Seismic processing applied to shale-gas reservoir characterization in Reconcavo basin

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Abstract

This paper is intended to present all the steps used in the seismic processing to characterize and interpret the 2D seismic line 0026-RL-1624, located between Dom João and Candeias fields, from the perspective of non-conventional reservoirs. It includes a new SVD (Singular Value Decomposition) method used to attenuate the ground-roll and direct wave, which had a very dispersive form in the shot domain, causing several problems in the visualization of reflections and, consequently, in the raw stacked data as well. It was later applied seismic attributes in order to have a better precision in mapping geological structures of interest and also interpret the main horizons present in the log well data. During the development of this work, the processing step were entirely performed by both Seismic Unix and SeisSpace/Promax, software developed by Landmark/Halliburton.

Introdução

The non-conventional reservoir have gained great relevance in the last decade, the main reasons that reinforce this tendency include the difficulty in exploring new findings within the field of conventional (Gómez, 2013). Furthermore, the Reconcavo basin located in Brazil, has been classified by ANP (Petroleum national agency) as one of having potential of shale-gas production among the brazilian basins, even though this approach has still not been fully applied in the national scenario (Alves, 2014). The hydraulic fracturing is the most common used technique to extract the oil directly from the source rocks (Andrade, 2013), however it brings a high-cost to oil companies and also damages the environment (Costa, 2013). For this reason, it is important to investigate the presence of natural fracturing inside the lithology of interest.

The Reconcavo Basin was the first producer of hydrocarbons in Brazil and it remained at the the top of the list of the biggest oil producer basins during 4 decades. It has its origin related to extensional efforts acted in Gondwana during the Mesozoic period and has high index of recoverable oil from its source rock, being the main one known as Gomo member, belonging to Candeias formation (Oliveira, 2012).

The contribution of geophysics in the prospection of non-conventional reservoir have been discussed by professionals of the area. Although of the existing methods being very efficient on geological mapping of large scale areas, it is still considered a challenge the characterization of intern structures within a certain lithology. The seismic data then have been adapted from its traditional use in order to optimize the production of non-conventional (Rabe and A., 2014)

Seismic attributes were initially developed for use in conventional reservoirs in order to extract information of interest from a certain data (Chopra and Marfut, 2005). However, according to (Zhang, 2010), it is possible to adapt these attributes for non-conventional cases, where we can facilitate the investigation of faults and fractures detection, using a TecVA attribute for instance, which might be of great help in the interpretation stage (Bulhões and Amorim, 2005).

Reconcavo basin

The Reconcavo basin is located in northeastern Brazil, having an approximate area of 11.500 km^2. It became one of the most famous brazilian basins for becoming the first oil producer inside the territory in 1937. The main oil system of this basin consists of Candeias-Sergi formations. Its source rocks have lacustrine origin belonging to Gomo and Taua members, while the reservoir rocks are predominantly stream-eolic sequences of Sergi formation. As we can see in Figure 1, the seismic line used

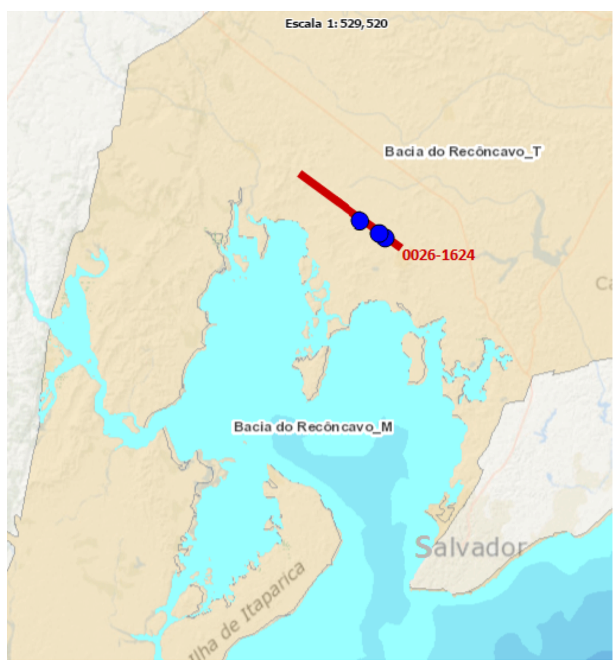

Figura 1: Location of selected wells and seismic line 26-RL-1624 in Reconcavo basin. Modified from BDEP-ANP website.

is located between Candeias and Dom João fields. It has an extension of approximately 13.7 kilometers and three wells carrying important data about the local lithology. The Candeias formation is subdivided between Gomo and Tauá members, being Gomo member the main oil generator of this whole basin for having shales rich in organic matter.

