Well Logging Analysis – *Rio Grande do Norte* Basin

Kâmia Denise Espírito Santo Craveiro
Instituto Superior Técnico, Avenida Rovisco Pais 1, 1049-001 Lisboa, Portugal

## Abstract

A hydrocarbon exploration begins with the geological recognition of probable hydrocarbon accumulation areas, which are confirmed by seismic survey and, to ensure certainty, it is necessary to drill a well. On those exploration wells measurements are made down the hole for the formation evaluation.

The evaluation of water, oil and gas saturations are attained by geological and petrophysical characteristics. To obtain such information it is necessary to use a combination of several sources, namely mud logging, coring, well logging and occasionally down the hole tests.

Due to the high risks associated with drilling activities, such as safety problems and environmental impacts, it is extremely important to have a very well designed and established drilling program. Therefore, the activities monitoring and control and a good knowledge of what types of formations will be affected, and its principal characteristics, are priorities to take into consideration.

Bearing in mind the sources for the formation evaluation, the present work aims to focus on wireline logs and its interpretation using Petrel E&P Software Platform. The case study is a basin in *Rio Grande do Norte* (Brazil).

Keywords: Formation Evaluation, Well logging, analysis, *Rio Grande do Norte* - Brazil

### 1. Introduction

Hydrocarbons are wide spread all over the globe and we are still very dependent on it. Its strong influence on international markets produces major impact on global economy which can lead to powerful divergences between societies. As a consequence, one can easily understand why the Petroleum Industry requires awareness and responsibility to provide the increasing population with one of its power sources.

A sustainable development includes not only the economic growth but also the social and environmental development.

Hydrocarbons exploitation has to be safe and conscious, bringing together several areas of expertise in order to reduce any uncertainties. Once indirect studies, such as reflection seismic to create a reservoir model, were made, it is necessary to drill a well and confirm the previous information. At this point, a formation evaluation must be carried out in order to distinguish between reservoir and non reservoir. In a reservoir one needs to distinguish between hydrocarbons and water. On the hydrocarbon areas, fluid saturations must to be calculated and the oil and gas distinction has to be made.

The present paper presents an overview of the principal well logging measurements and *Rio Grande do Norte* Basin as a case study.

### 2. Well logging

Well logging is a technique that measures rock properties against the depth in a wellbore.

The measurements can be classified in two categories: (1) natural phenomena and (2) induced phenomena. The measurements belonging to the first group are natural gamma radioactivity, spontaneous potential and others like temperature of the borehole, well diameter inclination of the hole, etc. The second group stimulates the geological formations with an appropriate emission and gathers the its response. The measurements made can be electrical, nuclear and acoustic.

There are some properties of geological formations that are quite important for these measurements:

- Porosity ;
- Permeability;
- Fluids saturation and capillary pressure;
- Electrical (resistivity, conductivity, dielectric permittivity);
- Elastic (Poisson's ratio, elastic modulus, compressibility).

Some of the required variables are directly obtained from well logging measurements, while others are calculated from the same measurements. The fundamental equation which serves as model for these calculations is the Archie Equation:

$$S_w = \left(\frac{R_w}{\emptyset^m R_t}\right)^{\frac{1}{n}}$$

The equation has it is mentioned above can only be used in clean sands.

## 3. Applications of the different measurements

The most important petrophysical parameters are: porosity, permeability, resistivity and fluids saturations.

Table 1- Main utilities of the measurements

| Log | Main utility |
|---|---|
| *Spontaneous Potential* | Distinction between permeable layers and impermeable layers |
| *Resistivity* | Identification of the fluids presence; determine saturations |
| *Natural Gamma ray* | Distinction between radioactive layers from non radioactive layers |
| *Density* | Formation density; determine porosity |
| *Neutron* | Porosity |
| *Photoelectric factor* | Lithological identification |
| *Sonic* | Porosity |
| *Electromagnetic* | Distinction between fluids |
| *Image* | Depositional sequence analysis, fracture analysis, heterogeneities |
| *Nuclear Magnetic Resonance* | Pore size distribution, porosity, permeability, fluids distinction, |

## 4. Well logging acquisition

The well logging attainment can be done by the following ways: wireline, tough logging conditions and logging while drilling.

