Estimative of mineral composition of Namorado Oilfield lithologies using well logs and a proportional integral derivative controller

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Abstract

This study aimed to simulate the influence of lithology on geophysical well logs using the mineralogical composition of the geological formations as a starting point and, conversely, the mineral content of a lithology was estimated from logs. Initially, the equations that calculate the responses of natural gamma ray (GR), resistivity (Rt), density (RHOB), neutron (NPHI) and sonic (DT) logs, besides porosity (ϕ) derived from RHOB, NPHI and DT, were identified. Hereafter, a code was developed implementing these equations in a forward modeling, considering petrophysical properties of each mineral which comprises every sedimentary rocks. To check the proper functioning of this code, the results were compared with published models. To infer mineralogy from logs, a Proportional Integral Derivative Controller (PID) algorithm was used as inverse approach. Then, real data of Namorado Oilfield in Campos Basin - Southeast Brazil were used to verify the performance of this approach. At the end, it was verified a good functionality of forward code to match results of the literature, as well as, the inverse approach, was useful at this stage with simple models, but showing good prospects for more complex models of logs in the future.

Introduction

Campos Basin is a sedimentary basin located along the continental margin of Southeastern Brazil, which has several oil fields (Figure 1). One of these, Namorado Oilfield, has a reservoir so-called Namorado Sandstone, which consists of turbidite sands interspersed with marl and shale, being deposited over a carbonate platform ramp (Guardado et al. 1990). Sequence analysis of cores made by PETROBRAS (1996) on this field, based on geological criteria such as particle size and similar constitution, formed the basis for Ninci (2009) classifies rock types in four different groups (Figura 2):

- Group 1: contains facies formed only by sandstone without interbedded with other lithologies and predominant cementation. Absence of shale/clay and medium to coarse grain size suggest a high potential for containing oil.
- Group 2: formed by sandstones with less capacity to contain oil than Group 1, being composed of finer grain or associated with clay.
- Group 3: include only sandstones and shales, containing carbonates (cemented facies and marl) in its constitution. These facies are placed in the same group because presence of cement makes the cemented sandstones have higher values than non-cemented sandstones on density log.
- Group 4: facies are predominantly formed by very fine sediments, such as silt and clay, being considered as non - reservoir.

In the present study, it was used the groups of well NA22 of Namorado Oilfield, which are shown in Table 1. Ninci (2009) proposed these groups and performed a statistical analysis of the values of GR, NPHI and RHOB for each facies and calculated mean value and standard deviation for each group. These values were used as input in the construction of a model considered as true in the inverse modeling. Thus, it was performed a forward modeling of how different lithologies of sedimentary rocks influence the basic logs, starting from the mineral composition of each lithology. These results were immediately compared with models of published by Rider (2002). In addition, it was developed an inverse approach to fit the mineralogical composition of lithologies starting from real logs, using geological and logs a priori information of well NA22.

Theory and Method

The first task achieved in this work was to identify and codify the equations that simulate the response of logging tools caused by the geological formations. For example, to simulate GR log, total natural radioactivity of rocks is linearly proportional to radioactive element concentrations, of which the most significant in the geological media are: potassium, thorium and uranium. Among them, potassium is the most significant because this directly makes part of the crystal structure of many minerals of rocks as microcline, sylvite, biotite, orthoclase, microcline, muscovite, etc. (Luthi, 2001). Thorium is associated with deposition of clay minerals due to the fact that it is electrically active and associate chemically with aluminum phyllosilicates (Worthington et al., 1985). Uranium appears associated with the presence of marine organic matter (SCHLUMBERGER, 1989). Thus, the equation programmed for the GR log is given by:

$$GR_{\log} = \sum_{i=1}^{n}\left(V_i . GR_{Mi}\right) + V_{sh} . GR_{Th} + \frac{V_{oleo}}{\phi} . GR_U \,, \qquad (1)$$

where:

- GR_{log} is the GR log response (°API),
- n is the number of minerals,
- i is the index of the minerals,
- V_i is the fractional volume of each mineral,
- GR_{Mi} is the average radioactivity of potassium in 100% of each mineral (°API),
- V_{sh} is the fractional volume of clays,
- ϕ is the porosity (fraction),

- GR_{Th} is the average radioactivity of thorium in 100% of each mineral (°API),
- V_{oleo} is the fractional liquid volume of hydrocarbons,
- GR_U is the average radioactivity of uranium in 100% of each mineral (°API),

