Electrofacies identification and evaluation in a well of the presalt of the Mero Field, Santos Basin

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Abstract

The importance of presalt carbonates reservoir in southeast of the Brazilian continental margin basins has been evidenced in the last decade. This paper aims to evaluate Barra Velha and Itapema formations analyzing well logs and sidewall samples for well 3-BRSA-1339a-RJS in Mero Field, in order to characterize reservoir properties. Different zones were identified and separated according to their properties from geophysical well log analysis. Then, estimate reservoir properties as clay volume, porosity, permeability and water saturation, which help to understand permo-porous characteristics and the individualization of reservoirs. Then, the electrofacies classification analysis was analyzed with the individualized zones and the reservoir properties. In this well, the Itapema Fm. presents clay content higher than the Barra Velha Fm., but the average permeability is 4 times higher in the Itapema Fm. In this sense, a good profile evaluation promotes the optimization of E&P processes, giving more robustness to the development of the field.

Introduction

The presalt province (Campos, Santos and Espírito Santo basins) was responsible for over 50% of the national production in 2018, and the Santos Basin led this production with the reservoirs of the Barra Velha and Itapema formations (ANP).

The presalt reservoir genesis and evolution are a geological puzzle due to their huge extension, volume and unusual textural and compositional features (Herlinger et al., 2017). Several authors (Dias, 2005; Moreira et al., 2007; Carminatti et al., 2008; Buckley 2015) have studied the tectonic and sedimentary evolution of Santos Basin, and one major challenge is to understand the heterogeneities and characterize the presalt reservoirs.

This paper aims to identify and individualize the presalt reservoir zones in the Barra Velha and Itapema Formations of the Mero Field, Santos Basin. For this, a workflow is presented to estimate the reservoir properties and to associate the electrofacies with these properties and the defined zones.

Methodology

The nuclear magnetic resonance (NMR) and conventional logs were correlated to individualize the best reservoir intervals, to estimate the electrofacies and the reservoir properties (clay volume, total effective porosities, water saturation and net pay) in Well 3-BRSA-1339A-RJS of the Mero Field (Figure 1).

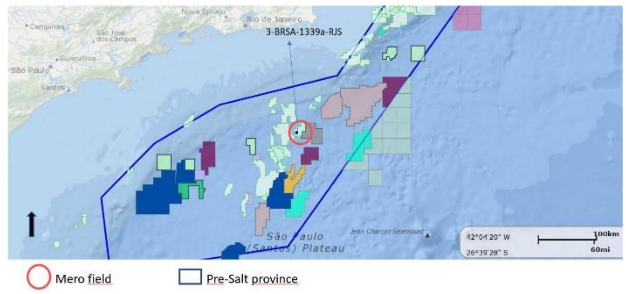

Figure 1: Location of the Mero Field and the well 3-BRSA-1339A-RJS.

The workflow used to evaluate the Barra Velha and Itapema formations was divided in eight stages (Figure 2): data loading and quality control, NMR analysis, well logs parameters definition, clay volume estimation (V_{clay}), water saturation calculation, electrofacies determination, net pay calculation and identification of zones.

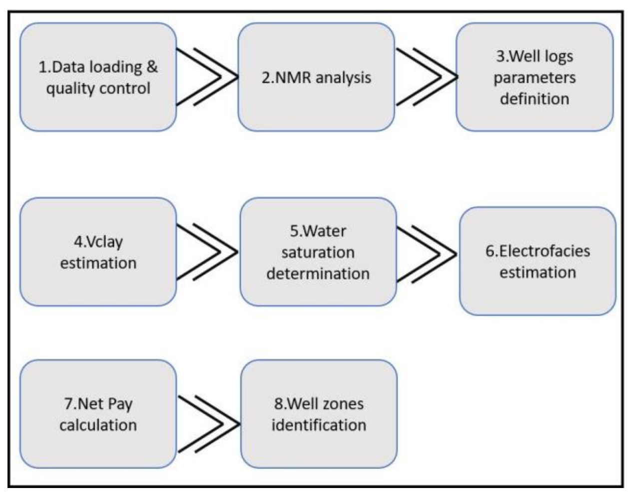

Figure 2: Workflow used to evaluate Barra Velha and Itapema formations.

1. Data loading and quality control

First, the data were checked and spikes were removed, missing data correction, depth shift (if necessary) and confirm orientation and sampling.

