Qualitative attributes in reservoir characterization of onshore Sergipe-Alagoas Basin

Mepen, Michelle; Marques, Daniel – Petrogal Brasil

Abstract

Sergipe-Alagoas Basin was generated during the South Atlantic overture and is located in the northeastern portion of Brazilian margin. This basin presents the most complete stratigraphic sections of evolution stages: pre-rift, rift, transitional and drift (Ojeda, 1982); In this study, the main targets of the area are focused on the porous and fractured carbonates from Ibura Mb./ Muribeca Fm. (Aptian, transitional regime) and the fractured Basement (Feijó, 1995).

This abstract aims to characterize the reservoir of onshore Sergipe-Alagoas Basin, in a qualitative way using calibrated acoustic inversion and its possible correlation with facies.

The acoustic impedance (AI) calibrated to the wells information and conjugated with other attributes, such as coherence volume and structural maps is a relative new approach in the area, important to reduce geological uncertainties and facies prediction.

The reservoir characterization using only acoustic impedance attribute is complex due to the micro porosity from the fine sediments that can mask the reservoir identification, and thus the association of many tools become significant to better understand the geological settings and indicate potential prospects.

Introduction

The reservoir of the area is known as an unconventional type, with heterogeneous properties, where its presence and quality are influenced specially by faults and fractures distribution (figure 1), and in secondary way by carbonate porosity, induced by diagenesis.

The area is characterized by an irregular basement morphology, where lows and horsts are recognizable all over the area (Figure 2); SW-NE main faults orientation are representative and transcurrence faults are also observed specially in the northeast portion (Figure 1 and 2).

This abstract intends to briefly describe the structural and geological settings of the area. The resulting inversion, its QCs and associated petrophysical (wells evaluation) and geophysical (attributes association with structural maps) analysis are also important tools that have the purpose to reach as better as possible facies correlation and its distribution across the area of interest.

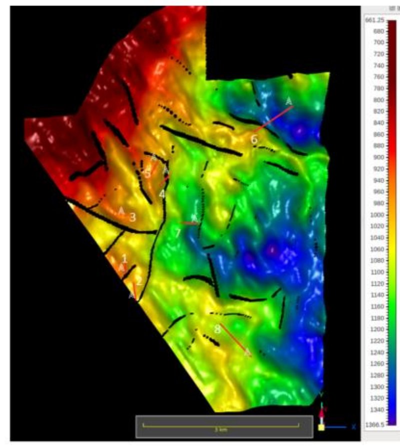

Figure 1 – Basement Structural map in depth showing the morphology configuration and the main faults along the area;

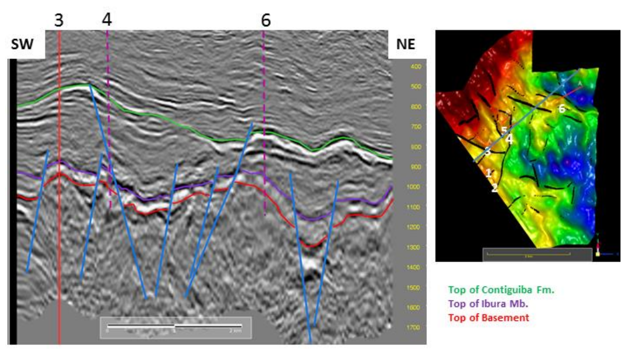

Figure 2 – Seismic section with SW-NE orientation showing the Basement characteristics; Horizons: Basement Top (red), Muribeca Fm./Ibura Mb Top (purple) and Contiguiba Fm. Top (green).

Inversion Methodology, Results and QC

Initial feasibility was performed with the seismic data in order to understand the ability to get a good well-to-seismic tie and generate a wavelet that represented the seismic character and geological features from the wells. This is a key step in any seismic inversion project as the quality of any result relies on a good understanding of the seismic data and wavelet quality.

