Lithology and Fluid Prediction in Lightly Explored Basins

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SUMMARY

In this paper we present a methodology for performing lithology and fluid prediction in lightly explored basins. We use the deep water area of the Orange basin, offshore South Africa to illustrate the methodology. In the Orange basin, there are numerous wells drilled on the shelf, however, there have been no wells drilled in the deep water.

Firstly, petrophysical analysis of the shelf wells is performed to determine end member properties of the sands and shales. From the analysis, rock property trends such as Vp versus Vs and Vp versus density are determined. In addition, the uncertainties associated with the trends are also calculated. A critical step in extrapolating from the shelf to the deep water is to use seismic derived interval velocities to improve the estimate of Vp as a function of depth. Using seismic interval velocities and well data, we derive expressions for Vp of the sands and the shales that are functions both of depth and seismic interval velocity.

The rock property trends are used to perform stochastic AVO modelling for single interfaces. The AVO modelling gives an estimate of the average response of interfaces such as shale-to-brine sand and shale-to-gas sand interfaces, as well as a measure of the uncertainty of the estimate. Therefore, a range of AVO responses is provided. Lastly, the AVO modelling is compared with AVO anomalies observed on the seismic data.

Key words: lithology and fluid prediction, South Africa, AVO.

INTRODUCTION

When working in lightly explored basins, the geoscientist is faced with a number of challenges, most of which are related to the lack of hard data. When reviewing seismic data the challenge is to make the most of what is available and try to answer questions such as:

- Could the bright amplitude on the seismic data be caused by hydrocarbons?
- Does the lack of seismic amplitudes rule out the presence of hydrocarbons?

Recent papers, such as Avseth et al. (2003) have shown the use of rock physics depth trends for lithology and fluid prediction. We use the deep water area of the Orange Basin, offshore South Africa to illustrate our methodology. The paper begins with a discussion of the geological aspects and then describes the methodology of extracting rock property trends from the well data and seismic velocity data. The rock property trends provide the link for the AVO modelling (Castagna, et al., 1993). Using the rock property trends, stochastic AVO modelling is performed that provides an estimate of the mean response as well as an estimate of the uncertainty. Lastly, the modelled AVO response is compared with the seismic data.

GEOLOGICAL BACKGROUND

BHP Billiton Petroleum (BHPB) holds a 90% equity interest in Blocks 3B/4B, located in the Orange Basin off the west coast of South Africa along with Global Energy who hold the remaining 10% equity. The blocks cover an area of approximately 21,500 km² in water depths ranging from 300 m to 2,500 m. The block lies to the south of two significant gas discoveries, the Kudu Field in Namibia and the Ibhubezi Field in South Africa, both of which are under appraisal. A location map is shown in Figure 1.

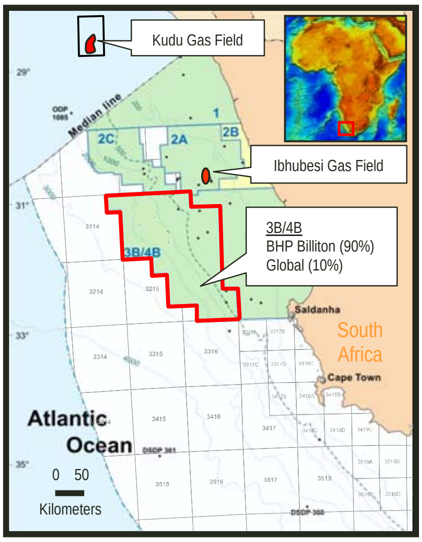

Figure 1. Map showing the location of Blocks 3B/4B.

BHPB is pursuing an oil play on Block 3B/4B, the elements of which have been proven to exist regionally by wells in the basin. Thick oil prone marine shales (Mid-Aptian age) have been penetrated in the DSDP 361 well and can be correlated to the 0-A1 well immediately to the northwest, south of blocks 3B/4B and as far north as Kudu in Namibia. Directly overlying the Aptian source rocks are sandstones of Early Albian to Cenomanian age proven in many shelf wells to the east. These clastic reservoirs were deposited in a deltaic setting on the shelf during relative high stands, and it's the low stand equivalent systems draping over a substantial pre-existing basement ridge that are being targeted in the deepwater. This ridge forms large, structurally low relief closures (average size 90 km²) but more importantly acts as a migration focal point for hydrocarbons, both from the east and the west

A substantial number of AVO anomalies have been observed at the Cenomanian reservoir levels, which typically are associated with the structural highs along the basement ridge. The Upper Cabernet Lead is one such feature. This lead is a combination structural/stratigraphic trap, which exhibits a broad conformance of amplitude to structure over a coarsely spaced 2D grid (6 by 8 km). The 2D was acquired in 2002 using a 6km cable, which resulted in good imaging at target levels.

