# Calculating the mud drilling invasion through geophysical well logs in theoretical reservoirs models

Abel Carrasquilla, LENEP/UENF, Macaé - RJ
Mariléa Ribeiro, LENEP/UENF, Macaé - RJ



This paper was prepared for presentation during the 11th International Congress of the Brazilian Geophysical Society held in Salvador, Brazil, August 24-28, 2009.



## Abstract

During drilling process, muds of different compositions are used, aiming to support the wall and to remove the debris originated by the action of the bit. These muds invade the geological formations and modify the well surrounding zones, mainly, in terms of porosity and permeability. In the present work, we used the approach developed by Ribeiro (2007) to determine the invasion diameter, which is similar to Tornado Charts methodology utilized by SCHLUMBERGER, inclusive, using the same ILD and LLD well logs. We tested this approach with different kind of theoretical reservoirs, with the presence of oil, water and gas in different proportions. This procedure shows fast and accuracy, because it considers better the characteristics of the invasion process.

## Introduction

After the drilling, geophysical well logs are deployed through the open hole, with the descending of some tools that register physical fields related with petrophysical parameters as porosity, density, etc., which integrates the basic set of information in the characterization of oil reservoirs (Anderson, 2001). One of these parameters is the electrical resistivity, which is related with the volumetric characteristics of the rocks that include the matrix and fluids present in the pores, generating, thus, some kind of information that define properties as the fluid saturation, types of fluids, etc. (Borah et al., 1998).

In the measurement of the resistivity, with the purpose to characterize the invasion process (Figure 1), currently the Laterolog Dual (LLD) log is very utilized, which uses the phenomenon of galvanic conduction into the geologic medium (Baker Hughes, 2002). This system possess two sets of seven electrodes in the same tool, called of LLD (Deep) and LLS (Shallow), which are considered as macro-logs and are recommended for conductive muds with saline base. The same ones aim to investigate great volumes of rock to obtain the resistivity of the virgin zone (*Rt*). Besides these logs, the micro-logs, as the spherical focused (SFL) and the Micro Spherical Focused (MSFL) exist, both with lesser distances between the electrodes, what fairly diminishes the investigation depth, reaching only the zones near to the borehole wall ($R_{xo}$) (Chen & Mueller, 1992).

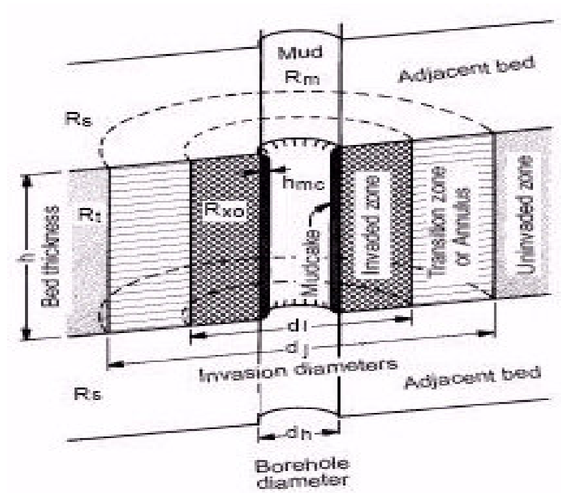


Figure 1. The logging environment (modified from Anderson, 2001).

On the other hand, another kind of log, the Dual Induction (ILD), which functions with the electromagnetic induction phenomenon, was introduced to minimize the mud/well effect existing in the galvanic profile, using as physical principle the inductive electromagnetic coupling between the transmitter, the receiver coils and the rocks (Ellis, 1997). The advantage in use this scheme is that it is not distorted, penetrating, indistinctly, in the mud and rock media. This combination of sensors allows the measuring of the virgin zone resistivity ($R_{ILD}$), but, when approaching them, it diminishes the radial investigation, permit only to attain average distances. ($R_{ILM}$). It is coupled, still, to a third combination of coils with lesser investigation depth, the Micro Focused Spherical ($R_{MSFL}$), allowing the measuring of shallower resistivity. In the same way, the use of the different frequencies in ILD and ILM tools besides the focused one provides different volumes and investigation depths, permitting to measure the resistivity of the invaded ($R_{XO}$) and virgin ($R_t$) zones, beyond to know $D_i$, becoming possible the correction of the invasion effect (Crain, 1984).

