Classification of porosity's type and permeability estimative on Aptian carbonate rocks using sonic and NMR logging tools

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Abstract

The main goal of this work was the classification of porosity type for carbonate rocks of aptian section using acoustic and nuclear magnetic resonance (NMR) logs. The adopted methodology (Anselmetti and Eberli.,1999) was applied on three wells which belong to the same basin. Besides the type porosity classification, this methodology also allowed to have a permeability trend curve for the area.

The good results obtained on these analyses bring up important information for the area. Moreover, the results assure a very important technical support for well evaluation while the rock data were not yet available, offering a more detailed knowledge of the permoporosity during the well appraisal period.

Introduction

Carbonate reservoirs, in general, have a large faciologic diversity and a complex porous system, due not only to the processes of formation of these rocks, but also to diagenetic processes suffered.

The identification of porosity's type, still in the preliminary stages of wells evaluation, may constitute an important tool to assist diagenetic and petrophysical studies.

The main goal of this study was to identify the predominant type of porosity, using the sonic log and a porosity curve coming from the NMR (Nuclear Magnetic Resonance) tool, in the Aptian carbonates of three wells belonging to the same basin.

The methodology employed is based on the results of Anselmetti and Eberli (1999), and in addition to identify different types of porosity it has also enabled the generation of a qualitative permeability curve indicating the principal regions of higher and low permeability.

We validated the method for permeability estimation by comparing the obtained results with the rock and PLT (Production Logging Tool) data.

Frequently, the porosity type information of carbonate rocks is not used during the evaluation phase of the well since it depends of rock data analysis, which can take a long time to be concluded. The same is applied to permeability, even when NMR tool is used, it is necessary a calibration of the NMR permeability curve with rock data for a more consistently indication of regions with different permeability trends.

Therefore, one of the main motivations for this petroacoustic study is to validate the methodology proposed by Anselmetti and Eberli (1999) for adquire the information of the porosity's type and permeability trends in carbonate rocks in a fast way, still during the logging phase. These procedures can offer an important technical support while the laboratory analyzes of rock samples are not completed or when they do not exist.

Object of analyse

In this paper we analyzed the Aptian carbonates of three wells (A, B and C) that belong to the Campos Basin. These carbonates belong to Macabu Formation, of Alagoas age, and Coqueiros Formation, of Jequiá Age, both from Lagoa Feia Group.

According to Winter et al. (2007) in Macabu Formation predominates microbial laminite and stromatolites, with localized dolomitization and/or silicification, with rare intercalations of sandy strata (Fig. 1-A). The carbonate sediments of this formation were unconformably deposited over the terrigenous sediments of the Coqueiros Formation or, more rarely, on the basaltic basement of the basin.

The Coqueiros Formation is represented by intercalations of layers of shale and lacustrine carbonates composed predominantly by bivalves (Fig. 2-B). These deposits of shells form thick porous layers, above 100 m, called coquinas bars. These packages were deposited in a high energy environment and constitute reservoirs producers of oil (Winter et al., 2007).