Steps of seismic processing

The seismic line 26-RL-1624 is the result of a seismic survey made in 1990. It has a total of 315 records, with 2001 samples and a sampling interval of 2 milliseconds. It also has both split-spread and end-on arrays with a varying number of channels starting from 100 until 150, and maximum coverage reaching 75 CDPs. The seismic processing steps adopted during this work were quite conventional compared to industry. The flow is presented in Table . The velocity field obtained after

Seismic processing steps	
1- Geometry	7- Residual statics
2- Statics correction	8- Velocity analysis
3- Edit	9- Pre-stack Kirchhoff migration
4- SVD Filtering	10- Edit
5- Velocity analysis	11- AGC gain
6- Stacking	12- Final stacking

Tabela 1: Seismic processing steps

the SVD filtering and the residual statics was much more accurate compared to the one made from the original data, which demonstrated efficiency in ground-roll attenuation. Therefore, it was possible then to apply a Kirchhoff prestack migration, which is quite sensitive to variations in the velocity field. The result is shown in Figure 5.

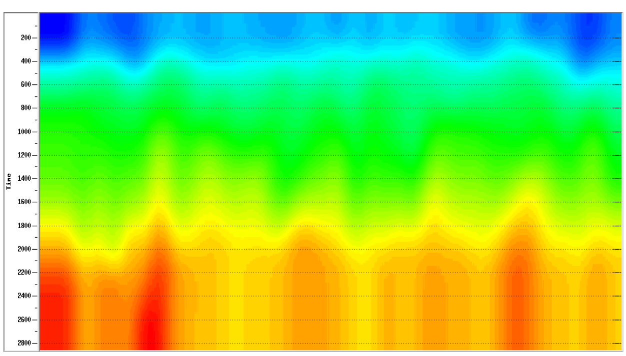

Figura 2: Velocity field obtained after the analysis.

SVD filtering method

The application of the singular value decomposition method (SVD) for filtering the seismic data has become quite usual in recent decades, as it promotes significant improvements of the signal-to-noise ratio, highlighting the events of reflection in seismograms. This method is extremely versatile being able to be applied in many forms.

Two types of SVD filter were applied to the original data one after another. The first filtering method focused in removal of the direct wave, which had great energy previously and did not bring relevant information about the subsurface. The removal of this wave caused the reflections of interest to become enhanced compared to the original data. The second filtering method emphasized the ground-roll attenuation, which was very dispersive in the original data, as we can see in Figure 3.

The theory of this method is described in the following and it was based in a work developed by Silva and Porsani, 2016. Let the vector $\boldsymbol{d} = (d_0, \ldots, d_M)^T$ represent the seismic trace and $\boldsymbol{D}_N$ represent the matrix with the seismic trace shifted in each column. τ represents the variable associated with the time shift, $\tau = 0, \ldots, N$. Matrix $\boldsymbol{D}$ has dimensions, $(M+N+1)$ x $(N+1)$.

The reduced SVD of the matrix $\mathbf{D}_N$ may be represented as (Golub and Van Loan, 1996),

$$\boldsymbol{D}_N = \sum_{\tau=0}^{N} \boldsymbol{\sigma}_\tau \boldsymbol{u}_\tau \boldsymbol{v}_\tau^T = \sum_{\tau=0}^{N} \tilde{\boldsymbol{D}}_{N\tau} \qquad (1)$$

Where $\tilde{\boldsymbol{D}}_{N_\tau} = \boldsymbol{\sigma}_\tau \boldsymbol{u}_\tau \boldsymbol{v}_\tau^T$ represent the eigenimage of index τ associated to a ST-SVD decomposition of order N.

The main difference between these two methods is that the SVD used for direct wave attenuation was applied shot by shot, horizontalizing the linear events through a vector of velocity p determined by the user, applying the method and then making the inverse process, while the ground-roll attenuation was applied from trace to trace, iteratively. The number of iterations created different results, so the values for N and $Niter$ adopted were both equal to 15, which had a good performance and also showed a great result as we can see in Figure 4.

