Lithological differentiation through wavelet transform and zonation process using geophysical well logs of Namorado Oilfield

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Abstract

On the geophysical well logging there is a great interest in improving the vertical resolution, with the aim to differentiate the lithology of geological formations through the well. This is of extreme importance in the petroleum industry, therefore, through this process is possible to separate the reservoirs from the seals, but also to determine the geometry and physical properties of each unit, with a view to the future tasks of commercial production. To achieve these goals, several techniques have been tested, such as log deconvolution, time-series analysis, multivariate statistical techniques, artificial intelligence techniques, etc. In this study, it was conducted a comparative study between two techniques to achieve this differentiation, such as Zonation Process (ZP) and Wavelet Transform (WLT). The used data come from the Namorado Oilfield, in Campos Basin, which is known to have a reservoir composed of a clayey-sandstone, especially difficult to be characterized by well logs. The results show that the differentiation derived from the WLT was superior to those found with the ZP, in both, the visual aspect of the layers and the improvement of the values of correlation between logs.

Introduction

One of the most important roles of geophysical well logs is tried to identify the lithology of geological formations crossed for the well (Ellis, 1987). To perform a lithological differentiation through logs, several techniques have been tested, such as log deconvolution (Aizman, 1990; Andrade, 1992; Guerra, 1994), time-series analysis (Da Silva, 1992), multivariate statistical techniques (Bucheb, 1991; Flexa et al. 2004), artificial intelligence approaches (Carrasquilla et al., 2008), etc. The present study has as the main goal to make a comparative study between two techniques to achieve the lithological differentiation, such as ZP (Davis, 1980) and WLT (Zhu, 2004), using data the Namorado Oilfield, which is known to have a clayey-sandstone reservoir, particulary difficult to be characterized by well logs.

Namorado Oilfield is located in Campos Basin, which has a tectonic - sedimentary evolution very similar to other marginal sedimentary basins of east coast of Brazil (Figure 1). This field was the first giant of Brazilian continental shelf to be discovered in 1975 by pioneering well 1-RJS-19. It is within the intermediary zone of the basin, which is in north-central portion of lineament accumulations of oil, at 80 km from the coast, in bathymetric quotas ranging between 110 and 250 m. This field presents as its main reservoir the Namorado sandstone, which has turbidite origin and lower Cenomiana age. This unit consists of sediments to the upper portion of Macae Formation and, in the area of the field, it occurs at varying depths between 2.900 and 3.400 m (Meneses & Adams, 1990).

Theoretical Aspects

WLT is a new signal processing technique based on Fourier Transform (FT), and, it has gained popularity in series analysis where the series varies significantly. FT is ideal for analyzing periodic series, since the basic functions for Fourier approximation are themselves periodic. When a series is examined that is transformed to the frequency domain by FT, the information of the series becomes less clear, although all of them is still preserved in the frequency domain. To overcome the above drawback, the Short Fourier Transform (SFT), also known as Windowed Fourier Transform, was proposed, aiming to replace the FT's sinusoidal wave by the product of a sinusoid and a localized window. Sliding windows of fixed size are imposed on the series, and the SFT computes the FT in each window, being further generalized to the WLT, where the variable-sized windows replace the fixed window. Also, the sinusoidal waves in FT are replaced by a family of functions called wavelets, whose scale defines a subsequence of series under consideration, with information is closely related to the frequency information. Although, the fastest to compute and easiest to implement in the wavelet family comes from Haar, where the series can be seen as the discretization of a function through the Discrete WT (DWT), which is based on the step function (Zhu, 2004):

$$X_{[a,b)}(x) = \begin{cases} 1 & if\ \ a \le x \le b, \\ 0 & otherwise. \end{cases} \quad (1)$$

On the other hand, ZP consists of iteratively collecting adjacent depths into zones composed of intervals that have similar log characteristics. The measure of similarity (or rather, of dissimilarity) is the squared distance, E^2. A greater squared distance between two adjacent zones indicates a greater dissimilarity between them. If two zones are identical, the squared distance between them will be zero. We will refer to zones by the subscript k, and the number of points within a zone as n_k. Because on the first iteration each zone includes only a single depth (that is, $n_k = 1$ for all k), the squared distance between every observation at depth i and its neighbor at depth i + 1 is given by:

$$E_k^2 = E_i^2 = \frac{1}{2}\left(x_i - x_{i+1}\right)^{'}\left(x_i - x_{i+1}\right). \quad (2)$$