Regarding the seismic, it could be verified to be of a relative good quality with high signal/noise ratio, and also a good frequency range content, in general between 6 – 70 Hz along the whole seismic time interval (0-1500 ms) (Figure 3). Some post-processing is recognized, but it was still possible to verify that it did not affect in a significant way the inversion results, being possible to characterize and estimate the facies.

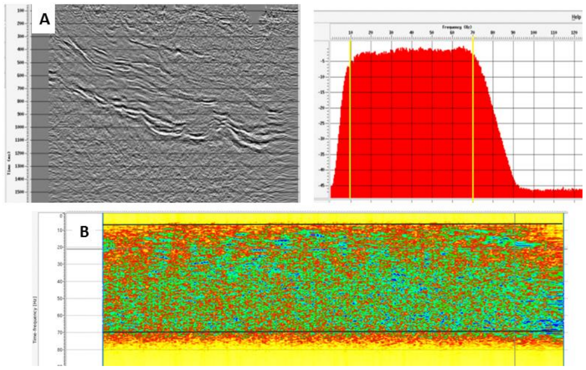

Figure (3A) – Post-Stack analysis on frequency content; (3B) Jason analysis on seismic frequency content.

Concerning the wavelet estimation for an acoustic inversion, a zero phase wavelet with 120 ms wavelength was estimated (Figure 4). The seismic amplitude spectrum for this wavelet presents more low frequency spectrum content and a smaller high content range (due to seismic post-processing). The seismic to well calibration was performed in a time window two and half times the wavelength (Figure 5).

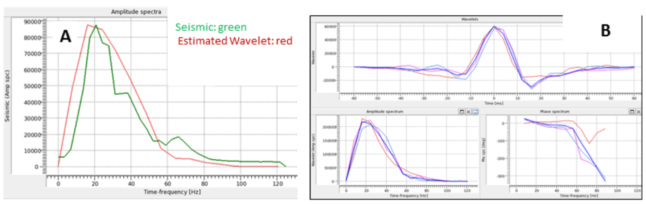

Figure (4A) – Seismic and estimated wavelet amplitude spectrum; (4B) Wavelet Estimation characteristics – phase and amplitude spectrum;

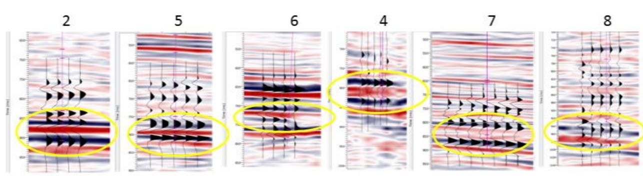

Figure 5 – Well and seismic calibration showing the synthetic seismogram; the yellow marked ellipses are the reservoir target interval.

The inversion algorithm used in this particular project was a Constrained Sparse Spike Inversion which is in itself a trace based inversion that does not necessarily honor the well logs at their location as the only contribution from the well comes in the form of the low frequencies and the wavelet. As the inversion problem itself is non-unique, the addition of different constraints into the algorithm allow the probable solution space to be reduced.

The inversion results present a relative high correlation to AI from wells logs (Figure 6), where was possible to observe in a qualitative way the reservoir distribution all over the area, regarding the impedance volume (Figure 7). On the other hand, the presence of fine sediments can also mask the reservoir distribution, because the micro porosity contribute to impress lower impedance values at the same range of the reservoir (Figure 8).

The Figure 8 shows along the Full band Impedance section, high values range (reddish color) represented by the anhydrite (top of Muribeca Fm./ Ibura Mb.) and tight carbonate facies, while the lower impedance range values (green/blue color) correspond to the shale facies and carbonates. It is also possible to verify in the graph below, the good relationship between the acoustic impedance from wells and porosity including also, in a general way, the facies represented by the indicated colors.

