Seismic interpretation and exploratory opportunities assessment in the Pre-Salt play, northern Santos Basin

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Abstract

This study presents an exploratory workflow performed in a dataset acquired in northern Santos Basin, near the Oliva field, southeast Brazil. The workflow consists of a multidisciplinary approach, comprehending geological, geophysical, petrophysical and geostatistical analysis applied to the available dataset (2D/3D seismic, basic well logs and stratigraphic markers from eight wells drilled in the study area). As a result, were defined two exploratory opportunities in the Pre-Salt Play, the leads named Açaí and Guaraná. The volumetric analysis undertaken established a volume of oil in place (VOIP) of 427 MMbbl (P50) for Açaí and 453 MMbbl (P50) for Guaraná structure. Comparisons between the volumetric results obtained during this research and those forecasted by ANP (National Petroleum Agency) and PETROBRAS concerning the pre-salt reservoirs came to assist and enhance the reliability of the present study.

Introduction

Located in the southeastern Brazilian continental margin, the Santos Basin has about 350000 km^2, reaching up to 3000 m thick of water column in the deepest parts. The Cabo Frio High marks the northern limit of the Santos Basin, in the border with Campos Basin, whereas the Florianopolis High defines the southern limit (Moreira e*t al*., 2007), close to the Pelotas Basin. In the last decades, many authors have been describing the Santos Basin geology and stratigraphy. For instance, Moreira *et al*. (2007) divided the basin record in four main litostratigraphic units, namely Guaratiba Gr., Camburi Gr., Frade Gr. and Itamambuca Gr. These units overlie the basement, composed by Precambrian granites and gneisses from the Ribeira Fold Belt (Cainelli & Mohriak, 1999).

The first exploratory campaigns in the Santos Basin initiated in the end of the 60's, with the first seismic surveys acquisition. Whereas the direct investigation only started with the 1-PRS-1 well drilling, in 1970. These pioneers investigations brought their first result in the end of the 70's, with the Merluza gas field discovery. As exploratory campaigns evolved, bigger volume of seismic and well data have been acquired, leading to more small sized discoveries in the post-salt sequence, which some of them are still producing (Coral, Estrela do Mar, Tubarão etc.).

In the last years, the Santos Basin became an important exploratory target in the Brazilian margin, receiving a significant amount of investments. This effort culminated in many discoveries of heavy oil and gas fields in the post-salt reservoirs, as well as light oil accumulations in the pre-salt sequence. The first ones are mainly related to turbidities reservoir, such as Atlanta and Oliva fields.

From 2006, pre-salt discoveries were announced, characterized by huge volumes, such as Lula field, Libra, Jupiter, in addition to many others (*e.g*. Búzios, Lapa, Sapinhoá etc.), Figure 1.

The pre-salt play is characterized by microbial/stromatolite carbonates from the Barra Velha Fm. and coquinas from Itapema Fm. (Aptian). The Itapema Fm. was deposited during the late rift phase of the basin in a lacustrine setting. Whereas the Barra Velha Fm. was deposited during the sag phase, in a transitional to a marine system.

According to Carminatti *et al*. (2008) and Gomes *et al*. (2008), the development of these large accumulations are due to four major factors: (1) presence of extensive and mature source rocks; (2) existence of intra-basin structural highs, which are important to hydrocarbon trapping and focalization; (3) microbial carbonate reservoir with high quality porosity and permeability; and (4) occurrence of a thick evaporite layer that acts as effective seal.

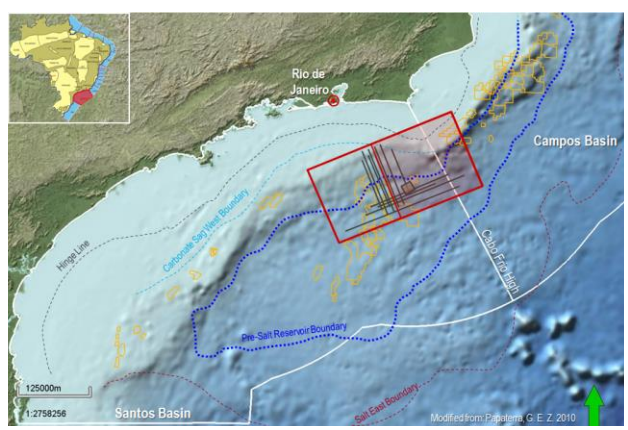

Figure 1 *- Santos Basin and study area (red filled square) location map. Modified from Papaterra (2010) and ANP – BDEP Webmaps.*

Method

The main objectives of this work included performing the oil & gas industry's standard workflow, to assess possible leads and prospects in the Pre-Salt play in Santos Basin northern area. Besides to surpass the available data challenges and limitations, this work aimed reach an exploratory evaluation that correlates to the known nearby discoveries and fields.

