Pre-salt Carbonate Characterisation Using 2D Dual-sensor Data and Rock Physics - Kwanza Basin Case Study

N. Pernin* (Petroleum Geo-Services), C. Reiser (Petroleum Geo-Services) & T Bird (Petroleum Geo-Services)

SUMMARY

The giant sub-salt discoveries from the conjugate Brazilian margin give encouraging support for analogous hydrocarbon potential offshore Angola. The challenge is to image the deep geology beneath complex salt geometries to confidently predict reservoir properties and distribution. Pre-stack relative inversion was performed on dual-sensor broadband 2D data from the Kwanza Basin and was correlated to the pre-salt carbonate succession in a discovery well. Well log analysis and rock physics confirm what is observed on the relative acoustic impedance volume. Two distinct types of carbonates with significantly different reservoir properties can be discriminated on the inversion volumes. This result demonstrates that the additional bandwidth from acquired deep-tow broadband seismic can reliably map reservoir properties even in deep challenging geological environments.

Introduction

The deepwater margin offshore West African remains under-explored compared to the prolific hydrocarbon province in the conjugate basins offshore Brazil. The giant sub-salt discoveries such as Gavea in the Campos Basin and the Tupi/Lula field in the Santos Basin (8-20 bboe) (Chakhmakchev and Rushworth, 2010) gave encouraging support to the potential for hydrocarbons in the pre-salt interval offshore Angola.

The Falcao-1 well in the Kwanza Basin offshore Angola provided proof of a pre-salt petroleum system as early as 1992, yet pre-salt exploration has been slow to develop offshore Angola. In 1996, the Baleia-1 well reached the pre-salt target and revealed a dolomitic reservoir containing a 300 foot oil column and estimated in-place volumes of 1 bboe (Henry et al., 2010). This was followed by other pre-salt discoveries including Lontra, Cameia, Mavinga, Bicuar, Azul and Denden.

Broadband seismic data acquisition is recognised to significantly improve the resolution of seismic imaging in complex geological contexts such as pre-salt by providing extended frequencies on the low and high side of the amplitude spectrum (mainly the low side for the pre-salt). Elastic properties can then be estimated more reliably through a Quantitative Interpretation workflow (Farouki et al., 2010, Ozdemir, H. 2009).

In this study, 2D dual-sensor towed streamer data acquired in the Kwanza Basin in 2011 (Figure 1) was used to perform relative seismic inversion. Elastic attributes and interpretation are displayed at the well A location on a pre-salt discovery where well information was available for seismic-to-well tie.

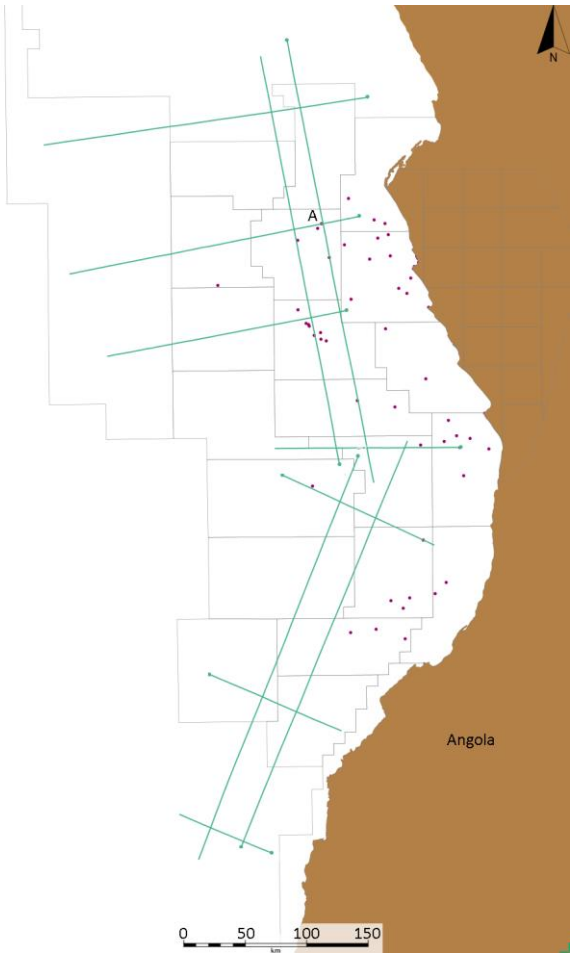

***Figure 1**: Well A and 2D towed dual-sensor streamer data (PGS) location in the Kwanza Basin, offshore Angola.*

Geological settings

As well as the conjugate offshore Brazilian basins, Angola's offshore petroleum systems are part of the Aptian Salt Basin geological province of the South Atlantic. This province extends in West Africa from the southern margin of the Niger Delta in the north, to the volcanic Walvis Ridge in the south (Brownfield and Charpentier, 2006). The geological history of these conjugate margins is common from Late Jurassic to Early Cretaceous rifting of the proto-Atlantic and led to similar structural and stratigraphic characteristics.