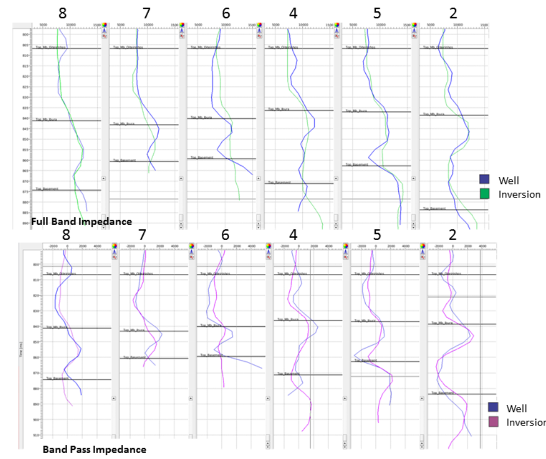

Figure 6 – Comparison between the acoustic impedance from well logs and the AI from the inversion results at the well location in Full Band and Band Pass modes.

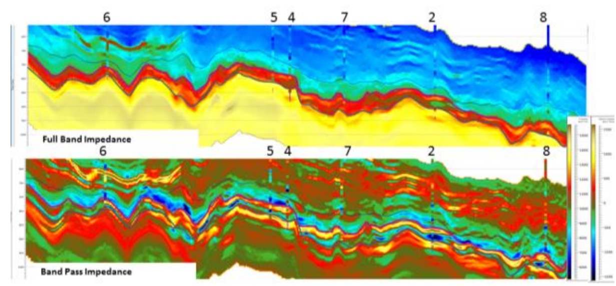

Figure 7 – Arbitrary impedance sections (Full Band and Band Pass) crossing some wells; Horizons: Muribeca Fm./Oiteirinhos Mb (blue), Muribeca Fm./ Ibura Mb. (purple) and Basement Top (dark blue), main target.

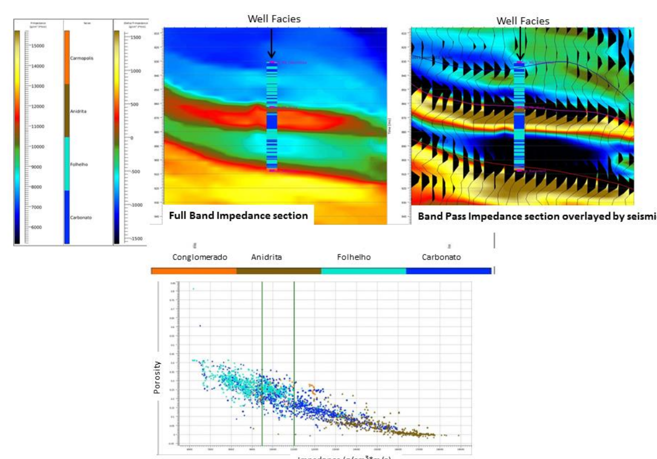

Figure 8 – Full Band and Band Pass impedance sections crossing well facies to evaluate impedance correlation with facies; Horizons in Band Pass Impedance: Muribeca Fm./ Oiteirinhos Mb. Top (blue), Muribeca Fm./ Ibura Mb. Top (purple) and Basement Top (red); Below it's possible to verify the AI vs Porosity graph with colors based on facies sample (cuttings) from the Basement Top to Muribeca Fm./ Ibura Mb. Top. Also, it's important to highlight a good relationship between impedance (based on wells), porosity and facies in general; The green lines represent the potential reservoir range properties.

Facies Prediction Results (reducing uncertainty)

Some correlation studies between impedance values and facies were done to try to distinguish in a better way the reservoir from the fine sediments using a petrophysical approach and/or in association with other attribute (geophysical approach). It's important to highlight that the reservoir target are represented by thin layer of fractured and porous carbonates right above the Basement and also the fractured Basement itself corresponds the main target in the area.