Thus, the knowledge of the invasion diameter is important and, for this reason, SCHLUMBERGER (1989) had used the Tornado Charts since many years ago. Meanwhile, another ways to calculate the invasion are very welcome to substitute this abacus, especially when the register is made automatically as another log. In this form, Ribeiro (2007) worked in a mathematical process to determine the invasion diameter, based on a simple polynomial function that calculates this distance from the dual resistivity tool. To accomplish this, it was used MATLAB (1999) scientific package to develop the programs, which solving the linear system through an inversion process. In the same way of Tornado Charts, this approach also uses the LLD and ILD logs, which give the values of the shallow ($R_{xo}$), middle ($R_{ILM}$ or $R_{LLS}$) and deep ($R_{ILD}$ or $R_{LLD}$) resistivities to calculate $R_t$.

**Methodology**

The methodology developed by Ribeiro (2007) was applied to synthetic data obtained from horizontally layered theoretical models. With this objective, it was used a three layers simplified model, which facilitates the input of the mineralogical composition of an oil reservoir and its subsequent analysis (Figure 2). The first and third layers are impermeable shales, with small percentages of minerals and with little interstitial water. The second layer, however, is sandstone reservoir, which has a varied mineralogical composition (quartz, calcite, dolomite, ilite, caolinite and montmorilonite), where oil, water and gas are present and the entire invasion process occurs.

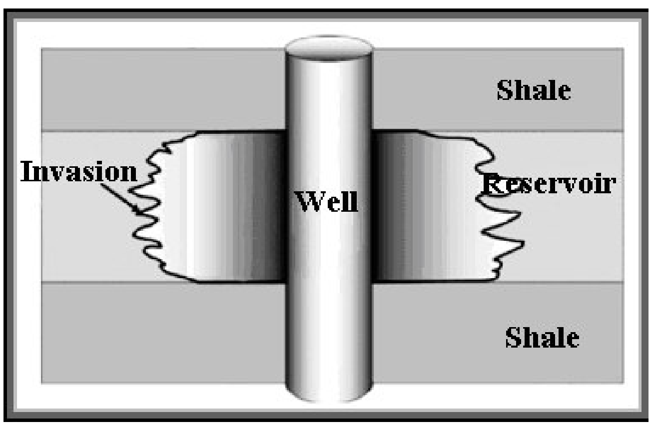


Figure 2. Model of three layers

**Results**

In Table 1 (Ribeiro et al, 2008), the first considered reservoir (Model 1) contains 40% of oil, 0% of water, 0% of gas and 60% of other minerals (quartz, etc.), with Rmf = 0.016 ohm.m and Rm = 0.005 ohm.m, which means the use of a conductive mud.

Table 1. Lithology of Model 1 with 3 layers.

| Lithology | Shale | Reservoir | Shale |
|---|---|---|---|
| Quartz | 0,20 | 0,10 | 0,20 |
| Calcite | 0,05 | 0,30 | 0,05 |
| Dolomite | 0,00 | 0,05 | 0,05 |
| Ilite | 0,25 | 0,05 | 0,20 |
| Caolinite | 0,15 | 0,02 | 0,15 |
| Montmorilonite | 0,15 | 0,05 | 0,15 |
| Water | 0,20 | **0,00** | 0,20 |
| Oil | 0,00 | **0,40** | 0,00 |
| Gás | 0,00 | **0,00** | 0,00 |
| Total | 1,00 | 1,00 | 1,00 |
| SIMULATION: Rmf = 0.198 and Rm = 0.088 ohm.m | | | |

Figure 3 shows GR (Gamma Ray) log clearly separating shales from sandstones layers of Model 1, but ILD sonde, however, does not show appreciable responses for $R_{ILM}$ and $R_{ILD}$, which may be due to the model and the mud are very conductive and, for this reason, the electromagnetic energy is unable to penetrate the geological formations (Ribeiro et al, 2008). LLD tool, on the other hand, clearly registers high resistivity values at shallow, medium and deep depths, which is an indication of the oil presence in the reservoir. By comparing the invasion radius $R_i$ ($R_i = D_i / 2$), in the case of the reservoir, we found that our calculations (NM-LLD), for the LLD case, is closer to synthetic result, leaving the ILD below the estimative and the Tornado Chart quite over, around twice.