NMR analysis

T2 distribution, total and effective porosities, and free fluid logs were used to analyze reservoir properties. Another relevant data was gamma-ray spectrometry (SGR). The logging tool used was CMR™ from Schlumberger.

2. Definition of well log parameters

Formation temperature (FTEMP) and Formation pressure (FPRESS) were estimated from temperature and depth of different well depths presented in drilling reports.

3. Clay volume estimation

The Larionov Method (1969) was used to clay volume estimation (V_{clay}). It is necessary to calculate the gamma ray index (GRI) to use this method:

$$\mathrm{GRI} = \frac{\mathrm{GR} - \mathrm{GR_{min}}}{\mathrm{GR_{max}} - \mathrm{GR_{min}}}, \qquad (1)$$

where GR is the value measured by the gamma ray log, and $\mathrm{GR_{min}}$ and $\mathrm{GR_{max}}$ are, respectively, the minimum and maximum values of the GR.

The Larionov (1969) equation for old rocks to estimate of clay volume is:

$$V_{clay} = 0{,}33\left[2^{2{,}0\times \mathrm{GRI}} - 1\right]. \qquad (2)$$

4. Water saturation determination

The water saturation was calculated from the Archie equation (Archie, 1942):

$$\mathrm{Sw^n} = \frac{\mathrm{aRw}}{\phi^{\mathrm{m}}\mathrm{Rt}}, \qquad (3)$$

where m is the cement exponent, n is the saturation exponent, and ϕ is the NMR total porosity. The m and n values were obtained from a neighbor well, where these values were measured in laboratory.

5. Electrofacies determination

The method used to estimate the electrofacies was the Multi-Resolution Graph-based Clustering (MRGC) (Ye and Rabiller, 2000).

MRGC is a multi-dimensional dot-pattern-recognition method based on non-parametric K-nearest neighbor (KNN) and graph data resolution. This method analyzes the data in an unsupervised manner and separate them into clusters, optimizing the number of clusters by logs used as input.

The gamma ray (GR), density (RHOB), neutron (NPHI), photo-electric factor (PEF) and sonic (DT) logs were used as input for clusters classification. No sampling nor clusters control were used in order to avoid bias in this process.

Three clusters with six, eight and twelve electrofacies were created. The cluster with eight electrofacies was chosen to analyze the individualized zones and the reservoir properties.

6. Net pay calculation

The following parameters were used for the net pay:

Effective porosity (PHIE)>= 0.06; Water saturation (Sw) <= 0.6; and clay volume (V_{clay}) <= 0.2.

7. Well zone identification

Finally, the Barra Velha and Itapema formations were segmented based on the analysis of well logs.

Results and Discussion

Table 1 presents the thickness, total and effective porosities, clay volume, permeability and net pay in the Barra Velha and Itapema formations of well 3-BRSA-1339A-RJS. Although both formations have similar porosity, Itapema Fm. presents higher permeability even having higher V_{clay}. This higher V_{clay} impacted the thickness of the net pay

Table 01: Comparison between the reservoir properties of the Barra Velha and Itapema Formations.

Properties	Barra Velha Fm.	Itapema Fm.
Thickness	289.5 m	235.5 m
Reservoir thickness	202.1 m	169.7 m
Total Porosity	14%	14%
Effective Porosity	13.2%	13,1%
Permeability	113.13 mD	444.93 mD
Clay Volume	4%	7%
Net pay	**190m**	**153m**

Figure 3 shows original and estimated logs of the well 3-BRSA-1339A-RJS in the Barra Velha and Itapema formations.

Ten zones or intervals were identified in the Barra Velha Fm. from the analysis of the well logs:

In the Barra Velha Fm. was identified ten zones from the analysis of the well logs: 1- from 5311 to 5350 m; 2- from 5350 to 5379 m; 3-from 5379 to 5435 m; 4- from 5435 to 5442; 5-from 5442 to 5468; 6- from 5468 to 5488; 7- from 5488 to 5503; 8- from 5503 to 5530; 9- from 5530 to 5545 m 10- from 5545 to 5587 m.

