Ultra-deep exploration potential in the Sergipe basin

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Abstract

Ultra-deep water areas of the Sergipe-Alagoas Basin (SEAL) are known for recent light oil, gas and condensate discoveries in the Upper Cretaceous section such as Barra, Farfan, Muriú, Cumbe and Moita Bonita. The exploration success rate for this recent campaign is very high at approximately 80%. This is thanks to the exploration campaign led by Petrobras and its partners since 2010 which applied advanced seismic acquisition and imaging technologies. Outcomes of a recent amplitude versus offset (AVO) analysis of multiclient multisensor seismic data SEAL Bonita 3D (2014 / reprocessed in 2020) and SEAL Pirambu 3D (2018 / reprocessed in 2020) totaling approximately 13000 square kilometers will be presented in this paper.

Introduction

Most of Brazilian hydrocarbon production comes from presalt Aptian limestone facies of the Campos and Santos basins. Several multi-billion-barrel, light-oil discoveries were made below salt. As a result, exploration efforts in these two basins shifted almost entirely from postsalt deepwater clastics to presalt carbonate reservoirs. However, Upper Cretaceous turbidite reservoirs have remained the focus of exploration in the Northern Equatorial margin of South America including Brazil basins such as Sergipe-Alagoas, Potiguar and Ceará.

Modern techniques and tools for acquiring and processing broadband seismic data enables improved risk mitigation during exploration as well as near-field studies. Currently, there are approximately 31500 square kilometers of multisensor broadband data available in the above-mentioned basins.

Almost all penetrated reservoir intervals in those areas have a distinctive seismic AVO character when the reservoir thickness is above seismic resolution. There are many well control points for calibration of AVO responses in the deep waters of Sergipe. Thus, validated attributes can be generated with high confidence levels and used for estimation of the remaining potential in the vicinity and away from known discoveries as it will be demonstrated further.

Area of the study

Two broadband 3D seismic surveys were recently jointly processed through anisotropic prestack depth migration to form contiguous coverage of approximately 13000 square kilometers. The merged dataset covers existing recent Petrobras discoveries and extends into deeper waters where the continuation of the Upper Cretaceous turbidite play will soon be further tested. The SEAL Bonita 3D was acquired in 2014 and subsequently reprocessed, along with the deeper water SEAL Pirambu 3D. Latest broadband processing and Full Waveform Inversion were utilized for velocity model updates. Figure 1 shows the location map for these surveys. There are a couple of smaller legacy conventional multiclient streamer 3D surveys illustrated with brown shapes. These legacy surveys were not used in this AVO study. A red outline southwest of the Bonita & Pirambu 3D surveys is a planned 2021 multiclient 3D program.

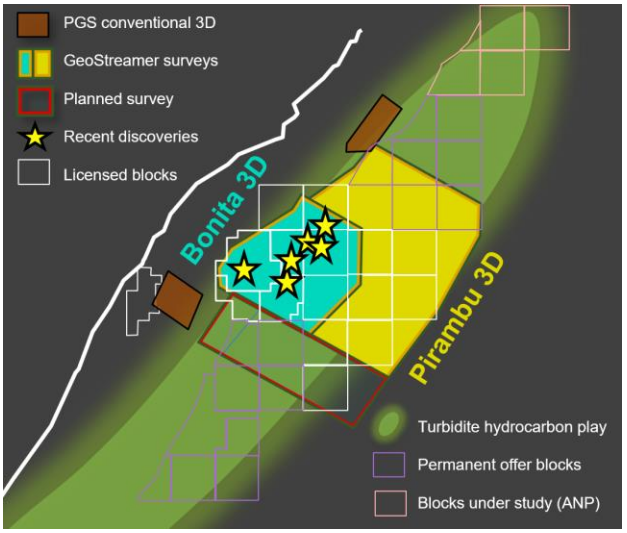

Figure 1 *- Schematic display of the study area.*

Main discoveries in the Bonita area are large stratigraphic features - Barra and Farfan discoveries. Light oil and condensate (38 to 44 degree API) are the main hydrocarbon phases in those accumulations. Seismic facies within the respective intervals indicate that these deep-water reservoir sediments were deposited in channelized and unconfined environments of the lower slope setting (Kattah et al., 2016) as a part of a regional turbidite play with notional extents which are shown on