As iteration proceeds and depths become grouped into zones, the dissimilarity between adjacent zones is determined as the squared distance between the zone means weighted by the number of depths within each zone. That is, the squared distance between zone k and zone k + 1 is:

$$E_k^2 = \frac{\left(x_i - \bar{x}_k\right)^{'}\left(x_i - \bar{x}_k\right)}{\left(1/n_k + 1/n_{k+1}\right)}. \quad (3)$$

This is the amount by which the merger of zones k and k+1 will increase the total sum of squares within zones. As noted previously, on the initial pass each zone consists of a single depth, so $n_k = 1$ for all k and the squared distances E_k^2 are given by Equation (2).

Method

To perform our methodology, logs from the Well Na04 in Namorado Oilfield were chosen. Then, the WLT approach of the Wavelet Module of MATLAB (2003) software was used, following by the coefficient correlation calculation between logs, using, in this case, the Statistical Module of MATLAB (2003). For the ZP approach, the Equations 2 and 3 were programmed using MATLAB (2003), and, afterwards, the coefficient correlation between logs was calculated, also using the Statistical Module of MATLAB (2003). Finally, a comparison between both approaches was made trying to identify the quality of the differentiation and which of them is the better option.

Results

Figure 2 (above) shows the basic well log suite of the well Na04 in Namorado Oilfield, where clearly it is shown the presence of a reservoir in the form of a high resistivity layer in the RT log at 3.040 and 3.100 m, which is also registered in RHOB log with low density values at the same depths. In a strange form, the DT, GR and NPHI logs do not show the presence of this reservoir, possibly because it has a considerable concentration of clay in its composition. On the other hand, these three logs plus the GR log show a lithological change above 3.120 m of depth, caused mainly by the presence of limestone in these depths. In the same figure (below), it is shown the correlations coefficients between logs, with high values (> 70%) for the relations DT-GR, DT-NPHI, DT-RHOB, GR-NPHI, RT-RHOB and NPHI-RHOB. Moreover, there are low correlations (<40%) for relations DT-RT, GR-RT and RT-NPHI. These results show that DT log has high correlations with other logs (GR, NPHI and RHOB), while the RT log shows low correlations with DT, GR and NPHI logs.

With the objective to compare with the Namorado Oilfield reservoir, it is shown in Figure 3 a classical reservoir with its synthetic logs (SCHLUMBERGER, 2000) and the calculated correlation coefficients of these logs through the software MATLAB (2003). In this figures (above), it is possible to observe three sandy horizons, with low GR, high NPHI high RHOB and high DT values. Although, the resistivity values change in accord the presence of oil and gas (high values), and, fresh or brine water (low values). As can be shown in this figure (below), there are high correlations (> 70%) in relations DT-GR, DT-NPHI, DT-RHOB, GR-NPHI, RT-RHOB and NPHI-RHOB. Moreover, there are low correlations (<40%) for relations DT-RT, GR-RT and RT-NPHI. As in the case of Namorado Oilfield, these results show that DT log has high correlations with other logs (GR, NPHI and RHOB), while the RT log shows low correlations with DT, GR and NPHI logs.

By comparing a classic reservoir (Figure 3) with the reservoir of Namorado Oilfield (Figure 2), in terms of correlations between the logs, it is possible to observe that the correlations which have GR, RHOB and RT logs experienced more increase (NPHI-RT and RT - RHOB) and decrease (GR-RHOB, NPHI-RHOB, DT-RHOB, DT-GR, RT and GR-GR-NPHI). This can be explained because the GR and RHOB logs are known as lithological logs, which would be very sensitive to the clay increase in the reservoir, detected through the increased natural radiation (GR) and the difference in density with sandstones (RHOB). Regarding RT log, it depends more of the fluid in the pore of the rock, but like clay is also conductive, this may cause changes in correlation with the other profiles. The DT log, on the other hand, depends more on the rock matrix, and, for this reason, it is not effect to much with the increase of clay in the reservoir, and its correlation remain almost equal with the other logs (DT-NPHI and DT-RT).