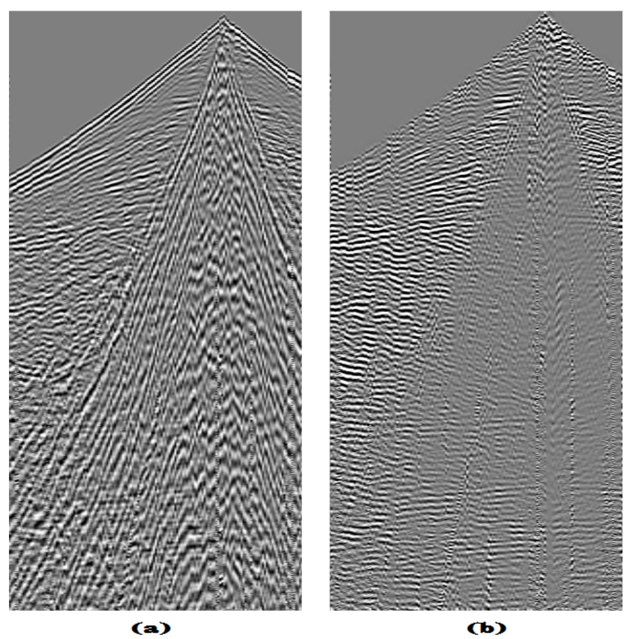

Figura 3: Figure showing a shot domain section before SVD filtering (a) and after its application (b).

Seismic attributes

The TecVA attribute is commonly used in industry for the investigation of presence of faults and fractures through the lateral continuity of the reflectors. It is considered a

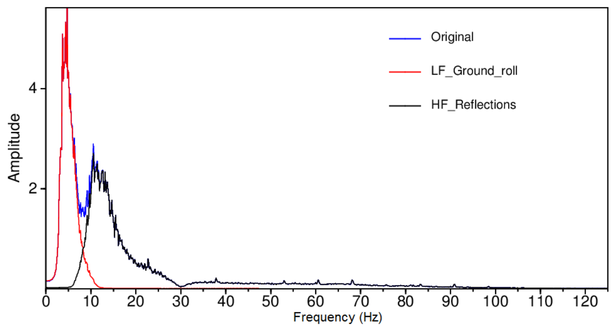

Figura 4: Average amplitude spectra of original and filtered shot-gathers data

technique of simple parametrization and fast processing, which is also very powerful for visualization of geological structures. There are basically two steps to apply this method. Firstly it is calculated the RMS amplitude or the absolute value of each trace, promoting an proportional estimate of its envelope through the equations 2 and 3:

$$\bar{X}_{RMS_i} = \sqrt{\frac{1}{M}\sum_{j=i-\frac{M}{2}}^{j=i+\frac{M}{2}} x_j^2} \quad (2)$$

$$\bar{X}_{ABS_i} = \frac{\sum_{j=i-\frac{M}{2}}^{j=i+\frac{M}{2}} |x_j|}{M} \quad (3)$$

Where M is the number of samples in the moving window, j is the position of sample and x_j is the amplitude of sample in position j. After this first step, Hilbert transform is used to apply a phase rotation to the data with the result of RMS amplitude. The result of the application of this attribute, as well as its interpretation, can be seen in Figure 6.

Results and interpretations

In this section, it is presented all final results obtained during the development of this work. As we can see in Figure 5, the final migrated stacked section has a good resolution after the filtering process, showing a better continuity in its reflectors. It is also possible to see the presence of many fault planes even before using TecVA attribute. After its application, it becomes easier to interpret as we can see in Figure 6.

The Figure 7 shows the locations of all 3 wells present on the seismic line. The well 7C-0186-BA does not show a GR (gamma ray) curve, in this case it was plotted a SP (spontaneous potential) instead, just to show the variation of lithology. All the 3 wells have markers, showing the exactly depth where some lithology begins, but none of them reach the basement rock. From this informations, it was possible to interpret all the horizons present, as we can see in Figure 8. Since none of the wells reach further than Sergi Fm., it was assumed that it was the last lithology before the basement.

Conclusions

The SVD method had a great performance both in ground-roll and direct wave attenuations, which made the interpretation of the data much easier afterwards, as we could see in Figure 3. According to Figure 6, it became much easier to determine presence of faults and fractures in this seismic line. Although the Reconcavo basin having a very complex geological set, it was possible to interpret the its horizons and indicate areas of interest for possible exploring of non-conventional reservoir of shale-gas, mainly in Gomo member without the necessity of hydraulic fracturing. This was only achievable through the information from well data in Figure 8.