The onset of rifting in Berriasian times led to the deposition of fluvial-lacustrine sediments (siliciclastic and carbonate deposits) in asymmetrical horst and graben basins. As deposition continued but extension slowed, adjacent rift basins were drowned by pervasive lacustrine deposits in what is known as the 'sag phase', creating anoxic conditions favourable for source rock preservation (Pasley et al., 1998). The induced topography provided the structure for the growth of carbonates during the sag phase.
The subsequent transgressive sequence (Grey Cuvo Fm) is Late Aptian in age and is represented by fluvial and lacustrine continental deposits grading upwards into intertidal evaporitic sediments (dolomites and anhydrites). A thick evaporite sequence ends the sedimentary cycle, which accumulated under a regionally extensive sabkha environment at the end of the Late Aptian (Uncini et al., 1998).

Rock physics

P and S wave velocities, density and gamma ray logs available for the well A were used for the rock physics analysis. From the well analysis and composite log information, a preliminary pre-salt interpretation has been performed (Figure 2a). Two carbonate levels (below the salt layer) can be discriminated: an upper interval of dominantly dolomitic limestone (referred to as 'carbonate 1') overlying a predominantly argillaceous limestone interval (referred to as 'carbonate 2'). An increase of shale content between the two intervals is observed on the gamma ray log. The density log is uniform across the two intervals but a sharp decrease in velocity occurs at the interface between the two intervals (i.e. carbonate 1 and carbonate 2), creating a distinct acoustic impedance variation.

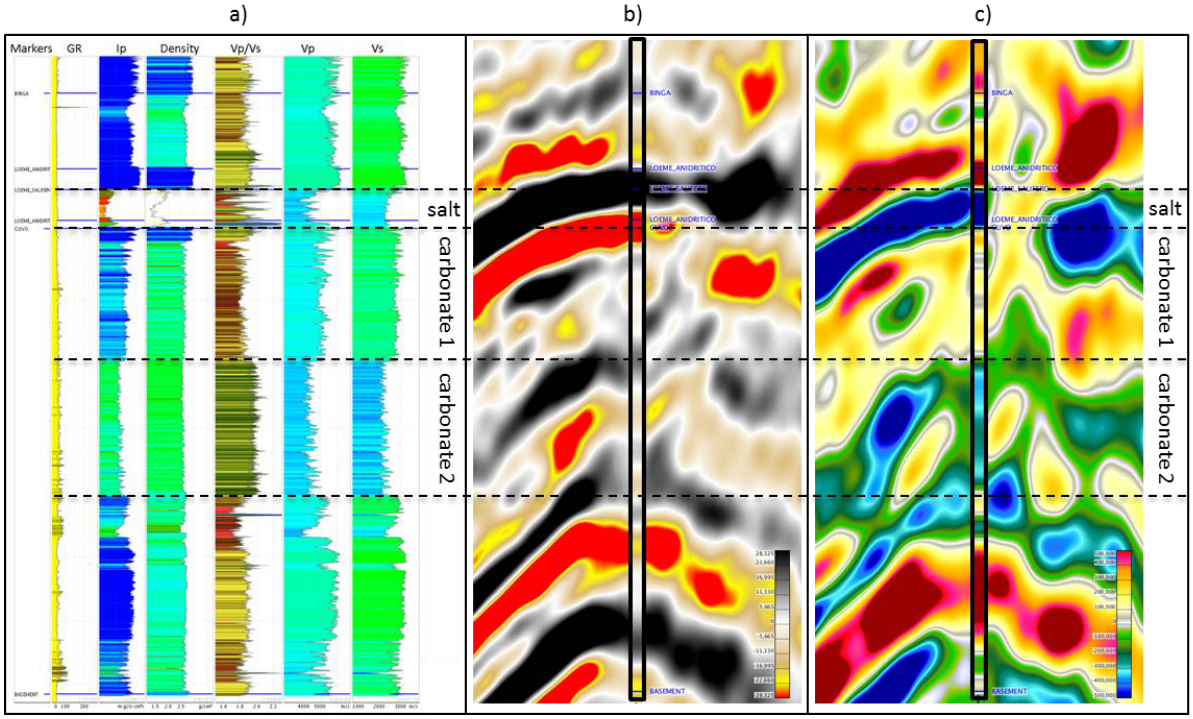

***Figure 2**: **a)** Interpreted well A logs **b)** Well-to-seismic tie at well A location based on full-stack seismic data **c)** Interpreted Ip inverted from well A logs and Ip-relative from seismic data*

Figure 3 presents the cross-plot of Ip (acoustic impedance) versus Vp/Vs from the well A data. A good separation between carbonate 1 (yellow filled circles) and carbonate 2 (blue filled circles) is observed in this Ip – Vp/Vs domain.

