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An Integrated Approach for Building Geologic Models Consistent with Seismic Data

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SUMMARY

We demonstrate how rock physics, when coupled with seismic interpretation, can lead to building geologic models that are consistent with seismic data. This approach was tested on the Bengo discovery, located offshore Angola. Two wells (discovery & appraisal) were used in this study to build a rock physics model which relates the seismic response to rock and fluid properties, which were later used for populating the geologic model. This study encompasses surface and subsurface elements including geology, geophysics, petrophysics, and reservoir engineering. However, in this abstract we will only focus on the geology and geophysics elements, which are critical for this study.

Introduction

We demonstrate how rock physics, when coupled with seismic interpretation, can lead to building geologic models that are consistent with seismic data. This approach was tested on the Bengo discovery, located offshore Angola. Two wells (discovery & appraisal) were used in this study to build a rock physics model which relates the seismic response to rock and fluid properties, which were later used for populating the geologic model. This study encompasses surface and subsurface elements including geology, geophysics, petrophysics, and reservoir engineering. However, in this abstract we will only focus on the geology and geophysics elements, which are critical for this study.

Background

The Bengo structure is located within the Lower Congo basin. The basin was originally created during the Early Cretaceous rift along the West African margin, which resulted in a series of horsts and grabens parallel to the present-day coastline that are offset by many east-west trending transfer zones. Target reservoirs in this area are found at from 1000 m to more than 4000 m depth and were deposited in middle to lower slope settings. These deep water reservoirs vary in style and consist of strongly to moderately confined channel systems that are typically sinuous and leveed with local ponded to distributive systems (Nasser, 2011). Figure 1 shows a seismic cross section through the Bengo structure highlighting the strong seismic response within the gas cap and a dim response within the oil column. This seismic line is highlighted on the RMS amplitude map in the upper left corner. This amplitude map was calculated between time-equivalent surfaces for the gas oil contact (GOC) and the oil water contact (OWC) at Bengo-1.

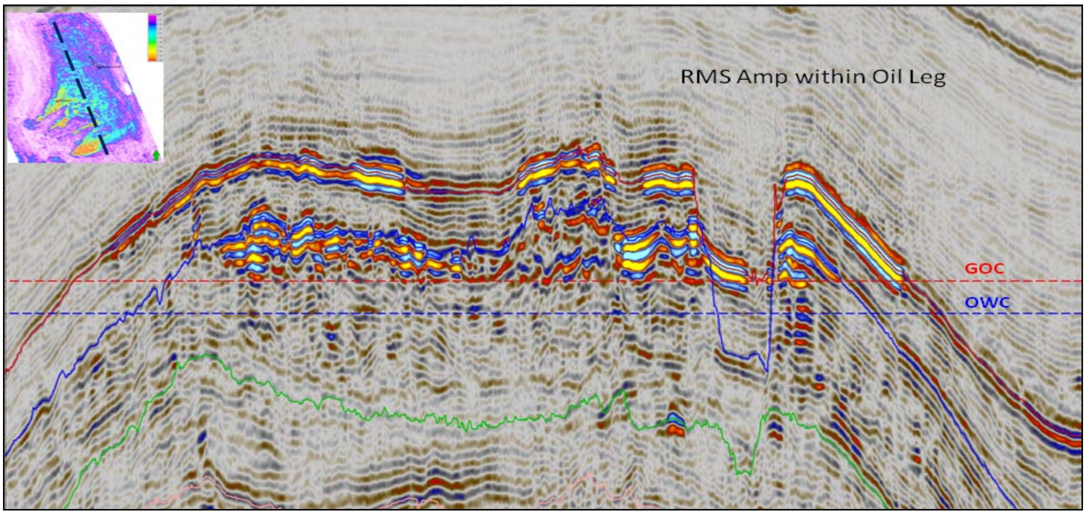

Figure 1 *A cross section from the Bengo seismic. The map on the upper left corner is an RMS map extracted between the GOC and the OWC.*

Rock Physics Analysis

In addition to the Bengo wells, several other wells in the area were used for more regional rock physics diagnostics work which was later applied to the Bengo study. Both the Voigt-Reuss averages and the upper and lower Hashin-Shtrikman bounds were used to assess the elastic moduli of the clean sands from eleven different wells in the area including Bengo. Figure 2 shows that the data points of the brine filled clean sands in these wells except Bengo fall between the two lower and upper bounds. This indicates that these are consolidated sandstones, that are moderately to well sorted with the potential for weak cementation. The Bengo sands, on the other hand, fall directly on the lower bound which indicates that these are unconsolidated, moderately to poorly sorted sandstones. This observation is confirmed by the recovered core from the Bengo-2 well.

