Santos Basin, Pre-salt and Post-Salt remaining exploration potential

Abstract Summary

This extensive study highlights the significant remaining pre-salt and post-salt potential in an open acreage area within the Santos Basin, Brazil's largest producing basin. By utilizing a reprocessed regional 3D seismic dataset, we identified multiple promising leads. The findings underscore the presence of key petroleum system elements and reveal significant exploration opportunities. The region's exploration potential is further enhanced by existing infrastructure for natural gas supply and distribution, making it an attractive area for future investments and development.

Introduction

A large-scale, constantly growing 3D seismic rejuvenation program called Santos Vision (yellow outline, Figure 1) undertaken by TGS has been ongoing since 2016 till present. The reprocessed data covers a contiguous area of approximately 50 thousand square kilometers, larger than the entire state of Rio de Janeiro by comparison.

The focus of this paper is the open acreage region encircled by the Aram, Mexilhão, Sagitário, Bacalhau and Uirapuru fields in the Santos Basin. It presents a complex and geologically diverse setting, representative of the basin's transition from post-salt to pre-salt petroleum systems. This area lies within the outer structural domain, characterized by significant interactions between rift-related basement structuring, Aptian salt tectonics, and post-salt sedimentation.

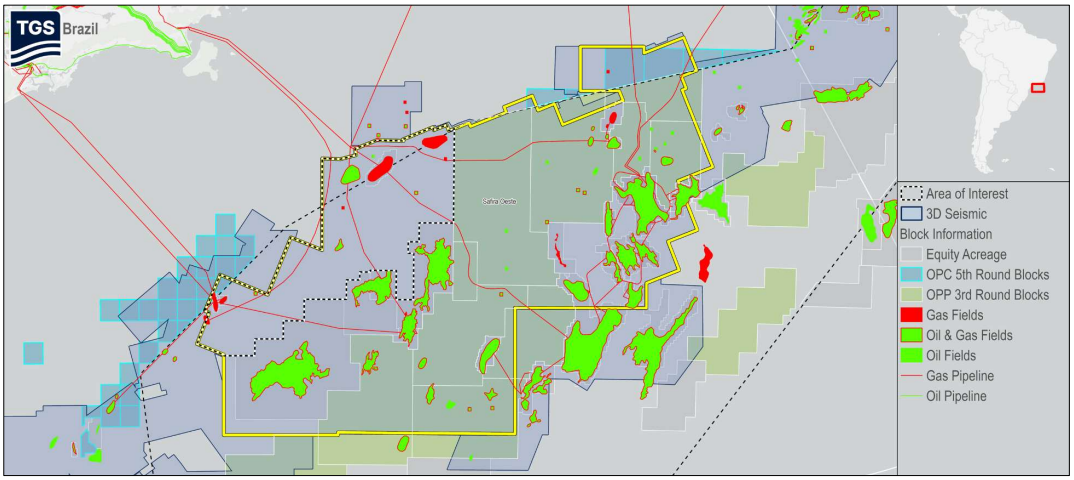

Figure 1: Schematic display of the study area (black doted polygon). The solid yellow line corresponds to the areal extent of the Santos Vision 3D program.

Pre-salt intervals include syn-rift and sag-phase carbonates and siliciclastic, often forming hydrocarbon-bearing reservoirs beneath a laterally variable salt thickness. The salt layer has been extensively mobilized, giving rise to salt domes, walls, and occasionally minimal remnant salt in some of the areas. Although large pre-salt structures have already been mapped extensively over the last decade, there is still potential to search for medium pre-salt structural traps in the area.

Post-salt sequences, particularly around the Mexilhão field, are dominated by Albian to Tertiary clastics and carbonates, forming drape and fault-controlled traps above salt structures. This transitional zone highlights the interplay between tectonics, sedimentation, and salt dynamics, offering high exploration potential in both established and emerging plays within the Santos Basin.

Method

This study involves the interpretation of a reprocessed dataset, specifically the Santos Vision 3D seismic survey, to identify and evaluate potential leads. The dataset is a merge of various reprocessed 3D seismic surveys which were Kirchhoff depth-migrated and combined into a seamless volume. The reprocessing included building a continuous velocity model and balancing amplitude and phase of the various datasets. To ensure seamless interpretation and integration, all processed 3D seismic volumes were carefully aligned on a consistent vertical scale. This vertical harmonization eliminates discrepancies between datasets, allowing for smooth transitions across volume boundaries and preserving geological continuity.

