Well-logging Correlation – Analysis and correlation of well logs in Rio Grande do Norte basin wells

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Master thesis

Abstract
During drilling operations one can obtain, with coring, mud-logging and well logging, all the information needed to study a formation in terms of its physical characteristics. With well logging data concerning resistivity, gamma radiation, density, porosity, existing faults, underground wave velocity and dips is recovered and send up to the surface during and after drilling.
Well logging methods allow the establishment of porosity, saturation and, indirectly, permeability parameters in order to take conclusions about the existence and location, along the drilled hole, of pay zones rich in hydrocarbon to exploit.
The work centered on the analysis and correlation of provided logs from tree wells located in Potiguar Basin, Brasil, with the objective of pay zone identification and to explain similarities between logs in order to get a general definition of the drilled formations.
Software Petrel was used in order to make a correlation between the wells, after a previous analysis. The correlation was successful and allowed to take conclusions about the porosity, permeability and saturation of the formation, as well as a general characterization of the constituting rock.

Keywords: drilling; well logging; analysis; correlation; Potiguar Basin

1. Introduction
The proper knowledge of the petrophysical properties of a reservoir depends on the investment in coring or well logging. Logging allows the access to physical data of the formations while drilling occurs, sending it to the surface to be analyzed through the drilling fluid. All the data helps formation evaluation and, in this specific case study, will be used to estimate porosity, permeability and saturation of the formation drilled in three well located in the Potiguar Basin, Rio Grande do Norte.
The estimation will be based on the analysis and correlation of six chosen logs, of which data is present in the three wells.
2. Logging

The purpose of well logging is the acquisition of physical data of the formations drilled in order to figure out where the payzones are. A payzone is a hydrocarbon rich formation which can be explored with profit. A formation with payzone characteristics is porous, permeable and saturated with hydrocarbons, so logging’s final objective is the estimation of the porosity, permeability and saturation of the formations. Logging tools acquire data concerning the resistivity, gamma ray emission, neutron interaction, density, seismic wave velocity, temperature, inclination and azimuth of the formations.

These tools are nowadays mostly placed in the bottom-hole assembly, 3 to 20 meters above the drill bit and measure the properties of the formations as the bit advances, in a practice known as Logging While Drilling (Hearst et al., 2000).

Not only the inclination and azimuth of the formations is measured, the orientation of the bit is measured and corrected with the help of a technique called Measurement While Drilling. MWD helps the driller reaching his objective in horizontal wells. Both LWD and MWD data is transferred to the surface through the drilling fluid column in wave form, although most of it is saved for posterior analysis.

The logs chosen to help determine the formation physical properties are the follows:

**Standard and Deep Resistivity:**
Resistivity logs measure the formations resistivity. This parameter increases with the porosity of the formation. If the formation has low permeability both standard and deep resistivity values are identical but, in the presence of a high permeability formation, the standard resistivity decreases significantly, unlike the deep resistivity. The higher the discrepancy of values between standard and deep resistivity, higher the permeability of the formation is.

**Spontaneous Potential:** Spontaneous Potential logs identify the changes of electric potential along the formation. These changes occur between permeable and impermeable formations. When hydrocarbons are present, the electric potential diminishes in the log.

**Gamma-ray:** In sedimentary basins, Potassium-rich formations emit gamma-rays by decaying of $^{40}\text{K}$. Some clay minerals are rich in Potassium, so gamma-ray logs are used to identify clay formation. As these formations are impermeable, the log can, in a way, identify the impermeable zones drilled. The most common tool used to count the gamma-rays and identify the percentage of clay is a Sodium Iodine, activated with Thallium scintillator.

**Density:** Density logs apply a principle of gamma-ray interaction with matter, known as Compton effect, to measure the density of the formation. The sensor counts the number of scattered gamma-rays, inferring the number of electrons interacted. This allows a measure of the atomic number of
the elements present in the formation and, consequently, its density. The density can be correlated with the porosity of formation, through this equation:

\[ \phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad [1] \]

This establishes that the porosity \( \phi_D \) with density log can be inferred knowing the matrix density \( \rho_{ma} \), the measured bulk density \( \rho_b \) and the fluid density \( \rho_f \).