Figure 1 (light green drape). Source rocks are represented with a regional low impedance event (Figure 2, pink horizon, white color event) below which can be interpreted as a highly condensed transgressive zone of Albian-Cenomanian-Turonian (ACT) age. It potentially contains mature kerogen rich rocks. Fracture zones and small faults generally developed above previous basement features are considered to be oil migration paths. Surrounding slope shales and other fine-grained facies provide the sealing units for these accumulations.

Method

A comparison of KPSDM (Kirchhoff Pre-stack Depth Migration) limited angle or partial stacks allows identification of amplitudes that appear on the far angles. In Figure 2, the "Near" stack mostly represents acoustic response from all the lithologies in the section of interest, however, the "Far" stack shows a distinctive low impedance (soft) stratigraphic feature which is bound to a favorable anticline structure. This anomaly corresponds to the Muriú discovery (light oil, 38-40 degree API).

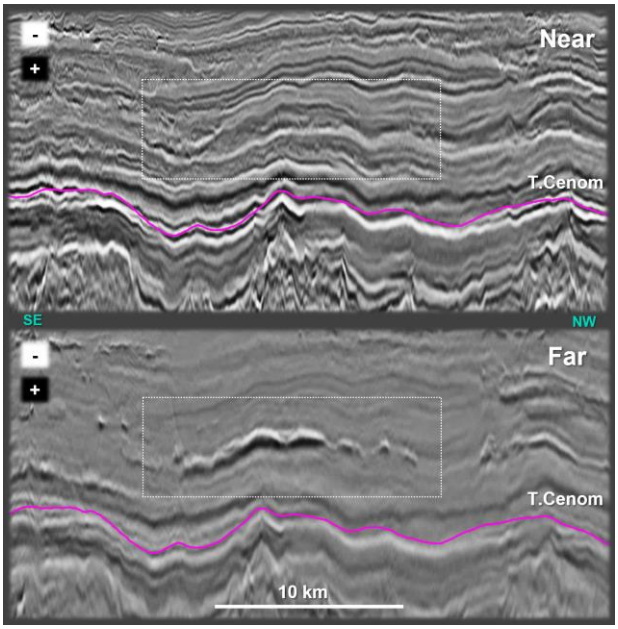

Figure 2 *- Near and Far limited angle stack sections through the Muriu discovery. The reservoir response is much clearer on the Far stack exhibiting an AVO anomaly (decrease of the amplitude versus offset/angle).*

AVO-based pre-stack seismic inversion was performed for estimating relative P-impedance (rel. Ip) and the relative ratio between P and S wave velocities (rel. Vp/Vs). Over the past years, this approach, in exploration, has proven to be a quick and reliable way of scanning big areas for potential leads (amplitude anomalies) without the need to build a low frequency background model (filling the gap between the 0Hz and the lowest seismic frequency). Given the broadband nature of the current dataset where there are rich recorded low and high frequencies present in the data, the match at the wells is good. This gives hope that amplitude response away from the wells can be trusted when looking for new leads and prospects.

Subsequent analysis highlights similar and well-known features in other areas within the survey. Figure 3 is a zoom out on the "Far" stack shown in Figure 2. It shows anomalies at the discovery wells - Barra, Farfan and Muriu as well as only subtle amplitudes at two reported "dry" wells present in the area. These wells are better explained with help of rel Ip and rel Vp/Vs in Figures 4 and 5. These figures show combined relative P-Impedance (background grayscale section) and relative P and S velocity ratio (colored drape). Warm colors represent low Vp/Vs values which coincide very well with known discoveries. The amplitude anomalies penetrated by those wells have a noticeable (low) contrast compared to the Muriú discovery well. Possible fluid escape features can be seen around these two "dry" wells. The attributes presented in this paper were successfully validated at Farfan, Barra, Cumbe, Moita Bonita and Poço Verde wells. The section in Figure 6 is centered on Farfan and Barra discoveries. Both reservoir intervals are shown inside the white boxes. The sandstone bodies stand out