The dataset used in this work was delivered by the Agência Nacional do Petróleo (ANP), through its exploration and production database (BDEP) to the Rio de Janeiro State University (Seismic interpretation post-graduation course), where the authors developed this academic research. One 3D seismic cube, twelve 2D seismic lines (both in time domain) and eight exploratory wells compose this dataset.

After loading the data into the interpretation software, the next step was correlate the seismic and well data, building a synthetic seismogram. The process of synthetic seismogram building corresponds to the modelling of the seismic response of the lithology registered by the well, aiming to tie the main amplitude contrasts recorded in both seismic and well logs. Subsequently the seismic tied to the wells, the stratigraphic and structural interpretation of the 2D seismic lines and 3D cube started, using also attributes that provided more accurate interpretation control.

Other important part of the study was the velocity model building to allow the depth conversion of the seismic and interpretations, constrained by the well stratigraphic markers. Due to the velocity model's intrinsic uncertainty, present in all depth conversion methods, some distortions may occur in the converted data. An example of this is changes in the structures closure, caused by thick overlying evaporite layers, such as pull-ups in the salt base. Depth conversion is a most critical stage of the workflow applied and, unfortunately, can affect the hydrocarbon volume estimation.

Simultaneously to the seismic interpretation and depth conversion, were also conducted a reservoir petrophysical study. However, since the wells available did not reach the Pre-Salt layer, the use of analogous areas in the bibliography assisted the petrophysical studies (*e.g.* Lula, Sapinhoá, Jupiter, Sururu, Berbigão, Atapu and Búzios based on Gaffney & Cline Associates, ANP, 2010). The Figure 2 display those analogous areas.

The last step of the workflow consisted of the risk and volumetric analyses, using Monte-Carlo simulation and following the guidelines proposed by Rose (2003). In this phase, as well as the petrophysical properties, the fluid parameters on the analogous areas available were important (same areas displayed in the Figure 2). All these parameters combined, allowed to estimate the volume of oil in place (VOIP) considering its minimum, mean and maximum values, in order to comprise the large range of reservoir quality variability.

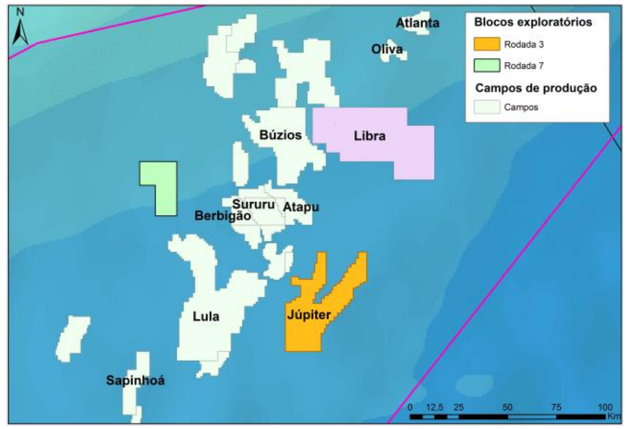

Figure 2 *– Analogous fields and exploratory blocks used to assist the petrophysical studies and to provide fluid properties.*

Results

Once the dataset available to this work has some limitations, such as a large area covered only by few 2D seismic lines, no wells reaching the Pre-Salt reservoir and lack of seismic processing velocities, comparison between surfaces mapped and well known nearby structures for quality check was necessary. For instance, the top of Pre-Salt structural map (Barra Velha Fm.) obtained resulted from the seismic interpretation and depth conversion show a reasonable match to the Libra and Búzios structures (Figure 3). Additionally to this horizon, were also mapped the Intra-Alagoas Unconformity and Top of the Rift horizons.