In the sequence, the WLT, with the Daubechies approach, and the ZP were applied, aiming to reduce and smooth the data without lack of information, which it is showed in Figure 4. This figure shows that these two operations eliminate the oscillations (noise) in the data, which permit to study better the correlation between the different logs. This figure also shows that, for the WLT results, it exists a strong correlation (above 50%) between DT-NPHI, DT-RHOB and NPHI-RHOB logs, average correlation (30 to 50%) between RT-RHOB, DT-GR, GR-NPHI and GR-RHOB logs, and, low correlations (below 30%) between RT-GR, DT-RT and RT-NPHI logs. For ZP results, on the other hand, it appears that there is a decrease in correlations DT-GR, RT-DT, GR-NPHI, RT-NPHI and RT-RHOB and an increase in correlations DT-RHOB, GR-RT, GR-RHOB and NPHI-RHOB. These changes are attributed to the difficulties of ZP soften the very varied logs, as it is the case of RT and GR logs, caused by the increase of clay in the reservoir. But in any case, we find that the results are superior to WLT, particularly from a visual interpretation of the logs.

In the case of comparing the best results (WLT in Figure 4) with those of the real logs of Namorado Oilfield (Figure 2), it is observed that the process of lithological differentiation through WLT causes a softening and bleaching in the profiles, without the loss of information, which results in an increase of almost all correlations, except the correlation GR-RT, which has precisely the logs that ranging more caused by the presence of clay in the reservoir.

Conclusions

Our work showed that the reservoir of Namorado Oilfield behave in a different way comparing with classic reservoirs, precisely because of strong presence of clay. This causes change in the correlation coefficients between logs, especially those who consider the GR, RHOB and RT ones, which are most sensitive to this change. Furthermore, the WLT approach was superior to the ZP one in the lithological differentiation, because it softens and brightens better the logs without loss of information and shows lesser oscillations in the results, which facilitates the work of the interpreter. This is reflected in higher values of correlation coefficients of almost all profiles, except the correlation GR-RT, whose profiles are those which have the most range, being more sensitive to the increase of clay in the reservoir. In the continuation of this study, we should compare the WLT approach with other techniques, such as deconvolution, time series, etc., particularly in the case of synthetic logs and reservoirs less complicated than Namorado Oilfield, in which it is possible to have better control of the interpretation.

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References

Aizman, L. 1990. Melhoramento da resolução para camadas delgadas de perfilagens existentes em áreas específicas de produção - exploração. Dissertação de Mestrado, UFPA, Belém, 71 pp.

Andrade, A.J.N. 1992. Deconvolução de perfis de poço. Dissertação de Mestrado, UFPA, Belém, 87 pp.

Bucheb, J.A. 1991. Aplicação de tratamento estatístico em dados de perfis de poços da Bacia de Sergipe - Alagoas. Dissertação de Mestrado, UFPA, Belém, 150 pp.

Carrasquilla, A.; Silva, J. & Flexa, R. 2008. Associating fuzzy logic, neural networks and multivariable statistic methodologies in the automatic identification of oil reservoir lithologies through well logs. Revista de Geologia, 21(1): 27-34.

Da Silva, H.P. 1992. Aplicação de análise de séries temporais em perfis de poço. Dissertação de Mestrado, UFPA, Belém, 113 pp.

Davis, J. 2000. Statistic and data analysis in geology. John Wiley and Sons, New York, 656 p.

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

Flexa, R.T.; Andrade, A. & Carrasquilla, A. 2004. Identificação da litologia nos perfis de poço do Campo de Namorado (Bacia de Campos) e do Lago Maracaibo (Venezuela) aplicando estatística multivariada. Revista Brasileira de Geociências, 34 (4): 571-578.

Guerra, C.E. 1994. Deconvolução de perfis de poço através do ajuste de energia. Dissertação de Mestrado, UFPA, Belém, 123 pp.

MATLAB. 2003. MATLAB User´s Manual, 676 p.

Meneses, S.X. & Adams, T. 1990. Ocorrência de resistividades anômalas no Campo de Namorado, Bacia de Campos. Boletim de Geociências da PETROBRAS, Rio de Janeiro, 4 (2): 183-188.

SCHLUMBERGER. 1998. Searching for oil and gas in the land of giants - Special edition on Brasil. Schlumberger, Argentina, 540 pp.

