Mineralogical analysis for a well in the Namorado Reservoir

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Abstract

In the development phase of an oil and gas reservoir, petrophysical characterization of sedimentary formations that compose the reservoirs assists both drilling and reservoir engineers on the important task of maximize the production of hydrocarbons. The larger goal is to minimize the costs of production operations. In this context, the records obtained by geophysical well-logging tools are used for the formations evaluation. In this research project, we discussed the methodology for estimation of mineralogical composition of sedimentary formations from geophysical logging for a single well. We will apply this methodology in the upper part of the Macaé formation, which the Namorado Reservoir is inserted, located in the Campos Basin, the north coast of the State of Rio de Janeiro. We will use some of the geophysical well-logs from the data set 'Campo Escola Namorado', ceded by ANP to the Brazilian institutions of education and research. In addition to geophysical well-logs, descriptions of core samples extracted from the wells, also contained in the data set 'Campo Escola Namorado', are fundamental to the mineralogical composition evaluation of the formations under investigation.

Introduction

In this project, we worked with the geophysical well-logs data for the well NA-01A in the depth interval 3025-3125m, having as main reference the sequential core samples analysis of the well NA–04 in the same range. The correlation can be made once the two wells are placed in the same geological context of the upper part of the Macaé formation (Tigre & Lucchesi, 1986).

From the similarity of these both wells, we can designate which mineralogical components are more prevalent in sedimentary facies and make them the basis for the calculation of the volume estimation of each component inserted in the well periphery. Figure 1 illustrates the location of wells in Namorado Reservoir.

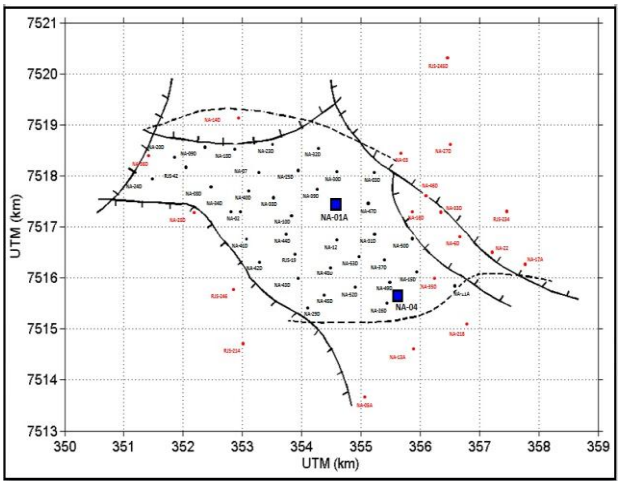

Fig.1. *– Namorado Reservoir Structural Map. Location of wells NA-01A and NA-04 marked in blue spots.*

Data

First, using *MatLab* we plotted geophysical well-logs data of Natural Gamma Ray (GR), Neutron Porosity (ϕ_n), Density (RhoB) and P-Wave Transit Time (DT_p) (Fig. 2). Then, observing the well NA-04 core samples (Fig. 3) and the lithological facies description (Table 1) we restricted the sedimentary formation composition to four main compounds: quartz, k-feldspar, calcite, clays and effective porosity. With this, we developed a model for the sedimentary formation that composes the surroundings of well NA-01A (Fig. 4).