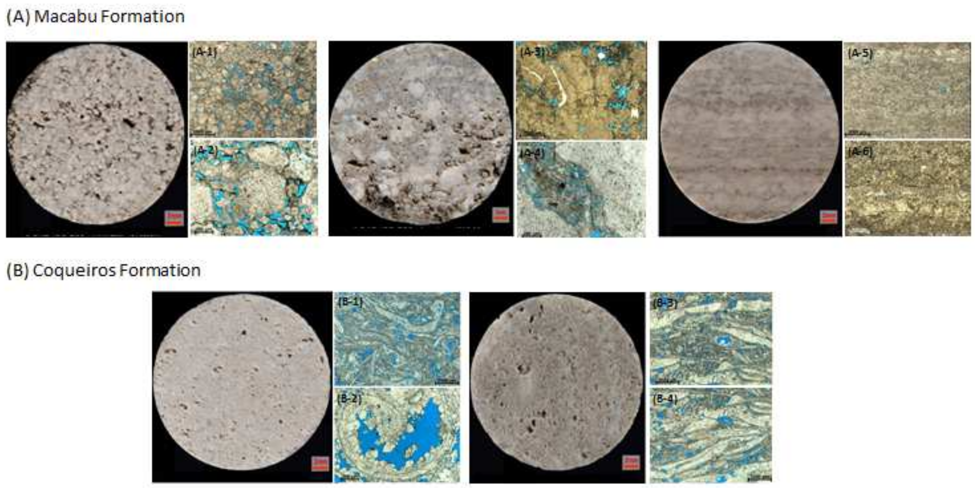

Figure 1 – Photos and petrographic thin sections in trasmitted light of some lateral samples of the well A from (A) Macabu Formation and (B) Coqueiros Formation. (A-1 and A-2) Spherulitite with intercrystalline and interparticle porosity, (A-3 and A-4) arborescent stromatolite with fenestral, inter and intracrystalline Porosity, (A-5 and A-6) nodular laminite with low intercrystalline porosity, (B-1, B-3 and B-4) Coquinas composed predominantly of bivalves e (B-1 e B-2) rare gastrópodes with interparticle and moldic porosity.

Excluído: –

Porosity's type classification

In the 1950s, Wyllie and other researchers found an empirical relationship between the total porosity of a sedimentary rock and the value of the transit time of a compressional wave (P-wave) along this same rock (Wyllie *et al*., 1956; Wyllie *et al*., 1958; Mavko *et al*., 2009; Rosa, 2010; Abreu, 2010).

This relationship is called "The Wyllie Equation" and, in terms of speed, it is written as follows:

$$\frac{1}{V_{rock}} = \frac{\phi}{V_{fluid}} + \frac{1-\phi}{V_{matrix}} \quad \text{..(1)}$$

Where:

- V_{rock} is the P-wave velocity along the rock;
- V_{fluid} is the P-wave velocity along the fluid that is present inside the rock's pores;
- V_{matrix} is the P-wave velocity along the rock's matrix;
- ϕ is the rock's total porosity.

With this equation, it is possible to find the P-wave velocity from the measured porosity. This velocity is commonly called V_{phi}.

The difference between the velocity directly measured V_{mes} and the calculated V_{phi} is called "Deviation" (Equation 2).

$$DEVIATION = V_{mes} - V_{phi} \quad \text{.................................(2)}$$

From Anselmetti and Eberli (1999), it is possible to identify the porosity's type in carbonate rocks through the deviation values as shown below:

• DEVIATION>500m/s or "Positive Deviation" indicates carbonate rocks with high diagenetic prosses: moldic, intrafóssil or vugular porosity. These range of Deviation values also may indicate an intense cementation level on rock.

• -500m/s<DEVIATION<500m/s or "Null Deviation" indicates carbonate rocks with interparticle or intercrystaline porosity, or with a high microporosity level.

• DEVIATION<-500m/s ou "Negative Deviation" indicates open fractures on rocks, which may cause a great decrease at V_{med}.

Once the Deviation curve suggests more than one interpretation, the results should always be examined in conjunction with other data, such as petrographic thin sections. It is important to emphasize that this methodology is only valid for carbonates.

To apply this methodology on the analyzed wells, were used:

- The sonic log data to obtain $V_{mes;}$
- The NMR total porosity as ϕ ;

- The average of P-wave over the fluid and matrix components to obtain V_{fluid} and V_{matrix}, respectively.

The deviation log curve from well A and B is displayed on track 2 of figure 2. This track is divided into three regions: brown, green and yellow corresponding to negative, null and positive deviation, respectively.

Through these colors, it is possible to check on the track 3 of the same figure 2, the deviation region belonging to each depth along the well.

The porosity's type obtained through rock samples description for each well is also indicated on track 2 of these figures by a red spot at the respective depth and on a deviation region corresponding to the porosity's type described.

The samples chosen for this analysis were those that have a non-negligible porosity. Those whose total porosity were considered very low in the laboratory reports were discarted. This choice is justified once rocks with very low porosities don't have a sufficiently pore quantity to cause a significant difference on V_{mes} due to changes on the porosity's type.

The criteria used to classify the samples from the reports was to describe them as having a positive deviation if they have any quantity of moldic or/and vugular porosity. The samples were classified as having null deviation if they possessed only intragranular or intercrystalline porosity, or microporosity.

The average hit rate on the classification of porosity's type throughout the three wells was 75%. From a total of 230 samples, 182 were classified in a manner consistent with what was found in the data analysis of rock.

On this work, the cut-off value used to divide the different deviation regions and that best fitted to the rock data, according to the adopted criteria of analyze, was ± 400m/s.

