Influence of clay volume estimation on net-pay in well 6-BRSA-497-ESS, New Jubarte Field, Campos Basin

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Abstract

Clay volume estimation is an important stage in reservoir characterization. Some areas show specific characteristics that can mask important information about clay volume. We present a comparison of the impact on the net-pay between clay volume estimation in turbidite sandstones from Larionov method for old rock and the method based on neutron and density logs. A well in the New Jubarte Field, Campos Basin, was chosen for that objective. The analysis of the impact of the both estimations on net-pay was performed and the results show that the method using neutron and density logs is the most suitable for the study area due to the presence of feldspar. In addition, Larionov's method proved to be very pessimistic on net-pay and without correspondence with the other logs.

Introduction

Campos Basin is one of the most important areas for petroleum exploration in Brazil. The beginning of the exploration is from 1950s in shallow waters with Petrobras campaigns for geophysical data acquisition. Now, it is the second petroleum and natural gas most producer basin in Brazil (ANP, 2020).

The oil discovery in the post-salt of the Parque das Baleias Complex, named as New Jubarte Field, was made on the year 2001 in the Cachalote, Baleia Franca, Jubarte, Baleia Azul, Baleia Anã, Pirambu and Caxaréu fields. Also, on 2001, in the Jubarte Field was made the first discover of petroleum in the presalt with the well 1-ESS-103A (Morais, 2013).

Turbidites reservoirs of post-salt are one of the most important in the Campos Basin. These reservoirs were the most producer of oil in the basin during many years. Turbidites reservoirs of the Carapebus Fm. are clean fine-to-gross sands with excellent permo-porous potential. An important aspect is that these reservoirs are arcosean sandstones with presence of feldspar in their composition (Winter et al., 2007).

In the oil and gas industry, the methods of exploratory evaluation on open-hole wells are based in well logging and formation tests. From the recorded signals by the sensors in wells, it is done the interpretation of the interest reservoir properties like clay volume, porosity, permeability and water saturation (Nery, 1990). Clay volume estimation is usually done using the gamma ray log (GR), which is linked with the natural radiation of rocks. Shales have high volume of radioactive elements like K_{40} and for this reason the records of GR log tend to increase in this lithology (Nery, 1990). GR log has been widely used over time for distinguish between clean and clayey formations (Rider and Kennedy, 2002; Freire et al., 2020). However, in newer rocks, the diagenetic effects are low and the presence of radioactive elements of potassium like feldspar and micas is high. This provides high radioactivity that is not related to clay minerals (Nery, 1990).

The objective of this work is to compare two methods to estimate clay volume one from the GR log and the other from the density and neutron logs. The latter is not influenced by the presence of feldspar. Then, we carry out analyzes these estimates, in three reservoir zones, on the net-pay calculation

Method

Well 6-BRSA-497-ESS, located in the New Jubarte Field, Campos Basin (Figure 1), was used in this work for evaluation of Eocene reservoirs. We individualized the Carapebus Formation in: Carapebus I, II, III and IV. For each one of them was done the estimation of the reservoir properties: clay volume, water saturation and net-pay, according to the workflow showed in Figure 2.

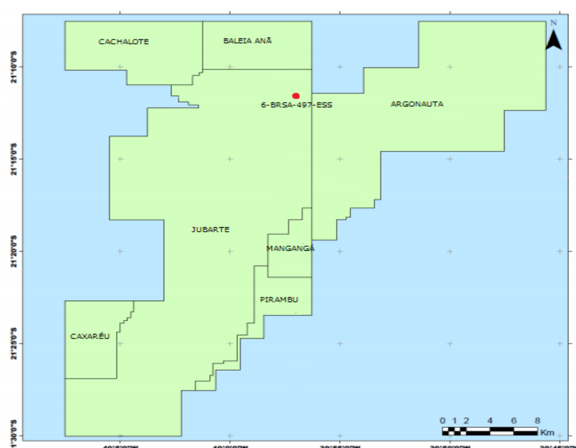

Figure 1: *Location of well 6-BRSA-497-ESS and the limits of New Jubarte Field, Campos Basin.*