**Neutron:** Neutron emission tools are used to estimate the formation porosity. These tool use isotopes of nuclear waste, for example Californium-252, as neutron sources (Hearst et al., 2000). The neutrons emitted interact with the formation and are detected with the tool sensor. The more a neutron interacts, the higher is the atomic number of the elements of the formation. This log can be used as well to infer the Hydrogen, Carbon and Oxygen present in the formation. An effective porosity \( \phi_{eff} \) can be calculated knowing the response of the neutron log \( \phi_N \) and the value obtained in the previous equation for \( \phi_D \).

\[ \phi_{eff} \equiv \frac{1}{2} (\phi_N + \phi_D) \quad [2] \]

**Sonic:** Sonic logs measure the travel time of seismic waves reflected through the formation. Wave velocity in inferred knowing the distance travelled. The waves emitted are slowed in porous formations and speed up in impermeable formations, such as shale. When fluids are present, only the primary seismic waves are measured. A porous and saturated formation is enables a longer travelling time in the sonic logs.

### 3. Local Geology of the case study

Potiguar Basin formations span from the lower Cretacic to Holocenic. The most ancient formations are conglomerates and sandstones disposed in a fluvial system (Araripe and Feijô, 1994). The region formations can be represented as follows, chronologically: Açú, Ponta do Mel, Quebradas and Jandaíra. Açú is conglomerate and sandstone rich; Ponta do Mel is a carbonate-rich formation originated from shallow seas. Ponta do Mel is dated from the neo-Albian period (Araripe & Feijô, 1994).

Quebradas formation is a sandstone and clay mixture from the Cenomanian. These sediments were deposited in a marine plateau environment (Araripe & Feijô, 1994).

Jandaíra is a sandstone/carbonate formation of which sediments were deposited in an ancient lake, dating from the Mesocampanian. This formation contacts with Açú and Quebradas (Sampaio & Schaller, 1968). An overview of the formations is disposed in picture 3.1.
4. Analysis and Correlation

The three wells were named "Seco", "Minor Oil" and "Produtor". Logs of standard resistivity, deep resistivity, spontaneous potential, gamma-ray, density and neutron logs were analyzed for the three wells. In addition a sonic log was analyzed for the “Seco” well. The depths analyzed are between 300 and 350 meters, in measured depth.

4.1. Analysis

"Seco" well: The porous and permeable zones are located around 307, 318 and 350 meters depth. The logs concerning these zones indicate low spontaneous potential values, around -60mV. The gamma-ray log shows low values as well, around 80gAPI. The density and neutron log values are crossed, which indicates a porous and saturated zone. The density values are around 2.1g/cm$^3$ and the porosity is around 35 porosity units. The sonic time logs indicate a higher time of response in the indicated depths, around 150s/f. As for the standard and deep resistivity logs it is noted a deviation of the standard resistivity from the deep resistivity, showing a permeable zone. The cited zones are highlighted in figure 4.1.1.
“Minor Oil” well: Porous and permeable zones where identified from 315 to 320 and around 350 meters depth. Gamma-ray logs show values around 100gAPI for both cases and the spontaneous potential values reach -30mV. As for porosity from density and neutron logs, zone 1 has higher porosity, with a density of around 2.15g/cm$^3$ and neutron porosity of 35 porosity units. Zone 2 has higher density, reaching 2.25g/cm$^3$ and a lower porosity than 1, reaching only 30 porosity units in the neutron log. As for permeability, it is higher in zone 2, because the deviation between the standard resistivity and the deep resistivity logs is more accentuated. The cited zones are highlighted in figure 4.1.2.

