

Exploration Opportunities in the Pre-Salt Play, Deepwater Campos Basin, Brazil

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ABSTRACT

Extensive acreage over the pre-salt hydrocarbon play in Brazil remains unexplored or underexplored with several conceptual models yet to be tested. Pre-Salt acreage discussed here includes exploration opportunities within the framework of the forthcoming 2017 ANP License Rounds.

Based on seismic interpretation of 3D PSDM surveys in the deepwater Campos Basin, we have identified several exploration trends and very large drilling opportunities in the sedimentary succession located immediately beneath the salt (totally 1,000 to 1,500 square kilometers of combined 4-way closures). As per analogies to other Brazilian pre-salt discoveries, these potential hydrocarbon accumulations are hosted by carbonate and siliceous microbialites. Seismic facies analysis and external geometries indicates that several reservoir facies and facies trend belts could be encountered.

Large outboard microbial platforms nucleated on top of volcanic complexes could introduce a new, high-risk frontier play that can consist of very large 4-way closures just beneath the main evaporitic succession in distal segments of the Campos Basin. Besides reservoir presence/quality, exploration risks for the play in this area would be related to hydrocarbon generation and migration. As with other microbial limestone accumulations, there is a potential for a self-sourced system to mitigate this risk.

INTRODUCTION

The discovery of the Lula Field by Petrobras and partners in 2006 opened a new E&P frontier in Brazil, the Barremian/Aptian pre-salt play in the offshore Santos and Campos basins. Several multi-billion-barrels discoveries have been made in carbonate reservoirs in the pre-salt sequences of these two producing Brazilian basins and their African counterparts. These recent Santos and Campos basin discoveries, after appraisal, are expected to add at least 10 Bboe to Brazilian proved reserves by 2022 (from ANP, 2014).

The Brazilian pre-salt play consists of rift/sag-sourced oils, accumulated in Aptian reservoirs (microbialites) in structural closures or paleo-topographic/depositional highs just beneath the salt (Figure 1). The overlying Aptian evaporites provide the sealing unit. In addition to the

microbialites, deeper coquina reservoirs have become important exploration targets in the pre-salt succession of Campos and Santos basins as proven by successful well tests on the Búzios (previously referred to as Franco) and Libra pre-salt discoveries.

Based on available Santos Basin well data, observed seismic responses, as well as in published analytical studies of the major commercial and non-commercial pre-salt discoveries in Brazil (e.g. Fontes and Zalan, 2014 and Petersohn *et.al.*, 2013), two main reservoir targets are recognized for the pre-salt within the study areas:

- a. late rift coquinas: lacustrine facies deposited at the Late Barremian to Early Aptian and,
- b. the younger rift/sag microbial limestones or microbialites: mostly lacustrine units deposited during the Aptian just before the establishment of the major evaporitic sag basin between South America and Africa. Microbial limestones are currently the major producing reservoir units for the pre-salt play in both Campos and Santos basins.

The microbialites that occur just beneath the base salt can be interpreted as “organosedimentary deposits that have accreted as a result of a benthic microbial community trapping and binding detrital sediment and/or forming the locus of mineral precipitation” (Burne and Moore, 1987, pp. 241–242). Microbialites formed in large, mostly lacustrine, settings due to the activity of extremophilic micro-organisms surviving in potential hypersaline and hydrothermal conditions during the Aptian thermal sag phase that followed the syn-rift deposition.

DATASET AND METHOD

PGS 3D PSDM multi-client surveys constitute the main database for this study (Figure 02; total PSDM 3D area – ca. 46,000 sq. km; 34,000 sq. km in the Santos Basin and 12,000 sq. km in the Campos Basin).