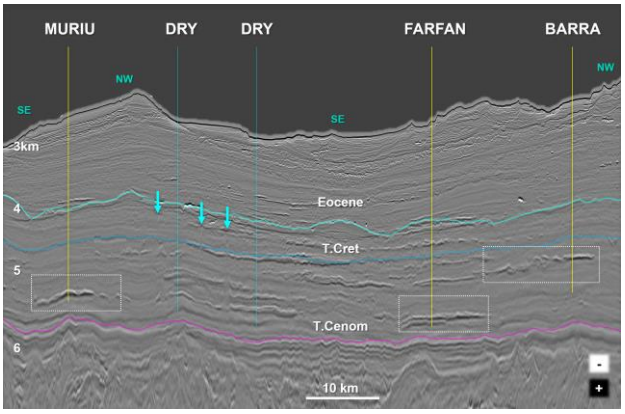

Figure 3 *- Far stack arbitrary line through selected discovery and dry wells. Note white trough events (top of low impedance interval) at known fields.*

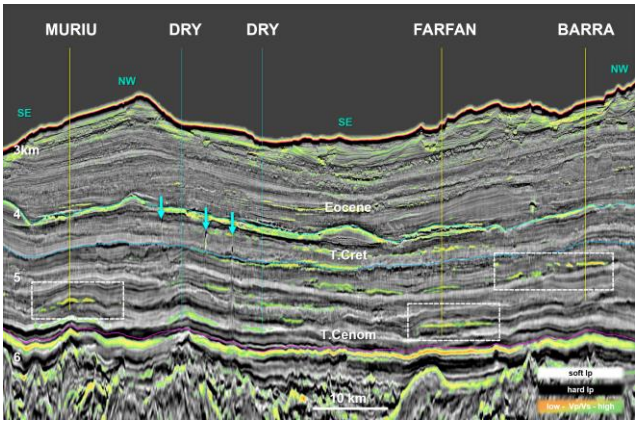

Figure 4 *- Combined relative P-Impedance (grayscale background) and relative Vp/Vs (color drape). Warm colors represent low Vp/Vs values at known discoveries.*

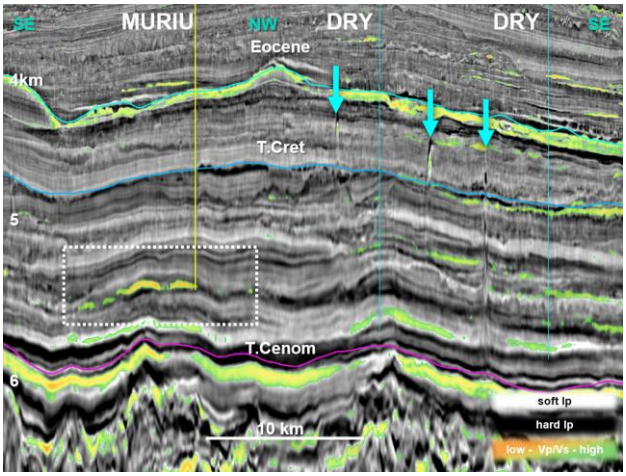

Figure 5 *- A zoomed image of the Muriú discovery and dry wells in the vicinity. Note the possible fluid escape features observed above the dry wells and their diminished amplitude contrast compared to Muriú.*

