

# Petroleum Prospectivity in the Namibe and Southern Benguela Basins, Offshore Angola

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## SUMMARY

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The underexplored offshore deepwater basins of Angola hold tremendous potential for hydrocarbons. These basins have marked similarities with the prolific hydrocarbon producing region of the Brazilian margin which abutted the Angola offshore area prior to the opening of the South Atlantic

In 2011, PGS in association with Sonangol acquired a 12,700 km regional 2D grid using a dual-sensor towed streamer systems to provide broadband seismic imaging to address the hydrocarbon potential of the frontier Kwanza, Benguela and Namibe basins of Angola. This high quality seismic has been used to enhance the knowledge of potential petroleum systems of the Namibe and Southern Benguela basins.

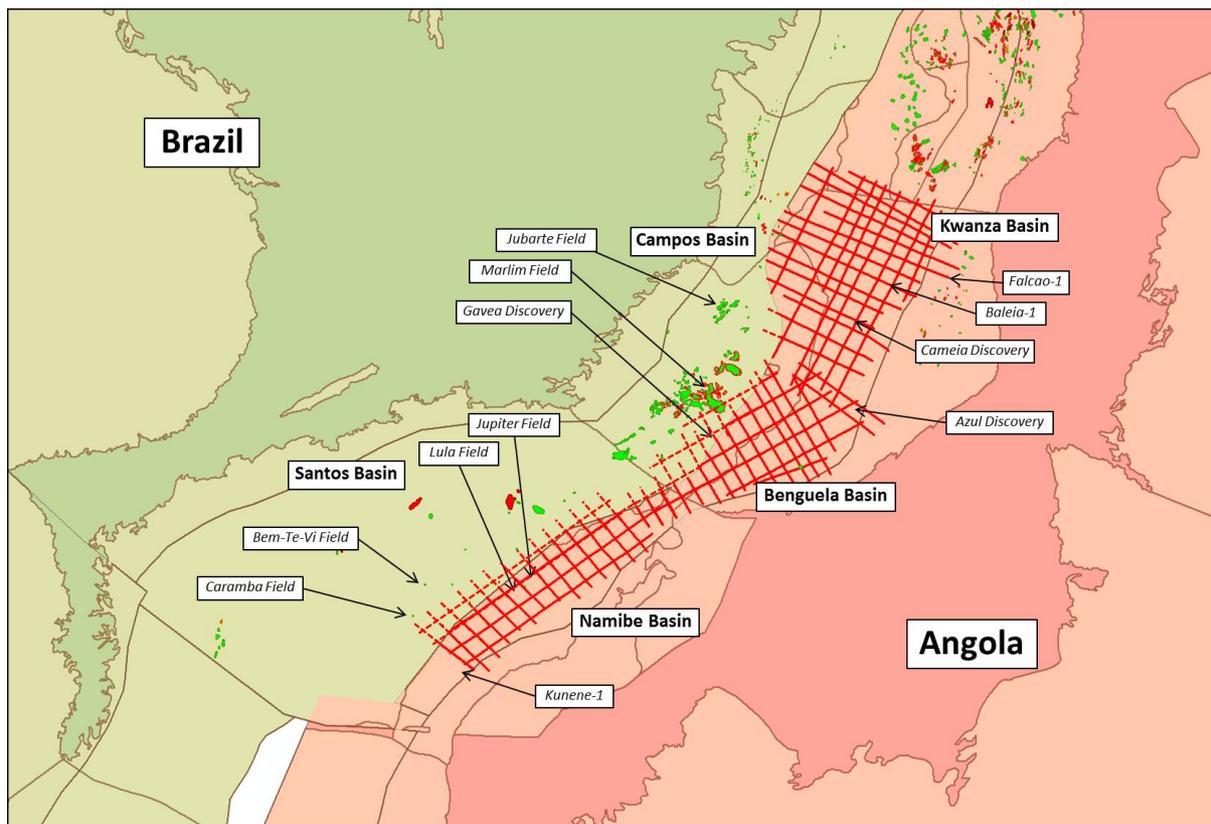
Horst and graben structures that formed during rift phases are now visible in the depth-migrated seismic data and are overlain by 3-5 km of post-rift sediments. Thick salt, which is well known to the north, extends into the southern Benguela and northern Namibe basins. Post-rift channel and fan structures can be identified as high amplitude anomalies throughout the basin. These are observed to pinch out on the flanks of volcanic high structures and salt diapirs.

The improved imaging and resolution provided by these data significantly de-risk exploration in a frontier deepwater area where well costs are high.