### 4.1. Wireline

In this acquisition mode, the probe is lowered down the hole connected to a cable. It can only be done after an interruption or conclusion of a drilling section. It can be made in open hole or cased hole. It has the disadvantage of being unfeasible to use when the well is not vertical.

It is very useful for formation evaluation because it can measure a very wide number of logs.

### 4.2. Tough Logging Conditions (TLC)

When the well bore conditions do not allow running the conventional logging, pipe-conveyed logging can be used, TLC for instance.

TLC is used when the inclination of the well bore is too high. In this mode, the probe with a cable is lowered down the hole with the help of the drill pipes. The cable is connected to a side entry sub of the drill pipe.

### 4.3. Measurements While Drilling (MWD)

With the evolution of the technology, it is possible to measure at the same time that the drilling is happening, leading obsolete the need to stop the operations to make measurements.

The first mode of these measurements during drilling was MWD.

MWD is essentially to assist the directional drilling. It reads the torque, the weight on bit, direction and azimuth of the bit.

### 4.4. Logging While Drilling (LWD)

Measuring while drilling has a lot advantages, not only the time saved, but also the possibility to log while the mud invasion is not too extensive, ensuring more accurate results. Therefore, due to the prior advantages mentioned and also because MWD does not provide the satisfactory input for formation evaluation, LWD was brought forward.

The LWD also measures while drilling and has a close performance to wireline logging, concerning the formation evaluation.

## 5. *Rio Grande do Norte* - case study

As a case study, only one well from the North of Brazil was studied and, for the analysis, it was used the Petrel E&P patented by *Schlumberger*.

The logs are from three wells, minor, dry and production well. For the interpretation was considered only the minor well logs. The data was provided by Partex Oil and Gas.

### 5.1. Geological Characterization of the basin

The basin covers an area of approximately of 21000 km$^2$ onshore and 27000 km$^2$ offshore according to Bertani *et al*. (1990) (*apud* Menezes, 2002).

The basin geological stratigraphy can be divided in three groups, namely FS1, FS2 and FS3.

The first group includes de geological formations of FS1a, FS1b e FS1c. On the FS2 group one can identify the formation of FS2a, FS2b, FS2c and FS2d. At last, the last group includes the FS3a, FS3b, FS3c and FS3c formations.

The geological description of all the formations mentioned above can be found at the table 2 below.

**Table 2 - Geological characterization of the basin formations. Ref.: Menezes, 2002.**

| Geological Formation | Lithological information |
|---|---|
| Sedimentary rock 1a– FS1a | Siliciclastic and carbonates rocks |
| Sedimentary rock 1b– FS1b | Conglomerates and sandstones |
| Formação sedimentar 1c – FS1c | Sandstones and mudstones |
| Sedimentary rock 2a– FS2a | Coarse to fine sandstones, siltstone and shale |
| Sedimentary rock 2b– FS2b | Calcarenites and calcilutites |
| Sedimentary rock 2c– FS2c | Sandstones and shales |
| Sedimentary rock 2d– FS2d | Oolitic calcarenites, calcilutites and shales |
| Sedimentary rock 3a– FS3a | Siliciclástica poorly consolidated |
| Sedimentary rock 3b– FS3b | Coarse sandstones |
| Sedimentary rock 3c– FS3c | Calcarenites and calcilutites |
| Sedimentary rock 3d– FS3d | Shales, siltstones and coarse to fine sandstones |

### 5.2. Tectonic Evolution

The *Rio Grande do Norte* basin is related to the formation of a rift (*Potiguar* rift) which is due to divergent boundaries associated to the Gondwana supercontinent separation during the Late Jurassic according to Françolin Szatmari (1987) (*apud* Menezes, 2002).

The first basin portion to be formed was its onshore.