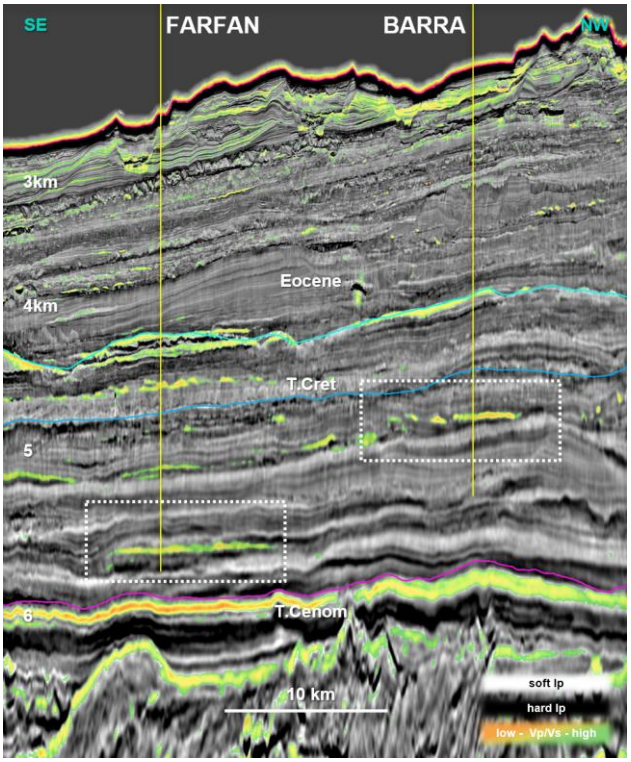

Figure 6 *- Zoom on Farfan and Barra discoveries. Combined relative P-Impedance and relative Vp/Vs. Warm colors represent low Vp/Vs values at known discoveries.*

very well from the background with the use of these elastic attributes. Similar attribute response was targeted when searching for additional locations of interest away from these wells.

The Sergipe discoveries confirm that there is a working petroleum system that can be associated with source-rocks equivalent to the Lagoa Feia unit. There is an expectation that the region could provide additional significant accumulations of hydrocarbons for Brazil. More survey specific examples will be shown in the next section where we will demonstrate additional potential within the Bonita and Pirambu 3D surveys.

Results

The entire ~13000 square kilometer area was scanned to identify new leads and features that would be good candidates for further analysis and derisking. Another objective was to trace those features back to the existing discoveries and see possible play extensions beyond the existing survey. Figure 7, shows those areas marked with letters A, B, C and D. Currently, there are no petroleum operators present in those sectors, however, as it will be shown in the following results, these areas still hold promising exploration potential. Potentially, a new 3D seismic survey will be acquired in 2021 or 2022 covering the Sector A. This might add approximately 4700 additional square kilometers to the existing broadband multisensor seismic coverage. The new acquisition will cover Permanent offer blocks (purple color) as well as acreage bid on in the last several bid rounds.

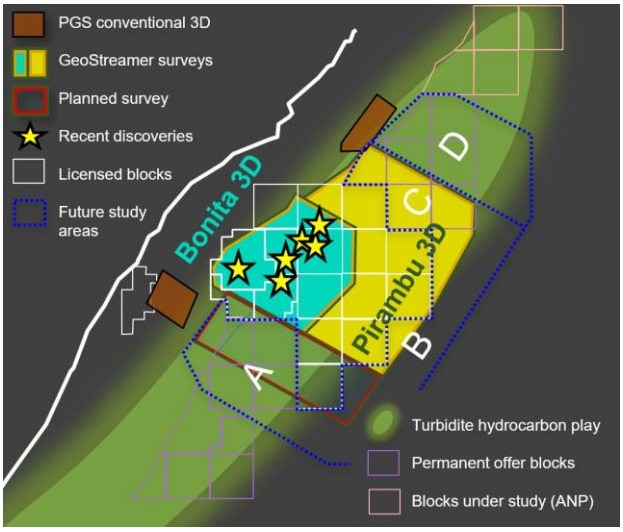

Figure 7 *- Areas (A, B, C and D) of promising exploration potential and planned new multi-client 3D programs.*

An arbitrary line that begins at the Moita Bonita discovery well location and ends at the border, where the planned survey over sector A will start, is shown in Figure 8. A relative low Vp/Vs anomaly (see red arrow) can be observed in the same hydrocarbon bearing stratigraphic interval penetrated by the Moita Bonita well. It is possible that this interval might hold analogous anomalies within the Sector A. Similar observations were made on the arbitrary line shown in the Figure 9. There are also bright and thick packages present on the left and right portions of the section at the source rock interval (~5700m).