## Introduction

The underexplored offshore deepwater basins of Angola hold tremendous potential for hydrocarbons. These basins have marked similarities with the pre-salt of the Brazilian margin which abutted the Angola offshore area prior to the opening of the South Atlantic (Figure 1). The Brazilian offshore margin has become a prolific hydrocarbon producer with massive reserves additions contributed from sub-salt giant discoveries such as the Lula and Jupiter fields of the Santos Basin and more recent discoveries such as Gavea in the Campos Basin. Analyses of oils from both sides of the Atlantic indicate similar source rocks, while seismic data show analogous structures.

The frontier Kwanza, Benguela and Namibe basins of Angola have seen a huge demand for high quality, detailed and innovative seismic data which can be set in a regional context, in order to assist in the exploration, understanding and de-risking of this potentially prolific hydrocarbon province. In 2011, PGS in association with Sonangol acquired a 12,700 km regional 2D grid using a dual-sensor towed streamer system to provide broadband seismic imaging to address the hydrocarbon potential of this region. Migrated to depth, these data give more accurate seismic imaging of pre-salt structures, thus improving the regional understanding of tectonic evolution, structure and geology. This better understanding enhances knowledge of potential petroleum systems, and provides new insights regarding the prospectivity of the Namibe and Southern Benguela basins, which will be summarised in this paper.



**Figure 1** Plate reconstruction by Getech (2011) at 122 Ma (Aptian), showing the close alignment of the Brazilian and Angolan margins with significant pre-salt oil discoveries. Red lines are the 2011 PGS regional 2D survey.

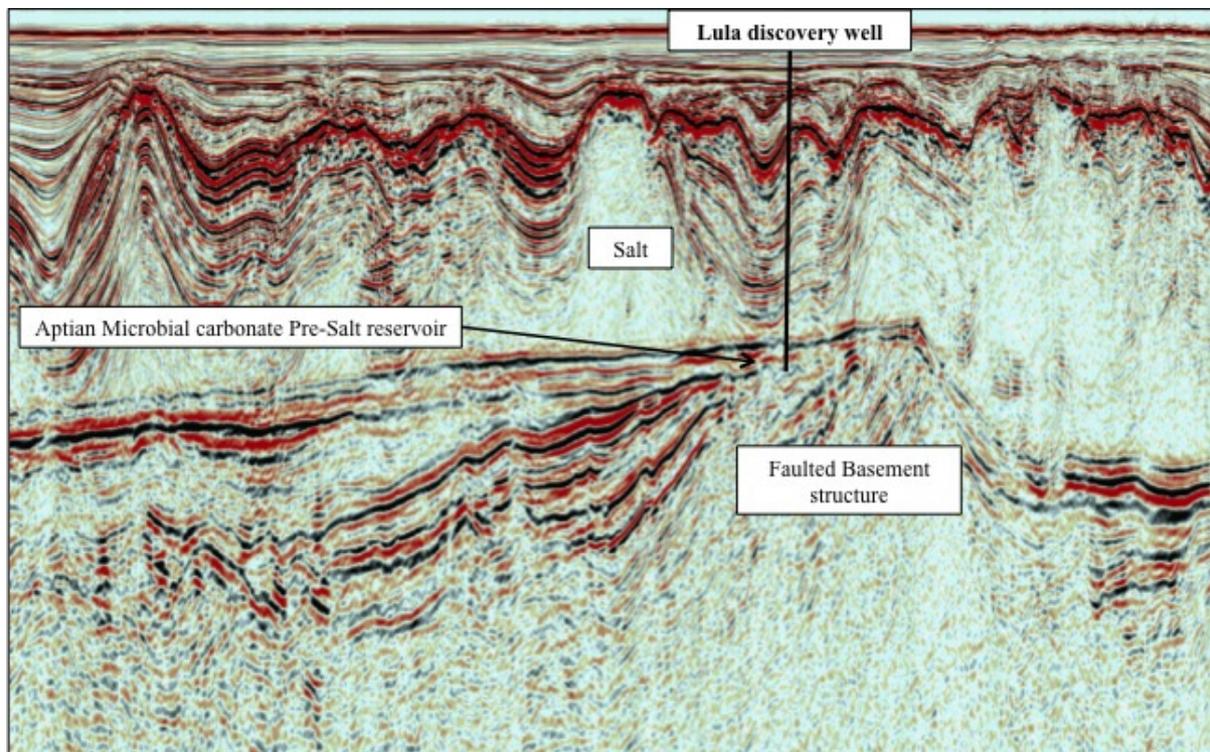
## Regional & Petroleum Geology

Both the Angolan and opposing conjugate Brazilian offshore basins are part of the Aptian Salt Basin geological province of the South Atlantic, which extends from the southern margin of the Niger Delta in the north, to the Walvis Ridge in the south (Brownfield & Charpentier, 2006). The basins of these countries share similar structural and stratigraphic characteristics due to their common origin during Late Jurassic to Early Cretaceous rifting of the proto-Atlantic.

