Use of outcrop analogues to predict lithology influence on the seismic signature

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Summary

There have been many studies of how Direct Hydrocarbon Indicators (DHIs) can help or hurt us when trying to distinguish fluid and lithology effects on seismic amplitudes. The integration of outcrop studies can enhance the interpretation of complex reservoirs in deep-water depositional settings. In this paper we present observations from world-class deep-water outcrops as analogues to deep-water Gulf of Mexico (GOM) reservoirs. We present the methodology of the investigation starting with outcrop studies, well log and seismic interpretation of deep-water sediments, forward and inverse modeling, and analysis of the DHI response. Examples of outcrops and 1-D models are presented.

Introduction

Drilling and production in deep-water can be risky due to reservoir complexity, engineering problems, and safety hazards. An understanding of deep-water reservoirs plays a key role in reducing risk in deep-water drilling and production. DHI's have been useful in identification of pore fluid types, but geologic complexities can impact the seismic signature in a way that may lead to misidentification of fluid indicators. Deep-water turbidite sequences have inter-fingered boundaries such as channel complexes, gradational contacts due to stratigraphic pinch outs, and abrupt changes in properties at scales well below seismic resolution. A better understanding of the lithologies and geometries that control fluid distribution can be achieved by applying outcrop observations as analogues to enhance the interpretation of subsurface information such as well logs, seismic data and regional geologic models. Here we present a case study of the Ursa field in the deep-water GOM and show the importance of understanding the influence of lithology on the seismic signature.

Method

To better interpret seismic DHIs it is essential to understand the influence of lithology on the seismic signature. Here we attempt to apply outcrop studies as analogues to a GOM deep-water reservoir using the following methodology:

- Deep-water outcrop studies in West Texas
- Identification of similar Turbidite features on well log and Seismic
- 1-D Seismic Modeling of composite Reflectivity coefficient for turbidite reservoir intervals
- 2-D Seismic Modeling
- Amplitude versus Offset response of these intervals

Later we will extend these models for application to turbidite reservoirs outside the GOM.

Examples

The world-class outcrops of the Permian Brushy Canyon Formation in the Guadalupe Mountains National Park and Delaware Mountains of West Texas are used as analogues to GOM deepwater sediments (Gardner et.al., 2003). The deep-water basinal system of the Brushy Canyon formed in an unconfined setting and has a high sand content. (Gardner et. al., 2003) In contrast the majority of Gulf of Mexico sediments are mud rich and form in confined settings due to the salt tectonics in the region (Meckel et. al, 2002).

Figure 1: Fine scaled turbidite beds ("Ethel" the lizard for scale ~25 cm)

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Common characteristics of deep-water outcrops that can also be found in GOM deepwater environments include fine-scaled bedding (Figure 1), and channels containing stratigraphic pinch-outs (Figures 2). Condensed sections or drapes act as barriers to fluid flow between sand bodies. Sand body continuity and connectivity in deep water systems are important because they help us to predict fluid migration or plan for various production scenarios.

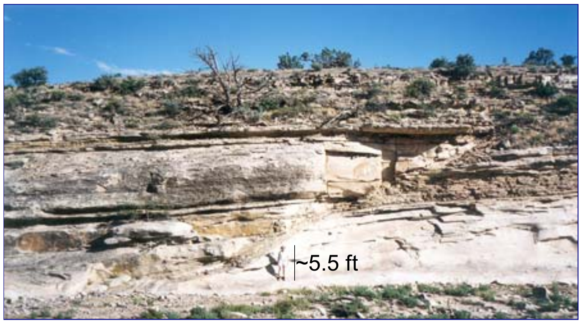

Figure 2: Channel of Brushy Canyon turbidite depositional system in West Texas

Brushy Canyon outcrops are applied as geologic analogues to the Ursa field in the GOM Mississippi canyon. Here, several amplitude anomalies represent economic reservoirs as well as zones identified as uneconomic "fizz gas" zones. The Ursa mini-basin is a deep-water depositional environment that is controlled by cycles of salt tectonics, subsidence, eustacy, and gravity flows. Sediment is focused into the basin by the sutures in the salt structures. In his study of the Ursa mini-basin, Meckel et. al. (2002) identified cycles of 3rd order continuous ponded facies and chaotic bypass facies which can be broken down into 4th order couplets of sheet sands and channelized systems that are bounded by condensed sections and divided internally by erosional surfaces. (Meckel et. al., 2002) In outcrop these features would be equivalent to the characteristic features shown in figures 1 and 2, inter-bedded sands and shales and channelized systems.

Various aspects of the turbidite sequences in the Ursa mini-basin were identified on well logs. Turbidite features appear on the gamma log (figures 3 & 4) as pulses of sandy intervals embedded in shale or mud rich intervals and as fining upward sand intervals representing Bouma sequences. The interval on the gamma log in figure 3 from 3.38 to ~3.44 km shows a stacked fan fining upward sequence that has an increase in porosity upward. The interval is brine saturated and therefore good to use for base modeling without interference from hydrocarbon saturation. The second marked interval from 3.53 to 3.57 km is a shaley interval with relatively high porosity values.

In the Ursa basin these types of events can be identified as bypass intervals and stacked fans.