Thus, all the equations for GR, Rt, NPHI, RHOB and DT logs were implemented in a code developed in MATLAB (2014), with which it was possible to simulate directly the responses of these logs starting from the volumes and number of minerals and fluids present in the formation. After this, these synthetic logs were compared with logs of published models, such as those that appear in Rider (2000) but not shown in this article

In the opposite direction, it was developed an inverse code to estimate the volume of the minerals that best adjusts the responses of the real logs. The system of equations that generate the logs is composed by 23 minerals and 3 fluids, which fits interactively the volume of each mineral, considering as first attempt *a priori* geological information from core and plugs, with the procedure stopping when there is a minimum error between real and simulated logs (Caetano, 2014). To accomplish this process it was used the PID control scheme, which joints proportional actions in time (P, depends on actual error, which minimizes the error), integral (I, accumulation of errors of the past, which resets the error) and derivative (D, forecasting future errors, which looking faster ahead the error). The PID control is currently the most widely used in industries, in procedures with single input and output, in which there is only one controlled input variable and a monitored output variable (Figure 3). The weighted sum of the three actions is used to adjust the process via a control element, for example, fitting a function in the other (Shirahige, 2007).

Results

Real logs of well NA22 are presented in Figure 4, showing also the studied portion of the well in red dashed rectangle. Based on this figure, it was proposed a model of 4 layers for this zone, considers the groups proposed by Ninci (2008) as true model (Figure 5). Figure 6, on the other hand, shows the simulated logs based on that model.

From the analysis of the lithology of this well (PETROBRAS, 1996), an initial attempt of mineralogical compositions is shown in Table 2 for each layer, which is derived from the classification of groups. From here, it was used the inverse code, which adjusts the volume of minerals so that the error between the true and synthetic logs is small (Figure 7). The mineral composition of each layer due to this fit is also shown in Table 2.

Interpreting the results of Layer 3 were analyzed, which, by analogy, can be extended to the other layers, it was observed that in this layer the water formation volume and the concentrations of calcite, mica and clay increased, but the volumes of dolomite, accessory minerals, anhydrite and gypsum decreased significantly. For this layer, the work of Ninci (2008) indicates sandstones and shales containing carbonates with cemented facies and marls, which are formed by calcite or dolomite that were, respectively, underestimated and overestimated in the initial model. On the other hand, the accessory minerals (siderite, anquerita, pyrite), anhydrite and gypsum were overestimated, while the porosity (volume of water) and the volume of clay minerals have been underestimated in the initial attempt.

Conclusions

Logs simulated using forward modelling, which starts with mineralogical composition of lithologies of different sedimentary rocks, agree with models published in bibliography. This served as the basis to simulate logs based in models derived from real data of Namorado Oilfield. In PID inverse scheme, moreover, fits obtained from logs allows to estimate how much specific minerals were underestimated or overestimated in the initial model. However, it is suggested to compare the results obtained by this methodology with real data of geochemical log, which record directly along the well the chemical elements as Si, Ca, Fe, etc., and indirectly minerals as SiO_2, $CaCO_3$, FeS_2, etc. Thus, this study developed a methodology to assess the mineralogical composition of geological formations using as starting geophysical well logs.