The syn-rift (pre-salt) stage of the Namibe and Southern Benguela basins is typified by a series of asymmetrical horst and graben basins, in which thick sequences of fluvial-lacustrine sediments were deposited in narrow deep lakes. In analogous formations in Brazil and to the north of these basins, burial of algal blooms and plant detritus, along with anoxic bottom waters lead to the formation of a world-class source rock. Reservoir rocks range from conglomerates and sandstones shed locally from uplifted horst blocks to lacustrine and fluvatile sandstones.

As active rifting ceased in the early Cretaceous, the early post-rift, or sag phase is characterised by the deposition of continental, fluvial and transgressive lagoonal rocks (Teisserenc & Villemin, 1990). On the Brazilian conjugate margin these sag phase sediments have attracted significant commercial interest since the 2006 discovery of the Lula Field (Figure 2). Topography created by the earlier rifted fault blocks provided the structure for the growth of carbonates during this sag phase, which form the main upper reservoir in Lula. The understanding of this structure has led to subsequent discoveries on both sides of the South Atlantic, e.g. the Jupiter Field.

In the southern Benguela and northern Namibe basins, sag phase sediments were overlain by a thick evaporite sequence, which accumulated as a result of repeated cycles of marine incursions across the Walvis Ridge into a restricted basin. In the southern Namibe Basin, where the salt appears to be thin to absent, 3-5 km of post-rift sediments overlay the syn-rift sections. Volcanic centres are found throughout the Namibe Basin and are associated with the early post-rift stage.



**Figure 2** Seismic line across the Lula Field (depth-migrated dual-sensor streamer 2D line).

## Seismic Acquisition and Depth Migration:

A 10 km dual-sensor streamer was deployed with a tuned source array with a volume of 4130 cu.in. The data were acquired with a 15 second record length in combination with the long-offset streamer configuration to penetrate the syn-rift sediments of the Kwanza, Benguela and Namibe basins.

The geology of the Namibe and Southern Benguela basins is complex, which has made the velocity model building a key part to the Pre-stack Depth Migration (PSDM) work. The confluence of two oceanic currents in the basin made a simple water velocity function unsuitable for the lines, so a variable water velocity was used. Anisotropy was incorporated throughout the model building stages. The lack of available well data meant that the anisotropy parameters were estimated based on previous experience within the region. The sediment model was updated using a variety of migration algorithms – Kirchhoff and Reverse Time migrations, both in anisotropic mode. The model was updated by picking RMO (residual moveout) curves using both offset and angle gathers. PGS's proprietary tomography software was used to update the velocity model. The resulting changes in velocity were constrained by the interpreted geological horizons – a key to the success of the depth model build was interactive interpretation of the horizons after each iteration of the model update.