Zhu, J. 2004. High performance data mining in time series: techniques and case studies. PhD Thesis, New York University, 275 p.

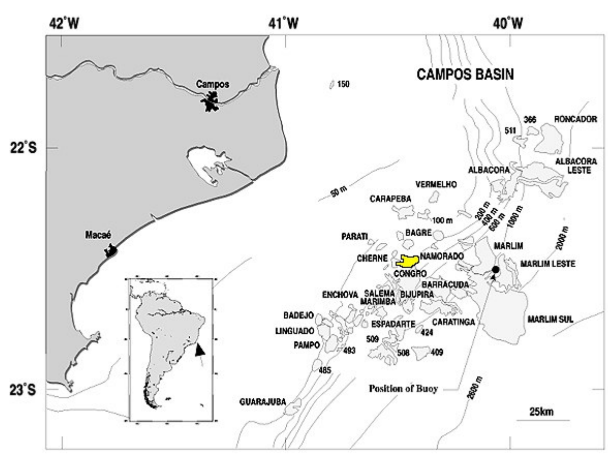

Figure 1: Main oil fields in Campos Basin, Southeast Brazil, including Namorado Oilfield (Source: ANP)

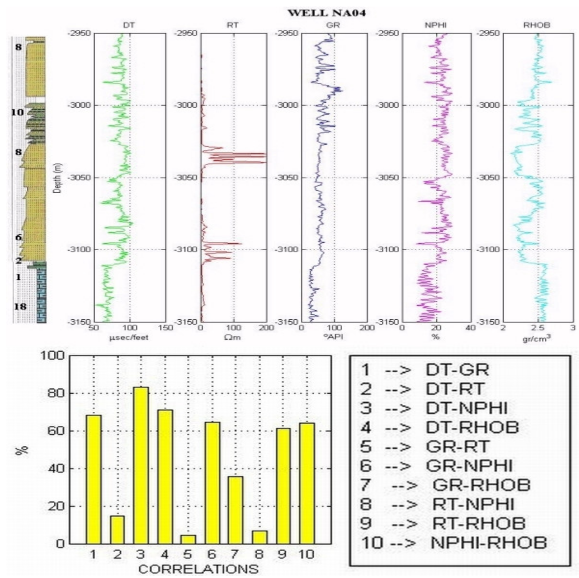

Figure 2: Above: stratrigraphic column and well logs (DT, RT, GR, NPHI and RHOB) of well Na04. 1=calcilutite, marl and shale intercalations; 2=conglomerate and carbonatic breccias; 6=amalgamated coarse sand; 8= massive medium sand; 10=sand with shale intercalations, and 18=ritmite (Source: ANP). Below: correlations between these logs (Source: ANP).

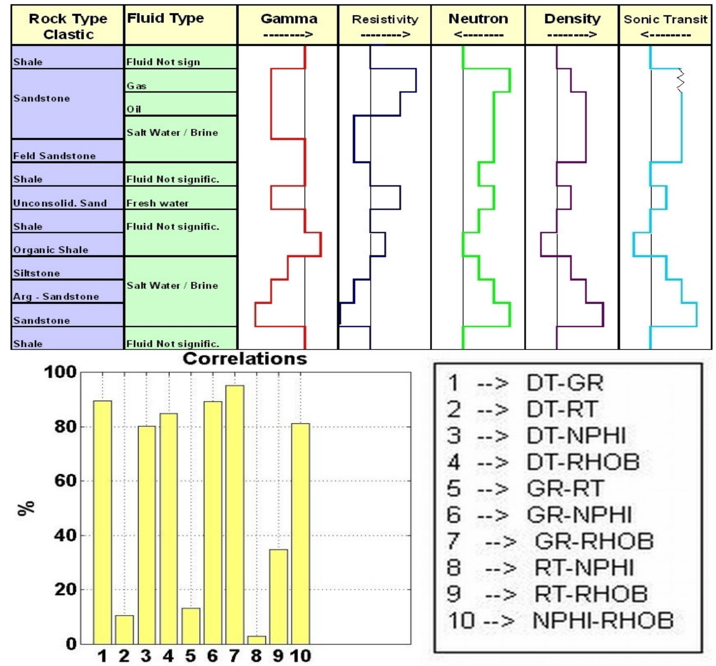

Figure 3: Above: classical reservoir and its well logs (SCHULUMBERGER, 1998). Below: correlations between these logs.