In the Santos Basin, the pre-salt succession was mapped within the PGS BMS-50/52 and BS-1_South 3D PSDM seismic surveys and the PGS 3D PSDM survey Santos Phase I: merged/reprocessed, covering partially the Gato-do-Mato, the Florim and the Búzios

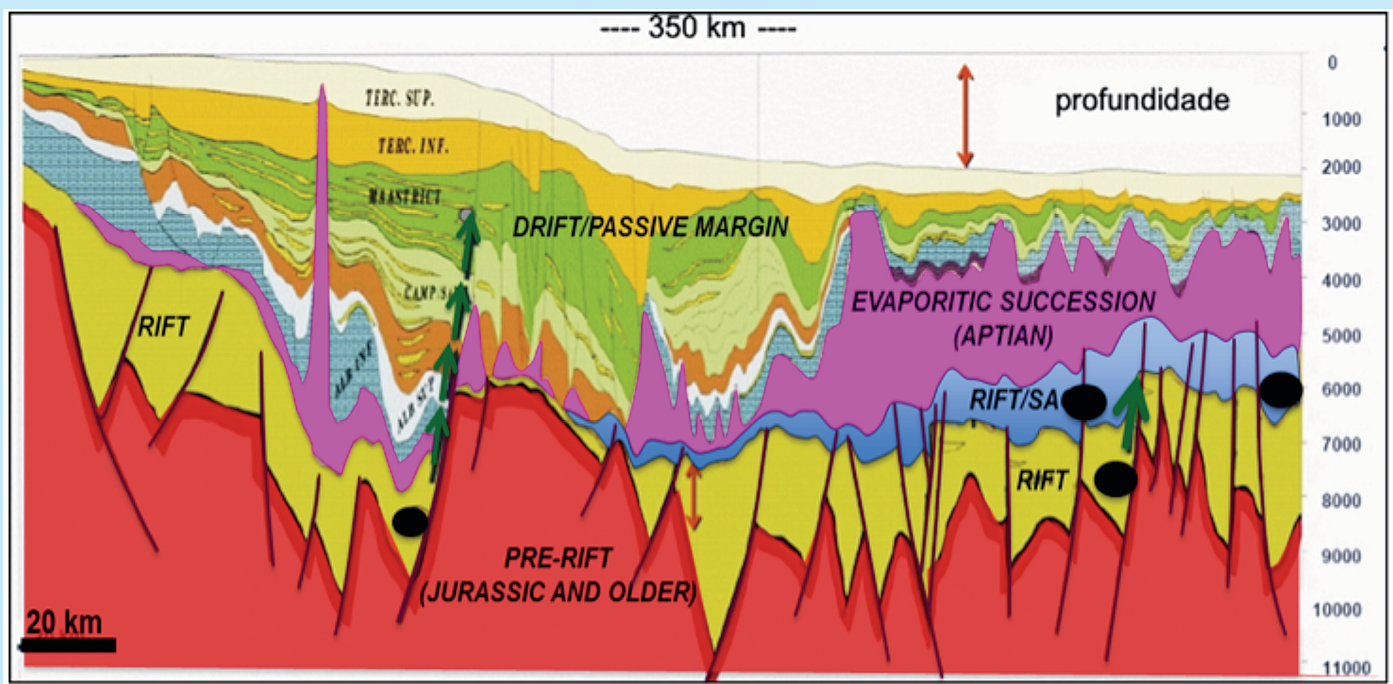


Figure 1: Pre-salt Play Summary: schematic cross-section, for Santos Basin. From IBP internet site, session compiled by Marco Antonio Pinheiro Machado (Cainelli, pers.com.).

(Franco) discoveries. The PGS BMS-50/52 (phases I and II) are located on the exploration trends of the Carcará and Sagitário discoveries. These multi-client surveys include both conventional and broad-band 3D seismic data and have been tied to the main control wells, the pre-salt discoveries and the producing fields through about 1,420 linear km of 2D regional PSDM broad-band seismic (Figure 02).