## Prospectivity:

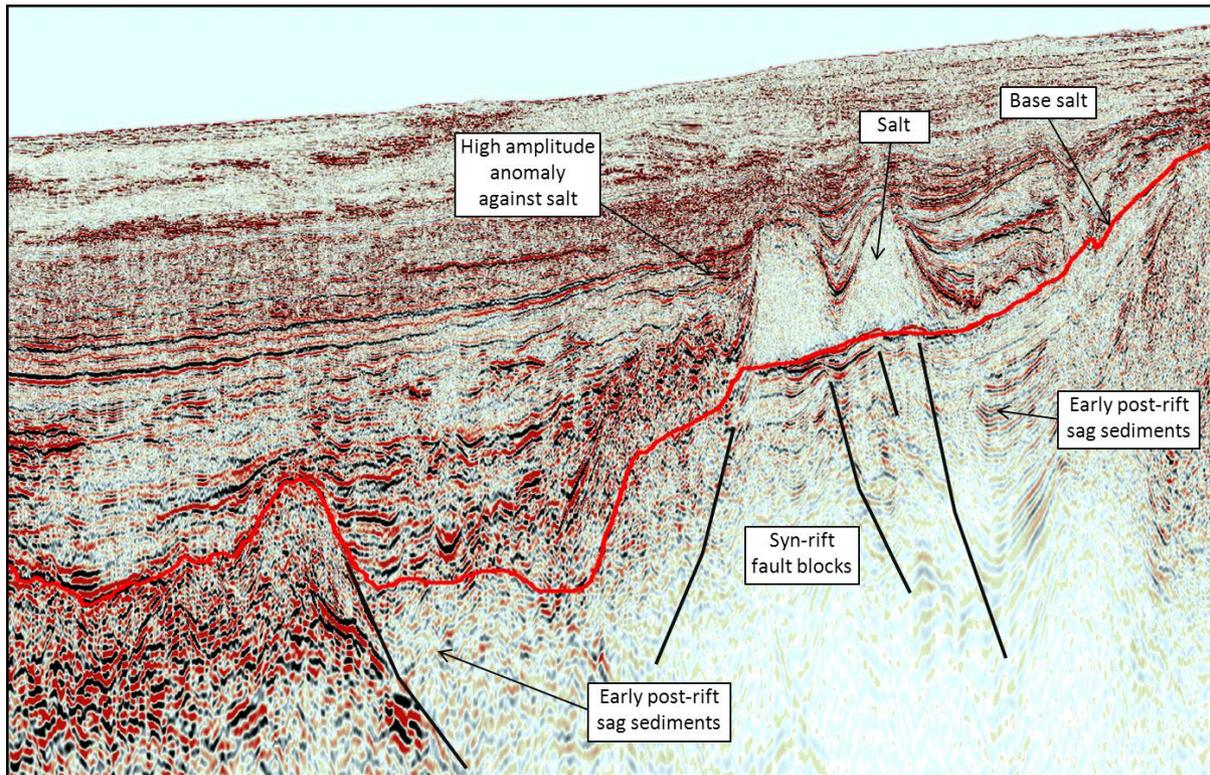
Both pre- and post-salt petroleum plays have been proven in the Angolan offshore, the elements of which are summarised in Table 1. In 1992, the Falcao-1 well penetrated the pre-salt section, encountering ~600 m of organic-rich lacustrine shales, and reservoir-quality carbonates. In 1996, the Baleia-1 well also drilled into the pre-salt and encountered a 300 foot oil column in a dolomitic reservoir with estimated in-place volumes reported to exceed 1 billion barrels (Henry *et al.*, 2010). Understanding and exploitation of this resource had been slow to develop, though Cobalt's 2011 Cameia discovery in Block 21, Maersk's Azul discovery in Block 23, and gas shows in Sintezneftegaz's post-salt Kunene-1 well in Namibia block 1711 are indicators of the hydrocarbon potential of the region.

<b>Source</b>	Syn-rift lacustrine and shallow marine shales, early post-rift deep marine shales
<b>Reservoir</b>	Syn-rift continental and shallow marine sands, sag phase carbonate banks, post rift deep marine sands
<b>Seal</b>	Syn-rift salt in the Benguela and northern Namibe, deep marine shales across the area
<b>Trap</b>	Multiple salt related traps, pinch outs on volcanos and basement highs, channels and fans

**Table 1** Overview of the main play elements of the Namibe and Southern Benguela basins.

In conjunction with gravity and magnetic data, the continental-oceanic crust boundary in the Namibe and Southern Benguela basins has been mapped as far out as 130 km from the coast. Horst and graben structures that formed in continental crust during rift phases are now visible in the depth-migrated seismic data (Figure 3). These are of significant interest for hydrocarbon prospectivity, particularly in areas where overlain by salt. This salt, which has, in the past been mapped only as far south as the Benguela Basin (e.g. Marton *et al.*, 2000), can be seen on the new seismic dataset extending into the northern Namibe basin, evident in places by diapirism.

Post-rift channel and fan structures can be identified as high amplitude anomalies throughout the basin. These are observed to pinch out on the flanks of volcanic high structures and salt diapirs, or as potential channels between volcanic centres. Post-rift sediment thicknesses are typically 3-5 km, placing any syn-rift and early post-rift potential source rocks within the oil window.



*Figure 3 Dual-sensor streamer 2D dip line over the Namibe Basin (interim depth-migrated, 2011).*

## Conclusions

Depth-migrated dual-sensor streamer seismic has improved the imaging of syn-rift and post-rift structures, enabling more confident identification and mapping of prospects analogous to those so prolific in the Santos Basin offshore Brazil. The improved imaging and resolution provided by these data significantly de-risk exploration in a frontier deepwater area where well costs are high.

## References

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