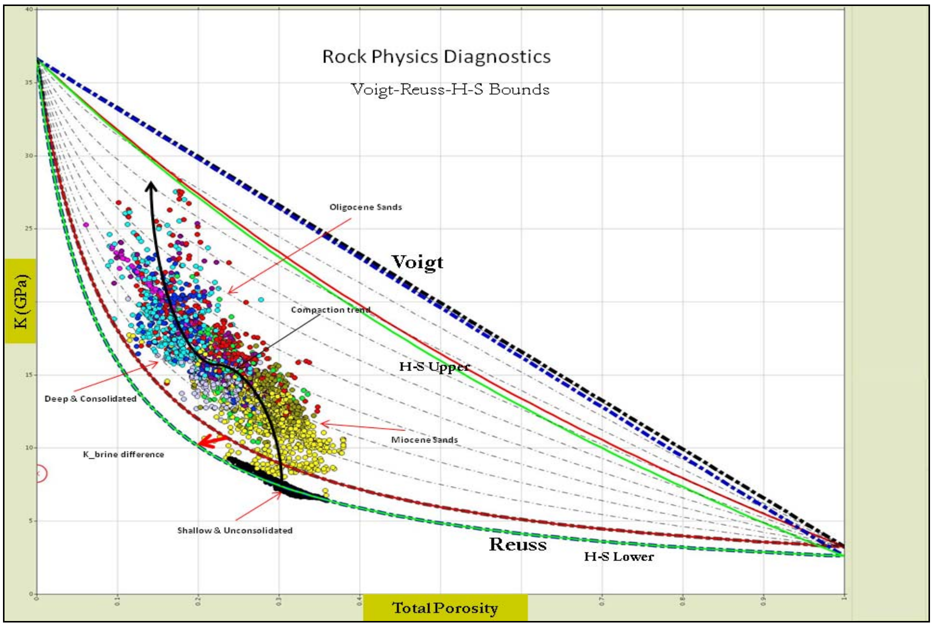

Figure 2 *A cross plot of the Bulk Modulus against Total Porosity of brine filled sands given the Voigt-Reuss averages and the upper and lower Hashin-Shtrikman bounds.*

Rock Physics Model and Seismic Forward Modelling

A trend based model (Nasser, 2010) was constructed at Bengo for the clean wet sands and shales in which porosity, shale volume and saturation were input and P-velocity, S-velocity and density were calculated as output. Figure 3 shows the initial model which matches the original log data but with different fluid saturations. Blue curves show the Vp, Vs and density response for brine filled sands, while green curves show the oil response only (assuming no gas) and red curves show the oil and gas response. Brown straight lines are the shale trends used in this model that extend beyond the displayed interval. A comparison between the synthetic gather based on well data and the original seismic gather is also shown in this figure to highlight the similarities between the two. Seismic gathers clearly have issues at higher angles for reasons which will not be discussed in this abstract. We have also modeled the expected seismic response by varying porosities, decreasing sand volumes, changing fluid types, and thinning gas and oil columns by moving the contacts upwards. Figure 4 shows the sensitivity analysis carried out to predict the seismic response given different volumes of sand and different thicknesses of the gas and oil columns. In this figure it is clearly seen that the seismic response of the hydrocarbon sand dims with decreasing the volume of sand as seen in *panels 1-4*. Moreover, the seismic response for the initial gas above oil scenario as seen in *panel 5* is very different from *panel 10* where gas is completely removed from the model. The same applies to the oil case in *panel 11* where the model has an oil column only which continues thinning by moving the OWC upwards until the model is filled with brine as in *panel 17*. In *panel 17* it is clear that a brine filled sand at this depth has a transparent seismic response similar to a shale response, which makes it hard to discriminate between the two. Final tests have indicated that porosity has a minimal impact on the seismic response, while both lithology (sand/shale) and fluid type (gas/oil/brine) have the greatest impact on seismic. These conclusions were used as the basis for interpreting the seismic data and conditioning the geologic model with the appropriate rock and fluid properties. The far response in the acquired seismic data is questionable due to erroneous behavior seen at far offsets/angles, and hence, due to the poor quality of the far angle sub-stack, the seismic interpretation was mainly done using the near angle sub-stack.