Concerning the reservoir related to the fractured carbonates that present similar acoustic impedance range regarding the fine sediments, some attempts were done to separate the reservoir from those shales:

(1) from the petrophysical approach the GR and it's relation with AI, NEU logs could distinguish, in a certain way, between carbonates and shales, and thus be a valued information to help differ these facies. The well logs used in this evaluation were based on PCA analysis (Principal Component Analysis), where the DEN is the log that most guided the functional density sampling (Figure 9) (Abdi H, Williams LJ., 2010); Two main interval evaluations based on reservoir wells were done: (A) along the interval related to Lower Ibura Mb. (figure 10, 11 and 12) and (B) focused on Basement (around 15 m below, depending on well). This last evaluation related to the Basement is important because the combination of low impedance that indirectly could be an effect of fractures, GR and NEU range could indicate some information regarding the distinction between fractured altered Basement and non-fractured crystalline Basement (Figure 11). Several crossplots regarding the well logs were done in order to understand the reservoir properties.

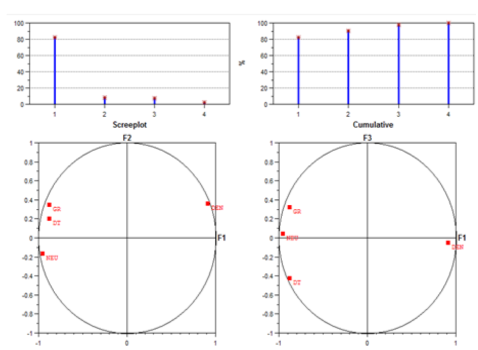

Figure 9 – PCA graph showing the logs and respective guidance on vector sampling

The Lower Ibura evaluation aims to differ the thin fractured and porous carbonates above Basement top from the shale facies. An eletrofacies workflow was done in order to reduce the uncertainty between those facies. The crossplots and its marked samples representative along the well logs were essential to identify the potential reservoir portion of Ibura Mb (figure 11).

It is important to highlight, that it was possible to reduce the uncertainty, but not to solve completely this issue on facies distinction, where the facies present smaller overlaps (Figure 12). In this case, elastic properties is essential to contribute to this workflow in order to separate those facies.

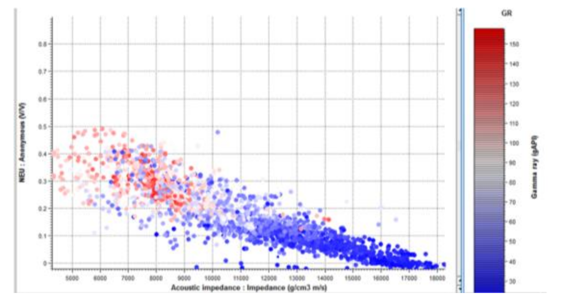

Figure 10 – Crossplot between AI and NEU, colored by GR range in Lower Ibura Mb.

The crossplot tries to identify at the same AI range what possible could represent according to the GR values the shales (higher GR values) and the carbonates.

A second crossplot considering NEU, GR and Density logs tries to focus in a specific area that could possible represent the reservoir according to its correspondence to the well logs. In a certain way, it was possible to sample the reservoir in lower Density and GR ranges and higher NEU values (Figure 11).

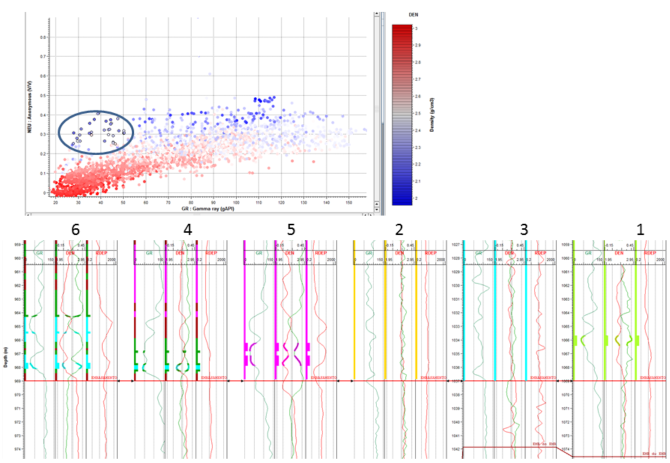

Figure 11 – Crossplot between NEU and GR, colored by Density and representative samples on well logs that corresponds the potential reservoir in Lower Ibura Mb.

