Offshore Brazil 2005 – Regional Update and Future Exploration

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Summary

Offshore geophysical data acquisition and offshore drilling have had an impact on every aspect of the Brazilian offshore petroleum industry since 1999. Seismic programs, massive non-exclusive, spec 2D and 3D data acquisition programs were conducted offshore the Brazilian coast at record pace in the last six years and were followed by diverse deep-water drilling programs. The new geophysical data libraries offshore Brazil brought modern technological era to seismic interpretation, prospect evaluation, reservoir characterization and reservoir geo-steering during deepwater development drilling.

The main producing basins offshore Brazil are situated in the east coast. Modern seismic interpretation has mapped, through high resolution imaging, the stratigraphy of hydrocarbon producing turbidite reservoirs, has posted correct geometries of salt structures and, beneath the salt, has uncovered the structures of the underlying syn-rift sequences that encompasses most oil bearing source rocks. Offshore, in the eastern and northern coasts of Brazil the seismic data acquisition targets the mapping of new reservoirs in deep water and their relationship with rift sequences source rocks.

Seismic resolution of whole lithologies offshore Brazil has improved substantially with the new technologies employed in data acquisition, data processing and data interpretation. Pre-stack time migrations with higher order NMO are now routinely performed whereas selected regional lines have been pre-stack depth migration processed. Regional 2D and 3D surveys acquired with long cables and large foot-print have provided new data libraries along the whole continental margin off Brazil, this modern portfolio of regional surveys 2D and 3D are larger in size to all historical data.

The results of regionally interpreted seismic lines and regional mapping of the outer shelf, slope and deepwater provinces of Santos, Campos and Espírito Santo basins are presented herein. The deepwater turbidite plays along the continental slope are interpreted from the modern data that allows for precise resolution image of the syn-rift source rocks, salt architecture, migration paths through faulting and salt windows, reservoir characterization and regional seal mapping. Future offshore exploration hence will continue aiming at better seismic resolution of the deepwater prospects and into the ultra deepwater plays of the salt wall mini-basins, the last frontier region of the continental crust petroleum province.

Introduction

Although Brazil has the longest north-south coast in the world, in addition to a large equatorial shelf, the petroleum resources of its offshore basins are only now being fully assessed. The Petroleum Law enacted in 1997 provided for a programme of market-orientated reforms of the industry and in December 1998, ANP announced the first annual block release, opening the Brazilian market to competition. In addition to the initial block distribution to Petrobras and partnerships, six highly successful bid rounds were conducted by ANP, the National Petroleum Agency, and the 7th bid round being conducted at the present time. From the 5th to the 7th bid rounds a distinct bidding model has been adopted in which oil and gas companies look for preferred areas albeit bidding is on smaller blocks.

Currently, 90% of the country's oil production is from the Campos Basin. New exploration opportunities range from deep water in frontier and proven basins to shallow water oil and gas plays as well as onshore oil and gas plays. Offshore, the offered areas of the first bid round were large, averaging 4,500 sq. km., equal to more than 220 GoM blocks, and have exploration periods lasting up to 9 years. The second bid round block average a smaller size, still averaging more than 50 GoM blocks. These were further reduced in the third and fourth bid rounds. From the fifth bid round to be current 7th bid round of 2005 blocks are substantially smaller size like GoM and companies bid for areas of interest encompassing many of these blocks.

By and large, most exploration interests are still in the Santos Basin, Campos Basin and Espirito Santo Basin offshore East Brazil (Fig. 1), where significant discoveries were made in 2003 and 2004. Among these is Golfinho Oil Field the first large accumulation in deepwater Espírito Santo Basin, Jubarte, Cachalote and Baleia Franca Oil Fields in the northern part of Campos Basin and the Mexilhão Gas Field in the Santos Basin. This investigation concentrates on a regional update of these basins based on the study of modern PSTM/PSDM regional seismic lines.

Offshore Basins – East Brazil

Three sedimentary basins underlie the shelf and slope off eastern Brazil, the Santos Basin to the south, the Campos Basin and the Espirito Santo Basin ton the north (Figure 1). These petroliferous basins are still under-explored despite the fact that large oil fields have been discovered in the deep-waters of Campos Basin (Fig. 1; Tables 1 & 2).

