Calculation of the invasion of drilling fluid resistivity profiles with borehole in models of carbonate reservoirs with varying mineralogical

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Abstract

It is well known the relationship between geological properties such as texture of the formations, and the petrophysical properties of reservoirs. This relationship is also dependent on the damage caused by the formation of drilling mud invasion, when the solid particles clog the porous medium. This invasion can modify the values of the profiles of the well, which can lead to erroneous estimates of oil saturation and reserves. This phenomenon is even more crucial in carbonates, where the porous system is complex because it can produce various types of porosity within the same array to intercrystalline, intergranular vuggy, fracture, etc. Moreover, the porosity also has a direct relationship with the mineralogical composition and may influence the responses of resistive profiles, which are commonly used to determine the diameter of invasion of mud into the reservoir. In this work, we simulate the process of breaking into a mud-base oil in a reservoir model of three layers, a salt, a carbonate and other shale. The methodology consisted of mineralogical variation in the layers, and calculate how this change affects the profiles of gamma ray and resistivity laterolog induction and calculating the diameter of invasion. The results show that under this condition, the profile laterolog presents more accurate results in calculating the invasion of the induction profile, given the lack of invasion caused by an oil-based mud compared to basic water and at its best record in the vicinity of well.

Introduction

The carbonate reservoirs represent a large share of oil and gas reserves in the world and therefore has been studied for a long time. To describe these reservoirs, the properties of depositional, diagenetic and tectonic rock, although a genetic origin, may be considered as fundamental properties, which include texture, plant, grain size, mineral composition and sedimentary structures. Other properties such as porosity, permeability and bulk density are intrinsically connected with the above. However, a set of properties of third order is found in the characterization of carbonate reservoirs, which includes the electrical resistivity, the velocity of acoustic wave propagation, natural radioactivity, etc., which depend on the porosity, fluid content, radioactive content, density, magnetic susceptibility and the acoustic characteristics. Moreover, the mineralogical composition refers to the original mineralogy, which has great significance in the study of diagenetic carbonates and provides important clues about the chemical evolution of the planet. There is, however, a reliable clue to the origin and flow distribution within the reservoir, because the carbonates have a wide variety of depositional environments. It is more practical in the study of this type of reservoir, replace the grain constituents, like skeletons, Peloids, clastic or ooids among others, by the mineralogical composition (Ahr, 2008).

From the mineralogical point of view, the carbonate reservoirs are mainly composed of carbonates caused by biological or biochemical processes, or of organic origin, although the inorganic precipitation of calcium carbonate ($CaCO_3$) from marine waters, is also an important proceedings (Choquette & Pray, 1970). The carbonates present as essential components mineralogical calcite and dolomite, occurring in different proportions and promoting the classification of limestones (carbonates>50%), where there is a predominance of calcite ($CaCO_3$) and dolomites, where there is a predominance of dolomite ($CaMg(CO_3)_2$) (Lucia, 2007). And the associated level enhancement, can be other carbonates such as siderite ($FeCO_3$), ankerite ($Ca(Mg, Fe, Mn)(CO_3)_2$), normal ankerite ($Ca_2MgFe(CO_3)_4$), magnesite ($MgCO_3$) and aragonite ($CaCO_3$ - the same chemical composition of calcite, but with different crystal structure). Besides these components, there may be impurities such as pyrite, anhydrite and quartz in their crystalline forms at rates lower than 5%, partially or completely filling the pore space (Clyde, 2010).

Moreover, when drilling a carbonate formation, can occur invasion of mud filtrate, whose magnitude will depend on its porosity / permeability, type of drilling fluid, the pressure difference between the mud column and training, the diameter of pit and the exposure time (Figure 1). This process will result in four different resistivity zones adjacent to the borehole wall due to this ion exchange between fluids: plaster, washed, transition and virgin. Dzuiba (1987) pointed out that the biggest problem of interpreting a resistivity profile is to understand the profile of invasion, as the filtered fluid may move the training, but still exists an unused portion of it.

In our study, as we are simulating the process of invasion of an oil base drilling mud, it is necessary to know the composition of the same, which is shown in Figure 2 (Bourgoyne et. al., 1991).