Acknowledgments

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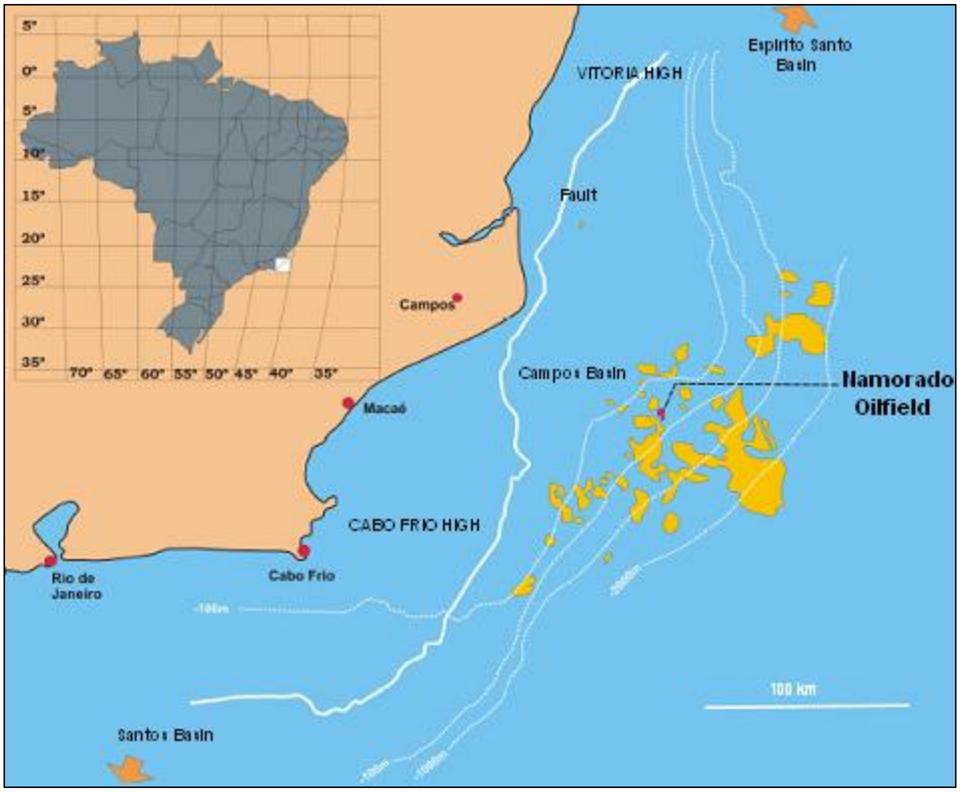

Figure 1. Map of location of Campos Basin along the continental margin of Southeastern Brazil, showing the distribution of the main oil fields, between them, Namorado Oilfield (modified from Ninci, 2009).

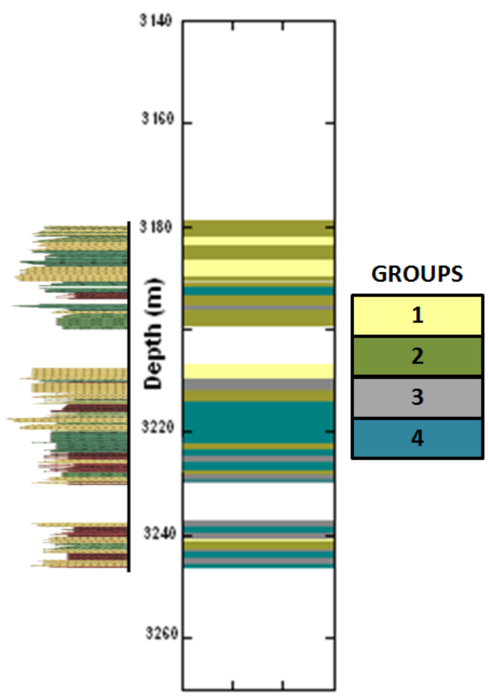

Figure 2. Stratigraphic section from core analysis (left) and groups proposed by Ninci (2009) based on the values of logs (right) of well NA22.

Table1. Facies, groups and statistical data of well NA22 regarding to GR, NPHI and RHOB log values (from Ninci, 2009).

Facies	Group	GR		NPHI		RHOB	
6	1	59.5±12.1	55.2±9.1	21.08±3.6	22.6±3.68	2.3±0.1	2.3±0.1
7		52.9±1.8		21.0±3.5		2.3±0.1	
8		54.0±7.3		23.1±3.6		2.3±0.1	
3	2	67.4±14.7	67.4±15.7	22.0±4.9	22.1±4.8	2.4±0.1	2.4±0.1
10		66.5±9.15		23.9±3.2		2.3±0.1	
11		77.1±19.5		21.7±3.5		2.4±0.1	
15		67.2±18.7		20.9±5.8		2.4±0.1	
9	3	52.4±12.1	47.9±14.6	18.1±6.5	13.0±5.7	2.4±0.1	2.5±0.1
21		57.5±21.94		16.4±6.9		2.5±0.1	
12	4	76.9±17.0	79.7±20.6	20.2±5.2	21.6±5.7	2.4±0.1	2.4±0.1
16		81.4±19.8		22.7±6.4		2.4±0.1	

6 - Amalgamated coarse sandstone
7 - Medium gradated or massive sandstone
8 - Medium gradated or massive sandstone
3 - Sandy muddy diamictite
10 - Interstratified shaly sandstone
11 - Finely interstratified shaly sandstone
15 - Interlaminar bioturbated sandstone
9 - Medium cimented sandstone
21 - Cimented sandstone with slip features
12 - Stratified clayey siltstone
16 - Interlaminar of siltstone and shale, deformed, bioturbated

