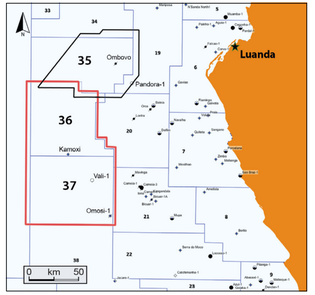
Deepwater Kwanza Basin

A Prospective Pre-Salt Province?

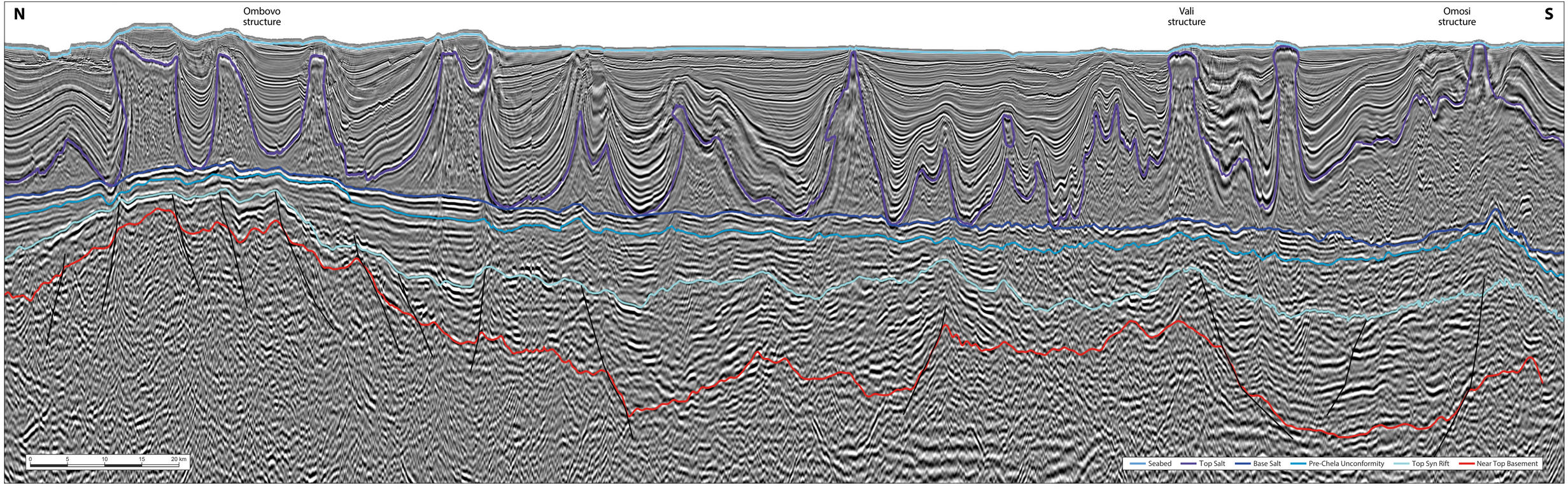
TGS acquired a high resolution multi-client 3D seismic survey over Blocks 35, 36 and 37 in the Kwanza Basin offshore Angola. A 3D Kirchhoff and Reverse Time Migration (RTM) Pre-Stack Depth Migration (PSDM) was undertaken to produce a more accurate velocity model, enhance event placement and improve salt boundaries and sub-salt imaging. As the first exploration period (January 2012 – December 2016) nears its end, we look at progress so far and consider a possible future exploration strategy.



Location map of Blocks 35-36-37 in the offshore Kwanza Basin.

TGS

Interpreted well tie line (PSDM-RTM) through some recently drilled structures in the Kwanza Basin, illustrating structural geometries, thick pre-salt syn-rift and sag phase sequences, salt diapirs and welds and post-salt raft tectonics.



Comparing the Brazilian and Angolan Conjugate Margin

Comparisons with Brazilian analogues can help with pre-salt exploration in the Kwanza Basin

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Brazilian pre-salt exploration success prompted enthusiasm for the conjugate Kwanza Basin. Eleven licence blocks were offered in 2011, with commitments to 3D seismic surveys and two pre-salt wells in each block before end-2016. As the first exploration period nears its end, we look at progress so far and consider a possible future exploration strategy.

Regional Setting and Well Results

Africa and South America were part of Gondwana until separated by Late Jurassic-Neocomian rifting, when horst and graben structures developed in trends roughly perpendicular to current coastlines. In both Brazil and Angola a transition is seen from proximal fluvial-alluvial clastic-dominated facies to widespread deposition of lacustrine facies. Carbonate reservoirs developed locally on or around horsts, whilst coeval organic-rich shales (associated source rocks) accumulated in the grabens. The end of major rifting is marked by a regional angular unconformity, with carbonates and shales infilling the late syn-rift to sag basins. Aptian microbialite (lacustrine carbonates) is the main pre-salt reservoir. Late Barremian to Early Aptian lacustrine bioclastic limestones (analogues to the Brazilian Coqueiros Formation) are the secondary reservoir. Increasing salinity of the lacustrine environment culminated in deposition of thick salt, which ended with the start of seafloor spreading and the resulting opening up of the restricted rift basin. Late Aptian-Albian shallow marine carbonates were deposited on the salt. Platform carbonates and their deepwater equivalents dominate the Albian–Cenomanian. The Upper Cretaceous to Tertiary is mainly characterised by siliciclastic deposition.