In the Campos Basin, the pre-salt succession was mapped and the exploration opportunities delineated within the PGS merged and reprocessed 3D PSDM survey from older conventionally-acquired datasets (Campos reprocessing phases I, II, III and IV). The Southwestern portion of this seismic data, Campos Phase IV, covers a recent pre-salt discovery in the Block BM-C-33 (Pão de Açúcar) and from this discovery the extension of the pre-salt reservoirs can be carried out onto the deeper water areas.

The Figure 2 also shows the main interpreted Environments of Deposition (EOD's) for the pre-salt microbial succession in the Campos

and Santos basins based on the seismic interpretation, available well control and analogues, both recent settings and outcrops of older rocks.

MICROBIAL SUCCESSION IN THE DEEPWATER SETTINGS OF THE CAMPOS BASIN

The pre-salt play within this survey area can be considered frontier. No

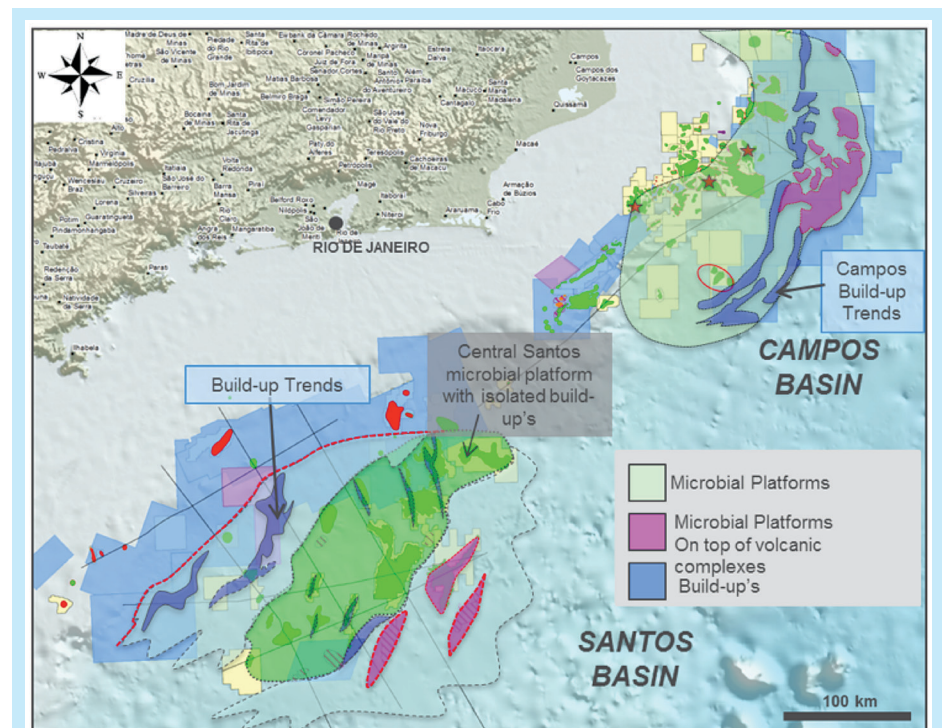


Figure 2: Location, Seismic dataset and pre-salt Environments of Deposition (EOD's) for the Santos and Campos basins.