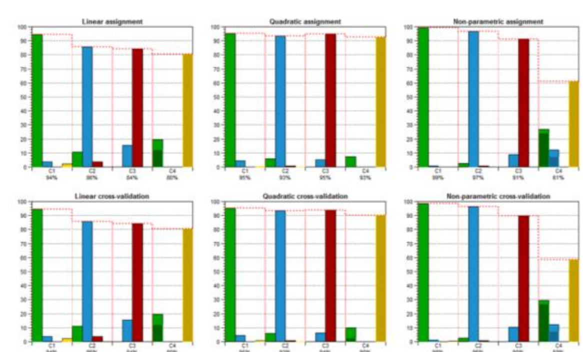

Figure 12 – Method and its cross-validation

The interval B focused on Basement tried to verify differences between altered Basement and non-fractured basement. In this context, lower AI and the associated GR range (lower values) could also comprise as an important logs to evaluate fractured zones, along wells. Figure 13 shows different crossplots representative of potential fractured zones.

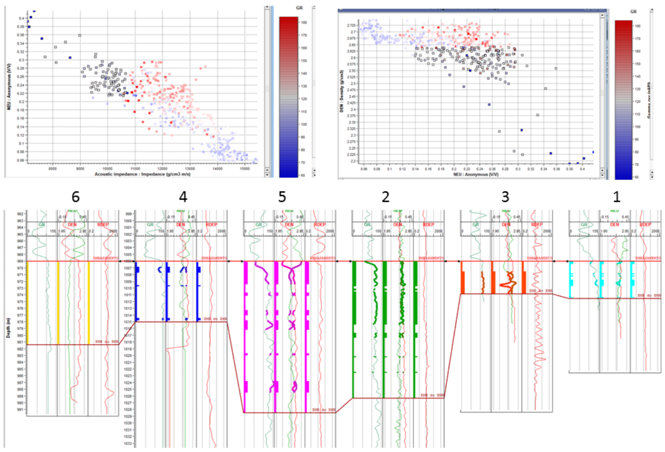

Figure 13 – Crossplot in the left corresponds AI, NEU logs, colored by GR with marked samples that represent potential fractured zones; the right the crossplot is represented by Density, NEU, colored by GR with the same marked samples that corresponds the potential fractured zones along the wells.

The well logs evaluation was important in order to try to identify the potential reservoir along Lower Ibura Mb. and fractured zones along Basement. In this sense, the possibility to reproduce the same ranges found on wells evaluation (crossplots and potential reservoir correspondence) considering the seismic attributes and geological concepts represents another approach using different set of data to point out potential reservoir areas with reduced geological uncertainty.

(2) coherence attribute could also help in a qualitative way considering the assumption that the fractures can be associated to faults; the facies uncertainty could be reduced in case to how close the facies are from faults on a structural high, including also the combination with low impedance values based on previous well evaluation (Figure 14).

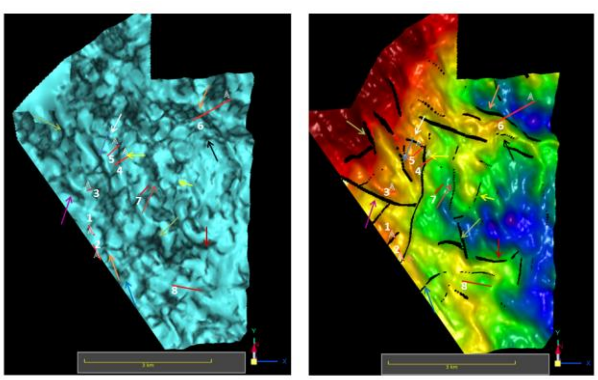

Figure 14 – On the left the coherence attribute extraction along Basement Top horizon, by side to the Basement structural depth map and interpreted faults. The colored arrows indicate the correspondence between the discontinuity related to the coherence attribute and the mapped faults; the red stick represent some wells located along the area.

