Introduction

The west-African Atlantic margin is an important region for the exploration and production of oil and gas, and the reserves drilled offshore Equatorial Guinea have proven significant, with 1.1 billion barrels of reserve proven as of 2015. The offshore exploration environment can be challenging, due to the deep water setting, complex geology and relatively sparse well data. High quality 3D seismic data is a vital tool for achieving exploration success in this region, and is equally dependent on accurate interpretation and analysis for its full value to be realised. The extremely high costs of exploration wells require the risk and uncertainty to be captured accurately. Using advanced seismic techniques to increase the success probability is of upmost importance before drilling.

In this study, prospects identified from a 3D seismic survey, in the Block W lease area, were investigated using a variety of seismic interpretation techniques, to de-risk the prospects and improve the overall geologic probabilities of success. The targets were marine shelf and margin clastic deposits of late Cretaceous age. The reservoir, charge and, critically, trap elements of the plays were analysed by combining novel seismic attribute products with interpretation and visualization techniques, AVO analyses, and conventional interpretations to obtain maximum information from the seismic data.

Geologic Setting

Block W is located in a frontier, deep water (1150-2200m) setting down-dip of the Ceiba and Okume producing oil fields (Figure1). The geology of interest in the area is composed of late Cretaceous marine sandstones and mudstones, transitioning from shelf environments to slope and bathyal settings away from the Equatorial Guinean coastline. Two major prospects were investigated in this study: the Caracal and Santiago prospects, of Campanian age. Marine shales of Albian-Turonian age have been modelled to provide the present day, mature source.

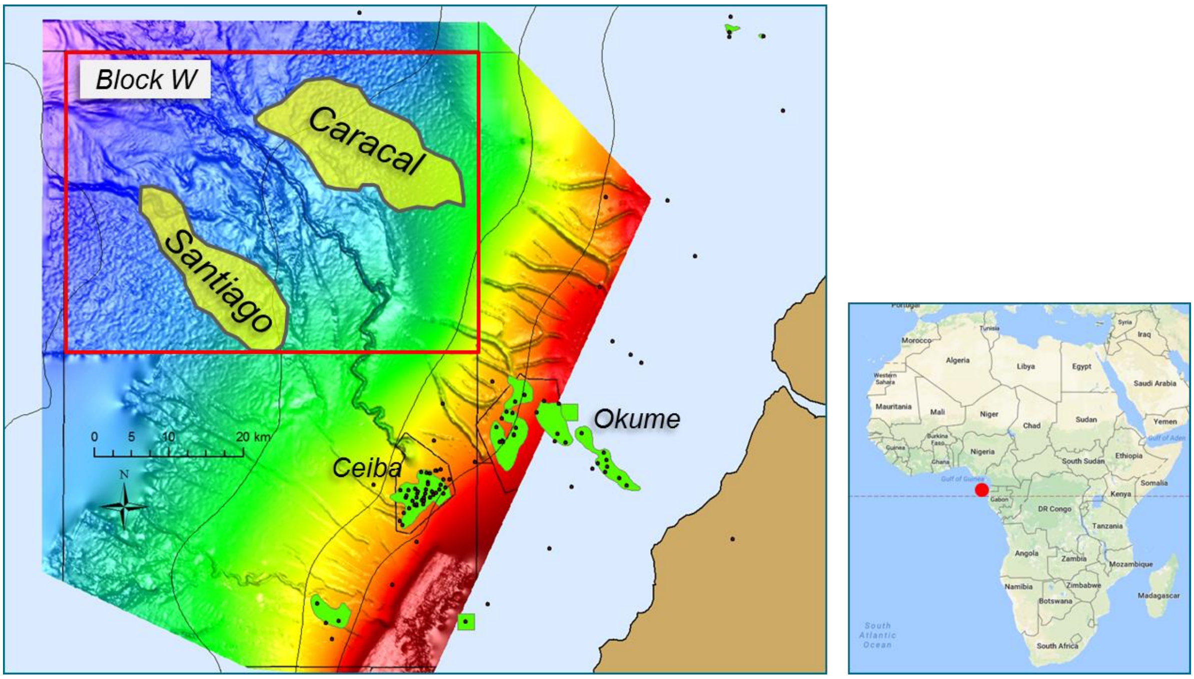

***Figure 1** Block W location map, indicating the Caracal and Santiago prospects (courtesy of PanAtlantic Exploration).*

Method

The acquisition of the seismic survey was completed in 2014 using slanted cable, and the processed Kirchoff pre-stack time migration volumes were delivered later in 2014. The survey area of approximately 2450km^2 covered the entirety of the undrilled Block W. Pre-stack gather conditioning and AVO analysis were undertaken prior to the cognitive interpretation workflows. The results were used as input and in combination with the cognitive interpretation results. AVO effects were both observed and modelled, of Class II and IIp (with phase change) types.