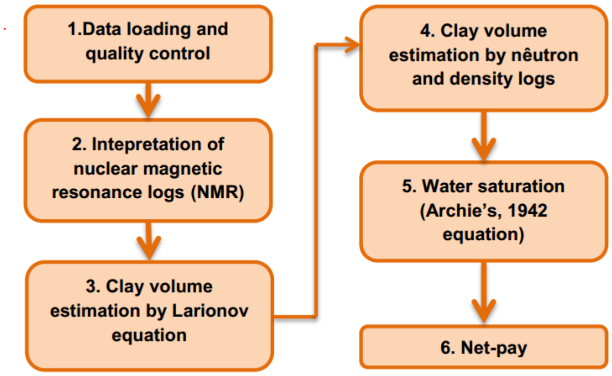

Figure 2. *Workflow used for reservoir properties estimation in the Carapebus Fm., well 6-BRSA-497-ESS.*

1. Data loading and quality control

We verified the data acquisition type (Logging while drilling or wireline) and the sample rate of the logs. The gaps in the curves were filled and was made an analysis of caliper and bit size logs.

2. Interpretation of the nuclear magnetic resonance logs (NMR)

T2 distribution, total and effective porosities, free fluid and permeability logs were used for reservoir properties analysis. In Carapebus IV (3186/3514 m), the NMR logs are available only in between 3186/3368 m. Thus, we performed the net-pay only in this interval.

3. Clay volume estimation from Larionov equation

The method for clay volume estimation using the GR log is based on the definition of sand (GR_{min}) and shale (GR_{max}) baselines. As the GR log is a statistical measurement, the values of GR_{min} and GR_{max} should be, respectively, the averages of the minimum and maximum of this log.

The gamma ray index (GRI) is given by:

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

where GR are the measurements of log. Then, IGR is used for the clay volume (V_{CLGR}) calculation from with Larionov (1969) equation, for old rocks:

$$V_{CLGR} = 0.33 \times \left[2^{2 \times IGR} - 1\right]. \quad (2)$$

An important aspect of this calculation is the definition of the GR_{min} value. In general, this value is low for clean sands. However, analyzing the composite profile description of the rocks, the lithological information of the study area and performing a statistical analysis of GR log, was chosen to use high values of GR_{min} for the four occurrences of the Carapebus Fm. This is because the Carapebus Fm. is a clean formation with presence of feldspar (Winter et al., 2007).

4. Clay volume estimation from neutron and density logs

The use of neutron and density logs to clay volume estimation tends to be beneficial in formations without gas. This is because the neutron log is sensible to the hydrogen presence in clay, while the density log does not. Besides that, quartz, calcite and dolomite minerals do not have high hydrogen volume (Paiva, 2019).

For estimation of clay volume from density (RHOB) and neutron (NPHI) logs, we used the equation:

$$V_{CLND} = \frac{X_1 - X_2}{X_3 - X_4}, \quad (3)$$

with:

$$X_1 = (RHOB_{cl2} - RHOB_{cl1}) \times (NPHI - NPHI_{cl1}), \quad (4)$$

$$X_2 = (RHOB - RHOB_{cl1}) \times (NPHI_{cl2} - NPHI_{cl1}), \quad (5)$$

$$X_3 = (RHOB_{cl2} - RHOB_{cl1}) \times (NPHI_{clay} - NPHI_{cl1}), \quad (6)$$

$$X_4 = \left(RHOB_{clay} - RHOB_{cl1}\right) \times (NPHI_{cl2} - NPHI_{cl1}), \quad (7)$$

where the values of $NPHI_{cl1}$, $NPHI_{cl2}$, $RHOB_{cl1}$ and $RHOB_{cl2}$ were defined by the limits of the line that indicates the zero clay volume in NPHI and RHOB crossplot. $NPHI_{clay}$ and $RHOB_{clay}$ were defined by the point that indicates 100% of clay volume.

5. Water saturation

We used the Archie (1942) equation for water saturation calculation:

$$Sw^n = \frac{aRw}{\varphi^m Rt}, \quad (8)$$

where for the parameters m (cementation exponent), n (saturation exponent) and a were used common values for sandstone, φ is NMR effective porosity and Rw was selected from Pickett-plot (1973) technique.

6. Net-pay

We used the following parameters for net-pay calculation: Vclay ≤ 0.20, φ (effective porosity) ≥ 0.15 e Sw ≤ 0.50.