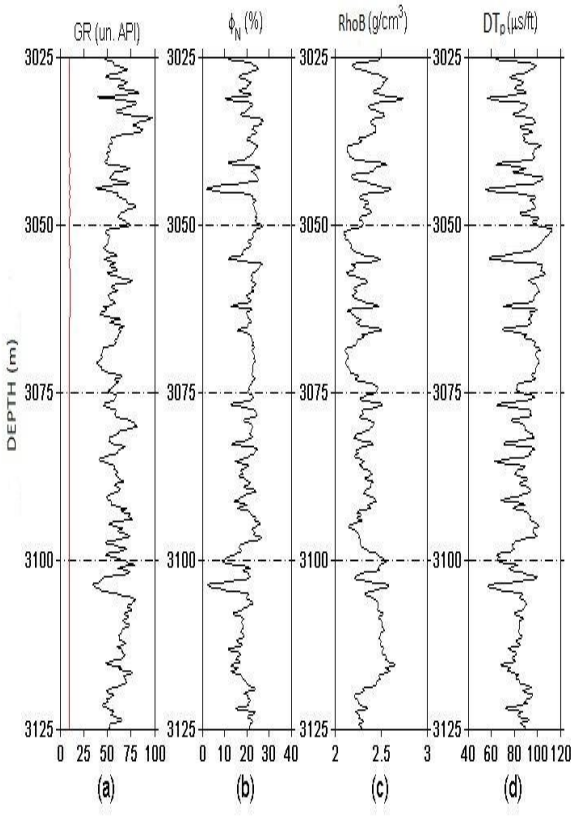

Fig. 2. *– Geophysical Well-logs at NA-01A.*

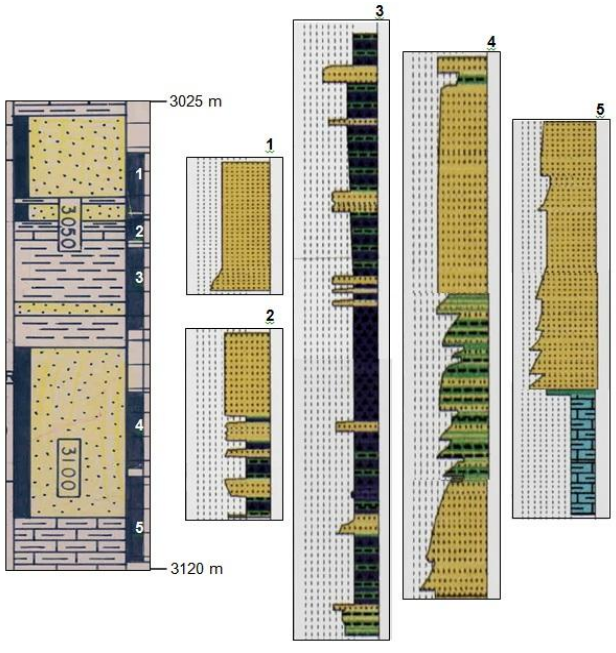

Fig. 3. *– Lithological column and core samples of well NA-04.*

Table 1 *– Facies descriptons from the core samples of well NA-04.*

Core	Depth Interval (m)	Facies Description	Main Constituents
1	3036.50 - 3042.80	Well sorted arcosean sandstone	Quartz, k-feldspar
2	3048.00 - 3053.90	Well sorted arcosean sandstone (top); interlaminations of clayey silt (bottom)	Quartz, k-feldspar, clay
3	3055.50 - 3072.70	Intercalations of cemented, clay-rich, arcosean sandstone; interlaminations of clayey silt and bioturbated calcareous shale (35-50% $CaCO_3$ content)	Quartz, k-feldspar, calcite, clay
4	3086.50 - 3100.80	Cemented arcosean sandstone with intermediate laminations of clayey silt	Quartz, k-feldspar, clay
5	3103.50 - 3119.50	Cemented arcosean sandstone (top); Carbonate-rich interval (bottom), with interlaminations and rhythmic intercalations of calcilutite, calcareous (35-50% $CaCO_3$ content) and shale	Quartz, k-feldspar, calcite, clay

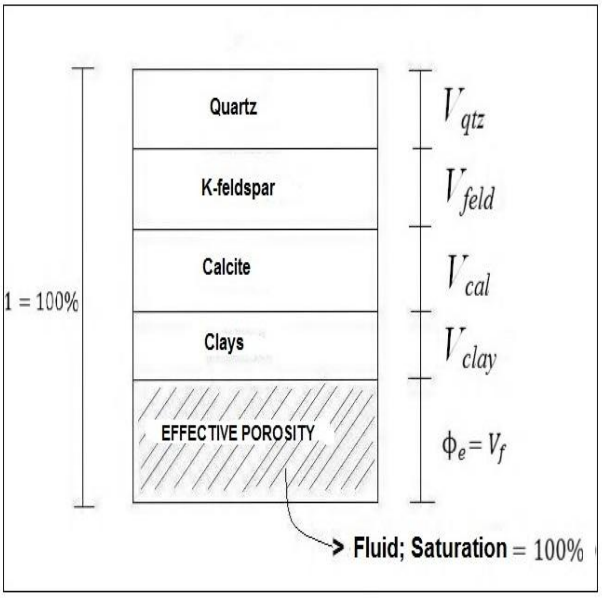

Fig. 4. *– Parallel-layers conceptual model for the sedimentary formation around well NA-01A (Schön, 1996)).*

