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De-risking the Frontier

A clearer image of the Namibe salt basin

PGS dual-sensor broadband GeoStreamer® data has been used to identify significant pre- and post-salt potential in the Namibe Basin, offshore southern Angola. This article aims to use the superior imaging offered by dual-sensor seismic data, combined with geoscience evaluation work, to present an understanding of the structural setting, reservoir facies and hydrocarbon charge of this frontier basin. It furthermore seeks to address some of the pre-salt exploration challenges in this basin that have also been encountered in the neighboring Kwanza Basin.

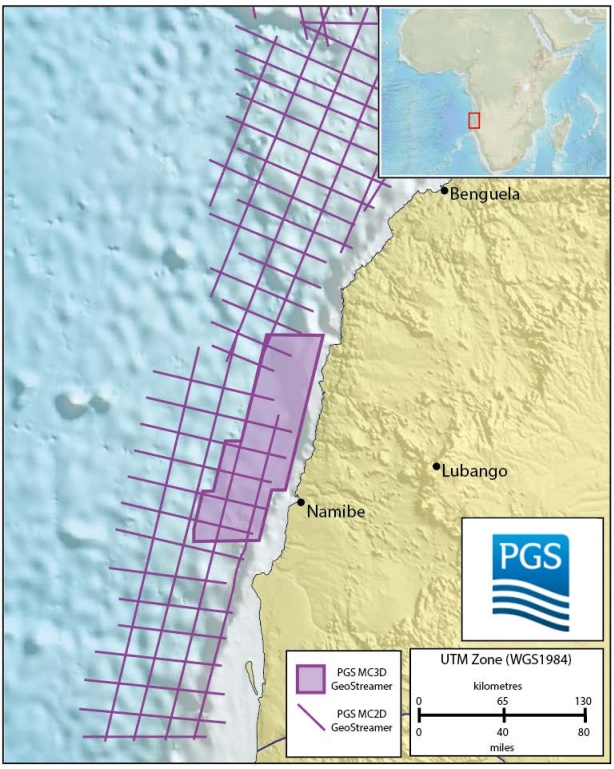


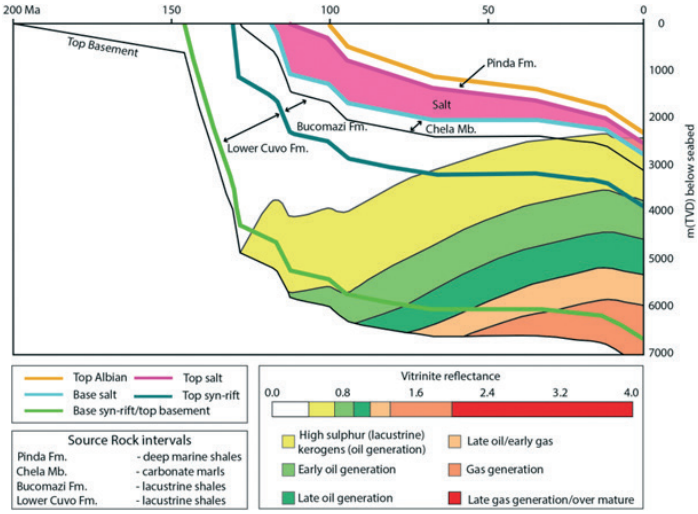
Fig.1 Basemap showing the location of PGS GeoStreamer® 2D data in Southern Angola and the recently acquired GeoStreamer® 3D survey over the Namibe Basin

The Namibe Basin represents a significant un-explored hydrocarbon province located onshore and offshore southern Angola. During the Late Jurassic to Early Cretaceous the eastern Atlantic margin of this part of West Africa developed as the conjugate to the prolific hydrocarbon bearing Santos and Campos basins. Although recent research describes the conjugate basins of Brazil and Angola as asymmetrical with each basin containing slightly different petroleum elements, discoveries of supergiant oil fields in the Santos Basin and Campos Basin resulted in a wave of pre-salt exploration optimism in Angola with some notable successes.