The ocean entrance began at Albian stage and it can be divided in the marine transgression and the marine regression phases which made the drift sequence. During the marine transgression the FS2a, FS2b, FS2d and FS2c formations deposited. On the other hand, during the regression phase the sediments were the FS3b, FS3c and FS3c formations. The regression is associated to a mantel plume that pushed up the FS2b formation. Due to this event, it is possible to find magmatic rocks in the basin

### 5.3. Interpretation

The main measurements used were: gamma ray (GR), compensated gamma ray (CGR), gamma ray spectroscopy (THOR, URAN, POTA), bit size (BS), spontaneous potential (SP), caliper (HCAL), induction shallow resistivity (AHT20), induction mean resistivity (AHT60), induction deep resistivity (AHT90), micro normal resistivity (HMNO), neutron porosity (NPHI), density (RHOZ), photoelectric factor (PEFZ), sonic porosity (SPHI) and interval transit time (DT).

#### 5.3.1. Layers distinction and lithological characterization

The considered measurements were between 128 and 405 depth units (d.u.).

It is possible to identify a cap rock, called zone A, due to the high resistivities (the highest of them all). Also, the shallow and deep resistivity match, which means that it is a tight formation. It was also observed that the porosity was low. And, thanks to the very low thorium contribution to the total (low) GR it was identified as carbonate formation. Due to its sealing behavior it could be a marly formation which goes down until 162 d.u.. The zone A can be seen in figure 1.

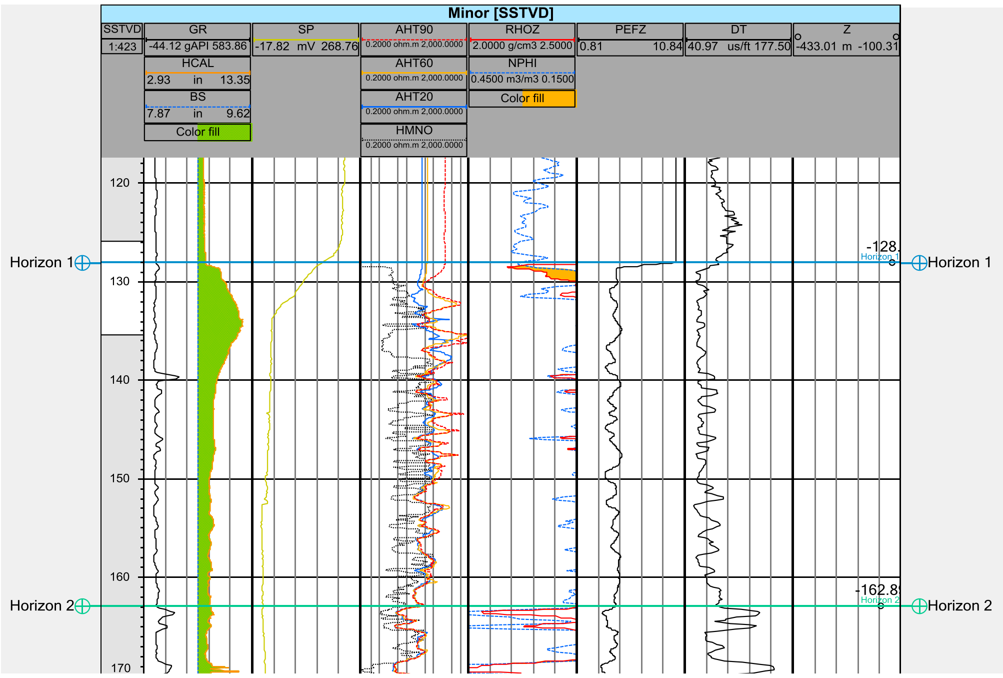


Fig. 1 - Zone A.

Between 162 and 191 d.u., the layer identified as B, can be characterized by unstable measurements of density and neutron which can possibly indicate that zone B is a transition layer between A and C1 zones. The B zone can be seen in figure 2.

The next layer, zone C1, goes down to 229 d.u., it has more stable characteristics. It can be seen at figure 3.