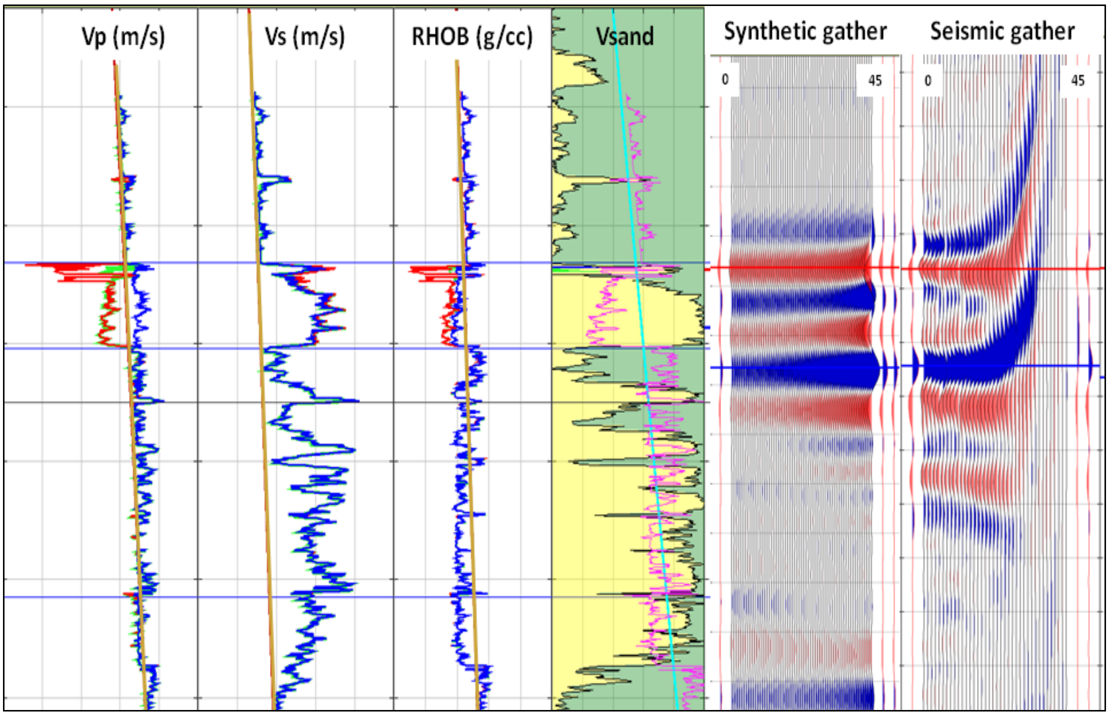

Figure 3 *The initial Bengo rock physics model with different fluid types and the expected synthetic seismic gather response compared to actual seismic gather.*