In this context, impedance sections showing the marked impedance range value that potentially could represent the reservoir (based on wells evaluation) close to the faults are shown in figures 15, 16 and 17. In this case one factor alone does not provide a good facies prediction, but some aspects combined, such as attributes (impedance and coherence), structural features and geological concepts could in fact reduce the uncertainty regarding the facies estimation.

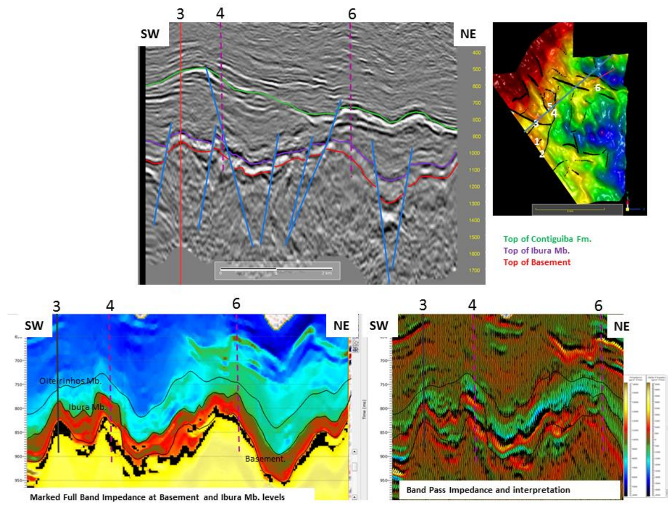

Figure 15 – Above, the Arbitrary seismic section with SW-NE orientation, crossing some wells along the area; Below Full Band impedance section showing the marked impedance that could potentially represent the reservoir along the area (green lines range from figure 8). On the right the Band Pass impedance section with the interpreted horizons: Muribeca Fm./Oiteirinhos Mb, Muribeca Fm./ Ibura Mb. and Basement Top, main target.

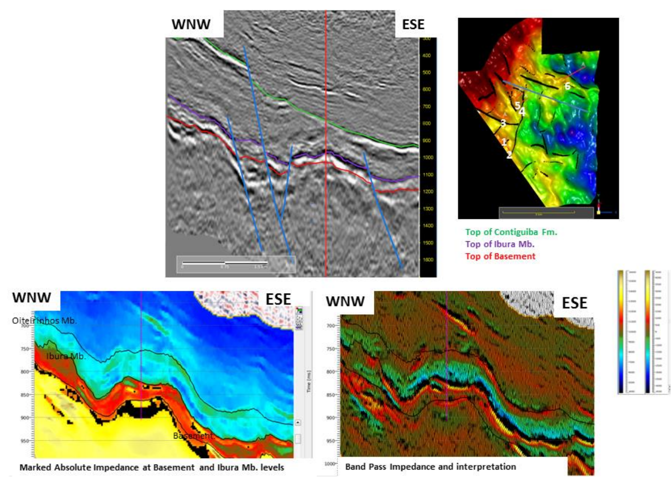

Figure 16 – Above, the Arbitrary seismic section with WNW-ESE orientation, crossing some potential location along the area; Below Full Band impedance section showing the marked impedance that could potentially represent the reservoir along the area (green lines range from figure 8). On the right the Band Pass impedance section with the interpreted horizons: Muribeca Fm./Oiteirinhos Mb, Muribeca Fm./ Ibura Mb. and Basement Top, main target.