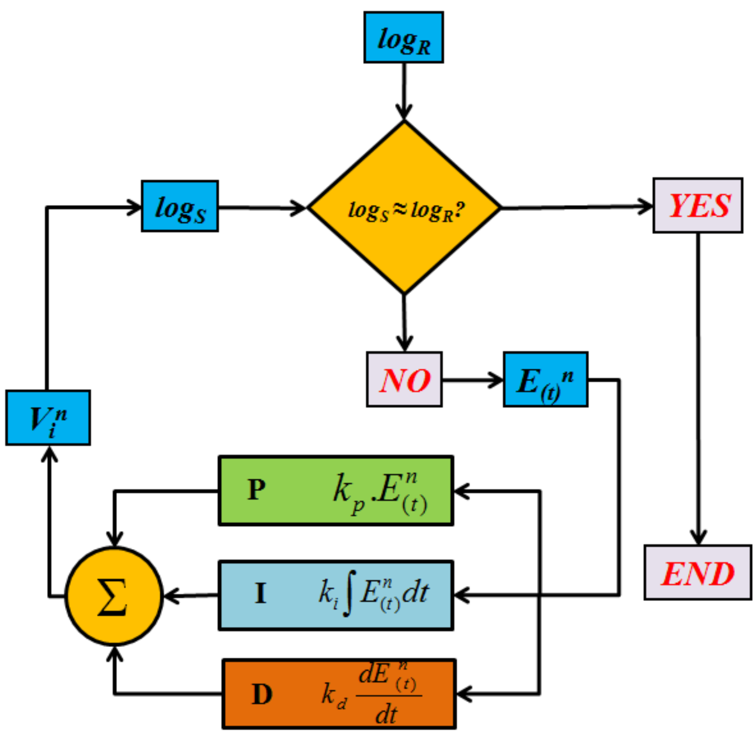

Figure 3. PID action control diagram, where log_R is the real log, log_S is the simulated log, $E(t)$ is the error, P means proportional, I is integral, D is derivative, $\sum$ is the sum and Vi is mineral volume (Shirahige, 2007).

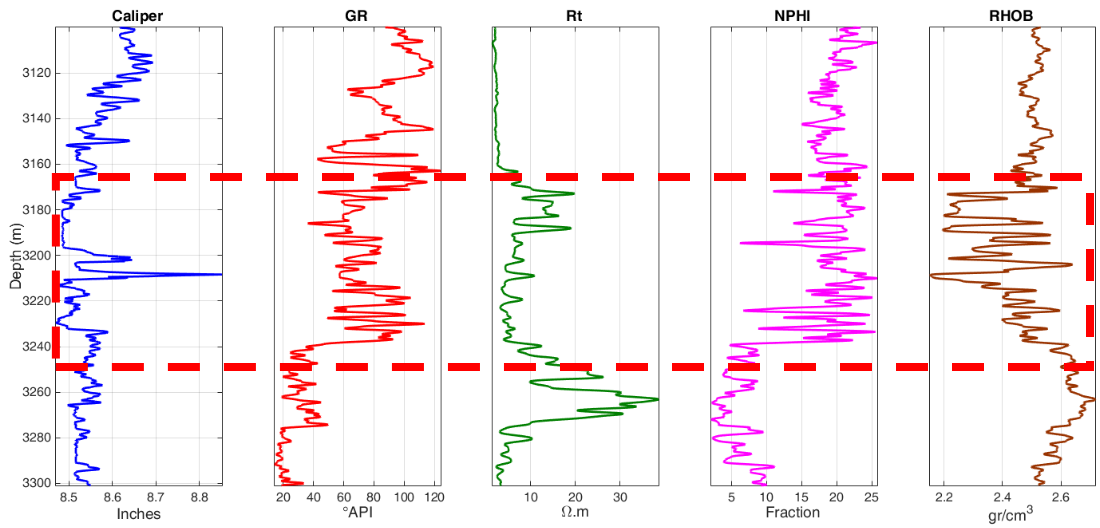

Figure 4. Caliper, GR, RT, NPHI and RHOB logs of well NA22 of Namorado Oilfield, showing in red dashed rectangle the studied horizon (Caetano, 2014).