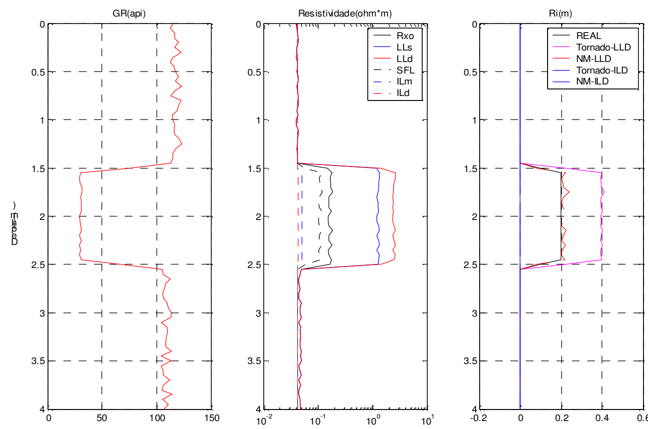


Figure 3. Logs and invasion diameter of the Model 1.

The Model 2 has the same mineral composition, but now with a resistive mud ($R_{mf}$ = 120.0 ohm.m and $R_m$ = 50.4 ohm.m), being the results shown in Figure 4. These results show that with this type of mud, both induction and laterolog logs measure resistivity values (above 1 ohm.m), differently with a conductive mud. The invasion radius, in this case, it is bigger with this kind of mud (0.2 m against 1.4 m) using NM-LLD.

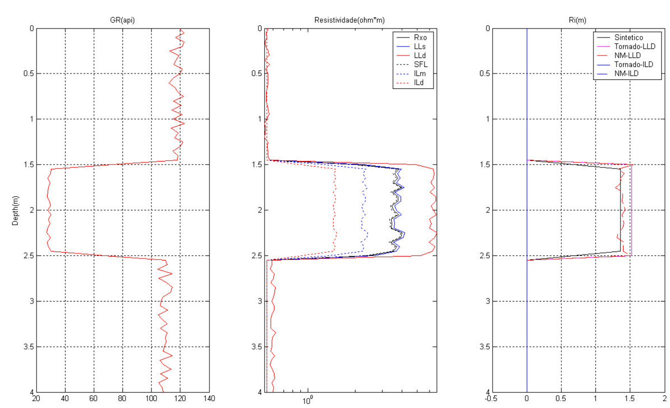


Figure 4. Logs and invasion diameter of the Model 2.

In the same way, the Model 3 is a gas reservoir containing 0% of oil, 0% of water, 40% of gas and 60% of other minerals with the same resistive mud of Model 2. The results in Figure 5 are very similar of Figure 3, meaning that the invasion is very similar, although the content of it is oil or gas.

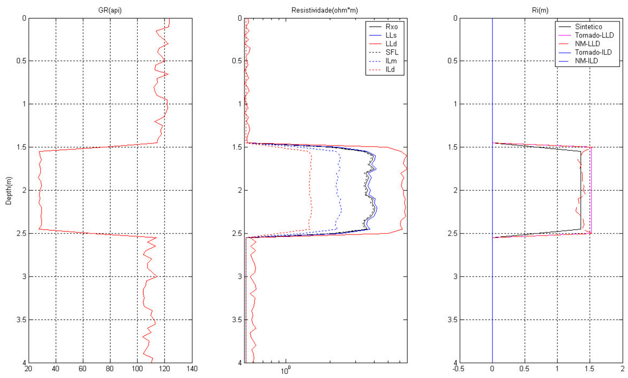


Figure 5. Logs and invasion diameter of the Model 3.

The next reservoir (Model 4) is an aquifer, composed by 0% of oil, 40% of water, 0% of gas and 60% of other minerals, with a resistive mud. Figure 6 shows the results of this model, with invasion radius up to 0.3 m. Both, galvanic and induction tools measure resistivity values until 3 ohm.m.

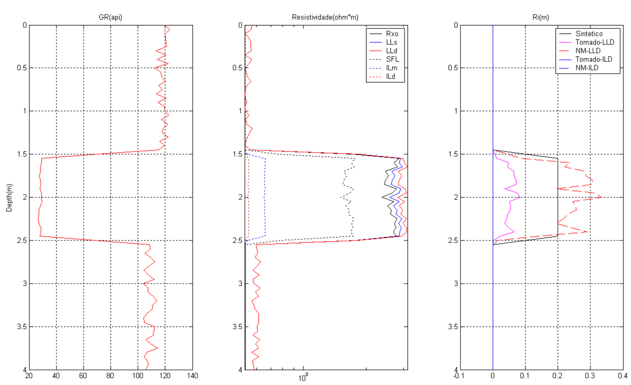


Figure 6. Logs and invasion diameter of the Model 4.