A Machine Learning (ML) algorithm was used to track seismic reflectors by analyzing variations in waveform properties across the area. The workflow began with automatic subsampling of the data into spatial distribution of representative initial waveforms. The algorithm then searched for similar waveforms throughout the entire 3D seismic volume. High similarity scores between the initial and newly identified waveforms increased their influence within the model, while poor matches prompted the algorithm to adapt evolving the initial waveform and reiterating the search process. The resulting mapped surfaces were then used to extract seismic attributes, highlighting features and anomalies that indicate the potential for hydrocarbons. These were classified according to presence of petroleum system elements, lead geometry, area estimates and key risk factors.

Results

The base of salt structural map in Figure 2 demonstrates structural highs in hot colors, which have been the primary focus for pre-salt exploration in the Santos Basin. The mapped leads, labeled A to E, align with trends like known nearby discoveries, including Sagitário, Aram, Bacalhau, and Uirapuru. Saddle zones divide these structures, creating a series of traps and multiple exploration targets. Additionally, deeper carbonate formations present stacked target potential.

The seismic section shown in Figure 3 provides a regional context, intersecting several of the mapped leads. The bright reflection from the Mexilhão field (yellow horizon), interpreted as turbiditic Santonian sandstones, extends towards northeast (leads A2 and A3), and across the fault towards southwest (lead A1), exhibiting similar amplitude responses and 4-way closures. Some of them have been tested, confirming the presence of hydrocarbons and yielding encouraging results for gas. Despite not being developed, the outcomes validate the system's potential and support further exploration. However, the pre-salt potential from Mexilhão and adjacent areas remains untested.

The largest pre-salt structure C2 exhibits a unique and complex play characterized by carbonate bodies intercalated within basalts, analogous to which Chagas *et al.* (2024) describe as the "intertraps play". This is the only lead within the study area tested at the pre-salt, the "Corcovado-1" 6-BG-6P-SPS well, and it showed promising results with oil shows. This lead presents strong, high frequency reflections, bounded by major faults as interpreted in Figure 3. However, the seismic facies advance into the undrilled adjacent leads B, C3 and D, transitioning to more laterally continuous sub-horizontal parallel reflections, and, in certain locations, with a chaotic internal seismic signal, characteristic of upper Barra Velha Formation, interpreted as top of K44 sequence (green horizons in Figure 3 and Figure 4). The zoom line from Figure 4 highlights the lateral continuation and possible connectivity of the K44 sequence from the Sagitário field into lead D.

Lead E is a positive structure cored at local high associated with the basement, interpreted as a carbonate mound. However, the presence of pre-salt source rock remains uncertain, and volcanic rock intrusions in this location pose potential risk factors.

The “S” labels from Figure 3 and Figure 4 are interpreted as the source rock interval at the syn-rift section, adjacent to the mapped leads, bounded by faults that may serve as hydrocarbon migration pathways. Besides, the source rock presence is primarily confirmed by existing fields, which provide supporting evidence of its continuity and effectiveness.

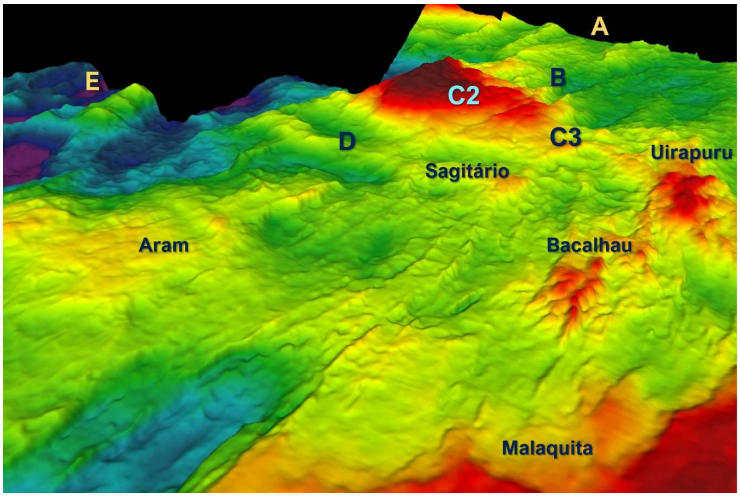

Figure 2: Base of salt depth map displaying the mapped structures and main identified leads - hot colors show main pre-salt structural highs and their spatial relationship within the study area.