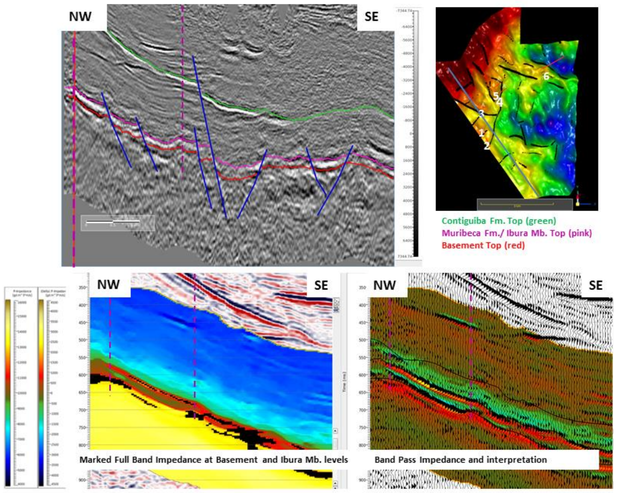

Figure 17 – Above, the seismic section with NW-SE orientation, crossing some potential location along the area; Below Full Band impedance section showing the marked impedance that could potentially represent the reservoir along the area (green lines range from figure 8). On the right the Band Pass impedance section with the interpreted horizons: Muribeca Fm./Oiteirinhos Mb (shallower), Muribeca Fm./ Ibura Mb. and Basement Top (deeper), main target.

Conclusion

This workflow was important in trying to reduce the uncertainties regarding the reservoir presence and its distribution, according to what was found in productive interval wells, especially in fractured Basement and fractured and porous carbonates from Ibura Mb. plays. In this context, the correlation and association between acoustic impedance, facies, structural map and other attributes has a goal to identify an analogous pattern regarding the reservoir condition found in the wells, using different type of data. In this sense, the wells evaluation was very important to identify and understand the reservoir properties.

As previous mentioned, the reservoir corresponds an unconventional and complex asset with heterogeneous properties. The reservoir thickness is on the limit of seismic resolution, but it is still possible to represent them indirectly by an association of impedance sections, coherence attribute, structural map indicating potential fractured areas.

Wells placed after this study corroborated the results of this workflow, however, in order to improve the uncertainty estimations a quantitative workflow should be explored. The introduction of additional elastic properties such as Vp/Vs and Density via a simultaneous inversion workflow could allow a more concise facies definition, unfortunately, a suitable pre-stack seismic dataset and elastic logs were not available. Another option to consider would be to perform a geostatistical inversion which would increase the level of detail in the results (beyond seismic resolution) and also provide multiple scenarios of facies and elastic properties that could be used to better capture the uncertainty envelop.

Acknowledgments

We would like to thanks Petrogal Brasil and Petrobras for supporting this abstract.

Beicip Franlab for providing the EasyTrace license and then being possible to do the wells evaluation and the reservoir characterization.

CGG/Jason for support on inversion workflow.

References

Feijó, F. J. 1995. Bacias de Sergipe Alagoas. Boletim de Geociências, 8: 149-161

Ojeda, H. A. O. 1982. Structural framework, stratigraphy, and evolution of Brazilian marginal basins. The American Association of Petroleum Geologists Bulletin, 66(6): 732-749

Latimer, R et al. 2000. An interpreter's guide to understanding and working with seismic-derived acoustic impedance data. The Leading Edge, March 2000: 242 - 256

Ellis; Singer (2007) Well Logging for Earth Scientists. 2007, 2008 Springer Science+Business Media B.V, 351-381

Tiab; Donaldson (2004) Theory and Practices Measuring Reservoir Rock and Fluid Transport Properties. Elsevier, 87-198

Abdi H, Williams LJ (2010) Principal component analysis. Statistics & data mining series, vol 2. Wiley, New York, pp 433–459