Methodology

To accomplish this work, we used the model proposed reservoir three layers in the work of Ribeiro et al. (2008) and Ribeiro & Carrasquilla (2008). The three layers are 20 m thick, with the first salt, the second layer of carbonates and finally a layer of shale. In this model, mineralogical changes are made in layers, mainly in the carbonate reservoir, to assess how this change may influence the profiles of resistivity and thus calculate the diameter of invasion.

Each layer of the model has the following mineralogical composition at different concentrations, which are mostly found in each type of lithology, as follows:

a) layer of salt, which presents in its mineralogical composition of halite, anhydrite, silvita, soda ash, gypsum and bischofita;
b) carbonate reservoir containing calcite, dolomite, pyrite, aragonite, anhydrite and quartz;
c) layer of shale, containing minerals such as olivine, mica, pyroxene, biotite, quartz and muscovite.

The percentage of each mineral in each layer may vary for each simulation or remain constant.

Moreover, we simulate the invasion of these bed-filtered by an oil base and assume that the shale and salt intrusion does not occur due to low permeability of both layers. However, carbonate is only the presence of oil as fluid formation, causing a raid based on its content and its saturated porous conditions.

With this model, which is intended to simulate the invasion process that occurs between the drilling mud-base oil present in the well, washed the area and the virgin zone. By varying the mineral composition with the effect of fluid displacement in the transition zone where the mud filtrate resistivity (R_{mf}) changes the value of the resistivity of the transition zone (R_{xo}) and the virgin zone (R_t), it is intended observe the influence on the profiles of resistivity and gamma ray (GR), and with them, when measuring the diameter of invasion. Still, such a variation can influence the boundary layer profiles measured in another layer. Finally, to make the records of each zone resistivity and invasion profiles simulate the induction (ILm and ILd measurements in medium and deep depths) and laterolog (R_{xo}, LLs and LLd, measurements at shallow depths, medium and deep), and invasion calculated as an additional profile in the last track, the second process developed by Ribeiro (2007). All calculations of this work were performed in MATLAB computing platform (2010).

Results

In the first case considered in this work, the carbonate reservoir was found containing a percentage of 35% hydrocarbons, 8% water, no gas, pyrite and other impurities included as percentages distributed among the rock forming minerals, according to Table 1. The simulation results are shown in Figure 3, where the profile shows high GR values in shale (70°API), low values in the carbonates (5°API) and intermediate values in salt (25°API). The profile shows resistive induction, respectively, figures for 2000, 1000 and 20 ohm.m for salt, carbonate and shale with the profile ILd; 2000 figures, around 100 and 20 ohm.m for the profiles R_{xo} and ILm. That is, there is little difference between these two profiles in the carbonates, which shows that there is a reasonable intrusion into the reservoir with a depth of around 1.7 m (calculated by the polynomial Ribeiro, 2007), with the estimated induction above the theoretical invasion of 1.5 m calculated with the formula Crain (1986). By its composition, the drilling mud base oil is less resistive than oil in this formation, with diesel this little mud invades the formation and invasion occurs more because of the water at the base of the mud. Thus, he has a lower resistivity in the transition zone and the relationship of resistivity values for the induction tool is ILm<R_{xo}<ILd.

The same model of Table 1 was used in a simulation with the profile laterolog. Since there is no mineralogical variations, there is, in this case, changes in GR profile, only the resistivity profile. Thus, the laterolog show, respectively, values of 300, 170 and 20 ohm m for salt, carbonate and shale with the profile LLd, significantly decreasing these values in relation to the induction of the previous model. For profiles ILm and Rxo resistivity values are 300, 50 and 20 ohm.m in salt, carbonate and shale, respectively, also showing a decrease in the first values in relation to the results of induction. As there is little difference between the profiles ILm and R_{xo} in carbonates, it shows that there is a reasonable intrusion into the reservoir with a depth of around 1.5 m, with an estimate of laterolog equal to the invasion theory. Exist, also in this case, a lower resistivity in the transition zone, the relationship of resistivity values for the tool will laterolog LLs<R_{xo}<LLd.