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The main characteristic events in the offshore basins off eastern Brazil consist of three stages, pre-rift, rift and post-rift. These events controlled basin stratigraphy and basin infill. The stratigraphic columns of all these basins are generally similar, with lacustrine sediments of the rift stage being covered by evaporites and carbonates of Aptian and Albian age and then blanketed by an overburden of open marine sediments (Asmus and Ponte, 1973; Figueiredo, 1985). The large discoveries in deep water off Eastern Brazil are in reservoirs of this open marine sequence (Mendes et al., 1998, Fainstein et al., 2003). Petroleum systems occur within the Brazilian marginal basins and are associated with: a) lacustrine syn-rift source rocks; b)-restricted marine and transitional environments and c) open marine transgressive sediments. The best source rocks are within the syn-rift sequence. Reservoirs and seals occur within the syn-rift, transitional and marine sediments.

A fairway of salt layers and salt diapirs that runs from Santos Basin towards north into Campos and Espírito Santo basins largely impact upon the structural architecture of offshore basins along the eastern continental margin. The salt fairway becomes progressively narrower towards north, and no salt is encountered in the equatorial margin. Salt diapirs cause the formation of hydrocarbon prospective structures along the entire eastern margin (Figure 2). Besides salt tectonism, structures along the eastern continental margin of Brazil consist of seaward tilted faulted blocks where anticline features are formed in association with block bounding listric faults.

In the Campos Basin, a regional unconformity marks the boundary between the Cretaceous and the Tertiary. Below this unconformity, there are marine sands, distal upper Cretaceous turbidites in deep-water and a transitional environment lithology of carbonates and salt layers, which lies immediately above the highly compartmentalized lacustrine syn-rift section (Mohriak et al., 1990). Above the Cretaceous/Tertiary unconformity, there occurs a pervasive distribution of thick turbidite sand reservoirs.

Lacustrine sediments of the syn-rift reached the oil generation window about Eocene time. Source rocks are separated from the main reservoirs by a salt layer, thus oil migration from source to reservoirs require migration pathways through salt windows. These were developed as a consequence of thinning or collapsing of salt layers during salt movement. Rift–phase faults permitted migration of oil from source to reservoirs. Where salt is absent, oil reached the younger reservoirs along faults related to salt movement (Figs. 3 & 4). The salt wall is particularly massive in deep-water Santos Basin where massive salt layers may preclude hydrocarbon migration from the syn-rift source rocks into the Upper Cretaceous and Tertiary reservoirs.

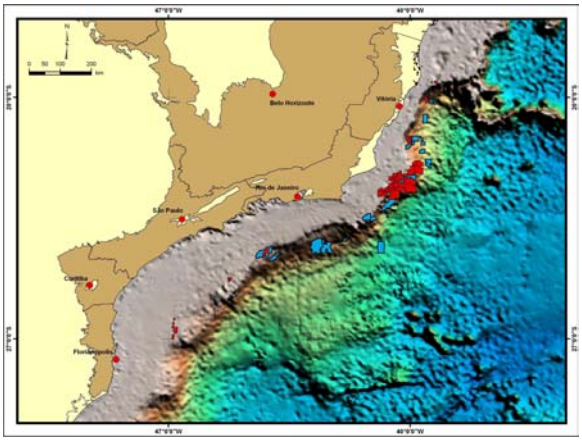

Figure 1: Morphology of the Brazilian eastern coast and the offshore realms of shelf, slope and rise that encompass the main oil and gas producing basins. The larger fields are situated on the continental slope. The turbidite slope play is the characteristic play offshore Brazil.

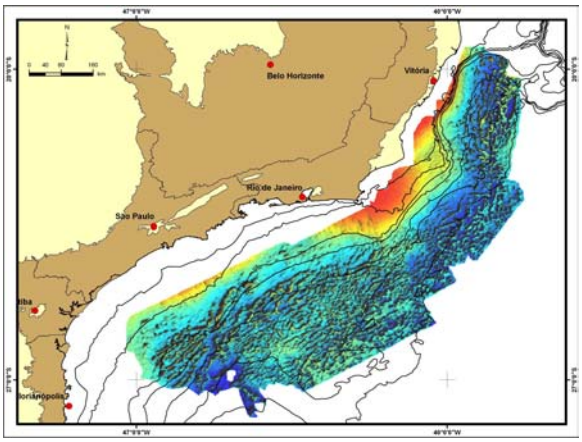

Figure 2: Depth map of the top salt horizon underscores the several structural domains offshore southeast Brazil. Prospects are framed by salt tectonics with clear trends of slope, turtle back structures, Albian Gap and salt wall minibasins displayed.