In Itapema Fm. was identified eleven zones (11-21), 11- from 5587 to 5605 m; 12- from 5605 to 5621.15m; 13- 5621.15 to 5631 m; 14- 5631 to 5667m; 15- from 5667 to 5681m; 16- 5681 to 5697m; 17- from 5695 to 5723 m; 18- from 5723 to 5731 m; 19- from 5731 to 5755 m; 7; 20- from 5755 to 5767m; 21- from 5767 to 5827 m.

Zones 01, 02 and 03 show low values for GR, but the spectral gamma ray (SGR) shows a gradual increase of uranium (U). Zone 02 differs in the behavior of the PEF, which is more "serrated", and DT and RHOB also present higher values. Total (PHIT) and effectivity (PHIE) porosities and free fluid (FF) are similar for these three zones.

Zones 04, 11 and 15 show the lowest values of RHOB, high values of DT. These zones have the best response of NMR logs for the Barra Velha and Itapema Formations. PHIT overpass 20%, the difference between PHIT and PHIE is low, and FF has high values.

Zones 05 to 10 present a slightly increase in thorium (Th), but potassium (K) content (SGR) is still low. In these zones the GR rarely exceeds 60º API. Apparently, GR has some cyclicity. Zones 06, 07, 08 and 09 present a decrease in resistivity, impacting water saturation (SW). There is also a high reduction of porosity.

Zones 17 and 19 present the highest V_{clay} in the analyzed formations. GR reaches around 90º API, SGR shows high K content, resistivities are low and the NMR logs present a high decrease, impacting the SW and, consequently, net pay.

In zone 21, there is a large reduction in FF and an increase in difference between the PHIT and PHIE. Zone 20 presents higher porosities and FF. The other logs show a similar behavior in both zones, with the exception of DT that presents a gradual decrease in zone 21.

When analyzing the descriptions of sidewall samples, the upper zones of the Barra Velha Fm. show predominantly stromatolites and spherulites. After the zone 08, there is an increase of grainstone and stromatolite, and a gradual reduction of spherulite. Itapema Fm. has no spherulite nor stromatolite, and there is a large number of grainstone samples. It is also important to emphasize the number of mudstone samples in zones 17 and 19, which the GR is higher than in other areas.

The GR, RHOB, NPHI, PEF and DT logs were used as input for the Multi-Resolution Graph-based Clustering (MRGC). The number of clusters chosen for the electrofacies was 8. The crossplots of reservoir properties (V_{clay} versus PHIT; DT versus V_{clay}; and DT versus PHIE) were colored according to the electrofacies, and splitted in Barra Velha and Itapema formations., as showed in Figure 4.

The crossplot analysis allowed to characterize the properties of the electrofacies. In the Itapema Fm., the electrofacies 8 indicates a higher V_{clay} (30-100%), with a high scattering of DT (50-95 us/f) and low porosity (1-12%), correlated with the greater presence of this electrofacies in zones 17 and 19.

The electrofacies 7 has a more assembled way, in both formations, presenting low V_{clay} (3-18%), porosity (5-10%) and DT (53-62 us/f).

The use of porosity and DT logs allowed establish boundaries to identify electrofacies 1, 2, 3 and 5, although data present more assembled in the Barra Velha Fm. while more scatter in the Itapema Fm. Electrofacies 1 has better porosities and higher values of DT.

Excepting electrofacies 8, all other electrofacies have V_{clay} values below 30%.

The electrofacies 4 and 6 could be merged considering its similarity. V_{clay}, porosity and DT values of these electrofacies are similar in both formations

Conclusions

The reservoir properties (clay volume, total and effective porosities, oil saturation and net pay) were calculated to better characterize the Barra Velha and Itapema formations in well 3-RJS-1339A-RJS. It was possible to individualize the Barra Velha Formation in ten zones and Itapema Formation in eleven zones, according to electrofacies evaluation. The zones with better reservoir properties are 4, 11, 15. While zones 17, 19 compromised of more clay, and zone 21 presents a reduction in free fluid. It has not yet been possible to identify the reason for this reduction with the available data. The best electrofacies with respect to the reservoir properties were also identified and correlated to the zones.