The last one is a mixed reservoir (Model 5), containing 15% of oil, 15% of water, 15% of gas and 55% of other minerals, with a resistive mud. Figure 7 shows the results, with an invasion radius lesser than the Models 2 and 3 (1 m against 1.4 m). In this case, again, both, galvanic and induction sondes, measure resistivity values between 1 to 4 ohm.m.

In all the studied models, it is not clear changes in GR log, which can be explained because the measurements in this log depend more of the geological formation matrix, and not the pore content changes, which are mud, oil, gas and water in our study.

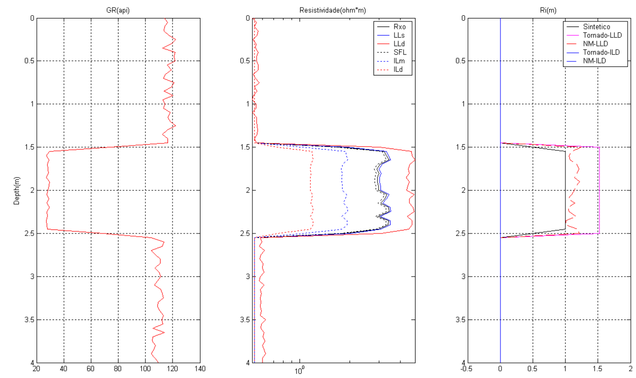


Figure 7. Logs and invasion diameter of the Model 5.

## Conclusions

Tornado Charts and its based commercial algorithms utilized in environment corrections for geophysical well logs are available long time ago, but, they still are based on simple invasion profile models, generally in delayed graphical processes. In this way, the sophistication of the modern tools is not followed by the improvements in the correction programs of this effect. Considering these facts, we used, in this work, the algorithm developed by Ribeiro (2007) with synthetic models, considering different types of reservoirs with different compositions of oil, gas, water and other minerals. The results are consistent and the process it revealed fast, efficient and exact, because the results are placed graphically in another track besides the other logs, which it facilitates the automatic recognition of the invasion depth provoked by the drilling mud in oil reservoirs. Thus, the results show that with the use of a resistive mud, both laterolog and induction tools can measure resistivities values. The invasion radius is bigger in the case of an oil reservoir with resistive mud, when compared with conductive one. With resistive mud, invasion radius changes a little with a gas reservoir and diminishes a lot in the case of an aquifer. Finally, when the reservoir has equal parts of oil, gas and water, the resistivity values of the log change a little, but, the invasion radius changes considerably from 1,4 m to 1,0 m, comparing when the reservoir contents only gas or oil.

## Acknowledgments

The authors thank the financial resources originated from CNPq, UENF-FAPERJ and PETROBRAS, in the form of scholarships and research funds, which help in a decisive way to accomplish this work. Also, we thank Darcy Ribeiro North Fluminense State University (UENF) by the computational support.

## References

Anderson B. 2001. Modeling and inversion methods for the interpretation of resistivity logging tool response. PhD Thesis, University of Deft, Holland, 203 p.

Baker Hughes. 2002. Introduction to wireline log analysis, Baker Atlas, 312 p.

Borah, N. M.; Mallick, R. K.; Choudhuri, B. & Rathores, Y. S. 1998. Mud filtrate invasion profile – Its influence on wireline logs and hydrocarbon producibility: a case study. SPE, New Delhi, India.

Chen S.X. & Mueller T.C. 1992. A Simple Approach to Mud-Invasion Correction for Dual Laterolog Resistivities, Oil & Gas. OGR 23962.

Crain, E.R. 1984. The Log Analysis Handbook, Vol. 1, Quantitative Log Analysis Methods.PennWell Books, Tulsa, 684 p.

Ellis, D.V. 1987. Well logging for earth scientist. Elsevier, New York. 532 p.

MATLAB. 1999. MATLAB – The Student Edition, User´s manual. Makron Books, São Paulo, 413 p.

Ribeiro, M. 2007. Geofísica de poço na delimitação do dano à formação produtora de petróleo causado pela invasão da lama de perfuração. MSc. Thesis, LENEP/UENF, Macaé, 92 p.

Ribeiro, M.; Carrasquilla, A. & Silva, J. 2008. Determining the invaded zone diameter in oil reservoirs provoked by mud drilling through geophysical well logs. Anais (CD) do III Simpósio Brasileiro de Geofísica, Belém.

SCHLUMBERGER. 1989. Log Interpretation Principles / Applications. SCHLUMBERGER Educational Services, Houston.