Results and Discussions

Figures 3 and 4 show the results for the evaluation of reservoir properties in well 6-BRSA-497-ESS. Carapebus I was discarded because the caliper and bit size logs are compromised, a possible breakout zone where well logs may be less reliable. Caliper (CAL) log is not compromised at other intervals, with exceptions of some breakouts in the Carapebus II, which does not have relevant influence on the quality of well logs. Performing a quick visual analysis, we observe that the GR log cannot differentiate arcosean sandstone of the Carapebus II, III and IV and the shales of the Ubatuba Fm.

In general, both methodologies of clay volume estimation show close results for Carapebus II, however for Carapebus III and Carapebus IV the results are very different.

Carapebus II and III show high GR and resistivity values, a medium sonic travel time (DT). GR presents a more variant behavior in the Carapebus III than Carapebus II. We interpreted these zones as a clean sandstone interval with some clay laminations due to neutron-density crossover. Free fluid and permeability are high and the water saturation is low in both intervals.

Carapebus IV was divided in two intervals based on data trends. At 3186/3304 m, the GR and resistivity logs are low and the neutron-density crossover indicates an interval of more closed sandstone when compared to Carapebus II and III. Free fluid and permeability are moderate and water saturation is high. At 3304/3368 m shows a decrease in free fluid volume and permeability, and an increase in GR.

Lower DT values in the Carapebus IV than the Carapebus II and III can be related to the compaction and cementation effects, because it is at a greater depth and has less porosity. The water saturation is also higher in the Carapebus IV, which helps to decrease DT.

The difference between total and effective NMR porosities represents the micropores. Analogously, the difference between effective NMR porosity and free fluid is the mesopores (Castro, 2019). Figure 3 shows that the higher decreases in macroporosity are associated with high clay volume from neutron and density logs (V_{CLND}). It is not observed this correspondence with the clay volume from GR (V_{CLGR}), because in the 2810/2821 m interval the NMR porosities are the same, indicating only macroporosity, and V_{CLGR} is high.

Figure 4 shows that both clay volume estimates in the Carapebus IV consider the 3304/3368 m interval with higher clay volume than 3186/3304 m. This clay volume increase is the cause of decrease in free fluid and permeability. Table 1 shows the mean values of reservoir properties. The thickness and net pay of the reservoir for Carapebus II using V_{CLND} instead of V_{CLGR} increase 3.28m. Furthermore, the mean of effective and total porosities of reservoir increase, and there is a decrease in water saturation and clay volume.

Carapebus III presents the highest difference between the two methodologies. The reservoir thickness is 14.25m greater using V_{CLND}. This difference is, principally, between 2810/2821 m, where V_{CLGR} consider as clayey interval while V_{CLND} shows a clean sandstone. The results are similar for most the reservoir properties, except for clay volume. This causes an increase on net pay and HPhiSo (thickness x effective porosity x oil saturation) of 84.89% and 90.63% percent, respectively, when V_{CLND} is used. Despite a decrease in the thickness of the reservoir in the Carapebus IV when using V_{CLND}, this interval is completely saturated with water (more than 99.00%). GR at 3235/3304 m is slightly lower than in the Carapebus II and III, suggesting a lower presence of radioactive minerals, which may be due to a greater diagenesis effect.

In the Ubatuba Fm. shales, V_{CLND} estimate lower values of clay volume than V_{CLGR}. Thus, V_{CLGR} is the most indicated method for clay volume estimation on this well.

Table 1: *Reservoir properties mean values in analyzed zones.*

PROPERTIES	**CII**		**CIII**		**CIV**	
	GR	ND	GR	ND	GR	ND
Thickness (m):	46.0	46.0	34.0	34.0	328	328
Reservoir (m):	36.3	39.5	14.5	28.7	33.4	4.6
PHIT (%):	28.8	29.1	29.8	29.7	19.7	20.3
PHIE (%):	27.8	28.2	28.7	28.2	18.7	19.3
Sw_Archie (%):	33.7	32.8	21.4	22.3	99.1	99.6
Clay vol. (%):	9.0	7.3	8.3	4.7	7.2	18.1
HPhiSo (m):	6.3	7.0	3.2	6.1	0.0	0.0
Net pay (m):	30.8	34.5	13.9	25.7	0.0	0.0
Net/Gross (m):	0.67	0.75	0.41	0.75	0.0	0.0

Conclusions

Methods based on gamma ray logs for clay volume estimation, like Larionov method, are not indicated to be applied in formations with feldspar presence. They get more pessimistic results on net pay than methods based on neutron and density logs.