METHODOLOGY AND RESULTS

The lithology and fluid prediction study consisted of four main steps. Firstly, petrophysical analyses were conducted on eight wells situated on the shelf to determine elastic properties of end member sands and shales. Next, seismic derived interval velocities were used to extrapolate rock property trends from the shelf to the deep water. The rock property trends were then used to perform stochastic AVO modelling for a number of scenarios. Lastly, the modelling was compared with seismic amplitude and AVO anomalies observed on the seismic data.

Petrophysical Analysis

Petrophysical analysis consisted of picking the elastic properties (ie, Vp, Vs and density) of end member sands and shales. Only regions of the log which the petrophysicist determine are good quality are used. The uncertainty of each pick is also determined. Figure 2a shows a graph of the sand and shale velocity picks as a function of depth below mudline and Figure 2b shows a graph of Vp versus density for all the wells used in the study. Note the regression 'curves' and corresponding error estimates that have been extracted from the density data in Figure 2b.

Seismic Interval Velocities

Seismic derived interval velocities were used to extrapolate rock property trends from the shelf out to the deep water. The target depth of the Upper Cabernet Lead is approximately 2600 m below the mud line. From Figure 2a, this results in a prediction of sand velocity ranging from 4,000 to 5,400 m/s.

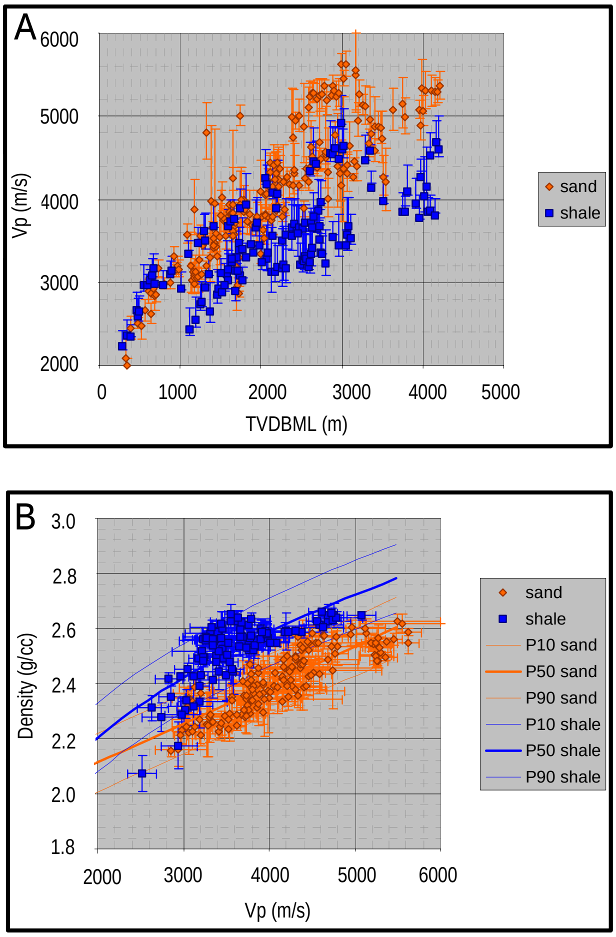

Figure 2. (a) Sand and shale picks showing Vp versus true vertical depth below mudline (TVDBML); and (b) Density versus Vp.

The well velocities, however, are inconsistent with the seismic derived velocities in the deep water. In the deep water, the velocity gradient is less than in the shallow water. Figure 3 compares a seismic derived interval velocity function from the deep water with the well velocity picks. The velocity function was derived by converting the migration velocities to interval velocities as a function of depth below mudline. A scaling factor of 0.95 was derived by correlating the VSP and checkshot data with the seismic velocities. The seismic derived velocities are approximately 20 to 30 percent less than the well velocities at the target depth.