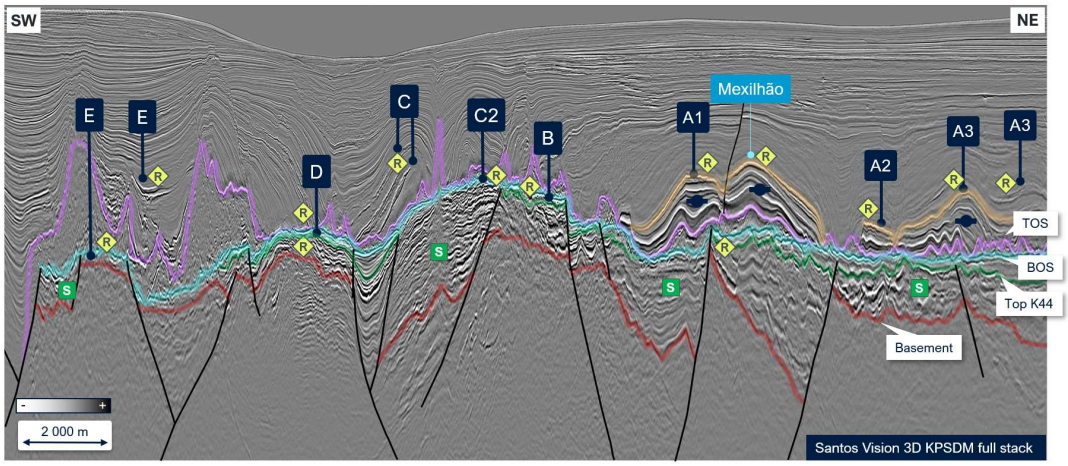

Figure 3: Arbitrary line throughout study area showing multiple pre and post-salt potential.

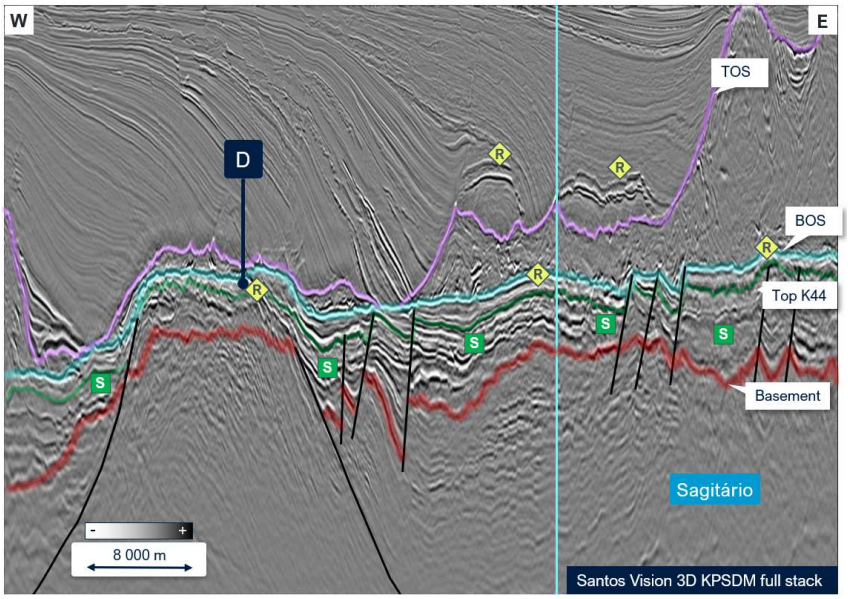

Figure 4: Zoomed seismic section highlighting the mapped lead D. The feature is interpreted as a potential extension of the adjacent Sagitário field.

Conclusions

The results of this work highlight the presence of multiple key petroleum system elements across the study area, reinforcing the region's promising exploration potential. Furthermore, existing infrastructure, particularly for the supply and distribution of natural gas supports future development efforts.

The primary reservoir targets in the pre-salt interval are lacustrine carbonates, including coquinas and microbiolite-bearing facies, which can be effectively recognized and mapped through their distinct external geometries and internal seismic facies characteristics. Key structural and stratigraphic trends in the Santos Basin such as the Bacalhau-Uirapuru layered microbial facies, the inboard carbonate platform (Sagitário trend), and the potential deeper stringer play remain largely unexplored and currently unleased.

Regarding post-salt potential, recent in-country gas initiatives are destined to enhance the viability of these opportunities by attracting further investments and encouraging participation from a broader range of industry players.

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References

ANP, Sumário geológico da Bacia de Santos, 2024.

Chagas, A. A. P., Araújo, C. C., Santos, L. A. As grandes descobertas do Pré-sal no Atlântico Sul, PETROBRAS, 2024.1089 p.