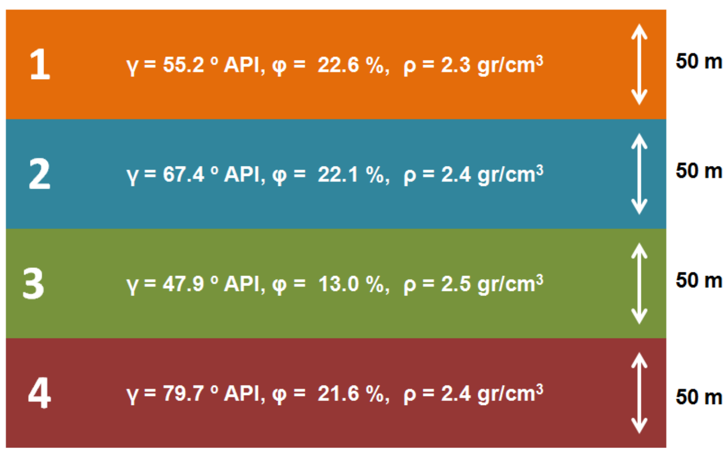

Figure 5. Model of 4 layers for the studied zone of well NA22 (Caetano,

Table 2: Initial attempt and fit of the mineralogy for model of Figure 5 (Caetano, 2014).

Minerals	Layers (% of minerals)							
	1		2		3		4	
	Input	Fit	Input	Fit	Input	Fit	Input	Fit
Quartz	40.0	41.4	45.0	45.2	38.0	39.9	39.0	44.4
Feldspar	30.0	33.9	4.0	8.2	-	-	4.0	6.3
Calcite	0.3	0.3	5.0	5.0	19.0	19.7	2.0	2.2
Dolomite	0.7	0.4	2.0	1.5	15.0	7.5	1.0	0.9
Anhydrite and gypsum	2.0	1.4	2.0	0.8	1.0	0.6	-	-
Evaporite	-	-	1.0	1.9	-	-	-	-
Mica and clay	3.0	1.2	20.0	16.5	15.0	17.3	33.0	27.0
Accessory minerals	4.0	1.7	0.5	0.2	1.0	0.1	1.0	0.6
Water	2.0	1.1	2.0	1.3	11.0	15.0	18.0	18.4
Oil	18.0	18.6	18.0	15.7	-	-	-	-
Gas	-	-	-	-	-	-	-	-