Although some samples were classified with positive deviation and correctly identified, some samples with moldic or vugular porosity also present intercrystalline or intergranular porosity, or high microporosity. In this case, the deviation will be greater or smaller depending on the predominant porosity's type, while still remaining in the positive region (deviation> 400m / s, yellow region). This is due to the fact that the deviation reflects the predominant porosity's type on the rock (Eberli et al., 2003).

This can be observed in the analysis of well B (Figure 2). A sample classified as having only moldic porosity, located at a depth of xx92,3m, has a deviation value of 1193m/s, while another sample classified as having intercrystalline and moldic porosity, located at a depth of xx85, 6m, has a deviation value of 430 m/s. As the relative amount of moldic porosity front intercrystalline porosity decreases, the deviation value decreases, until the sample has only intercrystalline porosity and a null deviation (-400m / s <deviation <+400 m / s, the green region). This behavior can be seen with the sample located at a depth of xx54, 5m which have a deviation value of 275m / s (Abreu, 2010).

On well B, we can see a negative deviation in the region of xx80m and xx90m of depth. This negative deviation is consistent with open fractures found in the same region through the acoustic image tool (Figure 3).

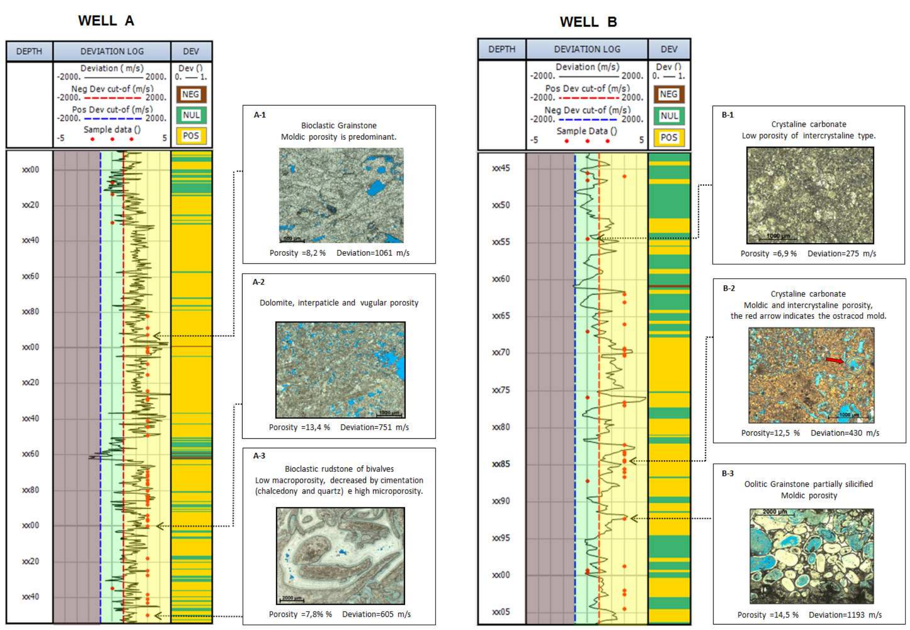

Figure 2 – Comparison between the porosity's type obtained by the methodology adopted and what was verified through rock data analyze for an interval of wells A and B.

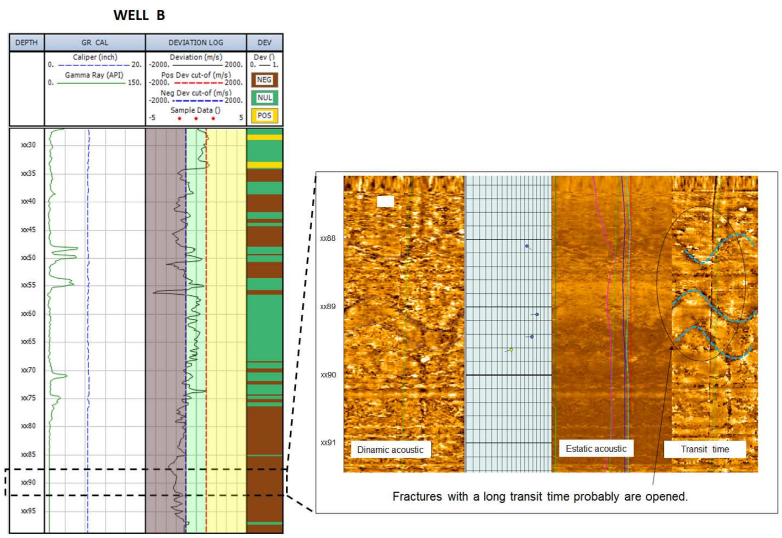

Figure 3 – Acoustic image logging tool indicates the presence of opened fractures at the same interval where deviation log presents a negative value on well B.