Historical - Modern Database

The historical legacy data acquired by Petrobras since its establishment in 1954 until 1998 consisted of 1,155,188 of 2D seismic data and 45,535 sq km of 3D data. Also, the historical data had two large oceanographic, seismic and magnetic databases were acquired by the REMAC and LEPLAC projects in the 70´s and 80´s. After 1954 until 1998, 18,484 exploration and development wells were drilled.

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The modern geophysical data after the Petroleum Law was established in 1998, consists mostly of speculative 2D and 3D seismic surveys these rapidly built up the modern library database. The spec surveys totals 342,287 km of 2D data and 178.020 sq km of 3D data. Speculative seismic surveys will provide, to the foreseeable future, the bulk of additional 2D seismic data and a considerable amount of the new 3D seismic data. A data bank formed by ANP encompasses well data and all geological and geophysical data. As such, not only seismic and other geophysical data would be available through the bank, but also studies in the area of technology related to E&P, such as improving recovery in low-permeability and heavy-oil reservoirs, horizontal drilling and simultaneous logging while drilling data would be stored. Extensive, modern, high-resolution 2D and 3D data acquisition all processed with pre-stack time migration expedite the definition of new prospects. The advances in deepwater drilling technology, have extended exploration and production operations routinely towards the continental slope and rise.

The modern seismic reflection database has focused essentially in the three offshore basins that have had the best hydrocarbon exploratory risk/reward ratio, the Santos, Campos and Espirito Santo basins, which have been covered by an unprecedented amount of 2D and 3D speculative surveys. The regional geophysical interpretation and petroleum geology of the East Brazil continental margin are described with basis on the modern non-exclusive 2D and 3D seismic data acquisition, gravity and magnetics. More recently production management of oil fields of Campos Basin are being monitored by 4D and 4C surveys.

Deep Water Plays

The principal oil reservoirs in deepwater are in shelf-derived turbidite sands encountered in the upper and lower continental slope from the Miocene to Upper Cretaceous and in distal marine turbidite channel sands of the lower slope. The presently producing fields in deepwater of Campos Basin have all been found during the period of 1985 to 1997. Among these are Marlim, Albacora, Roncador, Barracuda and Espadarte (see Table 1). The oil and gas plays are mostly confined to stratigraphic features of the higher horst blocks, in deep-water these are essentially the turbidite plays. The structural framework of deepwater plays is controlled by salt tectonics

Turbidite reservoirs are encountered in the upper and lower continental slope from the Miocene to Upper Cretaceous and in distal marine turbidite channel sands of the lower slope. These are found in the Upper. Cretaceous and Tertiary sequences. Recoverable reserves for the giant oil fields Albacora, Marlin and Roncador exceed 6 BBO.

Oil Fields Campos Basin	Water Depth	Reservoir: Lithology - Turbidites	Seismic Response
Marlim	650-1,050	Miocene-Oligocene	Hummocky high ampl.
Roncador	1,500-1,900	Maastrich-Santonian	High amplitudes
Marlim South	850-2,400	Miocene-Oligocene	Hummocky high ampl.
Albacora	230-950	Oligocene	Medium
Albacora East	800-1,000	Eocene	Medium/ high ampl.
Barracuda	800-1,150	Eocene	Conform/ hummocky
Marlim East	1,000-2,000	Miocene-Oligocene	Hummocky high ampl.
Caratinga	850-1,350	Eocene	high ampl.
Espadarte	750-1,500	Eocene	high ampl.

Table 1: Largest deep-water oil fields of Brazil (discovered before 1997 – all Campos Basin)

The deep-water plays require substantial exploration investments, during the contemporary period after 1997, more than 200 exploratory wells on water depths greater than 1,000 meters have been drilled. New oil discoveries have been made in Santos, Campos and Espírito Santo basins (see table 2), the most significant are the turbidite reservoirs encountered, along the continental slope, at the Jubarte, Cachalote, Baleia Franca, Baleia Anà and Baleia Azul oil fields on Block BC-60 of the North Campos Basin, the channel turbidite reservoirs of Golfinho Oil Field on the Espírito Santo Basin, and the fields discovered on North Santos Basin on blocks BS-400 (Mexilhão Gas Field), BS-500 and BS-4 (see Table 2).