V_{CLND} showed more coherent with clay laminations described in lithological profile, and in intervals with high decrease on NMR porosities logs. Therefore, this is the most appropriate method for clay volume estimation in arcosean sandstones, as is the case in well 6-BRSA-497-ESS.

The approaches showed great differences, mainly in the Carapebus III, on net pay and HPhiSo. This can be determinant for investment of resources on new studies in the area. Thus, the integration of different data during the analysis is fundamental to reach the more realistic scenario.

Clay presence is the main cause of porosity decrease in the Carapebus Fm. intervals, even when the clay volume is low. The clay minerals compromise, principally, the macroporosity of rock, also causing a permeability decrease.

Carapebus II and III show great permo-porous characteristics and can be considered interest zones for oil exploration, while Carapebus IV shows fully saturated with water in the analyzed well.

Acknowledgments

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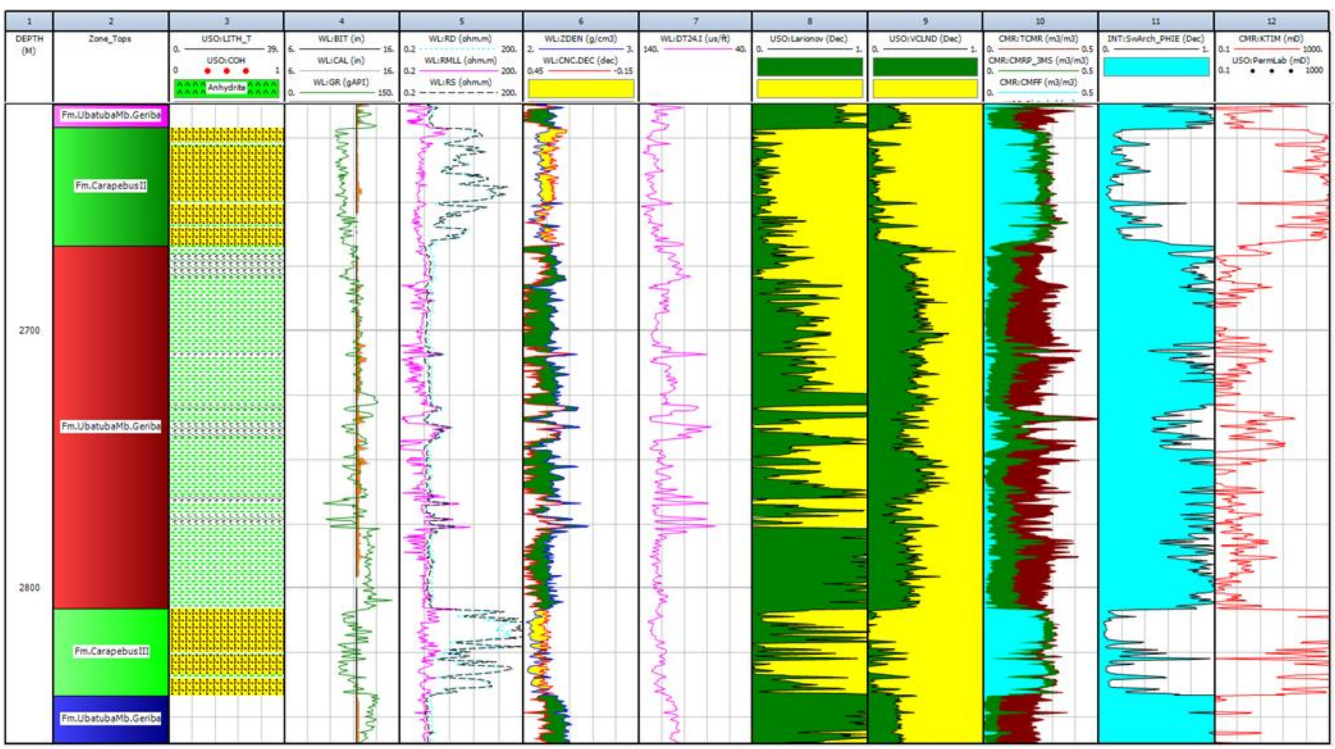