For the model of Table 2, there are variations in the percentage of some of the minerals present in each layer over the first model. In this case, the tank has 35% oil, no gas, 5% water, the same percentage of pyrite and other impurity percentages distributed among the other minerals. As shown in the same table, there are also small variations in the mineralogical composition earlier in adjacent layers. The simulation results are shown in Figure 5, noting a decrease in GR profile in salt, an increase in the shale and the same values in carbonates. The decrease in salt is due to the increase in soda ash (Na_2CO_3) and the slight decrease in sylvite (KCl). In the case of shale, the increase is due to the increase of mica (silicates K). The resistivity profile shows laterolog the same values as in Figure 4 for the first model, and the same estimate of the depth of invasion, showing that there is a dependency of the resistivity profile with the mineral composition of the training but with the fluids present in the porous.

Conclusions

These results show that the resistivity profiles do not differ significantly with the variation of mineralogical composition in the simulation of the invasion process, but a carbonate reservoir with fluid present in the porous medium. The differences in the profiles and resistive induction laterolog are more related to the filtrate invasion of drilling mud-base oil achieves greater depth and with the research profile in relation to the induction laterolog. This explains why, despite the mud being base-oil, diesel oil and little of it penetrates your filtered follows in the tank, which the two types of profile can register. With the simulated models, the GR profile changes slightly from one model to another, the changes happening in the salt (decrease in values of the profile) by the increased and decreased silvita kelp, and shale, the increase of mica (increase in the values the profile). Moreover, calculating the diameter of invasion is more accurate with the profile laterolog whose results match the theoretical profile of invasion, making the estimate by induction profile slightly above this theoretical value.

Acknowledgments

At the State University North Fluminense Darcy Ribeiro (UENF) for its infrastructure and support.

References

– Ahr, W. 2008. Geology of carbonate reservoirs: the identifi cation, description, and characterization of hydrocarbon reservoirs in carbonate rocks. John Wiley & Sons, Inc., New Jersey, 296 pp.
– Bourgoyne, A.; Millheim, K.; Chenevert, M. & Young F. 1991. Applied Drilling Engineering. 473 pp.
– Choquette, P. & Pray, L. 1970. Geologic nomenclature and classification of porosity in sedimentary carbonates, AAPG Bulletin, v.54, p. 207-250.
– Clyde, H. 2010. carbonate reservoir porosity evolution and diagenesis in a sequence stratigraphic framework. 444 pp.
– Crain, E. 1986. The Log Analysis Handbook, PennWell Books, Tulsa, USA , 876 pp.
– Dziuba, T. 1987. Mud filtrate effects on the laterolog in Alberta foothills carbonate. SHELL Canada Ltd. Journal of Canadian Petroleum Technology, p. 41-50.
– Lucia, F.J. 2004. Carbonate reservoir characterization - an integrated approach, 2nd edition, 336 pp.
– MATLAB. 2010. User´s Manual, 413 pp.
– Ribeiro, M. 2007. Geofísica de poço na delimitação do dano à formação produtora de petróleo causado pela invasão da lama de perfuração. Tese de Mestrado, LENEP/UENF, Macaé, 92 pp.
– 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.
– Ribeiro, M. & Carrasquilla A. 2008. Calculating mud drill invasion in theoretical reservoirs through geophysical well logs. Anais (CD) do 11th International Congress of the Brazilian Geophysical Society.
– SCHLUMBERGER.1989. Log Interpretation Principles / Applications. SCHLUMBERGER Educational Services, Houston, 143 pp.

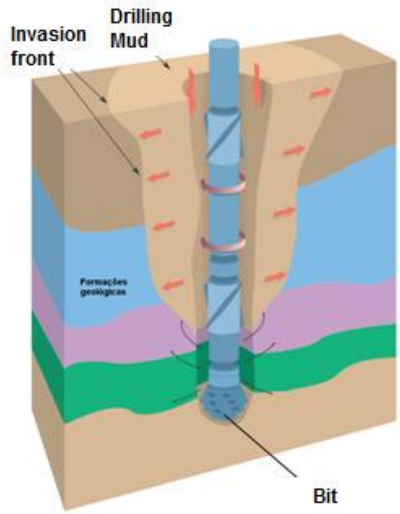

Figure 1. Invasion of drilling mud during (Schlumberger, 2009).