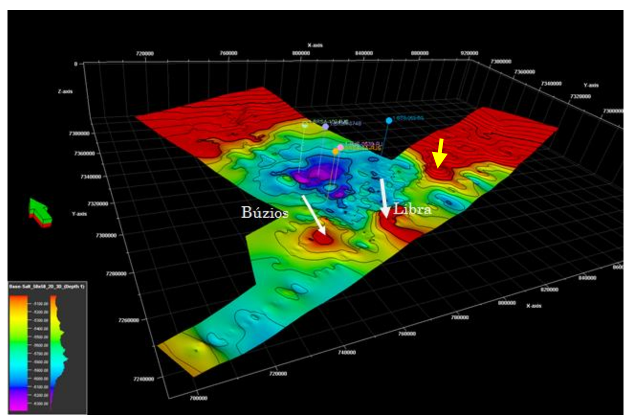

Figure 3 *– Top of the Pre-Salt reservoir structural map (Barra Velha Fm.) in depth. Correlation to Libra, Buzios structures and the possible lead location.*

Those depth converted maps, along with petrophysical and fluid properties (Table 1), were the input to the leads and prospects definition and assessment. Thus, two leads were defined, namely Açaí and Guaraná (Figures 4 and 5), which are two positive structures showing four-way closure on the base of salt horizon, with an area of 47 and 68.5 km2, respectively.

***Table 1** - Petrophysical and fluid parameters used to VOIP calculation. Φ: Porosity; SW: Water Saturation; NTG: Net to gross; FVF (Bo): Formation volume factor, oil. Based on Gaffney & Cline Associates, ANP (2010).*

	Min	Mean	Max
Φ (%)	4	10	14
SW (%)	15	21	31
NTG (%)	41	76	93
FVF (Bo)	1.45	1.50	1.55

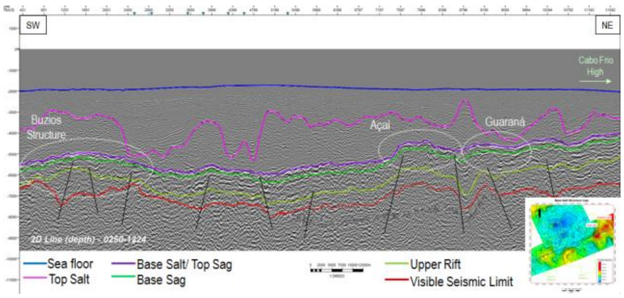

***Figure 4** – Seismic section (in depth) crossing Açaí and Guaraná structures.*

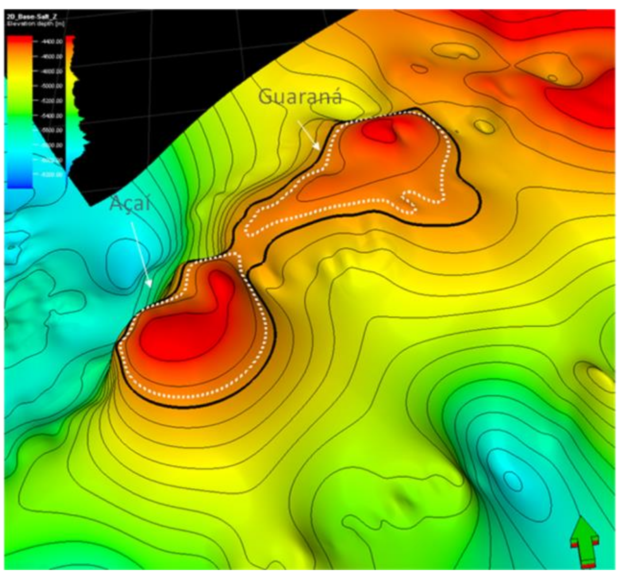

***Figure 5** – Açaí and Guaraná structural map (in depth). Spill point for each structure drawn in white and for both occurring associated drawn in black.*

The Monte-Carlo volumetric and risk analyses applied to the leads resulted in a VOIP of 427 MM bbl (P50) to the Açaí structure and 453 MM bbl (P50) to the Guaraná structure. Table 2 shows the complete range of volumes and the probability of success (POS).

Besides the the Açaí and Guaraná Leads evaluation as independent structures, a scenario of a unique structure occurrence was analyzed, considering the maximum spill point and a maximum correlation factor for the risks involving trap occurrence, source and seal effectiveness. Table 3 display the results of this alternative scenario.