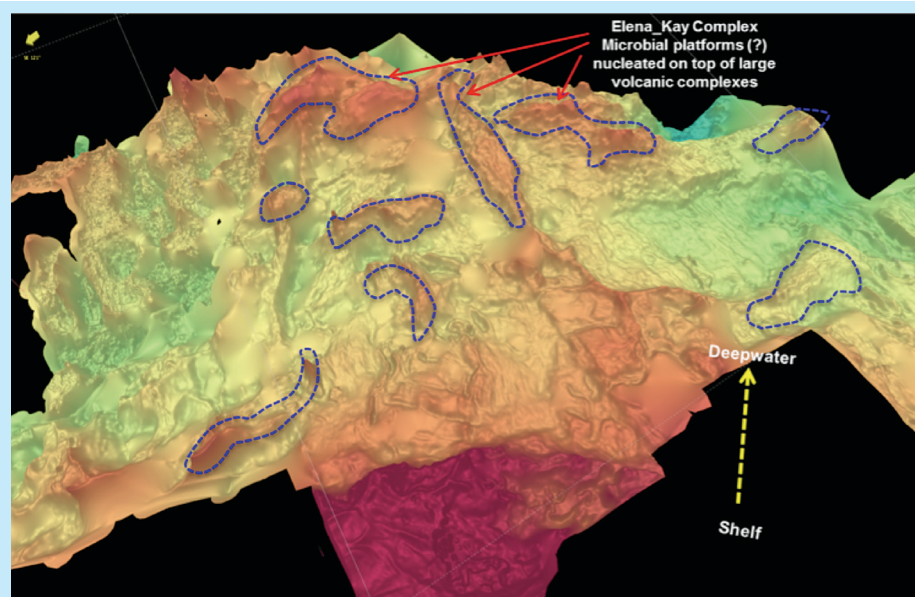


Figure 3: 3D perspective of the base salt structural map in the Campos Basin deepwater with pre-salt opportunities overlain as polygons.

pre-salt well penetration was available to calibrate the interpretation. The presented results are based on analogies with the Santos and the Kwanza basin discoveries. 3D seismic interpretation of the pre-salt section at the southern sector of the deep water Campos Basin has allowed the delineation of several pre-salt exploration segments.

3D seismic interpretation of the pre-salt section at the southern sector of the deepwater Campos Basin has allowed the delineation of several pre-salt sub-plays:

- i) Structural 4-way closures in coquinas and microbialites (Late Rift to Sag);
- ii) Stratigraphic/Combination Play in coquinas (Late Rift to Sag);
- iii) Microbial Build-up Play on rift shoulders (Sag microbialites) and;
- iv) Microbial Platform nucleated on top of and around large volcanic complexes (Figure 3).

Coquinas targeted exploration should be focused in the western part of the surveyed area while microbial reservoirs with potentially good permo-porosity properties seems to be located towards the present-day ultra-deep waters in the eastern part of the survey.

EXPLORATION OPPORTUNITIES

The announced 2017 ANP (Agência Nacional do Petróleo) license rounds will offer opportunities

within pre-salt acreage studied in this work.

A complex of large hydrocarbon exploration opportunities (4-way closures related to paleo-topographic/depositional highs at the base salt, here named Elena Kay Complex, Figures 3 and 4) were identified within the offered for the one of the ANP 2017 bid-rounds.

The interpreted depositional architecture indicates that the large microbial platforms were nucleated on top of volcanic complexes. This Late Barremian/Aptian volcanic event formed due to relatively young rifting processes on largely extended continental crust as shown Figure 4. Well control and analogues demonstrate that the main reservoirs in these platforms are potentially carbonatic (and/or siliceous) microbialites.

Main orientation of the Elena Kay Complex and the external seismic geometries of the individual leads