The recent exploration of the pre-salt plays in the Angolan Basins has been rapid with significant discoveries made away from the present-day shelf in the Kwanza Basin, such as Lontra, Orca and Bicuar, demonstrating the success of this play.

A large regional 2D dual-sensor broadband survey was acquired by PGS in 2011 and processed and migrated to a depth of 15 kilometers, allowing the basin architecture and pre-salt plays of the Angolan basins to be de-risked (Figure 1).

Analysis and interpretation of this 2D dataset, constrained by the PGS Access™ West Africa depositional sequence framework, highlighted the prospectivity potential of the Namibe Basin and subsequently a MultiClient 3D dual-sensor survey was acquired to better illuminate it. This 3D survey offers unrivalled imaging of the pre-salt section and allows more confident delineation of pre-salt reservoir facies.



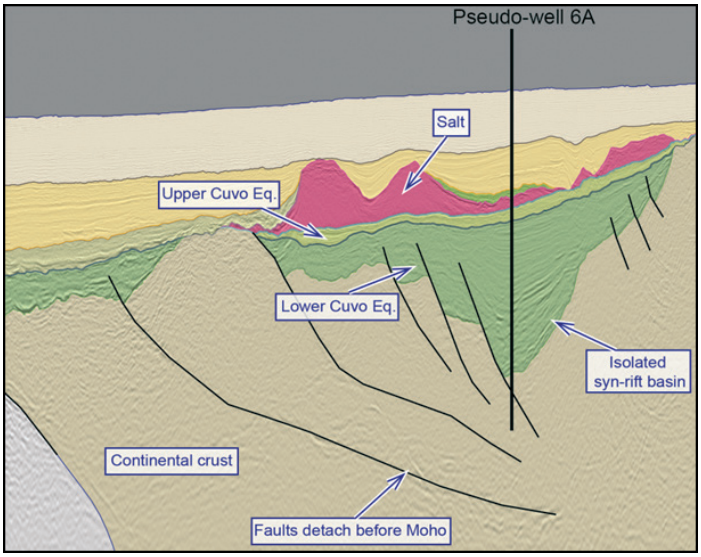


Fig. 2 Burial history modelling of Pseudo-well 6A, located in the centre of the Namibe Basin, showing encouraging oil generation results.

PETROLEUM SYSTEMS

Since the Namibe Basin is undrilled, the geological and hydrocarbon property information required to understand and de-risk the petroleum systems have been extrapolated from neighbouring basins in Angola and Brazil, constrained by a sequence stratigraphic framework. In addition, geological knowledge has been collated from the onshore portion of the Namibe Basin where the Cretaceous pre-salt stratigraphy outcrops and is exposed.

The source rock story:

From a regional understanding of the source rocks of the Angolan and Brazilian margins, those for the Namibe Basin are expected to occur predominantly in the pre-salt syn-rift (Lower Cuvo equivalent) and sag phase (Bucomazi equivalent) lacustrine sections, with potential for a secondary early post-rift source rock (Iabe equivalent) in the deeper water.

Regional temperature and geochemical information have been taken from well data in Angola and Namibia and appropriate ranges were selected as input for the modelling of source rocks. The results of this basin modelling work, conducted on pseudo well locations in the Namibe Basin, exhibit encouraging maturation profiles, with the Lower Cuvo Formation equivalent reaching early oil generation in the Eocene and the Bucomazi Formation equivalent in the Miocene (Figure 2).

De-risking the Frontier

A clearer image of the Namibe salt basin (cont.)

Reservoir facies analysis:

An understanding of the likely reservoirs of the Namibe Basin and their stratigraphic and spatial distribution can be established by comparing equivalent depositional packages between the conjugate basins of Angola and Brazil.

In the Namibe Basin, syn-rift reservoirs are expected to exist as formation equivalents to the Lower Cuvo Formation continental sandstones, the Upper Cuvo Formation fluvial to lagoonal facies and carbonates of the Bucomazi Formation. Post-rift reservoirs are expected to be comprised of shallow marine sandstones of the Iabe Formation, Pinda Formation (Binga Member) carbonates, and deep marine sandstones of the Landana Formation.