Angola has reserves of 8.4 Bbo (OPEC, 2015). Production peaked in 2008 at 1.85 MMbopd and declined to 1.65 MMbopd by 2014. Initial discoveries in Blocks 20 and 21 raised hopes that the Kwanza Basin pre-salt would be as oil-rich as the pre-salt of the Campos and Santos basins of Brazil. However, recent pre-salt well tests suggest that success is not a simple matter of drilling large four-way dip closures (4WDC).

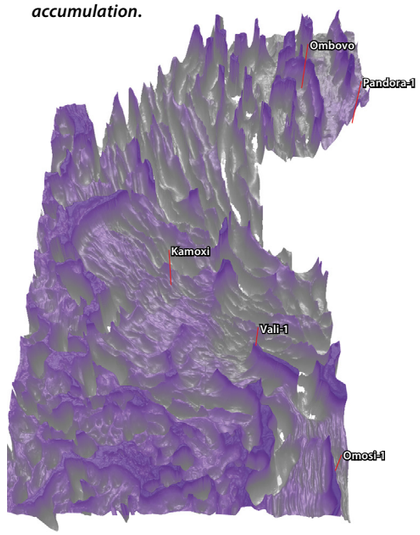
Four recent wells have been drilled in Blocks 35, 36 and 37. Ombovo-1 (ENI), drilled in 2014 in Block 35, was presented as an oil discovery (Adams, 2015). Kamoxi-1 in Block 36 (ConocoPhillips) tested a large 4WDC but was dry; the operator reported that "basically the reservoir wasn't developed there… the porosity just wasn't developed" (ConocoPhillips, 2015a). Omosi-1 (ConocoPhillips) in Block 37 tested a large 4WDC with a 160m gas column and the operator reported good reservoir facies and porosity at the well location (ConocoPhillips, 2015a). Vali-1 (ConocoPhillips) tested a 4WDC with a larger area at the Coqueiros level than at the microbialite, but the operator reported that the "well was plugged and abandoned as a dry hole" (ConocoPhillips, 2015b). Pandora-1 (BP), drilled in Block 19, just within the Block 35 seismic volume, in order to test the pre-salt microbialite and Coqueiros levels, was presented as an oil and gas discovery (Adams, 2015).

Comparisons with Brazilian Structures

Our research in the offshore southern Brazil basins and the Kwanza Basin indicates that the combination of modern pre-salt seismic depth imaging, Play Fairway Analyses and basin modelling studies have the potential to assist with hydrocarbon exploration. These methods allow us to increase our understanding of rift basin development and the timing of the source rock expulsion in relation to other 'sweetspot' petroleum system components (reservoir and seal presence).

Comparison of the seismic data at the structures tested in Blocks 35-36-37 with analogous structures in the pre-salt discoveries of the Espirito Santo, Campos and Santos Basins offshore Brazil is one way of assessing the chance of success in the Kwanza Basin. In particular, the Santos Basin pre-salt fields (on which much data has been published) and the Campos Basin Block BM-C-33 fields (Seat, Gavea and Pão de Açúcar) may be useful analogues for the Block 35-36-37 area with its thick salt cover. For many of these Brazilian fields, the primary reservoir was a high porosity and permeability microbialite carbonate facies (Macabu Formation) sealed by the overlying salt. The deeper Coqueiros Formation bioclastic limestones, at the top of the major rift phase and in the lower part of the sag basin, are a secondary carbonate reservoir. In the Kwanza Basin, the microbialite is reported to be the main reservoir for the Cameia, Lontra, Orca and other discoveries in the Cobalt-operated Kwanza Basin Blocks 20 and 21, (Cazier et al., 2014), which adjoin Blocks 36 and 37 to the east. A deeper syn-rift bioclastic carbonate reservoir (Coqueiros equivalent) was tested by Cobalt and found to bear light oil in the Bicuar and Orca discoveries.

Figure 1: Salt model for the study area, with grey depocentres and violet diapir crests. Regional tectonism and halokinesis are major controls on post-salt sediment deposition and accumulation.