“Produtor” well: The last well log contains three porous and permeable zones, located from 300 to 303, 308 to 310 and 338 to 340 meters depth. The gamma-ray log read a value of around 150gAPI for zones 1 and 2. The value is rather high and may infer that the sandstone has a considerable percentage of clay minerals. As for zone 3 the gamma-ray log shows a value around 120gAPI, considerable less than the other two. The spontaneous potential log is relatively steady around -10mV, showing no significant formation changes through the log. The porosity from the three zones is very high. Density values reach 2g/cm$^3$ and neutron porosity values reach 45 porosity units for the three zones, much higher than the zones described in “Seco” and “Minor Oil”. The standard resistivity deviation from the deep resistivity is more accentuated in the “Produtor” zones, showing a more permeable formation as well. The chosen zones are highlighted in figure 4.1.3.
4.2. Correlation

The selected logs of the three wells were correlated with Schlumberger Petrel software. The depth measure used in the correlation was the standard true vertical depth. The results are displayed in 4.2.1.
The correlated logs in figure are, in the left track, density and neutron porosity, in the middle track are spontaneous potential and gamma-ray and, in the right track, are displayed deep and standard resistivities. Horizons were placed to distinguish different formations.

Between horizons 1 and 2, there are low neutron porosity values of around 0.1m³/m³ and high density, around 2.5g/cm³ and higher. Gamma-ray logs show values of around 0gAPI and a sudden decrease of spontaneous potential is noted. There is little deviation between standard and deep resistivity logs, so the permeability is low as well. The formation between horizons 1 and 2 is a carbonate.

Between horizons 2 and 3 neutron porosity increases up to values between 0.3 and 0.5cm³/cm³, a very high porosity. The density decreases to 2.3g/cm³. There is no neutron-density crossover despite of this. Gamma-ray values increase up to 150gAPI and remain high through the formation, while spontaneous potential logs values remain stable, only with a steady little increase in “Minor Oil” well. There is little deviation as well between deep and standard resistivity logs, showing low permeability through the formation. The formation between horizons 2 and 3 is clay-rich.

Between horizons 3 and 4 neutron porosity values remains stable and similar to the previous formation values, around 0.3 to 0.4cm³/cm³. The density logs show a decrease of the formation density, to values around 2.2g/cm³. A neutron-density crossover is then shown in some points, which means this is a saturated and porous formation. Gamma-ray values decrease from the previous formation, so the clay percentage decrease as well. Spontaneous potential increases a bit from the previous formation. There is a clear deviation (filled with green color in the figure) between deep and standard resistivity logs, showing a permeable formation. The formation between horizons 3 and 4 is sandstone-rich with some clay, especially where the gamma-ray log values are higher. This is also the formation with payzone potential.

After the correlation, and using equations [1] and [2], an estimation of the porosity of the formation was calculated for the “Produtor” well, at 350 meters depth. The matrix density value used is 2.7g/cm³, the fluid density value is 0.9g/cm³ and the density log value is 2.1g/cm³. The neutron porosity log value is 0.3. The obtained values were the follows:

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<table>
<thead>
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<tbody>
<tr>
<td>ϕ_D</td>
<td>0.33</td>
</tr>
<tr>
<td>ϕ_N</td>
<td>0.3</td>
</tr>
<tr>
<td>ϕ_eff</td>
<td>0.315</td>
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</tbody>
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Table 4.1 - Porosity from density, neutron logs and effective porosity at 350 meters depth in “Produtor” well.
The software was unable to import the available information of density and standard resistivity logs from the “Minor Oil” well, so they could not be studied. However, the available data was similar to the data imported for the remaining wells, so the formations of “Minor Oil” well are similar to the other two, with all due differences.

5. Conclusions

The formation between horizons 3 and 4 is the most porous and permeable, consisting of sandstone with a low percentage of clay minerals. The highest porosity values reach 0.315. There is a visible formation correlation between the three wells, with some minor differences in depth, as seen in the logs, so the geology of the sites drilled is roughly the same.

Although “Seco” well shares the same formation characteristics of the other two, it’s not productive. A porous and permeable formation doesn’t necessarily contain hydrocarbons.

The formation between horizons 1 and 2 is a carbonate, between 2 and 3 is a clay-rich formation and, between 3 and 4, a sandstone-rich. This concludes that the overburden formation spans from the surface, down to roughly 180 meters depth. The reservoir trap spans from 180 meters down to 320 meters depth. Finally the reservoir formation spans from 320 meters down.

6. References