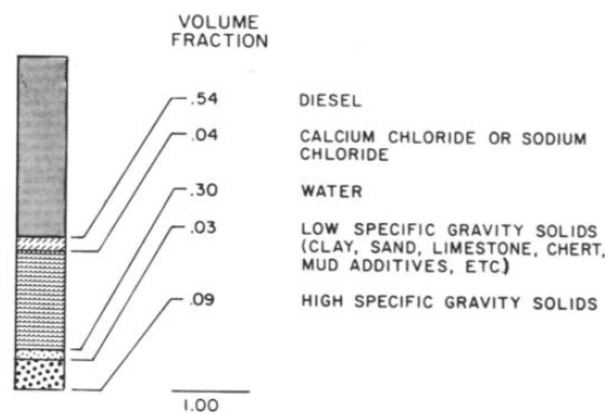

Figure 2. Composition of oil-base mud (Bourgoyne, 1991).

Table 1. Mineralogical variation in the percentage in each layer of the first model.

SALT		CARBONATE		SHALE	
Mineral	**%**	**Mineral**	**%**	**Mineral**	**%**
halite	50	calcite	25	olivine	30
anhydrite	15	dolomite	20	mica	10
silvita	15	aragonite	15	quartz	20
bischofite	00	pyrite	01	biotite	05
kelp	00	anhydrite	01	pyroxene	00
gypsum	20	quartz	05	aragonite	05
water	01	water	08	water	30
oil	00	oil	35	oil	00
gas	00	gas	00	gas	00