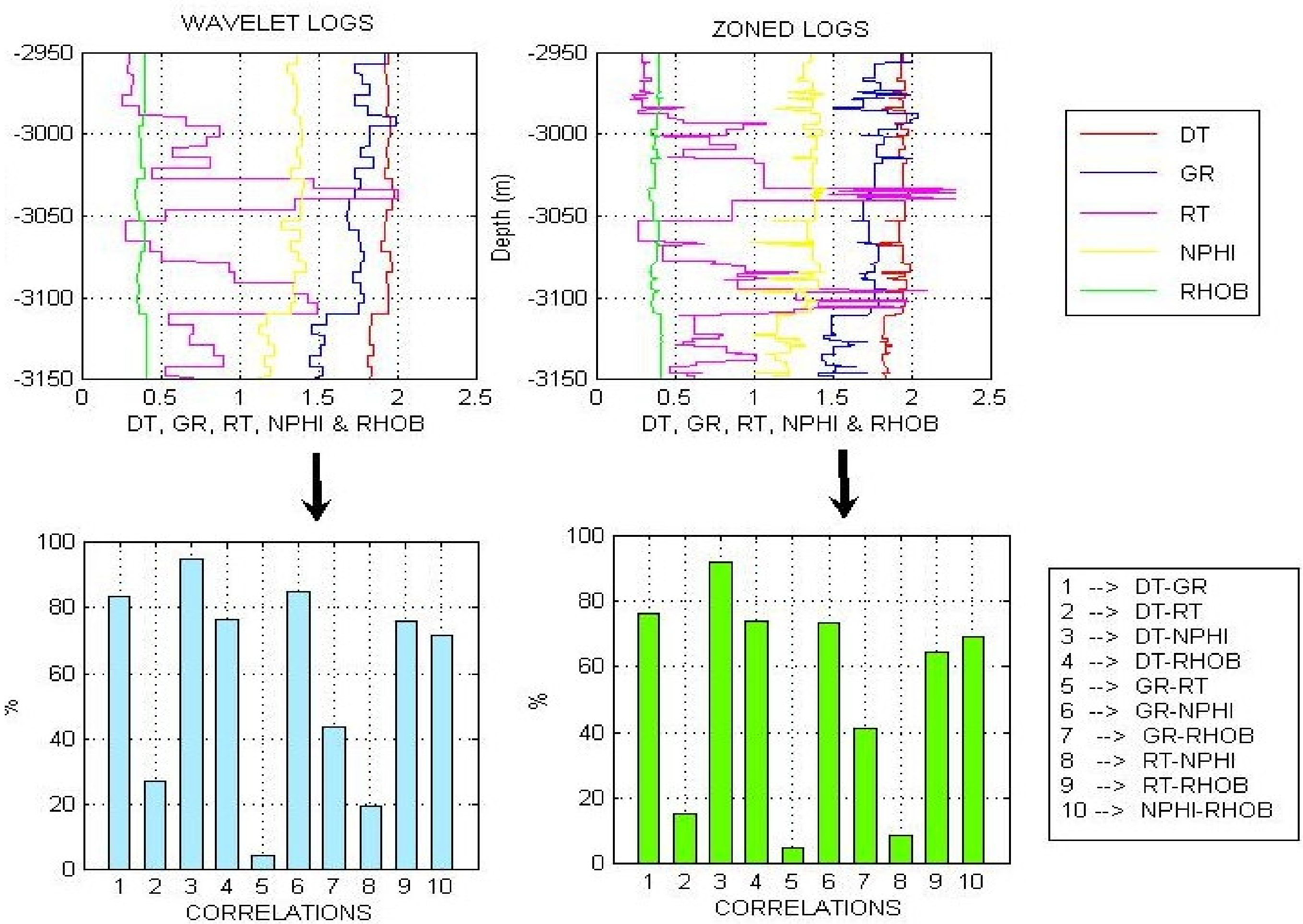

Figure 4: Above: wavelet and zoned logs of Well Na04 in Namorado Oilfield. Below: correlations between theses logs.