The next area of interest is Sector B (eastern side of the Pirambu 3D survey). It is an elongated ultra-deep zone

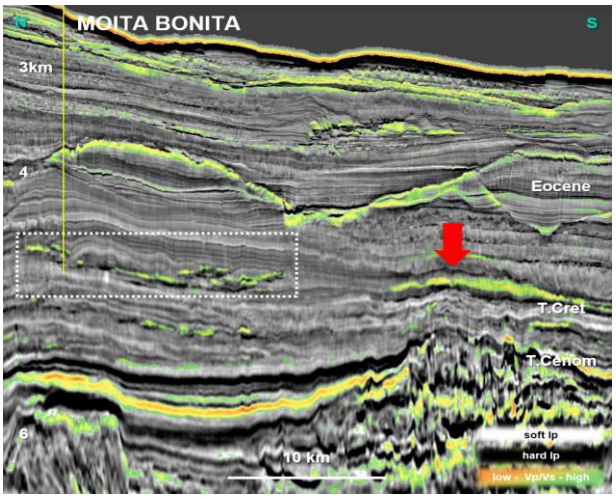

Figure 8 *- Arbitrary line 1 – Moita Bonita to Sector A.*

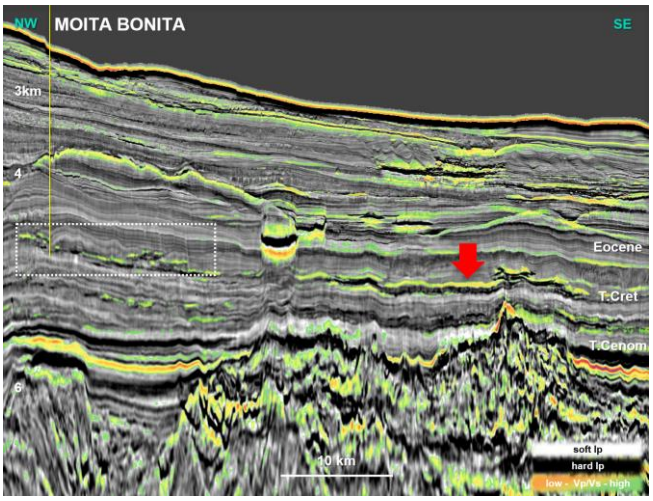

Figure 9 *- Arbitrary line 2 – Moita Bonita to Sector A.*

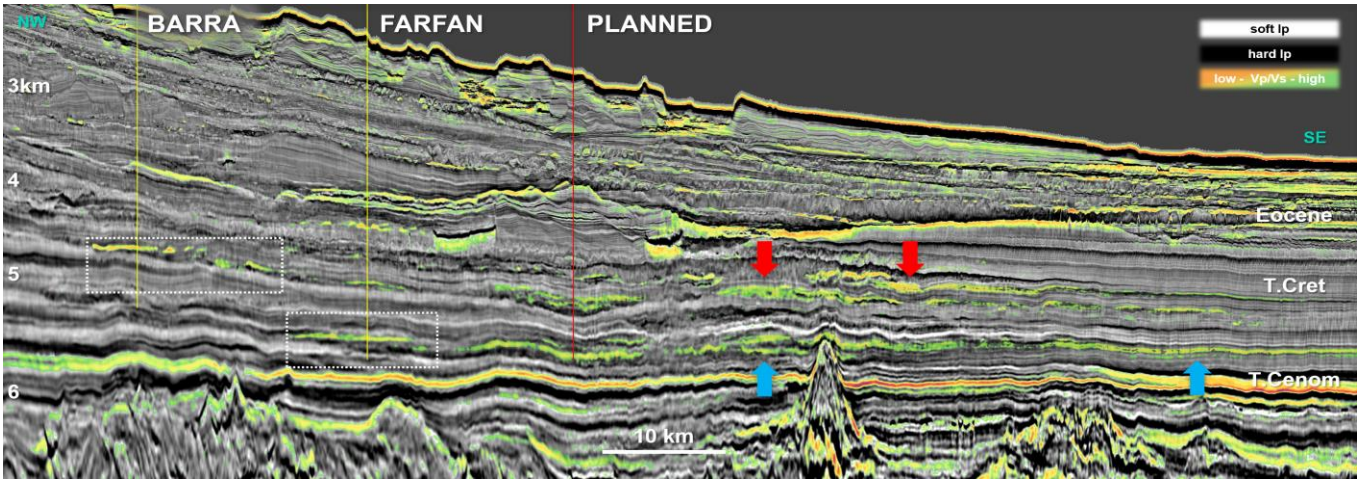

Figure 10 *- Arbitrary line 3 - Barra, Farfan to the northern edge of Sector B.*

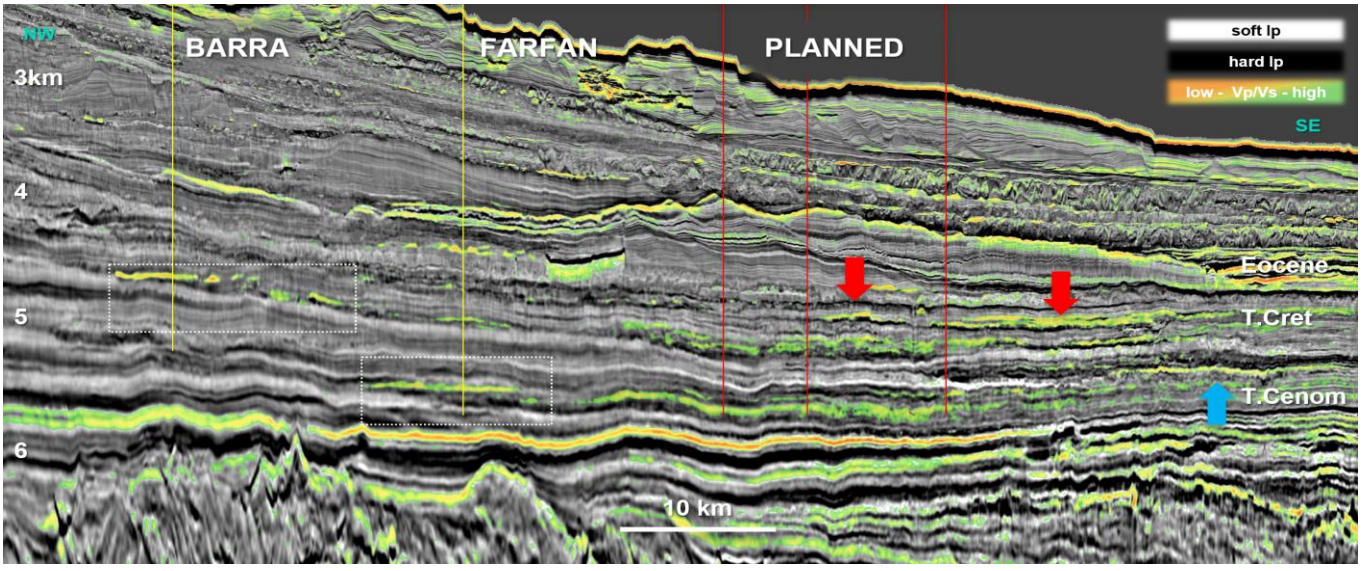

Figure 11 *- Arbitrary line 4 - Barra, Farfan to the northern edge of Sector B.*

which is oriented southwest to northeast (Figure 7). The arbitrary lines in Figures 10 and 11 connect known successful wells up-dip to the northern border of Sector B. Data hints that the hydrocarbon play could extend into this zone. Though, it is known that there is a volcanic ridge present within the area, it does not occupy the entire sector. Figures 10 through 13 demonstrate that the Top Cenomanian to Top Cretaceous thickness remains almost the same within the existing 3D surveys, and it is likely extending into Sector B. The red and blue arrows in these four figures point to anomalous features present at the same stratigraphic levels as the Barra and Farfan discoveries.