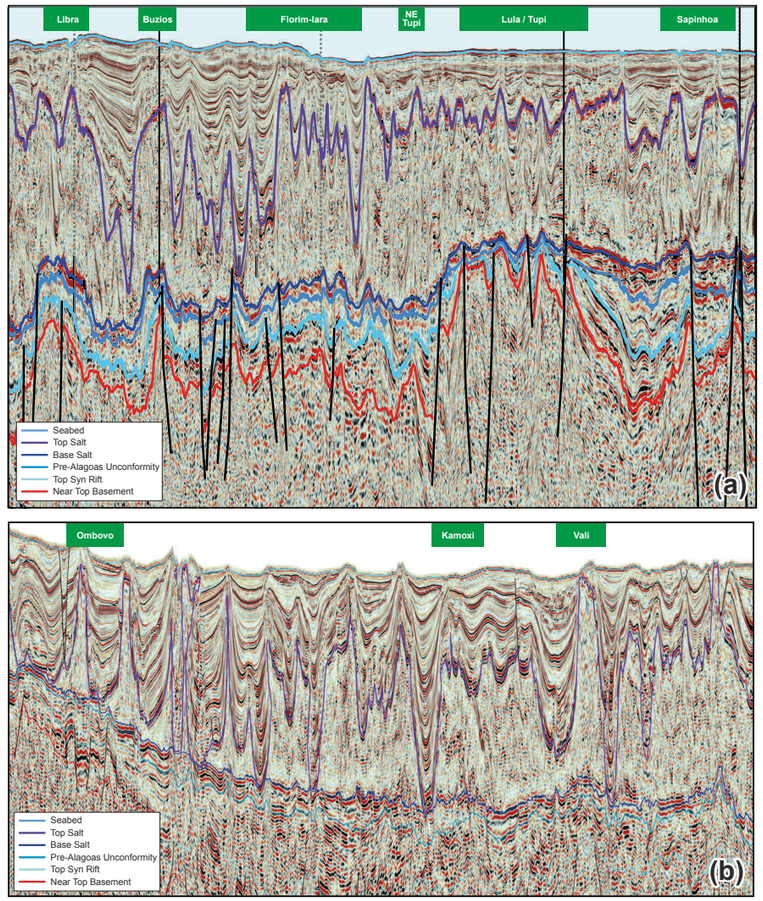


Figure 2: A distinctive high amplitude seismic facies is associated with extensive development of the prolific, high porosity 'microbialite' carbonate reservoir in the Santos Basin, Brazil (a). This same seismic facies is seen to be developed at some but not all of the tested prospects in the Kwanza Basin (b). The association of this seismic facies with large four-way dip closures is a primary test for lead development. High resolution pre-salt imaging is a pre-requisite for definition of the pre-salt seismic facies.

Our Santos Basin seismic facies and Play Fairway Analysis, calibrated against 20 pre-salt wells (TGS, 2013a), shows a high correlation between the development of a specific seismic facies and pre-salt fields/discoveries. This facies (high amplitude, good to moderate continuity, parallel to sub-parallel reflectors, locally with some progrades) is shown by the well data to be high porosity microbialite carbonate. This is the main pre-salt reservoir lithology in the Santos Basin. Most of the known pre-salt fields in Santos (Buzios, Libra, Florim, Iara, Tupi/Lula) occur on large 4WDCs within the area of this seismic facies (Figure 2a). A very similar seismic facies is observed at the Ombovo structure. It seems poorly developed at the Vali structure and absent at the Kamoxi structure (Figure 2b). This observation may be an indicator as to regional seismic prediction of presence (if not quality) of the main pre-salt microbialite reservoir.

The base of the microbialite succession is defined by a major sequence boundary that is known as the Pre-Alagoas unconformity in Brazil and the Pre-Chela unconformity in Gabon and Angola. The underlying section contains the coqueiros/coquinas successions and has been an oil-producing reservoir in the Campos Basin since the discovery of the Badejo and Linguado fields in the 1970s. They are typically present as stacked banks of reworked shelly fragments deposited along lake margins and are found in deep to shallow lacustrine environments. The corresponding seismic facies is moderate to good amplitude, moderate continuity, parallel to sub-parallel (TGS, 2013b). Coqueiros reservoirs have been reported as oil-bearing at Seat and Pão de Açúcar in the Campos Basin, in the Libra, Buzios and Lula fields in the Santos Basin (Figure 2a). Such facies can also be seen at the Ombovo and Vali structures, but not at Kamoxi (Figure 2b).

Conclusions

Carbonate reservoirs are complex, with rock heterogeneities at all scales and variations in porosity and permeability that are difficult to predict. High resolution PSDM is a pre-requisite to exploration for pre-salt targets underneath thick salt cover but may not be sufficient on its own. Several crucial factors are at play in making the petroleum system work as oil or gas prone: the timing and amount of local syn-rift stretching and continental margin collapse, local and sub-regional heatflow, salt thickness and halokinetic effects. Seismic facies analysis (calibrated against well data) and Play Fairway Studies, such as those that TGS have conducted in Brazil, can help to further reduce the risk in screening pre-salt structural leads.

References available online ■