Acknowledgments

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References

Alves, R. J., 2014. Reservas e produção de gás e petróleo em reservatórios não convencionais, Boletim SBGf, 87:26 27.

Andrade, J. B., 2013. Gás de Xisto: Desafios e Perspectivas, INCT - Energia e Meio Ambiente, Brasília, DF.

Chopra, S. and Marfurt, K. J., 2005. Seismic attributes - a historical perspective, Geophysics, 70(5):3 28.

Costa, F. N., 2013. Riscos ambientais da produção de gás de xisto no brasil, Agência Internacional de Energia.

Gómez, N., 2013. Brasil desperta para o gás não convencional, América Economia, 421.

Golub, G. H. and C. F. V. Loan, 1996. Matrix computations: Johns Hopkins University Press.

Bulhões, E. M., Amorim, W. N., 2005. Princípio da sismocamada elementar e sua aplicação à técnica de volume de amplitudes (TecVa): Ninth International Congress of the Brazilian Geophysical Society, Salvador, Brasil.

Oliveira, L. S., 2012. Estudo de Fraturas e Diagênese em Folhelhos Produtores de Hidrocarbonetos do Membro Gomo da Formação Candeias, Bacia do Recôncavo: Correlação Tipos de Fraturas X Evolução Diagenética, Universidade Federal da Bahia.

Rabe, C. and A., F., 2014. Combinando geomecânica e sísmica para otimização de produção em reservatórios não convencionais, Boletim SBGf, 87:23 25.

Silva, M. G., Porsani, M. J. and Ursin B., 2016. A single-trace singular value decomposition method with application to the ground-roll removal. Society of Exploration Geophysics.

Zhang, K., 2010. Seismic Attribute Analysis of Unconventional Reservoirs and Stratigraphic Patterns, University of Oklahoma.

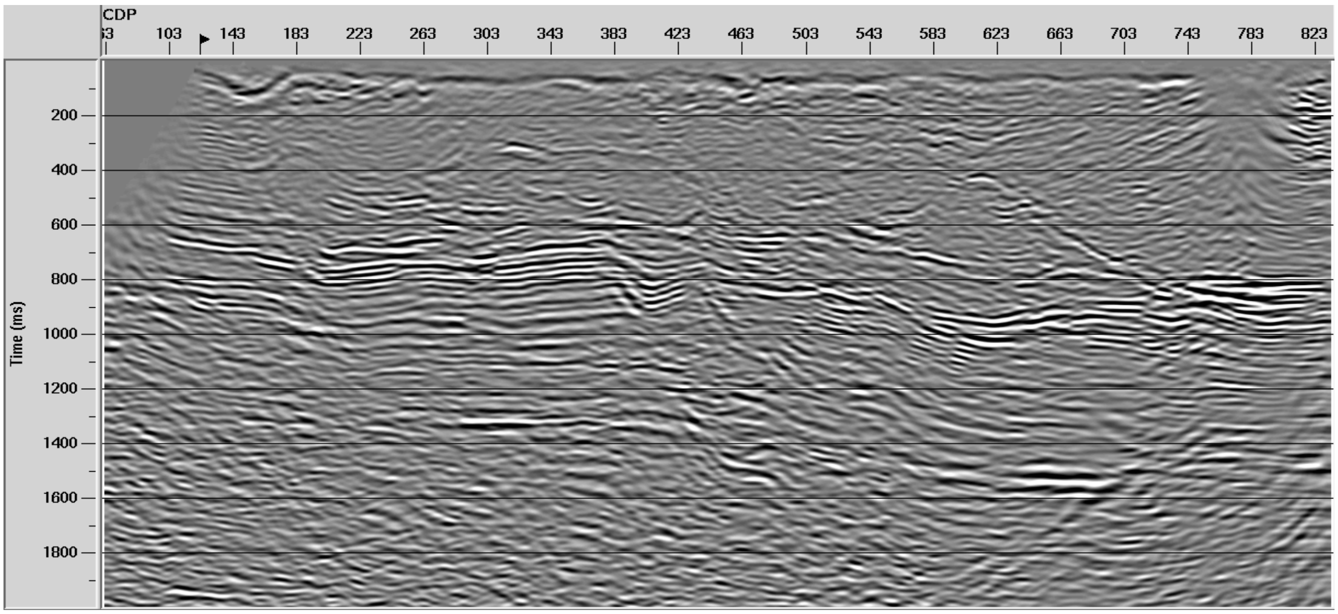

Figura 5: Final stacked section.