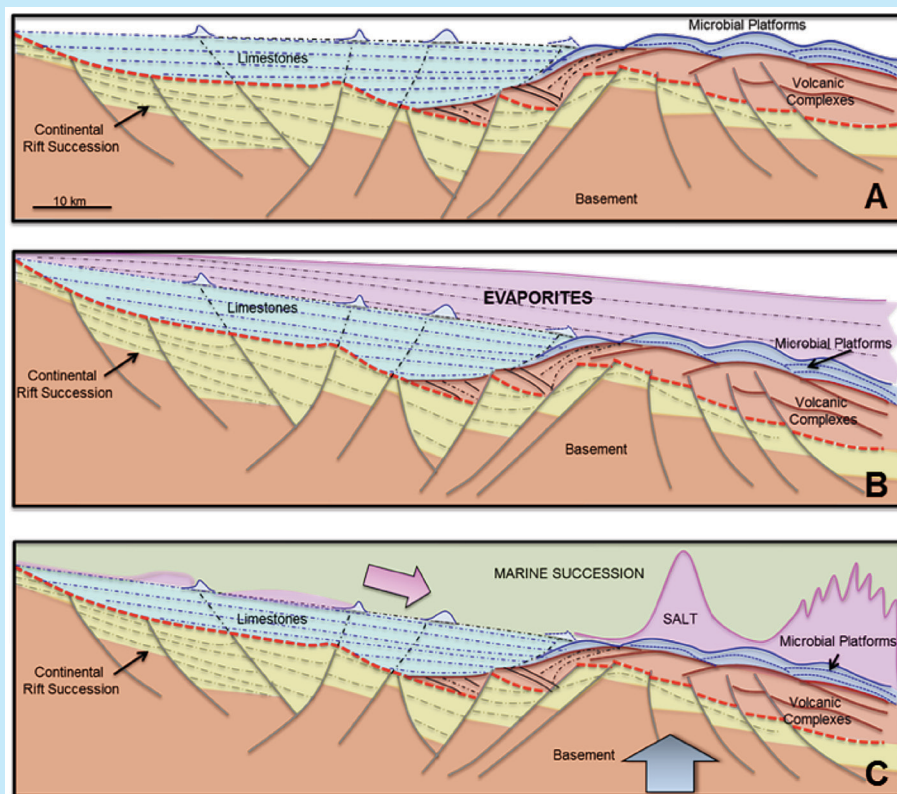


Figure 4: Evolution Elena Kay Complex of leads and prospects. A: microbial deposition in association with hydrothermal circulation and volcanism; B: main evaporitic succession deposition; C: Late tilting and halokinetic flows (pink arrow) and inversion/uplift processes (gray arrow) delineating the final geometric configuration of the Elena Kay Complex.

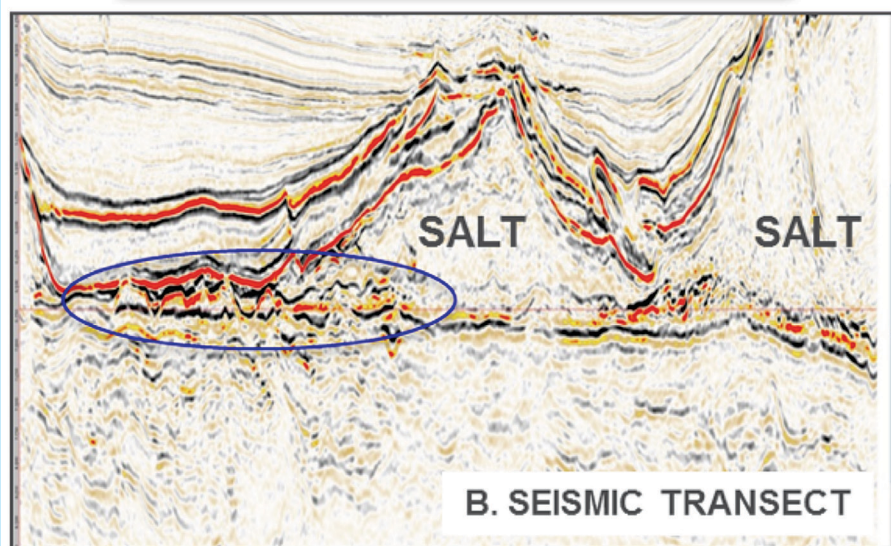
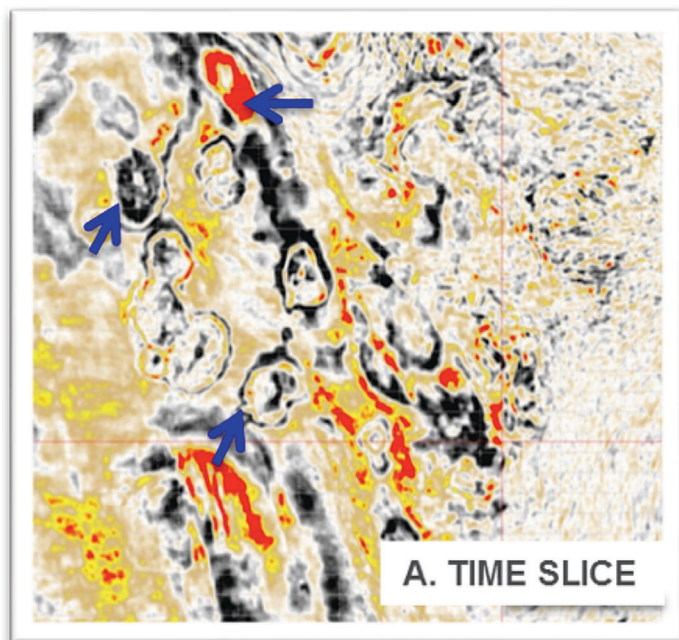