There is a great increase of the GR and of neutron porosity. The high GR is greatly due to uranium isotopes. Both increases point out to a shaly formation. The high measured porosity from neutron log is in fact only thanks to the presence of bounded water of the shale and not really to high porosity of the formation. It is also possible to observe the decrease of the resistivities and the density. The photoelectric factor indicates clastic matrix of the rock.

The last layer was called C2 and goes down until the end of the log (405 d.u.).

This layer has a slight decrease of the GR comparing to the previous layer. There are some small layers of cleaner sands, due to its low GR and the neutron/density crossovers. Nonetheless, the C2 zone has the same behavior as C1.

Although C1 and C2 have some differences, they all have common characteristics such as shale presence, tight formation, low porosity, and, as it can be checked by the photoelectric factor, they are clastic rocks. Thus, they were considered to belong to the same formation, C layer, which is a shaly clastic.

The shale disguises the porosity found on the logs because of its bounded and capillary water, so the porosities obtained are higher than what they really are.

Other interesting points that could be mentioned are the high picks of GR found at C2 zone and which may indicate fractures where clay minerals and uranium were deposited over time. Also, in C1 zone there is a highlighted separation between the shallow and deep resistivities, not

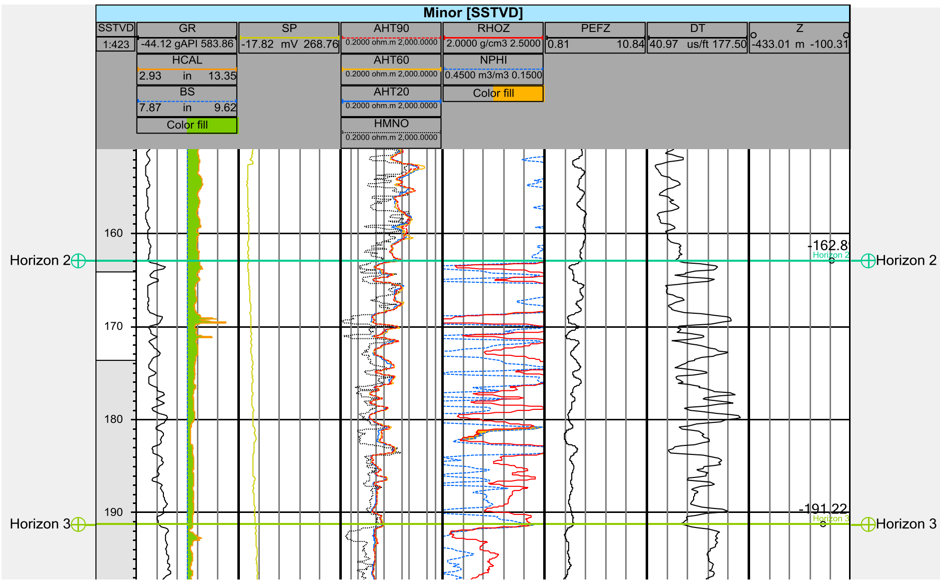


Fig. 2 - Zone B.

because it is a hydrocarbon area but because the tool is measuring mud stuck on the caves at the wellbore walls. Those caves can be seen with bit size and caliper tools.