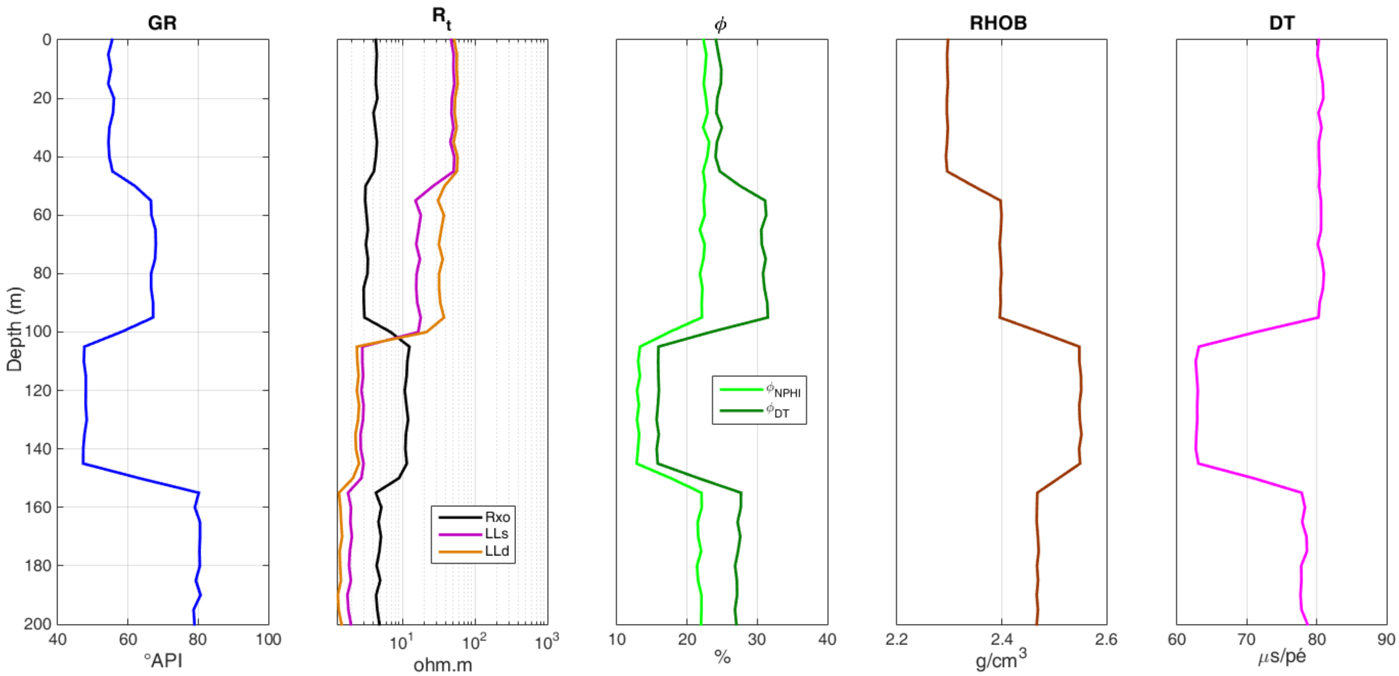

Figure 6. Simulated logs for model of Figure 5 to be fitted with the initial attempt of Table 2 (Caetano, 2014).

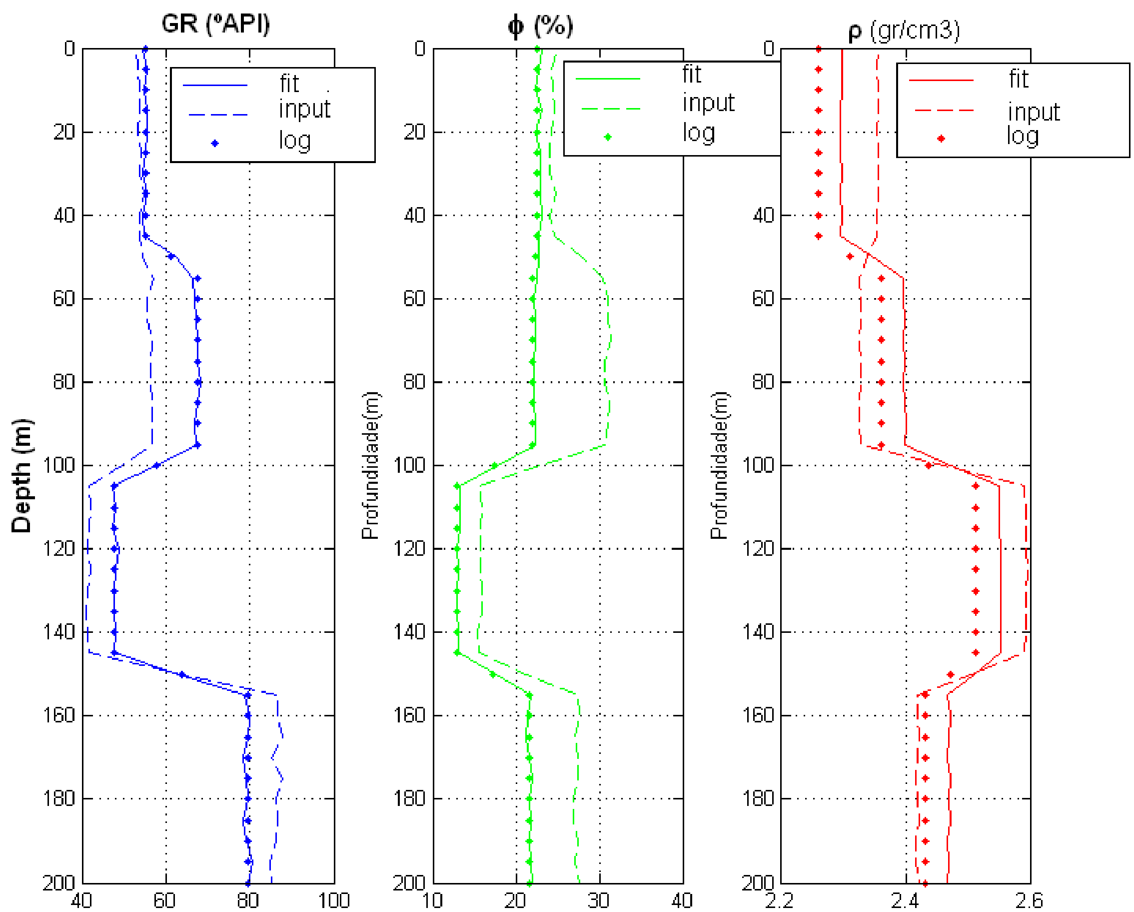

Figure 7. Initial, fitted and simulated logs for model of Figure 5 (Caetano, 2014).