Cognitive Interpretation workflows were applied to reveal the geologic information that would allow the risk factors for the play elements to be reduced over just using conventional interpretation techniques. This initially entailed applying a structurally oriented, edge-preserving noise cancellation to the stacked seismic cubes, and then bandwidth extension to achieve a broader spectrum at target level. This improved reflector continuity, increased the signal to noise ratio, and enhanced the vertical resolution for better interpretability of the events and better definition of structural and stratigraphic features. The results of the data conditioning were then used as inputs to techniques using frequency decomposition to reveal stratigraphic morphologies and facies changes, structural attributes for subtle fault detection, and textural attribute analysis for identifying active parts of the petroleum system. Use of these techniques not only allowed more information to be derived from the seismic than could easily be done from the reflectivity alone, including revealing previously unseen information, but it also accelerated the process to enable the work to be completed within the span of a two-week project.

Reservoir De-Risking

Reservoir facies are interpreted to be of channel, overbank and crevasse splay complexes deposited in a deepwater, turbidite influenced environment. Accurate interpretation of the depositional systems is necessary to ensure the presence of good quality reservoir sand bodies can be predicted effectively. As the complicated stratigraphy can be difficult to interpret from seismic amplitudes alone, cognitive interpretation workflows were required to better reveal the nature of the stratigraphic facies present.

Frequency Decomposition and RGB blending was effective at revealing the depositional morphologies present. The frequency response of seismic reflectivity is a function of bedding geometry and thickness, lithology, fluid effect and depth, characteristics important for the interpretation of stratigraphic facies. By taking three different frequency magnitudes and assigning them respectively to a red, green and blue channel, it enables their relative weights to be easily interpreted as the frequencies tune with different stratigraphic bodies. Two different methods of frequency decomposition were applied: a continuous wavelet transform, with high frequency sensitivity suitable for identifying large scale facies changes, and an adaptation of matching pursuit decomposition, which was better suited to identifying individual events within larger bodies.

Interpretation of these frequency decomposition results within the defined prospect bodies was difficult to do in a stratigraphically conformant fashion, as internal reflections were characterised by a lack of continuity and hence hard to pick. To surmount this obstacle, iso-proportional slices in between continuous top and base surfaces were generated, and used for extraction of the frequency decomposition results. This proved effective at revealing the variations in depositional morphology through geologic time, and highlighted parts of the systems not previously seen within the seismic.

The end result of this was that because the interpretation of the reservoir became more confident, the probabilities of success for encountering sands of reservoir quality were adjusted, and increased by 10% for both Caracal and Santiago.

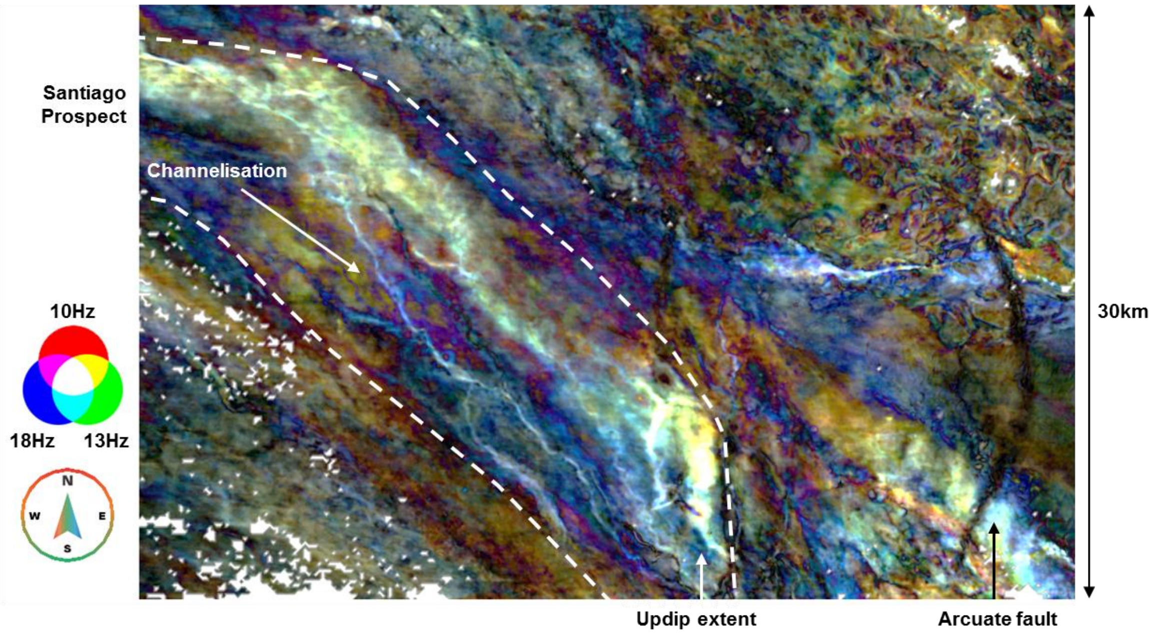

Figure 2 *Intermediate iso-proportional slice of the Santiago prospect with RGB blend of 10, 13 and 18Hz magnitudes mapped, allowing reservoir sand presence to be better interpreted and predicted.*