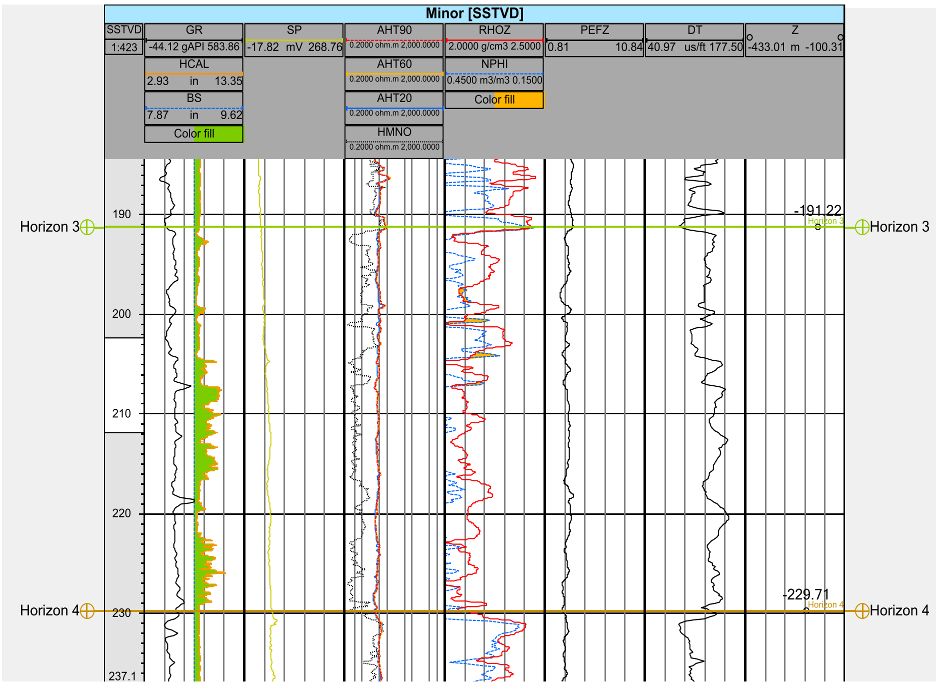


Fig. 3 - Zone C1.

### 5.3.2. Fluids differentiation

At first sight, it could be said that the most likely hydrocarbon bearing formation is the C2 at the cleaner sands layers. But, when it is considered the SP log, it is possible to see that the fluid is water. The reaction of the resistivities is similar to the one that could be expected from a hydrocarbon. This water is not saline water, due to the low salts concentration, the water has a resistive behavior close to the hydrocarbon's.

According to the NMR results, the C2 zone has only water.

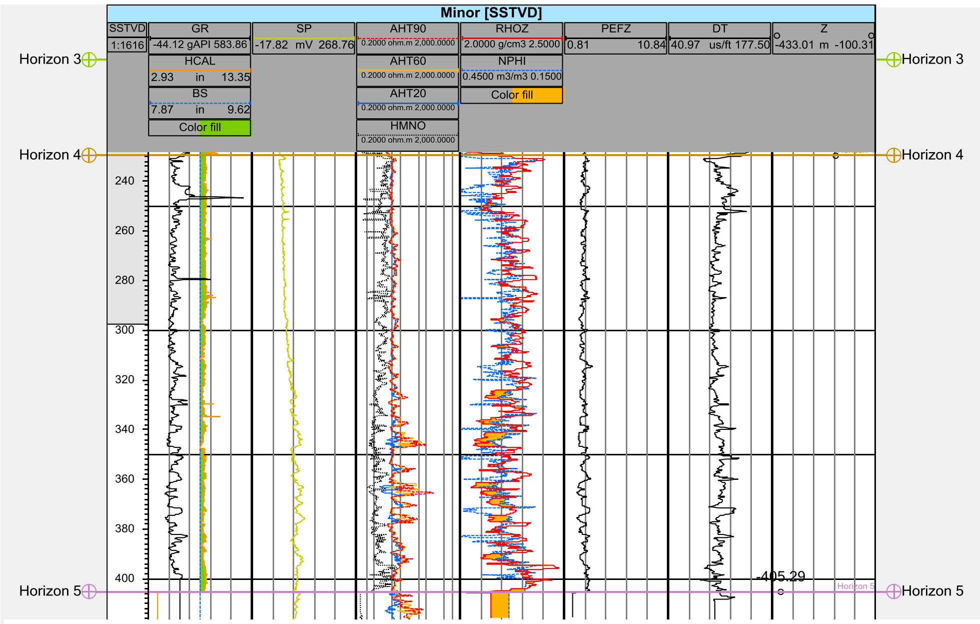


Fig. 4 - Zone C2.