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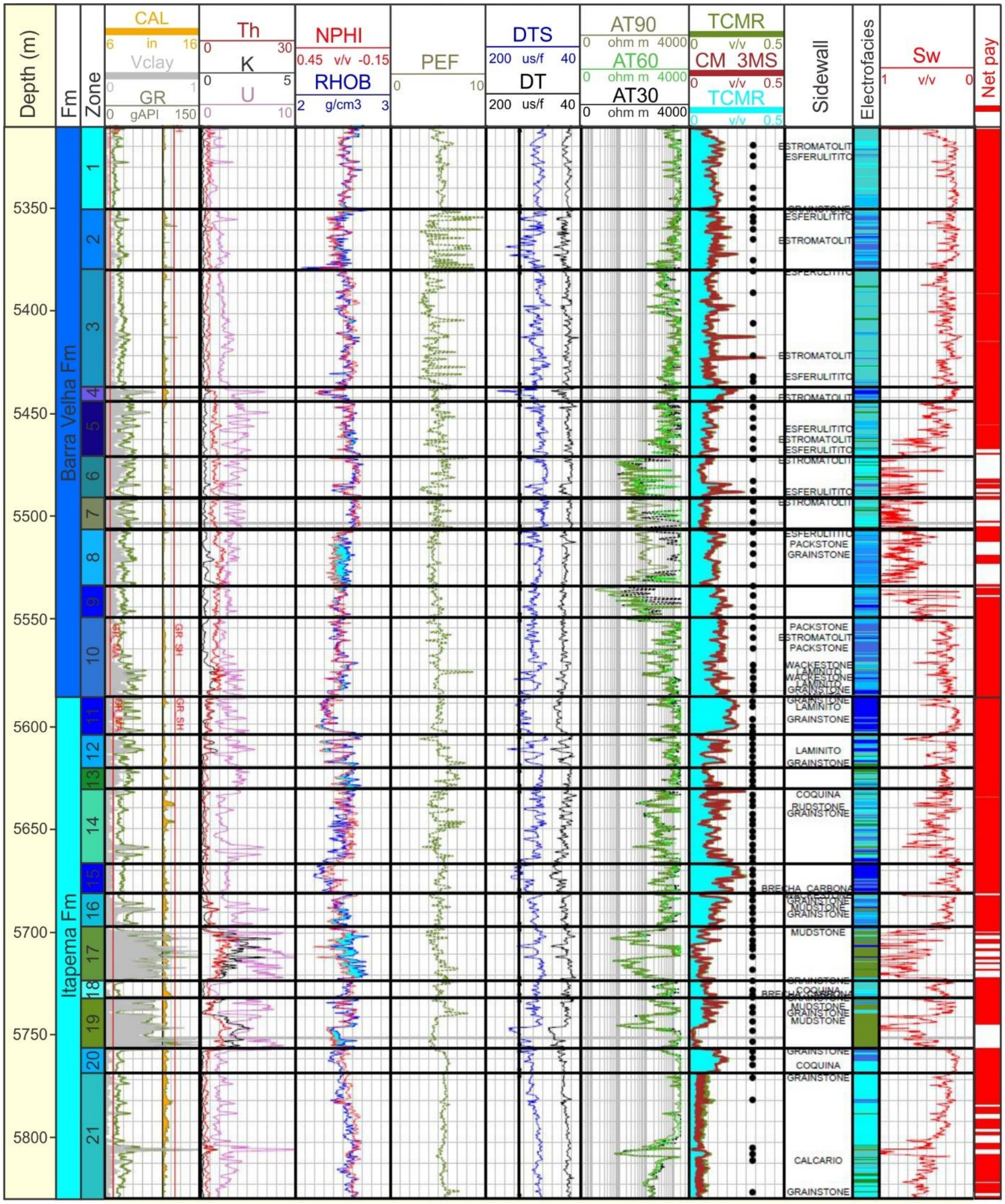

Figure 3: Evaluation of well 3-BRSA-1339A-RJS. Tracks:1) Depth; 2) Formations; 3) Zones; 4) Gamma ray (GR), Clay volume (V_{clay}) and Caliper (CAL); 5) Spectral gamma ray: thorium (TH), potassium (K) and uranium (U); 6) Density (RHOB) and neutron (NPHI); 7) (PEF); 8) Sonic (DT) and sonic shear (DTS); 9) Resistivities: shallow (AT30), medium (AT60), and deep (AT90); 10 NMR logs: total porosity (PHIT), effective porosity (PHIE), free fluid (FF) and sidewall core; 11) Sidewall core lithology; 12) Electrofacies; 13) Water saturation (SW);14) Net pay.