The analysis in this work suggests that, from the good correlation of the results with the rock data, the methodology proposed by Anselmetti and Eberli (1999) is valid for the carbonates of Aptian section in the region of analyzed wells.

The deviation log curve and the permeability

The deviation log curve, obtained for each well, suggests a possible relationship of direct proportion to the permeability curve obtained through the magnetic resonance tool "nmrPerm," here called "K_NMR."

To investigate this relationship we made a crossplot of "log(K_NMR)" versus "Deviation" for all data adquired on the three wells. The crossplot suggests that relationship between these curves is linear (Figure 4). Even for Macabu or for Coqueiros Formation.

The points used on these crossplots belong only to areas in which it was possible to calibrate the "K_NMR" curve with a significant amount of rock data.

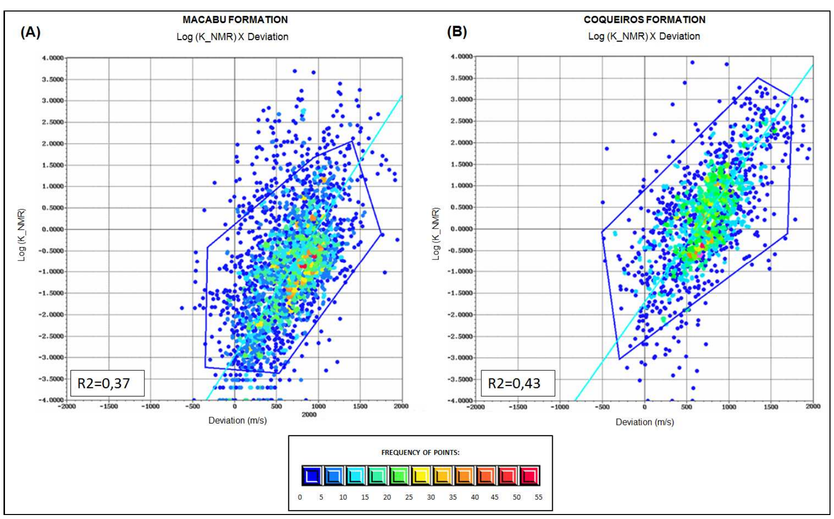

Figura 4 – Crossplot between the logarithm of permeability “K_NMR”, obtained through NMR logging tool calibrated for Timur-Coates using rock data, and the deviation log curve for (A) Macabu Formation and (B) Coqueiros Formation

The relation found in the crossplots of Figure 4 is different from that observed in the work of Ansemeltti and Eberli (1999), where variations in permeability values were inversely proportional to variations in deviation value.

One hypothesis for the direct proportion relationship seen in Figure 4 is that the majority of carbonate rocks which has been analyzed on these wells has moldic and vugs porosity with interconnected pores, which causes the permeability increases in accordance with deviation log curve.

It is important to emphasize that the work of Ansemeltti and Eberli (1999) was made for oolitic carbonates, which differ widely from microbial carbonates and coquinas studied here.

When setting a line regression to each of the crossplot of Figure 4, we obtained linear equations that relates "K_NMR" and "Deviation" for the analyzed region; for Macabu and Coqueiros Formations (Equations 3 and 4, respectively).

$$K_{MACABU} = 10^{(-2,9714 + 0,00304 \times Deviation)} \qquad (3)$$

$$K_{COQUEIROS} = 10^{(-1,7153 + 0,00276 \times Deviation)} \qquad (4)$$

Where the permeability (K) unit is “mD”, and deviation unit is “m/s”.

It was observed that the permeability curve generated with these equations, here called “K_Deviation” curve, shows the same trends of “K_NMR” curve.

The "K_Deviation" curve also seems to corroborate with the permeability values obtained by rock data.

To improve the results we also compared the “K_NMR” curve and "K_Deviation" curve with "PLT" data, which presents the interval contribution for each flow zone during well production.