#### 5.3.3. Calculation results

Table 3 - Results from the analysis.

| Unknown | Value |
|---|---|
| $V_{sh}$ | 0.40 |
| $\phi$– Density | 0.15 |
| $F$ | 36 |
| $R_t$ (ohm.meter) | 6 |
| $R_O$ (ohm.meter) | 16 |

## 6. Conclusion

It is easy to recognize the great asset the well logging measurements can be on a formation evaluation. Nonetheless, the combination of information from different sources is important for the accuracy of the results.

As it was mentioned before, the present work aim was to interpret the well logging measurements from a well at the Rio Grande do Norte Basin.

From the analysis made, using the logs and the NMR, it was possible to observe the presence of water in C2 zone. C2 zone was identified as FS2a geological formation.

Possible conclusions are that if there is a reservoir it might be on the well neighborhood area.

These possibilities can be verified with the analysis of the other wells logs or with the study of the layers below the C2 zone.

## 7. References

Bassiouni, Zaki – **Theory, Measurement, and Interpretation of Well Logs**. 1ªed. Texas, EUA: SPE Textbook Series Vol.4, 1994. ISBN 1 55563 056 1

Bradley, Howard B. – **Petroleum Engineering Handbook**. 3ª ed. Texas, EUA: Society of Petroleum Engineers, 1992. ISBN 1-55563-010-3

Ellis, Darwin V.; Singer, Julian M. – **Well Logging for Earth Scientists**. 2ª ed. Dordrecht, Holanda: Springer, 2008. ISBN 978-1-4020-3738

Glover, Paul – **Petrophysics MSc Course Notes**. Universidade de Laval. Canadá. 2002.

Gomes, Jorge S.; Alves, Fernando Barata – **O Universo da Indústria Petrolífera, Da**

**Pesquisa à Refinação**. 2ªed. Lisboa, Portugal: Fundação Calouste Gulbenkian, 2011. ISBN 978-972-31-1398-3

Luthi, Stefan – **Geological Well Logs: Their use in reservoir modeling**. 1ªed. Berlin, Alemanha: Springer, 2001. ISBN 3-540-67-840-9

Rider, Malcom – **The Geological Interpretation of Well Logs**. 2ªed. Escócia, UK: Rider-French Consulting Ltd, 2000. ISBN 0 9541906 0 2

Serra, O. – **Fundamentals of Well-Log Interpretation. 1. The Acquisition of Logging Data**. 3ªed. Holanda: Elsevier, 1988. ISBN 0 444 42132 7

Vasconcelos, E.P.; Lima Neto, F.F.; Roos, S. – **Unidades de Correlação da Formação Açu**. Congresso Brasileiro de Geologia, Brasil, 1990. Pereira, M.F.C – **Material de Apoio à Cadeira de Geologia de Sistemas Petrolíferos**. Lisboa, Instituto Superior Técnico, 2012/2013.

Gomes, Jorge S. – **Material de Apoio à Cadeira de Diagrafias e Avaliação de Formações**. Lisboa, Instituto Superior Técnico, 2012/2013.

Thesis:

Menezes, Leonardo – **Caracterização Faciológica e Parametrização de Análogos a Reservatórios Petrolíferos Fluviais da Formação Açu (Unidade Açu – 3) – Bacia Potiguar**. Brasil: Universidade Federal do Rio Grande do Norte, 2002. Relatório de Graduação

Reyes Pérez, Y.A. – **Caracterização da Geometria de Depósitos Sedimentares na Borda Sudoeste da Bacia Potiguar**. Brasil: Universidade Federal do Rio Grande do Norte, 2003. Dissertação de Mestrado.

Soares, Ubiraci – **As Relações entre Tectonismo e Sequências Deposicionais no Rifte Potiguar – Porção SW do Graben de Umbuzeiro, Bacia de Potiguar Emersa**. Brasil: Universidade Federal do Rio Grande do Norte, 2000. Dissertação de Mestrado.

Magazines:

Bryant, Ian; et al. Basin to Basin: Plate Tectonics in Exploration. **Oil Field Review**. Schlumberger, Outono, 2012.

Ablard, Peter; et al. The Expanding Role of Mud Logging. **Oil Field Review**. Schlumberger, Primavera, 2012.