The resolution of this 3D dual-sensor broadband survey has allowed for seismic facies to be characterized and delineated with greater confidence in the pre-salt section. These facies could then be compared to drilled analogues seen in equivalent dual-sensor broadband data in Kwanza, Santos, Campos and Espirito Santo basins (Figure 3).

In the early syn-rift section, equivalents of the Lower Cuvo Formation continental sandstones from Kwanza and the Lower Guaratiba sandstones of Santos can be interpreted, characterized by higher amplitude seismic facies with possible fan-like geometries. Above these, equivalents of the shallow marine sandstones of the Upper Cuvo Formation (Kwanza) and Upper Guaratiba (Santos) can also be delineated.

In the sag-phase section, seismic resolution allows the description of multiple facies characters and their spatial distribution to be mapped in relation to the rift structures. Here, depositional facies such as grainstone shoals, microbial build-ups, coquinas and tidal dolomites can be inferred based upon matching of their seismic reflector amplitude, frequency and continuity characters to equivalent facies in the Kwanza and offshore Brazilian basins (Figure 3).

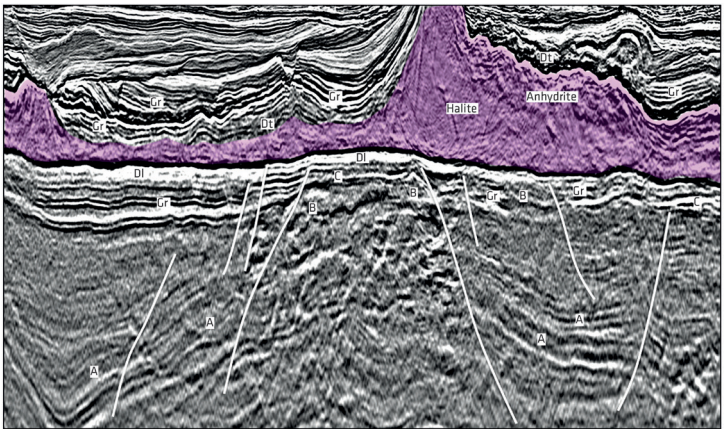


Fig. 3 An example of the imaging resolution in the pre-salt section with an inferred seismic facies interpretation. A, Alluvial fans; B, microbial build-ups; C, coquinas; Gr, grainstone shoals; Dl, lagoonal dolomites; Dt, tidal dolomites

In the post-rift section, facies distribution is noticeably influenced by salt movement. Here, grainstone shoals and sand-dominated mass flow deposits can be interpreted with numerous plays provided by salt withdrawal collapse features and ponding of sands in palaeo-lows.

Sealed by salt:

Aptian salt deposits are well known in the Kwanza, Santos and Campos basins where they act as the main seal for multiple fields and discoveries. Interpretation and mapping on the new 3D dataset has shown that the salt deposits are far more extensive in the Namibe Basin than previously identified in conjugate margin reconstructions (Torsvik et al., 2009) or in 2D data. Within the salt itself, different seismic reflector characteristics are recorded suggesting the presence of massive halite as well as bedded anhydrite layers.

Large pre-salt structures:

The 3D seismic dataset over the basin was acquired towing 12 dual-sensor streamers with a streamer length of 8,100 metres. These acquisition parameters allowed for the deep structures and faults to be successfully imaged and the architecture of the basin to be confidently interpreted.

Numerous syn-rift structures are seen within the pre-salt section associated with tilted fault blocks and subsequent inversion events. Overlying the syn-rift, the sag-phase similarly displays complex structural geometries with multiple sub-salt closures in which hydrocarbons can be trapped.

Because of the resolution of the data in the sag-phase section, the relationship of the reservoir facies to these syn-rift structures can be understood. On the flanks of the structures, facies interpreted as grainstone shoals can be seen to be onlapping or pinching out against the highs, with the timing of rift activity clearly influencing the deposition of these facies. Towards the crests of the structures, facies interpreted as coquinas can be seen to be accruing along with possible

microbial build-ups, onlapped by grainstone shoals. Overlying these, in the late sag-phase, facies interpreted as shallow marine dolomites are interpreted in the central part of the basin, immediately underneath the salt and likely associated with the onset of restricted basin circulation.

