashed line indicating the neutron zero for porosity reading. As the well is predominantly carbonate, the porosity value is read directly from the curve.

In the second well, 3-SHEL-27-RJS, porosity curves were also plotted on a logarithmic scale ranging from 0.3 to 0. The findings reveal that the formation's porosity is approximately 15% across most of the area, as indicated by the two conventional logs (Figure 4). The porosity initially increases at the beginning of the formation and reaches its peak around 5255m, followed by gradual a decline. Throughout the well, there are significant variations in porosity across the three logs, with indications of hydrocarbons within the red dashed square in Figure 4. Moreover, as the depth increases, the porosity generally rises, but there is a sudden drop in the porosity log at 5315m depth in both the density and NMR porosity logs. Towards the end of the well, the porosity increases considerably, reaching levels comparable to those found in the uppermost reservoir (Figure 4).

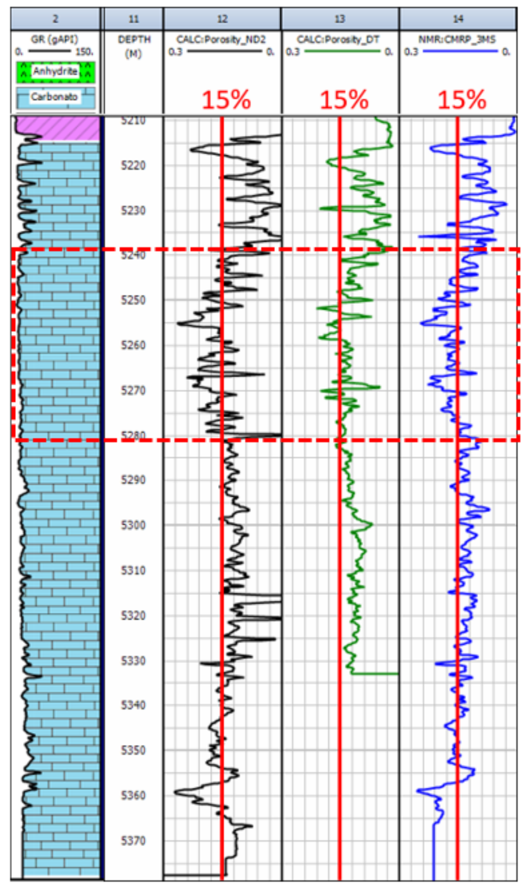

Figure 4 – Log assembled with density porosity curves (black - track 3), sonic porosity (green – track 4), and effective porosity from NMR (blue – track 5), in addition to the lithology with gamma ray (Track 1) and depth (Track 2).

Additionally, the neutron and density logs show an increase in porosity at the depth where traces of hydrocarbon were detected (Figure 5). The lithological characterization of these curves allows for the identification of the presence of the carbonate layer, which, as seen in Figure 4, is consistent throughout the well.

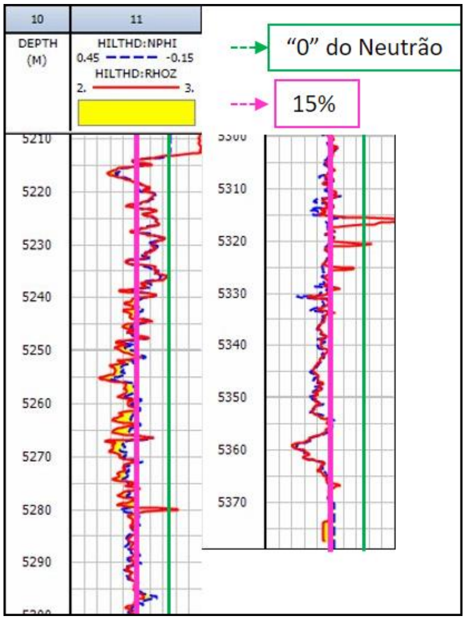

Figure 5 – Density-neutron log. The log displays density represented by a red curve and neutron by a dashed blue curve, with a green dashed line indicating the neutron reading for porosity. Since the Barra Velha Formation in this well is predominantly composed of carbonate, the porosity value can be directly read from the curve.

Conclusions

The two wells yielded valuable insights into the carbonate reservoirs of the Barra Velha Fm.

- 1-SHEL-26-RJS

The well's porosity values were found to be low, suggesting its unfavorable potential for hydrocarbon exploration. Analysis of the dominant carbonate composition revealed that the rocks were predominantly compact, thus confirming the observed low porosity. Consequently, these outcomes prompted the abandonment of the well as a plausible site for oil and gas extraction.

- 3-SHEL-27-RJS

The porosity analysis conducted in this well revealed a significant increase in porosity values between depths of 5240m and 5280m, indicating the presence of hydrocarbons. However, the presence of a compact rock at 5315m raises concerns about the connectivity of the oil column, which may potentially impact the productivity and overall viability of the well as an oil and gas prospect.

In conclusion, the analysis of the two wells provided valuable information regarding the carbonate reservoirs of the Barra Velha Formation. While the porosity values of well 1-SHEL-26-RJS indicated low potential for hydrocarbon exploration, the porosity analysis of well 3-SHEL-27-RJS showed a promising increase in porosity values, indicating the presence of hydrocarbons. Overall, these results provide important insights for future exploration and production efforts in the region.

Acknowledgments

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