Figure 3: *Well logs for well 6-BRSA-497-ESS for the interval that comprises the Fm. Carapebus II and III. Tracks: 1) depth; 2) formations; 3) lithologies; 4) gamma ray (GR), caliper (CAL) e bit size (BIT); 5) deep resistivity (RD), shallow resistivity (RS) e resistivity from micro laterolog (RMLL); 6) density (ZDEN) e neutron (CNC.DEC); 7) sonic travel time (DT24.I); 8)*

Larionov clay volume; 9) nêutron and density clay volume; 10) nuclear magnetic resonance logs: total porosity (TCMR), effective porosity (CMRP_3MS) and free fluids (CMFF); 11) water saturation (SwArch_PHIE); 12) permeability (KTIM).

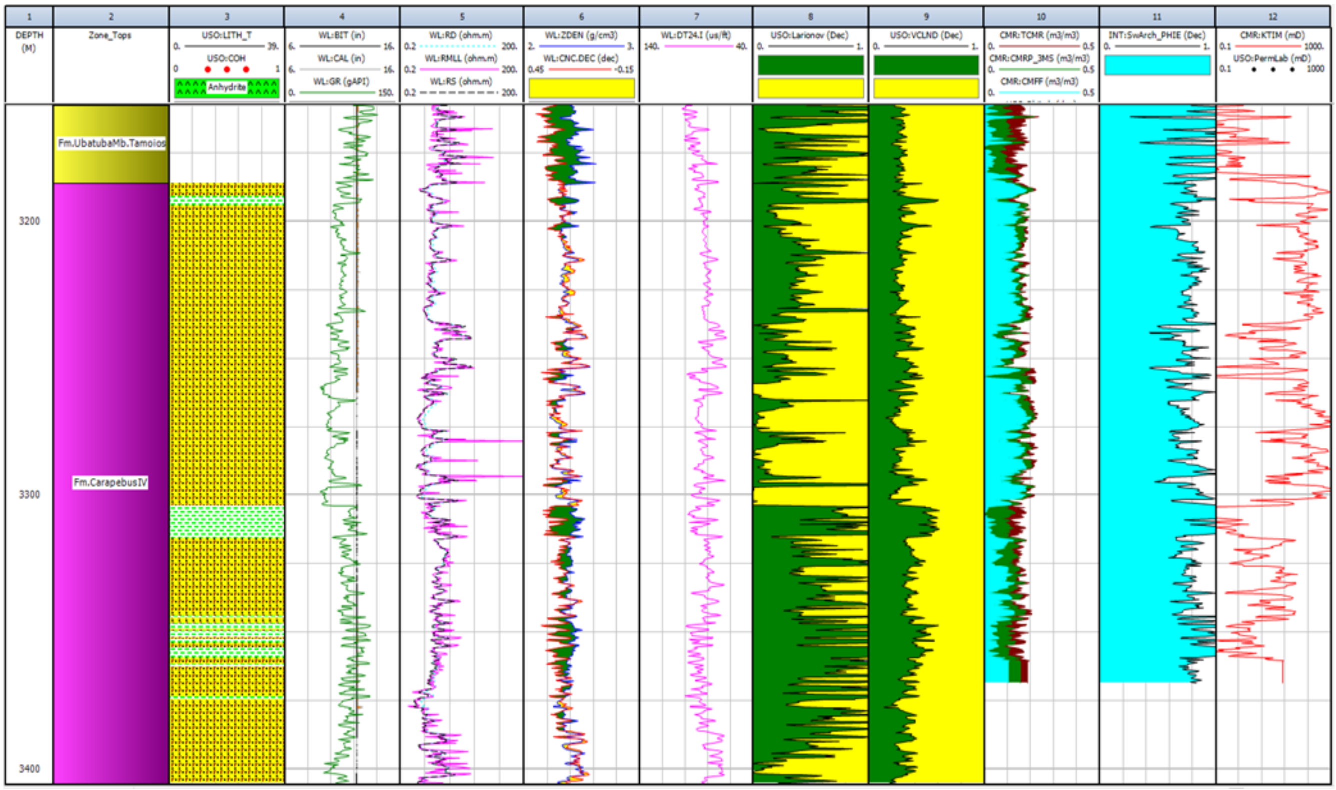

Figure 4: *Well logs for well 6-BRSA-497-ESS that comprises Carapebus IV Fm. with the same tracks that Figure 3.*