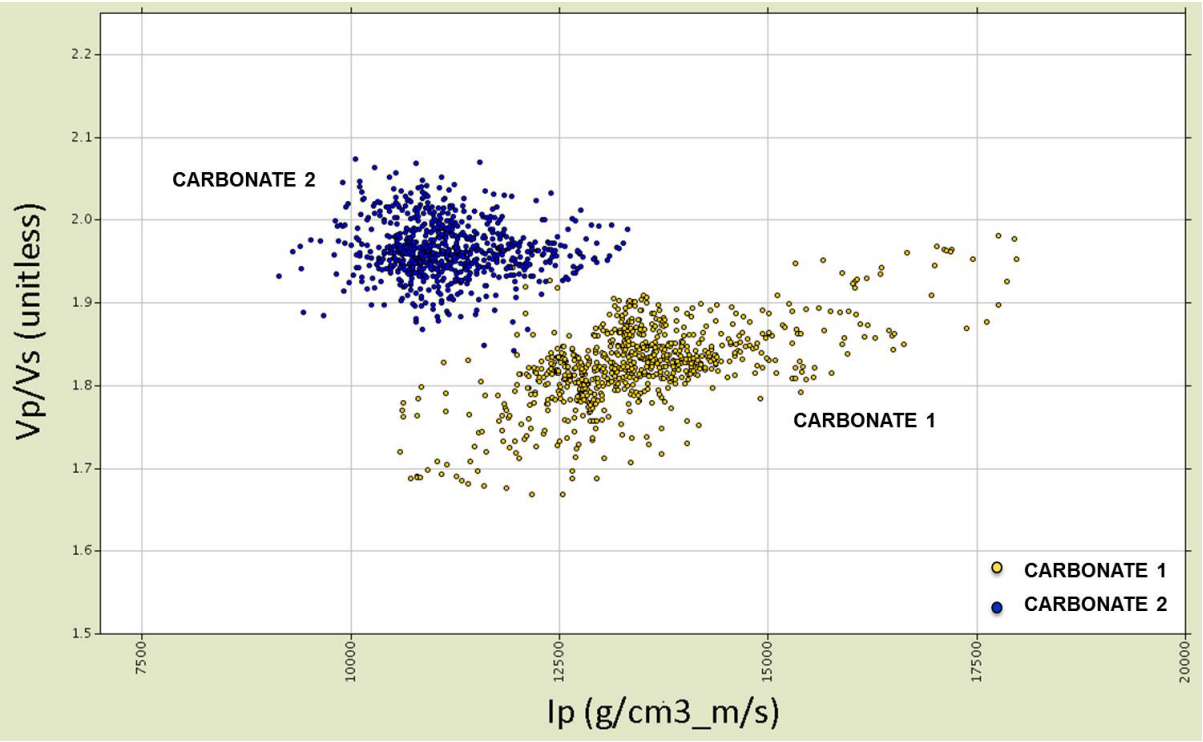

***Figure 3**: Ip-Vp/Vs crossplot using well A logs.*
Carbonate 1 interval (in yellow) and Carbonate 2 interval (in blue) can be clearly discriminated

Relative seismic inversion of pre-salt interval

The relative pre-stack inversion process provides elastic attributes (P-impedance (Ip), S-impedance (Is), Vp/Vs…) using seismic Amplitude Versus Offset (AVO) analysis. The inversion is entirely reliant on the information available over the bandwidth of the recorded seismic signal, which in case of dual-sensor data is one or two octaves broader than conventional marine streamer data at the low frequency end of the spectrum.

A well-to-seismic tie is used to correlate the well log information to the 2D seismic lines, and to the relative elastic attributes. Using the sonic and density well logs data, reflection coefficients can be computed. The convolution between these reflection coefficients and a wavelet leads to a synthetic trace at the well location (displayed along the well path, Figure 2b). The comparison between the real seismic trace and the synthetic can be used to evaluate the match between the well and the seismic information. A zero phase statistical wavelet was estimated from the seismic data and used for the well-to-seismic tie at well A location (Figure 2b).

A good match between the well and seismic data can be observed for Ip (Figure 2c) section. The Ip log is displayed on the well trajectory and can be compared to the pre-stack relative seismic inversion performed on the seismic line without any use of a low frequency model. Even at these burial depths and, with limitations on the angle of incidence range due to the presence of the salt and anhydrite, the relative inversion result matches to the well log information very well leading to a greater confidence and understanding of the pre-salt reservoir and its distribution.

From the seismic Ip (relative) elastic attribute, the two distinct pre-salt layers can be discriminated: a high impedance layer (carbonate 1) just below the salt, above a lower impedance layer (carbonate 2).

We also observed that due to the large depth and the geological context (pre-salt), the Vp/Vs elastic attributes is of much poorer quality due in large part to the lack of higher angles of incidence at the reservoir target level.

Conclusions

Pre-stack relative inversion was performed on a 2D dual-sensor towed streamer dataset and focused on the pre-salt interval at the well A location in the Kwanza Basin, offshore Angola. A good seismic-to-well tie gives confidence in the seismic inversion results and the interpretation of relative acoustic impedance. The discrimination between two types of pre-salt carbonates reservoirs observed on the impedance volume (Ip) is confirmed by the well logs analysis and the elastic attributes cross-plot. The two reservoir lithology units appear to be different (dolomitic limestone vs argillaceous limestone) but a further rock physics study with additional wells and/or more interpreted logs such as porosity, oil saturation is expected to add a more deeper understanding to these initial inversion results.

Acknowledgements

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