Challenges of CO^2 contamination:

A number of recent exploration wells in the southern Kwanza Basin have encountered CO^2 contamination in pre-salt reservoirs, interpreted to have displaced an earlier oil charge. This CO^2 has been geochemically typed to mantle, either sourced via deep-seated faults penetrating the Moho or resulting from shallow exhumed mantle degassing.

A basin structure and architecture study of the Namibe Basin was undertaken as part of the PGS Access™ project using shipborne gravity and magnetic data combined with 2D GeoStreamer® data (Figure 4). This work has identified that CO^2 contamination can be derisked through the interpretation of crustal types, mapping of volcanic hotspots and the interpretation of fault propagation depths. Similarly, areas of gravity highs can be assigned to areas of ridged lithosphere reducing the likelihood of the presence of exhumed mantle.

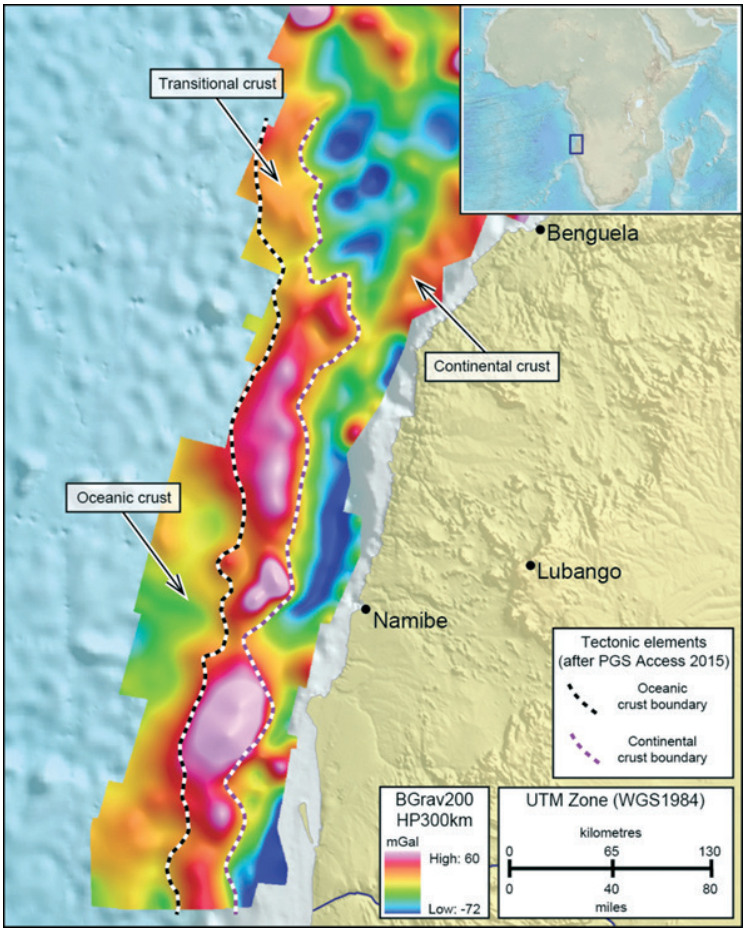


Fig. 4 Basemap showing the shipborne gravity data in Southern Angola highlighting the structural architecture and the location of the Namibe Basin

SUMMARY

The Namibe Basin is an under explored and undrilled province with considerable hydrocarbon potential. PGS dual-sensor broadband data, combined with targeted geoscience work has identified the key elements of a working petroleum system whilst reducing the known exploration risks. Basin modelling results suggests the likely generation and expulsion of hydrocarbons from syn-rift source rocks whilst gravity modelling work has predicted a reduced risk of CO^2 contamination.

The resolution and imaging of the seismic data permits the identification of numerous pre-salt reservoir facies, analogous to those of conjugate and neighbouring pre-salt basins, and demonstrates the relationship and distribution of these facies to the syn-rift structures.

Open acreage, an anticipated licence round and modern MultiClient data make the Namibe Basin a highly attractive focus for frontier exploration.