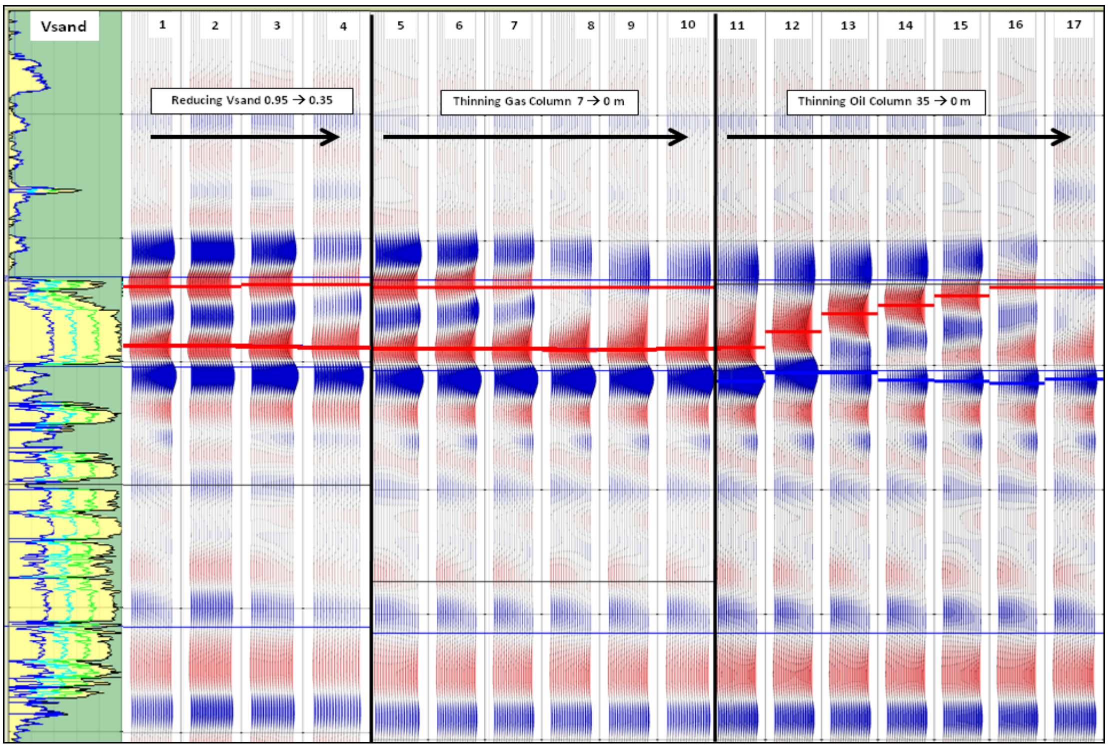

Figure 4 *A set of synthetic seismic gathers showing the effects of thinning both gas and oil columns on the seismic response.*

Rock Physics Model and Seismic Forward Modelling

As was discussed in the previous section, a relationship was observed between the seismic response, or acoustic impedance, and both shale volume and fluid type within the hydrocarbon-bearing interval. The net/gross property was modelled using Sequential Gaussian Simulation with a combination of well data and the relative acoustic impedance (co-located co-kriging with 0.9 correlation coefficient). Once the initial static model was generated, including porosity, net/gross, fluid saturations, thicknesses, and faults, the Bengo-specific rock physics model was used to calculate the elastic response (Vp, Vs, and density) of the reservoir. These properties were used as input to generate synthetic seismic angle sub-stacks using a convolutional process and then compared with the seismic data. The model rock and fluid properties were then modified until a good match with the seismic data was achieved. This workflow is summarized in Figure 5 and shows the improvement compared with the original model and therefore lower uncertainty in volume estimation.

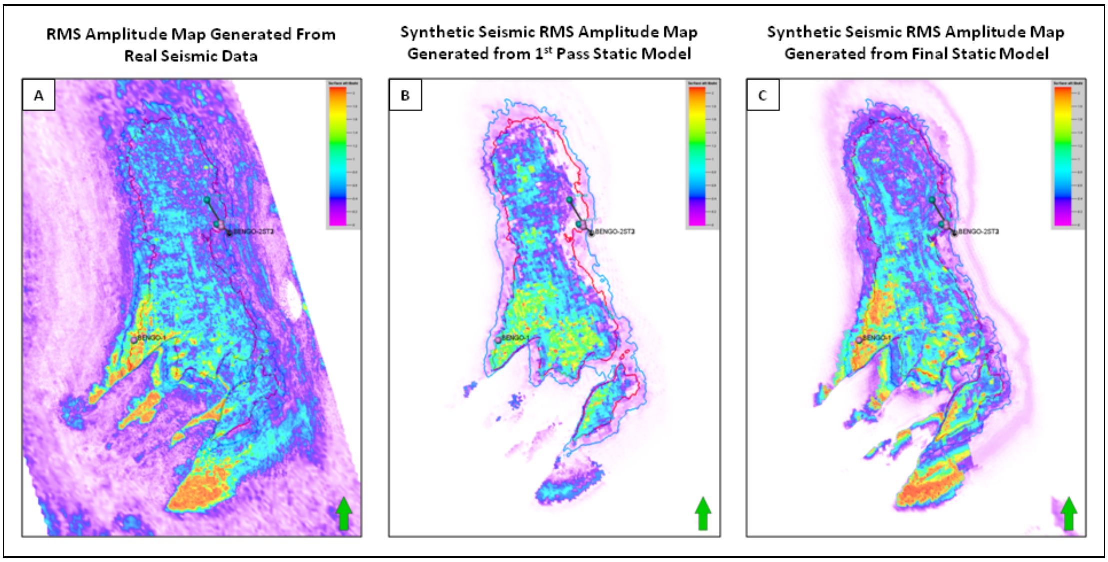

Figure 5 *Comparisons between the seismic RMS amplitude map (A) and both the synthetic seismic from the first pass model (B) and the final static model (C). The three maps were extracted between the GOC and the OWC to highlight the oil column.*

Conclusions

Given the right rock and fluid conditions, and good quality seismic data, the integration of rock physics with seismic interpretation during geologic model building should lead to models that are more consistent with seismic data and hence have lower uncertainty. As a result this adds more confidence in the estimated volumes in place, thus allowing more informed development decisions.

References

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