Field /Basin	Water Depth	Reservoir: Lithology - Turbidites	Seismic Response
Jubarte	1,240-1,359	Maastrich-Santonian	Bright-spot
Cachalote	1,300-1,500	Maastrich-Santonian	Bright-spot
Baleia Franca	1,450-1,480	Maastrich-Santonian	Bright-spot
Golfinho (Esp. Santo)	1,460-1,500	Maastrich-Santonian	Bright-spot Hummocky
Mexilhão (Santos)	1,450-1,500	Campanian	Bright-spot
BS500/BS4 (Santos)	1,700-1,800	Eocene/ Maastrich	Hummocky channels

Table 2: Most significant new deep-water discoveries off East Brazil (all discovered between 1998 and 2005).

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Seismic Responses

Tertiary deepwater turbidite reservoirs tend to be associated with high to medium seismic amplitudes, with some hummocky internal character Tables 1 & 2). Seismic amplitudes for Upper Cretaceous turbidite reservoirs range from low to high with a combination of parallel-conformable with hummocky character. Turbidite fields are usually trapped by a combination of structural and stratigraphic trapping mechanisms including faulting, pinch outs and channel cuts. Turbiditic sands are also often stacked as they tend to gravitate toward paleo-lows.

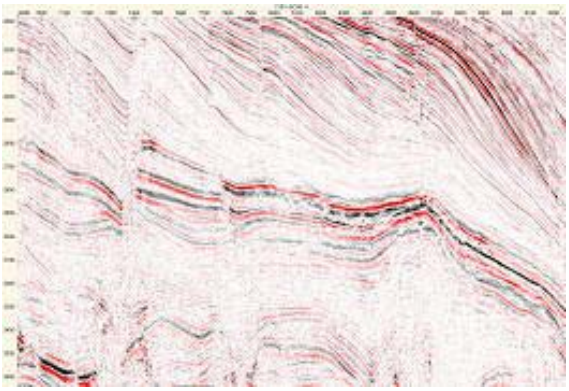

Figure 3: The seismic response signature of the giant Marlim Field is seen as bright, hummocky amplitudes. The thick Mio-Oligocene is characteristically situated along the continental slope.

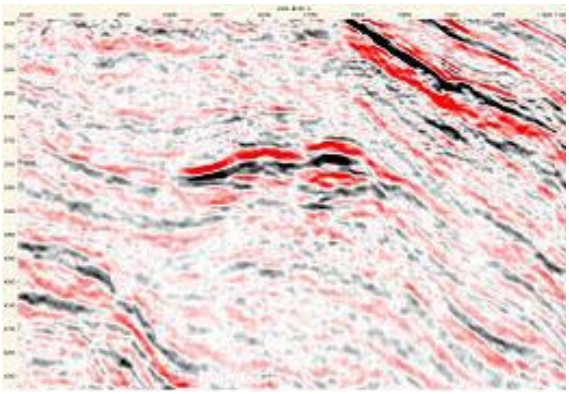

Figure 4: The seismic bright-spot response signatures of compartmentalized sections of Roncador Field are hummocky amplitudes of thick Maastrichian-Santonian turbidites along the continental slope.

The seismic examples clearly shows the key factors responsible for these large fields of the deep water Campos Basin (Figures 3 & 4), these include: a large turbidite reservoir which can be draped over basement horst blocks, a thick pre-salt source section nearby, large faults that facilitate hydrocarbon migration from source to reservoir, and regions of thin or welded salt below the reservoir that also help facilitate hydrocarbon migration. Hydrocarbon migration from the pre-salt source rocks into post-salt reservoirs is critical. Faults and salt welds are necessary to provide pathways for oil and gas. .

Conclusions

This study of regional mapping made through the structural and stratigraphic interpretation of Espírito Santo, Campos and Santos basins provides a regional view of all the prospective reservoirs and seismic markers.

The major productive fields, and the new significant oil and gas discoveries offshore eastern Brazil are all found along the continental slope. These yield characteristic seismic amplitude signatures that provide a framework for future exploration and development.

Acknowledgements

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