Trap De-Risking

Likelihood of effective trap was considered the biggest risk for the Santiago and particularly Caracal prospects. As a combination stratigraphic-structural play, low relief inflections of structure were interpreted to indicate the presence of subtle faults with little displacement. As most of the lineations show little to no offset, and are very hard to interpret from reflectivity data, attributes were used in attempt to image them more clearly. Attributes based on semblance and amplitude changes proved ineffective, however a detailed dip calculation revealed pervasive, vertically continuous dip trends that were interpreted as indications of very subtle faulting. In order to interpret these results in context, the dip attribute, seismic, and AVO fluid indicators were combined together using volume opacity (Figure 3). This clearly revealed the relationships between the three elements, and provided encouraging evidence that the structures may provide an updip trap for stratigraphic hydrocarbon accumulations.

Based on this analysis, the trap probabilities of success were increased by 15% for Caracal and 10% for Santiago.

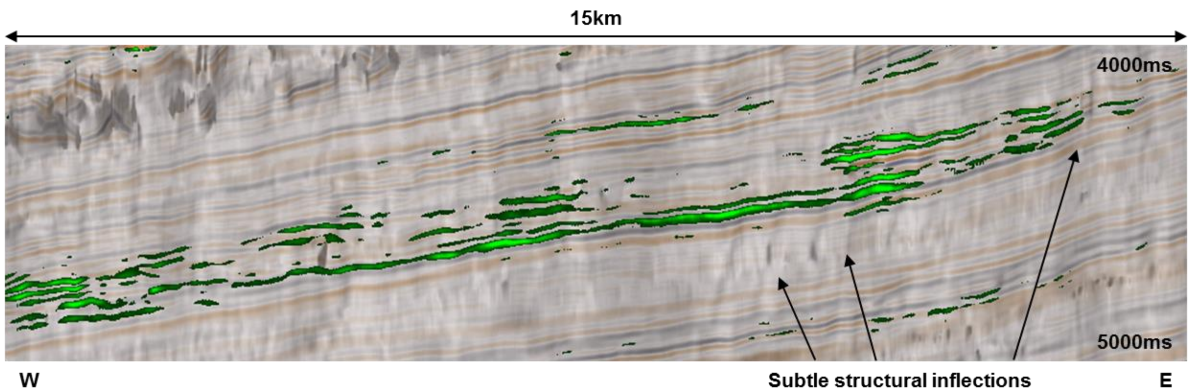

Figure 3 *Opacity blend of Class II AVO (Green), Dip attribute (Greyscale) and seismic inline through the Caracal prospect, indicating possible low relief faults, including one that appears to truncate the fluid response updip.*

Charge De-Risking

Charge was not considered as significant a risk as trap, however seismic features of interest possibly indicative of mobile hydrocarbons warranted investigation, particularly at Santiago. A number of vertically pervasive, sub-linear or arcuate zones of low amplitude, chaotic seismic reflectivity can be observed around the dataset, aligned with the crests of consistent but small scale antiformal trends in the seismic structure. These were interpreted as faults along which hydrocarbons are migrating as they match descriptions of similar features in other datasets (Alafarj and Lawton, 2012).

In order to understand the geometry of these features and their relationships to the prospects, a Diapir attribute identifying zones of chaotic but low amplitude reflectivity was calculated, and blended with the seismic data using opacity. This allowed the complex morphology of these features to be interpreted, and showed these are rooted at depths greater than those covered by the seismic cube used. This enhanced the interpretation confidence that these are hydrocarbon migration chimneys.

For the charge risk factors, the probability of success at Caracal was increased by 15%, and at Santiago was judged to remain the same

Conclusions

In the frontier, deep water setting of Block W, the cognitive interpretation workflows provided results that significantly influenced several of the risk factors for the Caracal and Santiago prospects. The confidence of encountering reservoir sand was increased using frequency decomposition and RGB blending to image the depositional systems better, the confidence in the active petroleum system was increased by analysis of the interpreted hydrocarbon migration pathways, and the probability of an effective trap mechanism using low-relief faults was increased by analysis of the structure using a Dip attribute. The integration of visualisation techniques made interpreting these results faster and easier than by using the seismic alone, and revealed previously unseen information. Ultimately, the adjustments made to the risk factors increased the cumulative geological probabilities of success by 12% for Caracal, and 9% for Santiago, leading to dramatic increases for the risked reserve potential for both prospects.

Acknowledgements

Thanks are due to the Equatorial Guinea Ministry of Mines, Industry and Energy for permission to show this data, and to PanAtlantic Exploration for their participation.

References

Alarfaj, M. and Lawton, D.C. [2012] Interpreting fault-related gas leakage. *CREWES Research Report*, **24**, 1-10.