***Table 2** – Volumes of oil in place (VOIP) and probability of success (POS) of the Leads Açaí and Guaraná.*

Volumes	Lead	P90	P50	P10
VOIP (MMbbl)	**Açaí**	184	427	793
POS		29%		
VOIP (MMbbl)	**Guaraná**	244	453	785
POS		24%		

***Table 3** – Volumes of oil in place (VOIP) of the Leads Açaí and Guaraná, considering maximum dependency relationship.*

Volumes	Lead	P90	P50	P10
VOIP (MMbbl)	Açaí + Guaraná	226	514	1043

Discussion and Conclusions

The hydrocarbon accumulations in the sag section of the Santos Basin are associated to intra-basin structural highs, uplifted during the rift phase. These structural highs play an important role in the trapping and hydrocarbon focalization process of the Pre-salt accumulations.

In the study area were evaluated two leads in the Pre-Salt play, whose volumes of oil in place (P50) were estimated in 427 MMbbl for Açaí Lead and 453 MMbbl for Guaraná Lead (see complete results in Table 2). Risk analyses were also undertaken, showing a probability of success (POS) of 29% to the Açaí Lead and 24% to the Guaraná Lead. Additionally, were considered an alternative scenario using a correlation factor between both structures, bringing a VOIP (P50) of 514 MMbbl (see complete results in Table 3).

Regarding the risk analyses, the trap was considered the most critical parameter, since the study area is covered only by few poor-quality post migrated 2D seismic lines. To better evaluate those leads and reduce risks, it is recommended the usage of seismic data with more recent acquisition and processing techniques, such as broad band and PSTM/PSDM, in order to get better deep structures imaging, reducing the effects caused by noise, multiples and artifacts. The application of the velocity field from processing along with the wells constraint in the depth conversion method is also highly recommended.

Other important risk factor relates to the reservoir quality and segmentation, since the area is located very close to the Cabo Frio high and a large amount of igneous rocks may be present.

There is no 3D seismic survey covering the study area so far, however the national regulatory agency (Agência

Nacional do Petróleo – ANP), showed intention to investigate that area with a 3D acquisition (Figure 6), according to the ANP Multi-year plan (Abelha, 2015). This ANP planning show the interest and exploration potential of the area and could confirm the structures size and position.

Finally, other positive characteristic that could facilitate the future leads development is the presence of a vast outflow and ports infrastructure (Pethersohn et al., 2013) (Figure 7).

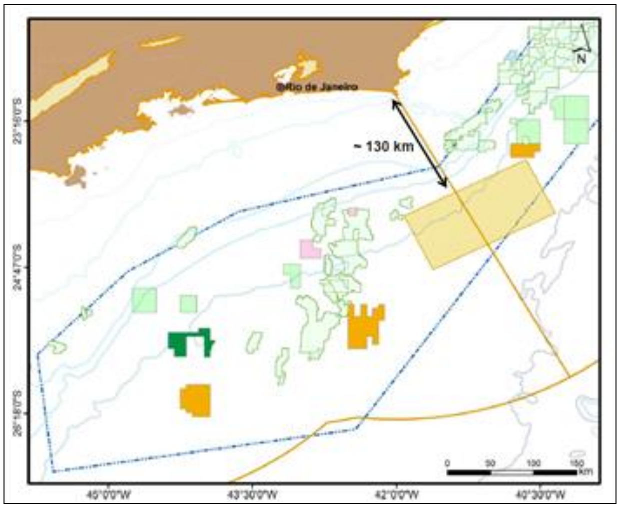

***Figure 6** – ANP 3D seismic survey possible location (light orange rectangle). Extracted from Abelha (2015).*

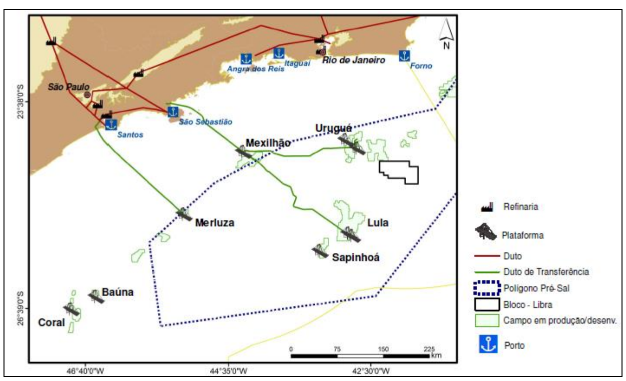

***Figure 7** – Development infrastructure available close to the study area. Extracted from Pethersohn et al. (2013).*

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