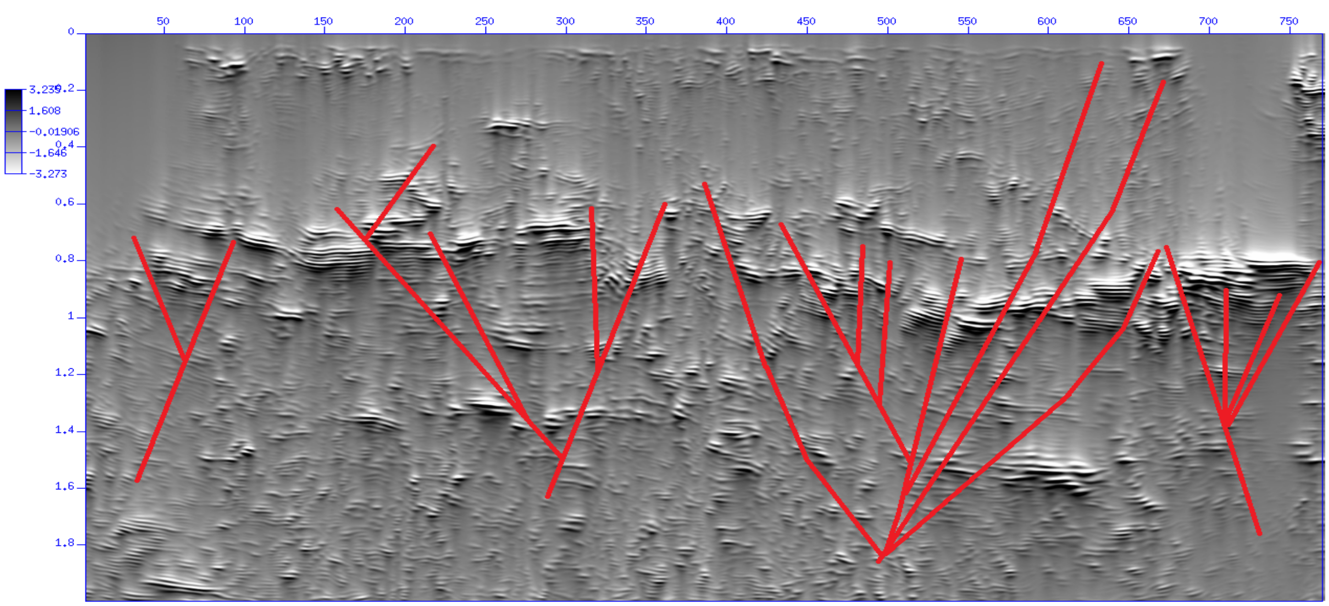

Figura 6: Final stacked section with TecVA attribute and faults interpretation.