Mineralogical Inversion

Considering the model depicted in Fig. 4 and assuming that all rock pores are filled with fluid, we have the following expression:

$$V_{qtz} + V_{feld} + V_{cal} + V_{clay} + V_f = 1$$

Making use of *Law of Mixtures*, which says that "in a multi compound system each component contributes volumetrically to the properties of the mixture in the ratio of the volumetric fraction of one component times its property" (Dewan, 1983; Nery, 1990), we have the equations:

$$RhoB_i = Rho_{qtz}V_{qtz} + Rho_{feld}V_{feld} + Rho_{cal}V_{cal} + Rho_{clay}V_{clay} + Rho_fV_f$$

$$\phi_{n_i} = \phi_{n_{qtz}}V_{qtz} + \phi_{n_{feld}}V_{feld} + \phi_{n_{cal}}V_{cal} + \phi_{n_{clay}}V_{clay} + \phi_{n_f}V_f$$

$$GR_i = GR_{qtz}V_{qtz} + GR_{feld}V_{feld} + GR_{cal}V_{cal} + GR_{clay}V_{clay} + GR_fV_f$$

$$DT_{p_i} = DT_{p_{qtz}}V_{qtz} + DT_{p_{feld}}V_{feld} + DT_{p_{cal}}V_{cal} + DT_{p_{clay}}V_{clay} + DT_{p_f}V_f$$

$$1 = V_{qtz} + V_{feld} + V_{cal} + V_{clay} + V_f$$

where, V_{qtz} (quartz volume), V_{feld} (feldspar volume), V_{cal} (calcite volume), V_{clay} (clay volume) and V_f (fluid volume) are the values to be discovered; $RhoB_i$, ϕ_{ni}, GR_i and DT_{pi} are the records of the well-logging tools in depth *i* of the well; and the average response values of each tool for each constituent of the rock are represented in the following table (Table 2).

Table 2 *– Physical properties of each rock constituent*

Rock Constituent	*DT_p (µs/ft)*	*Rho (g/cm^3)*	*GR (API units)*	*ϕ_n (%)*
Fluid (f)	185.00	1.10	0.00	100.00
Quartz (qtz)	55.50	2.65	1.00	-1.80
K-Feldspar (feld)	69.00	2.54	171.00	-0.60
Calcite (cal)	48.10	2.71	12.00	0.20
Clays (clay)	86.00	2.54	76.00	29.00

Using matrix notation, we have the following:

$$\begin{pmatrix} Rho_{qtz} & Rho_{feld} & Rho_{cal} & Rho_{clay} & Rho_f \\ \phi_{n_{qtz}} & \phi_{n_{feld}} & \phi_{n_{cal}} & \phi_{n_{clay}} & \phi_{n_f} \\ DT_{p_{qtz}} & DT_{p_{feld}} & DT_{p_{cal}} & DT_{p_{clay}} & DT_{p_f} \\ GR_{qtz} & GR_{feld} & GR_{cal} & GR_{clay} & GR_f \\ 1 & 1 & 1 & 1 & 1 \end{pmatrix} \times \begin{pmatrix} V_{qtz} \\ V_{feld} \\ V_{cal} \\ V_{clay} \\ V_f \end{pmatrix} = \begin{pmatrix} RhoB_i \\ \phi_{n_i} \\ DT_{p_i} \\ GR_i \\ 1 \end{pmatrix}$$

Inserting values from Table 2, we have:

$$\begin{pmatrix} 2.65 & 2.54 & 2.71 & 2.54 & 1.10 \\ -1.80 & -0.60 & 0.20 & 29.00 & 100.00 \\ 55.50 & 69.00 & 48.10 & 86.00 & 185.00 \\ 1.00 & 171.00 & 12.00 & 76.00 & 0.00 \\ 1 & 1 & 1 & 1 & 1 \end{pmatrix} \times \begin{pmatrix} V_{qtz} \\ V_{feld} \\ V_{cal} \\ V_{clay} \\ V_f \end{pmatrix} = \begin{pmatrix} RhoB_i \\ \phi_{n_i} \\ DT_{p_i} \\ GR_i \\ 1 \end{pmatrix}$$

We can observe that the matrix equation type is:

$$A \times X = Y$$

Next,

$$X = A^{-1} \times Y\,.$$

In this case, X corresponds to the mineralogical volumes and in this way, we made a *MatLab script* that calculates the volume of each component at each depth *i*, in the range of 3025-3125m, using the method of least squares.

Results

At the end of the calculations, we generated plots illustrated in Figure 5 and 6, representing the estimated volumetric percentage of each constituent separetely, and showing the volumes of each constituent in the whole formation, respectively.