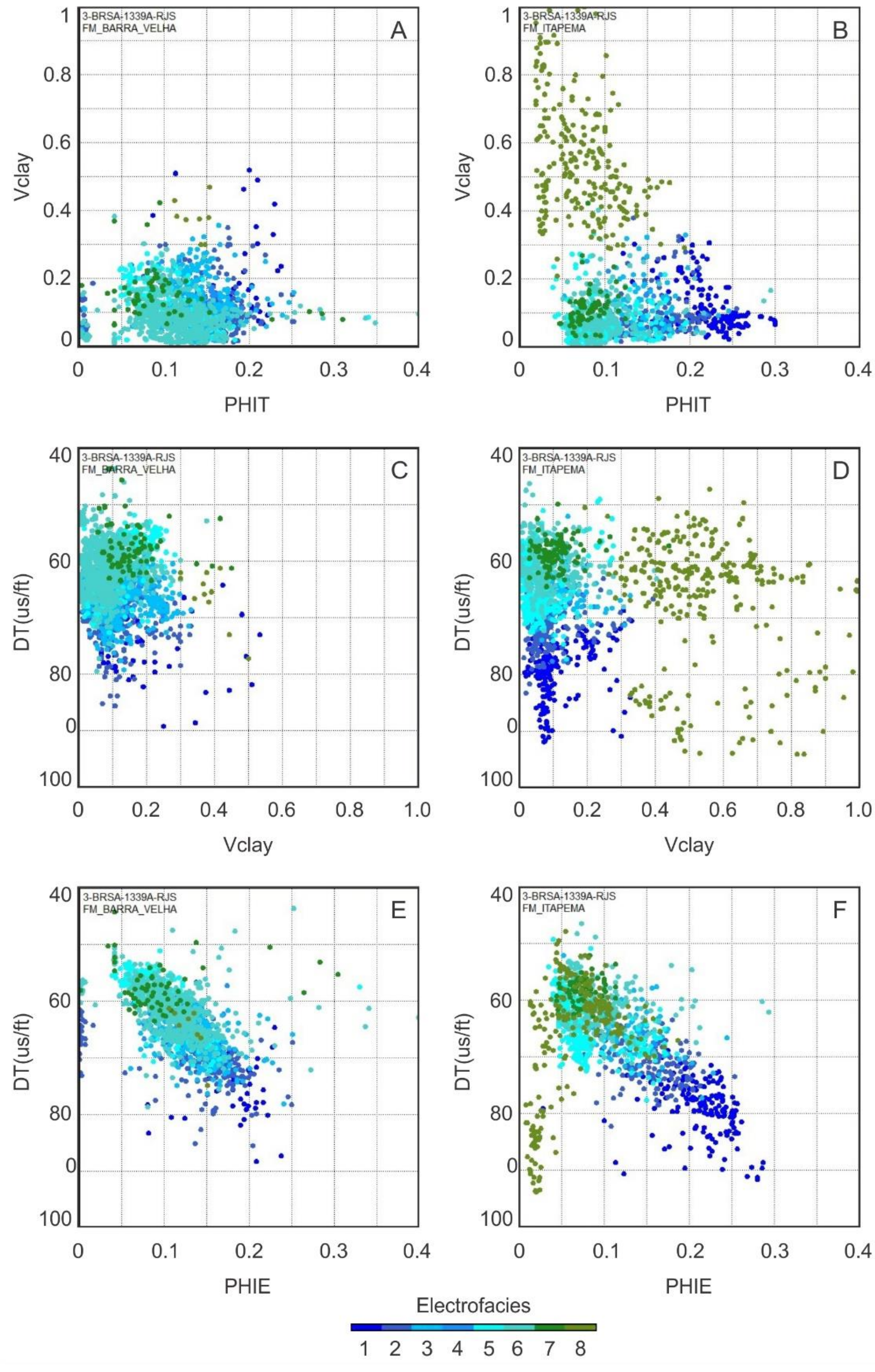

Figure 4: Clay volume (V_{clay}) versus total porosity for the Barra Velha (A) and Itapema (B) Formations; (PHIT). Sonic (DT) versus clay volume (V_{clay}) for the Barra Velha (C) and Itapema (D). Sonic (DT) versus effective porosity for the Barra Velha (E) and Itapema (F) formations.