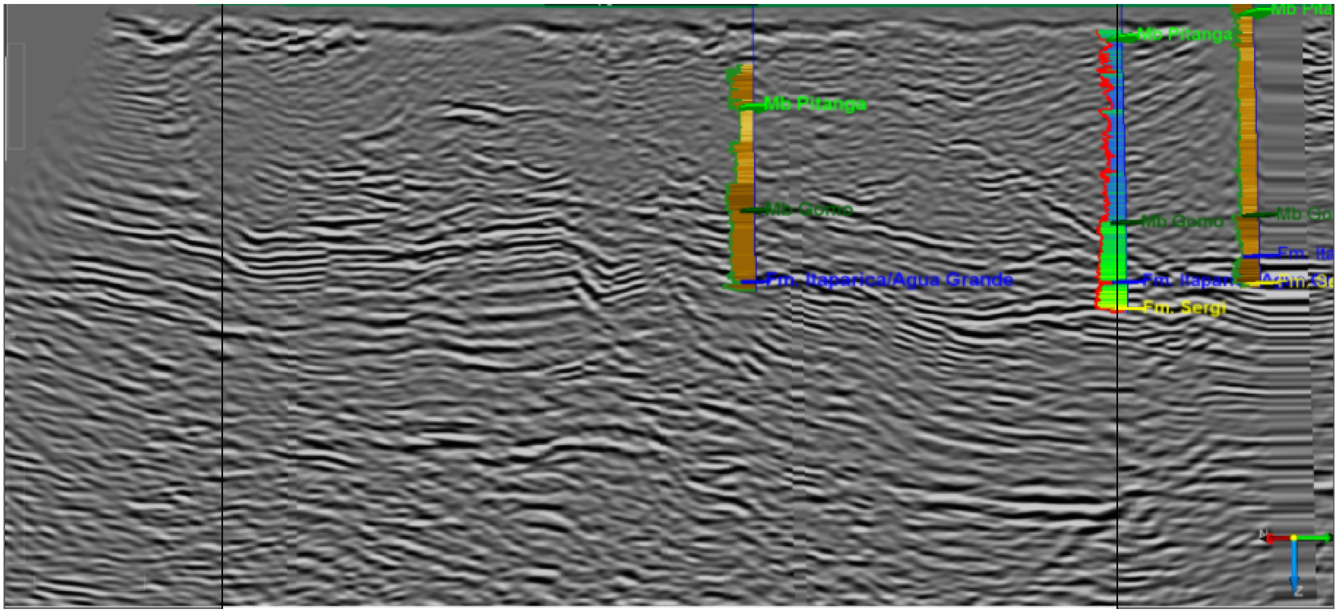

Figura 7: Final stacked section showing location of the wells used.

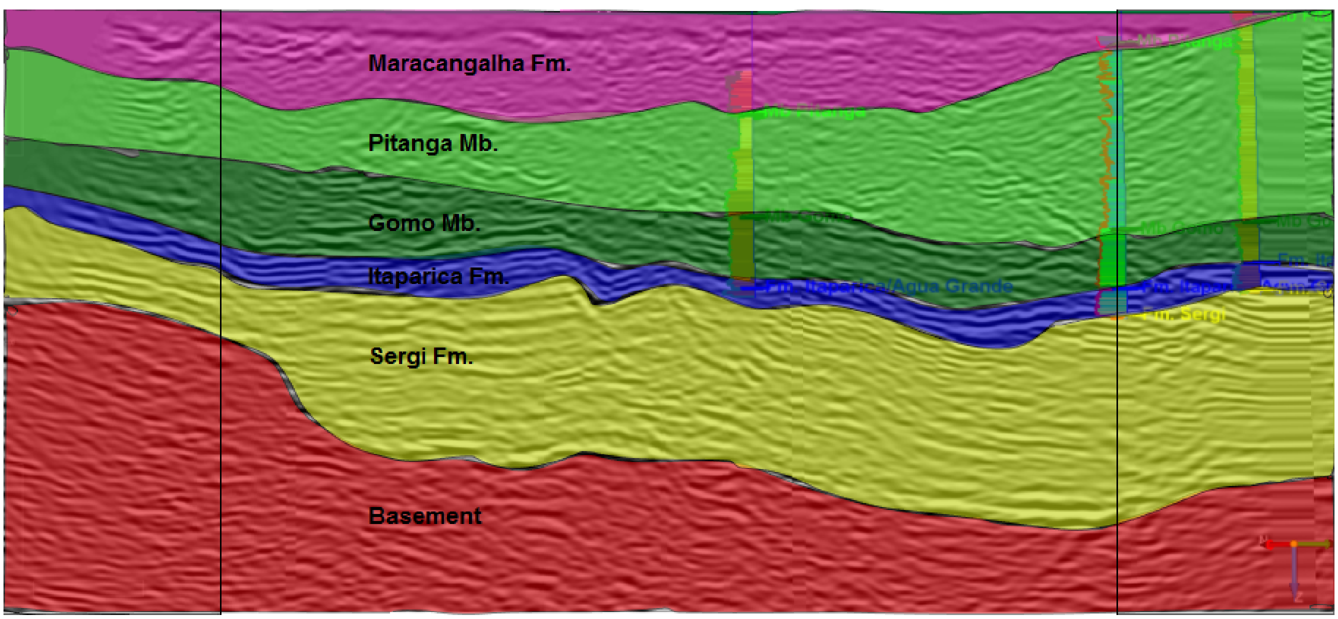

Figura 8: Interpreted horizons on final stacked section