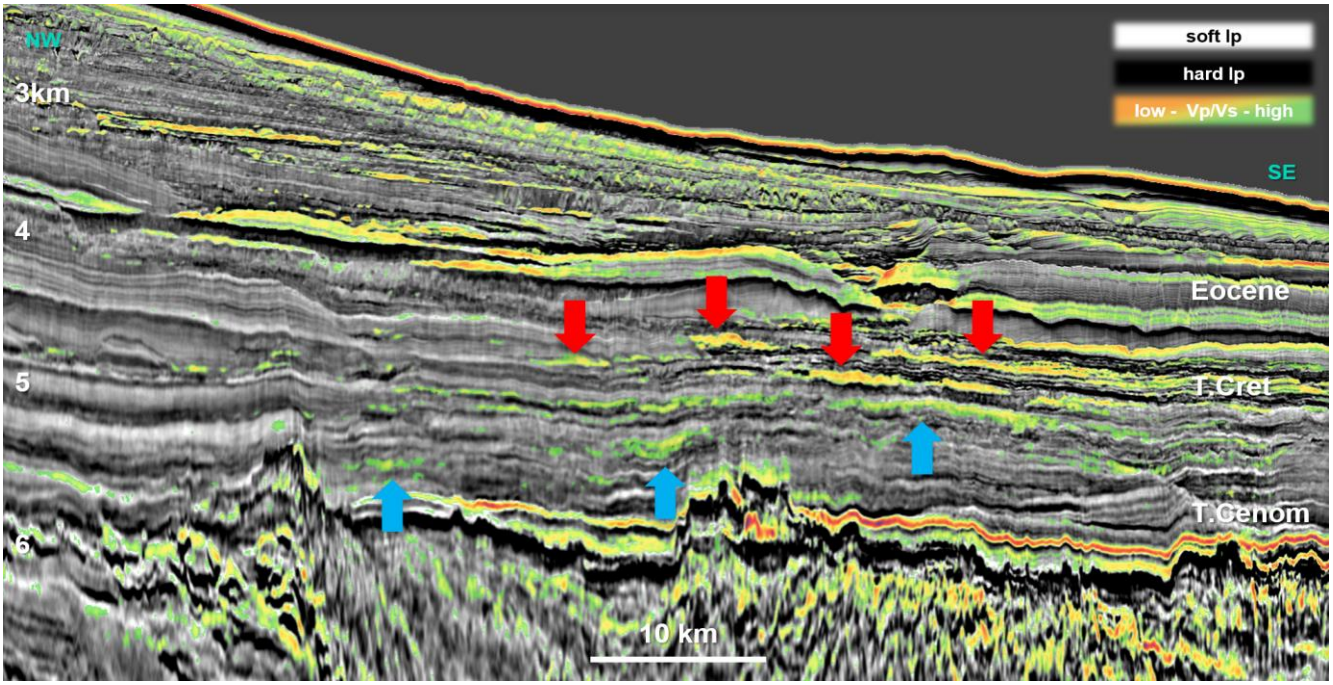

Figure 12 *- Arbitrary line 5 - Sector C to Sector B*

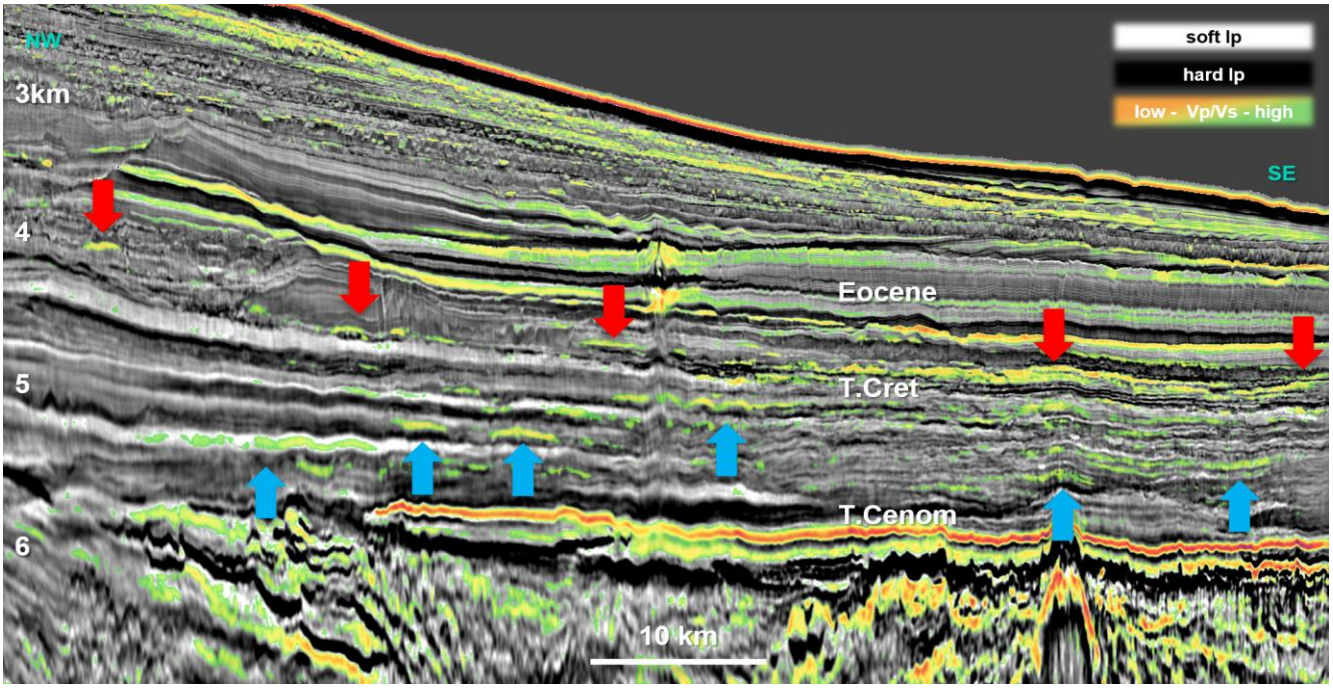

Figure 13*: Arbitrary line 6 - Sector C to Sector B*

Conclusions

The SEAL-Bonita and SEAL-Pirambu are two jointly processed multisensor seismic surveys representing 13000 square kilometers. Barra, Farfan, Muriu, Moita Bonita and Cumbe are well known discoveries by Petrobras in the area. The fields are covered by these 3D programs. The hydrocarbon play extension further into the deep water area will soon be tested by ExxonMobil and partners. Most of the leads identified in the area have a stratigraphic component for hydrocarbon trapping. High-quality 3D seismic data together with an improved understanding of source-rock in the basin is critical in de-risking these opportunities.

The presented AVO based seismic analysis has proven to be a very efficient tool for screening the entire 3D area. The accurate measurement of low frequencies as well as the broader range of frequencies on the high-end side of the spectrum, lead to a good match at known discoveries and dry wells. These reliable frequencies provide confidence that the amplitude anomalies in other parts of the surveys can be trusted. In the case of the dry wells, it has been shown with these attributes that there are potential fluid escape features present in the interval targeted by those wells.

A set of arbitrary lines was designed to tie the existing discoveries to most remote parts of the survey such as areas close to the edges of Sectors A, B and D. Further interpretation and analysis of the attributes generated from data, suggests that the Upper Cretaceous turbidite play may extend to the ultra-deep waters of the sector C as well as to the southwest (sector A) and northeast (sectors C and D). Currently, sector C is covered by the existing 3D and promising amplitude anomalies have been identified. There will be new multisensor broadband surveys acquired in zones A and D in 2021-2022. Thus, the Sergipe-Alagoas basin represents significant exploration potential for explorers in the years to come.

Acknowledgements

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References

S Kattah, Y Balabekov, [2016], The revival of turbidite hydrocarbon plays in Brazilian offshore basins. Rio Oil and Gas 2016