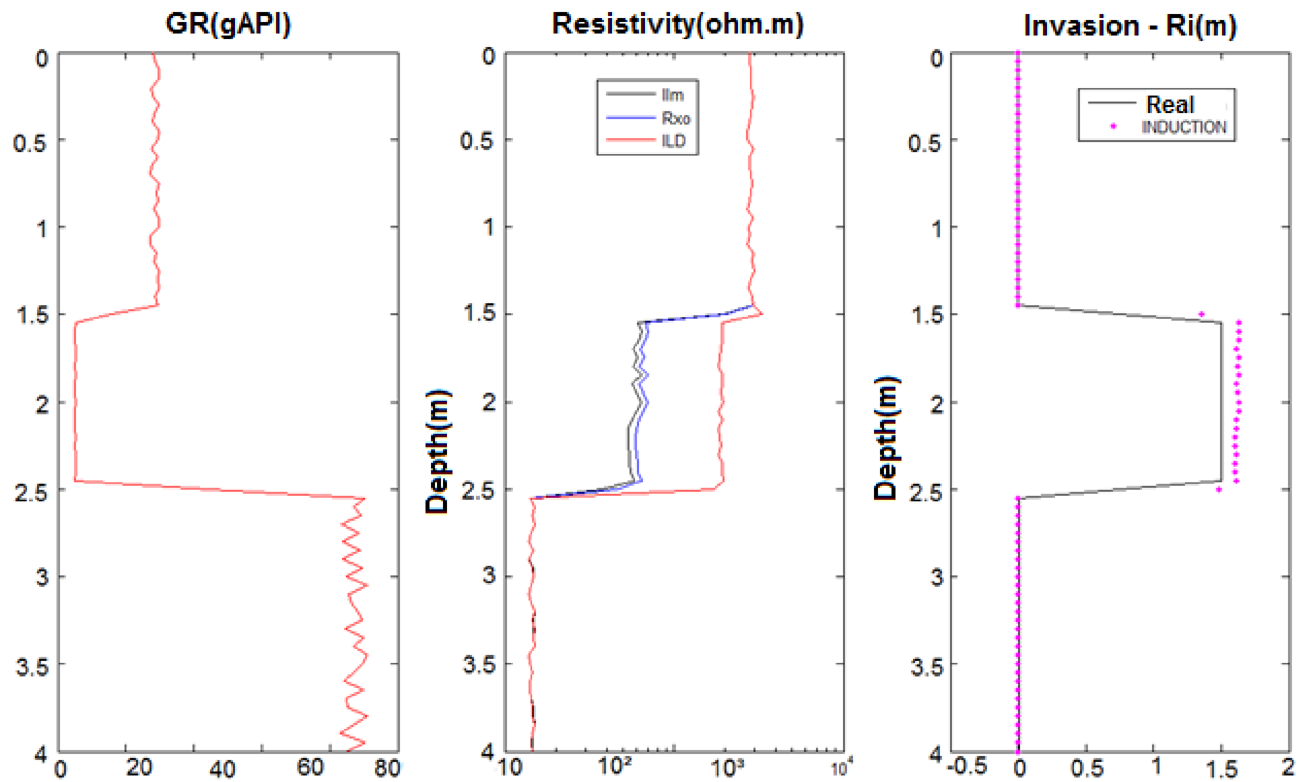

Figure 3. Profiles GR, resistivity and invasion by the tool induction.

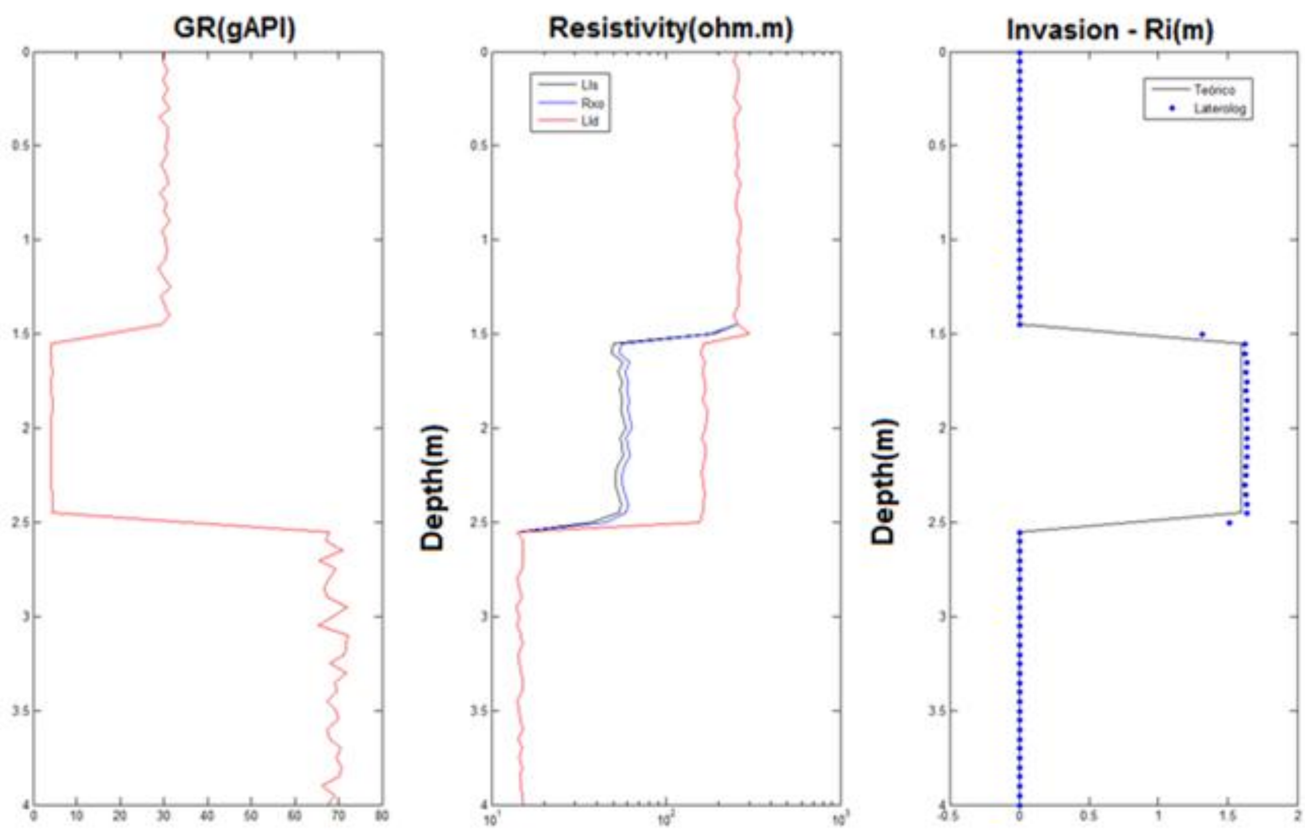

Figure 4. Profiles GR, resistivity and invasion by laterolog tool.