This comparison was made with a mean over the permeability curves (calculated in a window of 15m) and displayed on a linear scale for a given producer interval on wells B and C (Figure 5). When compared, the "K_Deviation" curve provides a better correlation with the position of the observed flow on PLT data than the “K_NMR” curve.

From these results it can be concluded that using equations 3 and 4 is possible to obtain a qualitative curve able to identify the highers and lowers permeability zones for the Aptian carbonates analyzed.

This method was used to obtain the “K_deviation” curve for another well, called well D. This well belongs to the same region and still does not have any analyzed rock data. Comparing the PLT data, it is possible to see that the generated permeability curve indicates qualitatively the point of maximum production flow along the lower cannonaded interval, unlike the curve "K_NMR" (Figure-6)

Conclusion

The presented results in this study suggest that the methodology proposed by Anselmetti and Eberli (1999) can be successfully used in the region of the analyzed Aptian carbonates to identify the porosity’s types. Moreover, using this methodology it was possible to generate a curve that estimates qualitatively the permeability of the reservoir.

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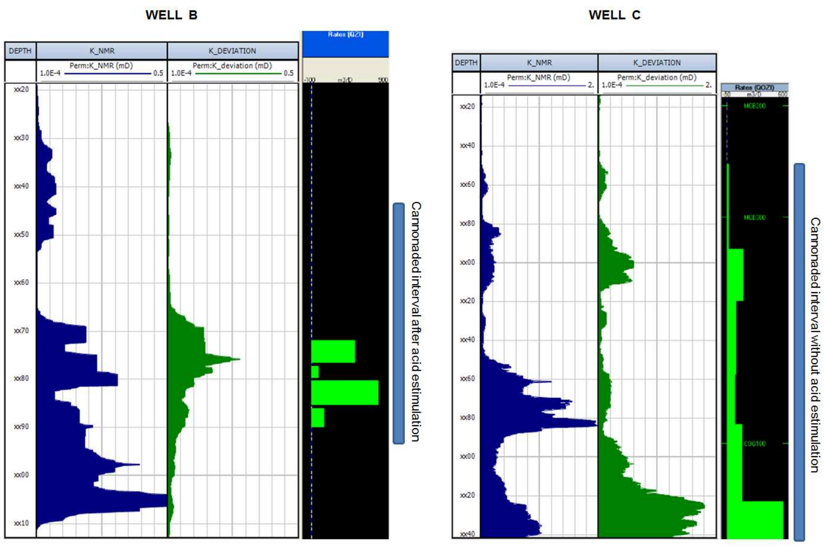

Figure 5 – Comparison between the permeability obtained from NMR (K_NMR), from the deviation log curve (K_Deviation) and PLT data, which presents the interval contribution for each flow zone during well production, for wells B and C.

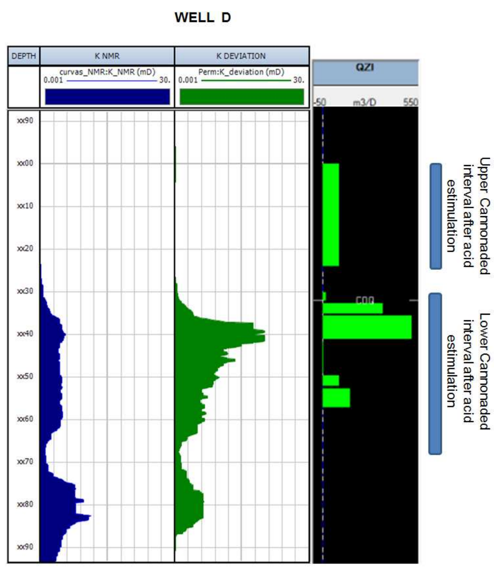

Figure 6 - Comparison between the permeability obtained from NMR (K_NMR), from the deviation log curve (K_Deviation) and PLT data, which presents the interval contribution for each flow zone during well production, for well D.

Since the methodology used just depends on the NMR total porosity and sonic log data, It is possible to use it along the evaluation phase of a well, anticipating information that usually depends on laboratory tests.

This methodology must be validated through rock analyses for region of interest before be applied in wells that still do not have rock data.

PLT data corroborate with the mean generated permeability curve, suggesting the effectiveness of the method. However, it is still necessary more studies to reach this confirmation. It is necessary to analyze a larger number of wells, verify the application of the method in other areas, as well as further investigation of the real reason for the good correlation between PLT dat and "Deviation" curve.

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