Figure 5: Seismic examples of potential hydrothermally-triggered microbial build-ups.

and prospects combined with pre-existing fault-control suggested that hydrothermal fluids controlled the different reservoir facies distribution (Figure 5).

Significant hydrothermal structures found in Yellowstone Lake consists of hard, porous siliceous material protruding vertically from crater-like depressions. These irregular, conically-shaped “spires” discovered in Bridge Bay in 1997 could be used as a potential recent analogue to this pre-salt setting in the Campos Basin and the Kwanza Basin (Casier *et.al*, 2014). The silicilythes in South Oman could

also represent viable analogues to the proposed siliceous microbial reservoir models proposed in this study (Al-Siyabi, 2005).

MAIN PETROLEUM SYSTEM ELEMENTS

A qualitative to semi-quantitative analysis of the petroleum system elements for aforementioned exploration opportunities is presented.

Structural closures (e.g. Figure 6) are expected to be low-risk as there is high confidence in the time-depth conversion for the mapped PSDM

surveys. Uncertainty could be related to the size of the opportunities that could range from tens to a few hundred's square kilometers.

Trap integrity/seal capacity will carry a low risk due to the presence of a thick evaporitic succession (top seal) and this is supported by analogues in African and other Brazilian pre-salt discoveries.

Reservoir presence and quality combined would be of low to moderate risk as demonstrated by inboard well controls (BCM-33 well penetrations and wells in the Marlin, Albacora, Caratinga fields), the observed seismic continuity of the EOD's into the Campos Basin deep water area and seismic geometries.

Source rock presence could represent the highest risk elements for these opportunities as seismic data indicates that the rift/sag successions are potentially dominated by volcanic rocks. However, by analogy, with other microbial reservoir units in Brazil and Oman, this risk can be mitigated by inferring a self-sourced system in which microbialites deposits (silica or carbonate) in addition to being the reservoir would also contain a high organic content to generate large volumes of hydrocarbons in order to fill these traps. Source-rock maturation would also be of low to moderate risk, although this should be properly evaluated and taken into account any overlaying thick salt which could impact on the geothermic and maturation.

The presence of large amounts of CO₂ in the fluid could also represent a moderate to high risk on the more distal prospects/leads where a more attenuated continental crust is expected.

With no pre-salt well penetration in the studied area, we have estimated that the POS (Probability of Success) for the introduced exploration opportunities would be on the average of 15 to 20% with expected volumes reaching multi-billion barrel level as per other similar pre-salt discoveries in Brazil.