Clearly, the well derived velocity trends need to be modified to take into account the slower velocities in the deep water. This is done by regressing the well velocities with the seismic derived interval velocities at the well locations. This produces estimates of interval velocity for both the sands and the shales that are functions both of depth and seismic interval velocity.

Using the above method, we obtained rock property trends of the form:

Sands

$Vp = C_1 + C_2*depth + C_3Vint$ +/- error

$\phi = C_4 + C_5*Vp$ +/- error

$Vs = C_6Vp - C_7$ +/- error

Shales

$Vp = C_8 + C_9 * depth + C_{10} Vint$ +/- error

$\rho = C_{11} * Vp^{C12}$ +/- error

$Vs = C_{13} Vp + C_{14}$ +/- error

Where C_1 to C_{14} are constants.

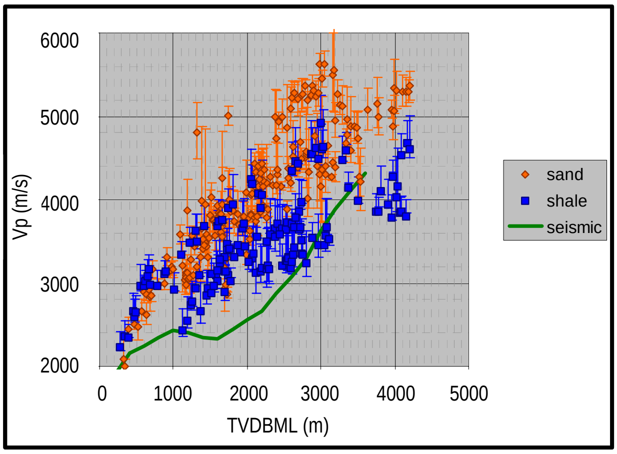

Figure 3. A comparison of Vp versus depth below mudline for the well picks and the seismic derived velocities.

AVO Modelling

The rock property trends were used in conjunction with an estimate of the fluid properties to perform stochastic AVO modelling. Figure 4 illustrates the general methodology.

Frequency distributions calculated for the Upper Cabernet Lead are shown in Figure 5. In this case, the far stack was chosen, since this was modelled as providing the optimum separation for fluid discrimination. The curves show that on average, a shale-to-shale and a shale-to-brine sand reflection coefficient would be close to zero, and that a shale-to-gas sand reflection coefficient would be a small negative number. However, there is a large range in the modelled responses. For example, a gas sand could range from having a large negative reflection coefficient to a small positive reflection coefficient.

The AVO response of an oil was also modelled. A light, high GOR oil was chosen since a geochemistry study indicated this to be the most likely oil type. The modelled response was close to the gas response

Comparison of Modelling with Seismic data

Figure 6 shows a far stack across the Upper Cabernet Lead. The data has been phase matched to a nearby well. The lead consists of a series of bright events, which on the basis of seismic phase are interpreted to consist of low impedance units. The events show a broad conformance to structure, although this is based on a coarsely spaced grid of 2D seismic data. Amplitude extractions performed on the far stack (Glinsky, et al., 2004) showed that the 'on structure' to 'off structure' amplitude ratio was consistent with the presence of hydrocarbons.