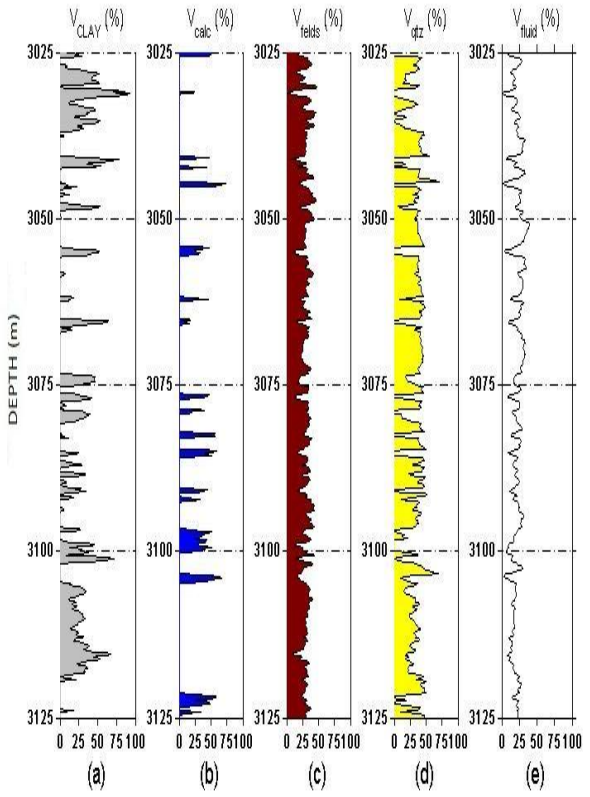

Fig. 5. *– Plots of volumetric estimation of each mineralogic component in NA-01A.*

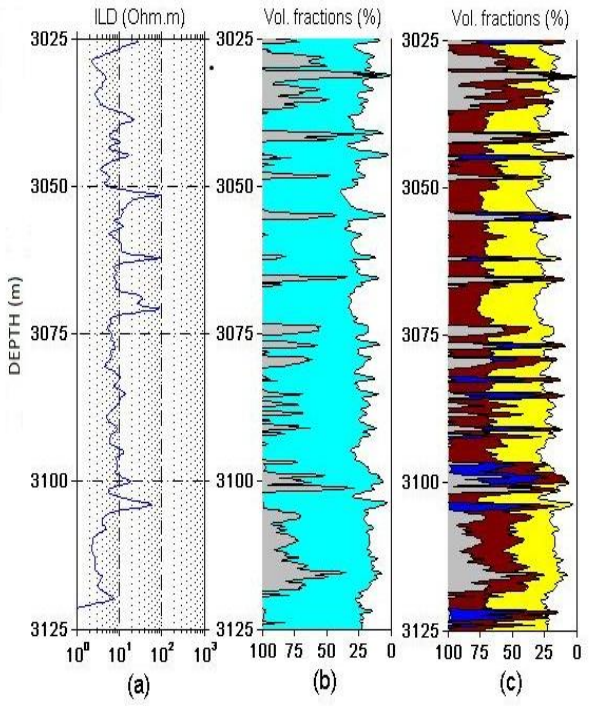

Fig. 6. *– Plots of volumetric fractions of mineralogical components composing the whole formation in NA-01A.*

Conclusions

Obviously, the rocks that compose the wall of the well are not only formed by quartz, k-feldspar, calcite and clays, they are formed also by components with completely different physical properties compared to the ones we used in this project. However, when analyzing the core samples, we can say that most rocks of the formation are formed by these four minerals, once these same minerals are most easily found in any geological formation. So, they are reasonable parameters for a volumetric estimate calculation.

The clay minerals have a particularity in virtue of their genesis, showing a wide variety of clay minerals in geological formations, with different physical properties. Because of that, the values used in the calculations have a large range of variety because of the argilosity for each formation. Since argilosity is a parameter of difficult characterization, it implies several corrections, not applied in this work.

It should be noticed also that throughout the analyzed extension of the well there is always a significant percentage of fluid volume, and we can see in the sequential analysis of core samples that this may not necessarily be interpreted as indication of hydrocarbons but should be called "Washed-out zone", influenced by the drilling fluid.

With these final remarks, we can see that the mineralogical inversion method gives us helpful information for assessing the productive potential of a well. This result, combined with core samples and sample logs, can help considerably in reducing the operational costs of the well to be explored.

Acknowledgments

We appreciate the support from PIBIC-ON/CNPq-MCT.

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