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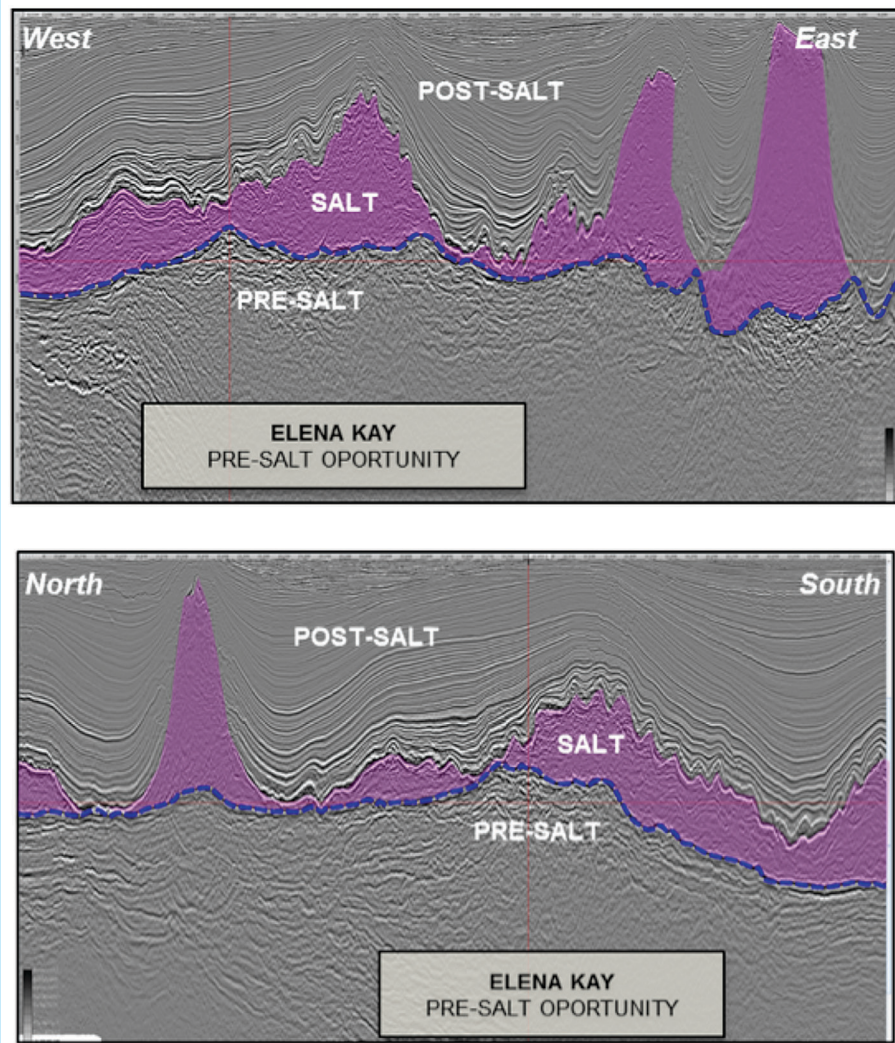


Figure 6: Seismic transects for one of the large hydrocarbon exploration opportunities in the Campos Basin deep water settings.

CONCLUSIONS

Since 2006 exploration in the Santos and Campos basins has been a success story for the pre-salt play. Additional Campos and Santos basin pre-salt acreage is still available for future exploration efforts;

In the study area, several large pre-salt exploration opportunities were identified. Some of them are in acreage that will be offered by ANP in 2017 bid-rounds;

The target reservoirs of the pre-salt succession are lacustrine carbonatic or siliceous microbialites and coquinas which can be recognized and mapped by their external geometries and internal seismic facies characteristics;

Large outboard microbial platforms nucleated on top of volcanic complexes could potentially introduce a new, high-risk frontier play that could reveal very large hydrocarbon volumes just beneath the main evaporitic succession in distal segments of the Campos Basin.

Besides reservoir presence/quality, exploration risks for the pre-salt play in the studied area would be related to source-rock presence and maturation.

As for other hydrocarbon accumulations in microbial reservoirs, we could contemplate the possibility of a self-sourced system to mitigate the source-rock presence risk.