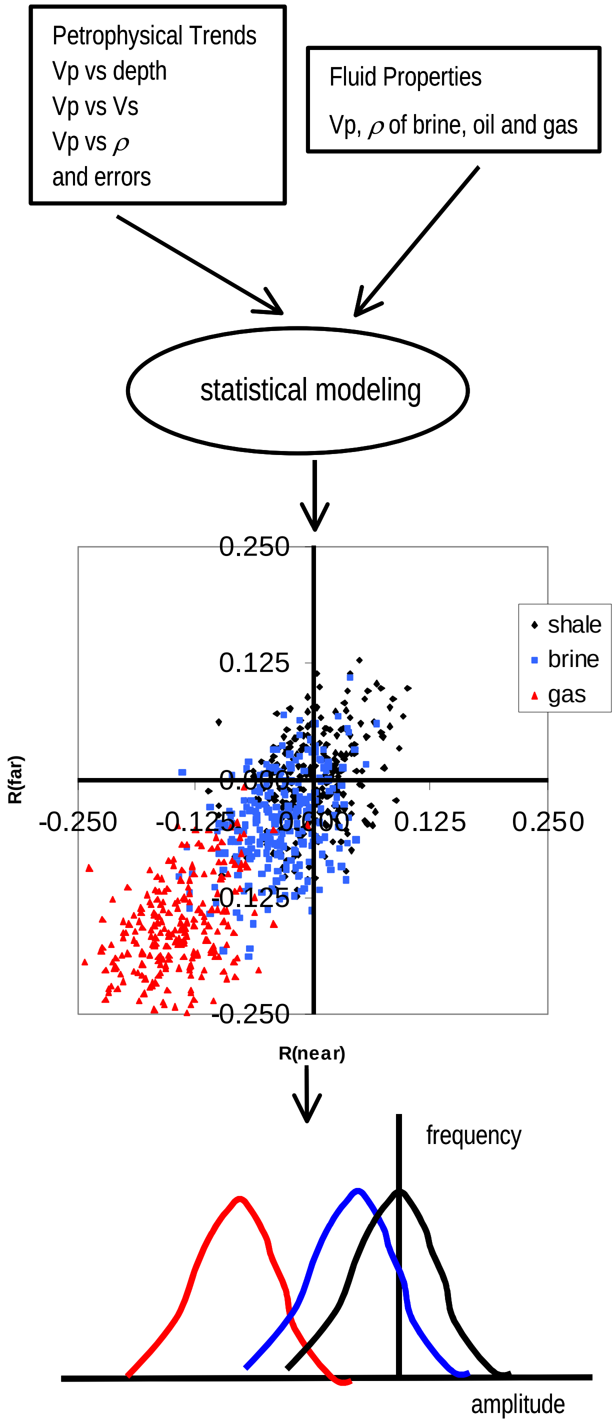

Figure 4. AVO modelling methodology. Petrophysical trends and fluid property are used to generate near stack versus far stack 'shotgun' plots. The line that best discriminates between fluid type is calculated which in this hypothetical case is close to 45 degrees. The points are collapsed onto this line in the form of a frequency distribution. If the points are collapsed onto a line at 90 degrees, we get a near stack response, and if the line is 180 degrees we get a far stack response.

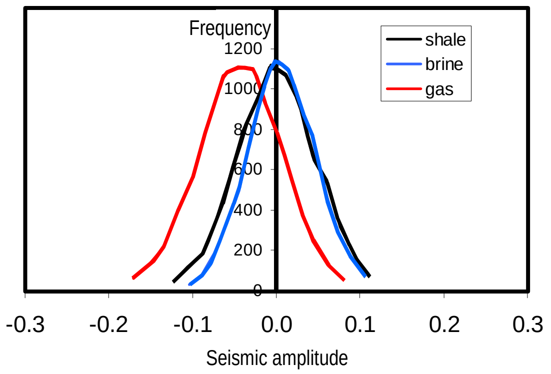

Figure 5. Frequency distribution curves for the Upper Cabernet Lead for the far angle stack.

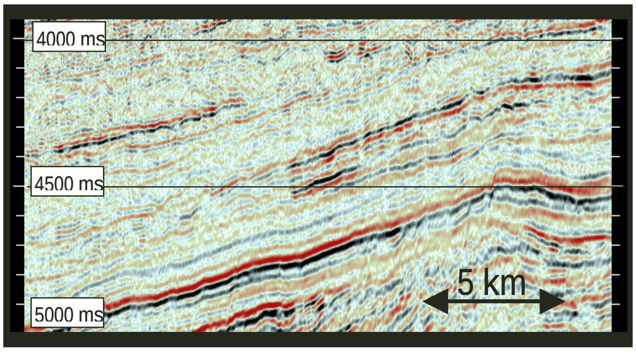

Figure 6. Far stack seismic data across the Upper Cabernet Lead.

CONCLUSIONS

In this paper, we have outlined a methodology for lithology and fluid prediction in lightly explored basins using data from the deep water area of the Orange Basin, offshore South Africa. The process is quite simple, and consists of four main steps: (i) extraction of rock property trends using well data; (ii) extrapolation of the rock property trends using seismic derived interval velocities; (iii) stochastic AVO modelling; and (iv) comparison of the modelling with the seismic data.

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