Table 2. Mineralogical variation in the percentage in each layer of the second model.

SALT		CARBONATE		SHALE	
Mineral	**%**	**Mineral**	**%**	**Mineral**	**%**
halite	40	calcite	15	olivine	25
anhydrite	15	dolomite	25	mica	15
silvita	14	aragonite	18	quartz	30
bischofite	00	pyrite	01	biotite	05
kelp	25	anhydrite	00	pyroxene	00
gypsum	05	quartz	01	aragonite	05
water	01	water	05	water	20
oil	00	oil	35	oil	00
gas	00	gas	00	gas	00

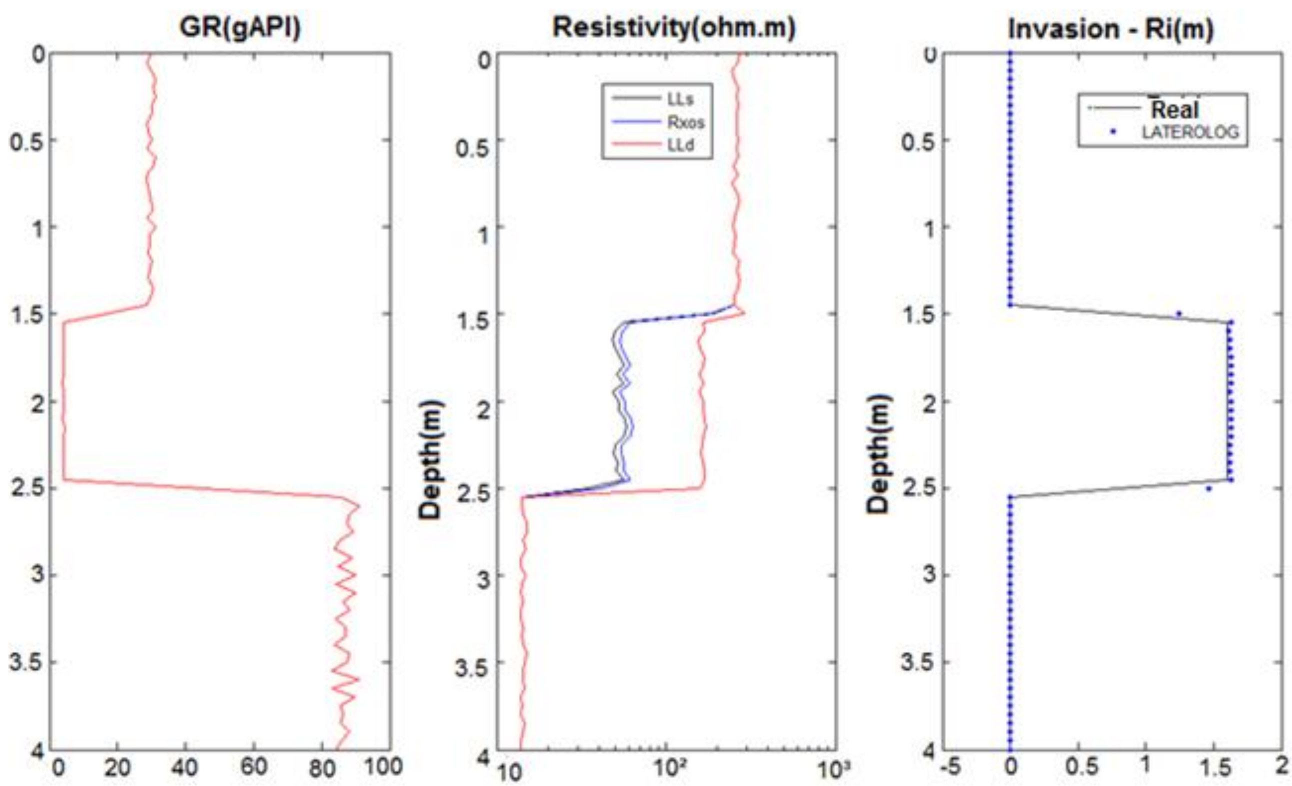

Figure 5. Profiles GR, resistivity and invasion by laterolog tool.