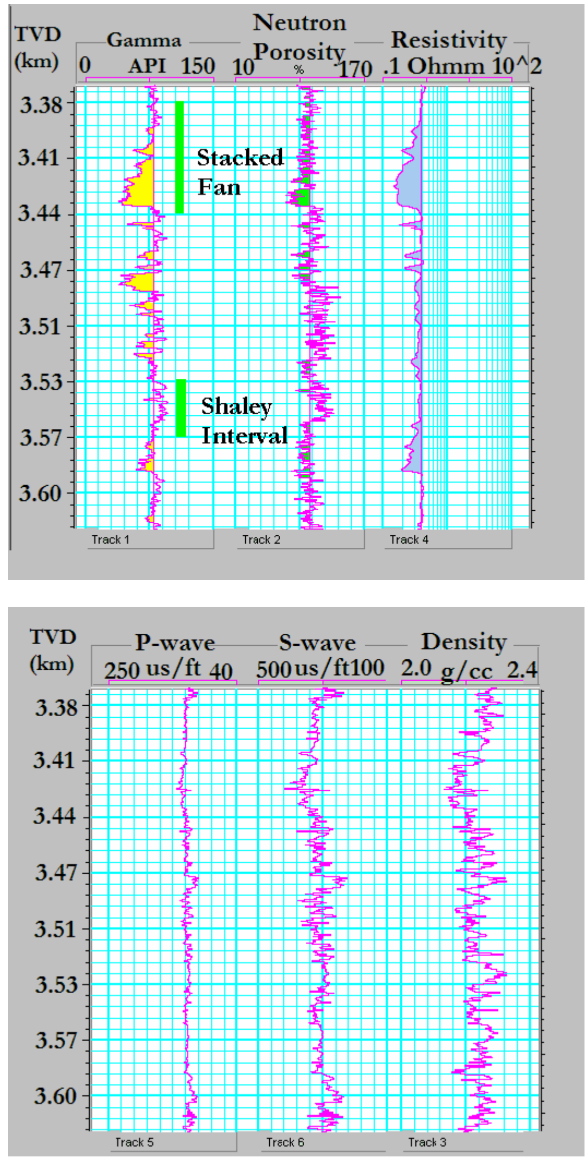

Figure 3: The Ursa log displays gamma, porosity, resistivity, P-wave and s-wave travel tmes and density. The green bars show the turbidite intervals, which were modeled to compare to reflectivity coefficient. S-wave was calculated in Hampson-Russell software using the Castagna mud-rock equation, which assumes brine saturation.

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Figure 4 shows the third turbidite interval that was modeled. In this interval we can see from the gamma log fine-scaled bedding overlying a thicker sheet of sand. The turbidite intervals in figures 3 and 4 were are representative of turbidites that are below seismic resolution and therefore typically interpreted using a single "reflection coefficient”. We can look in detail at the finely bedded interval in figure 4.

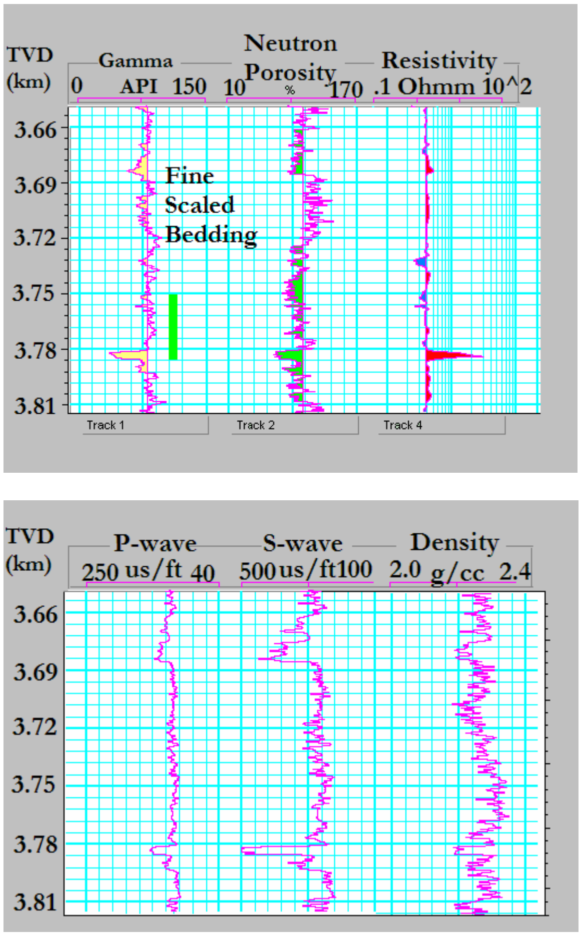

Figure 4: The Ursa log displays gamma, porosity, resistivity, P-wave and s-wave travel times and density. The green bars show the turbidite intervals, which were modeled to compare the reflectivity coefficient. S-wave was calculated in Hampson-Russell software using the Castagna mud-rock equation, which assumes brine saturation.

To estimate the seismic lithologic response of the thin beds, synthetic seismic traces generated for the lower interval 3.75-3.78 km on the logs. No shear log was acquired, so shear velocities were computed using the Greenburg-Castagna equation for mudrock assuming brine saturation (Mavko, 1998). To generate the traces a 30 Hz Ricker wavelet with a 100 ms wavelength and a 4 ms sample rate were used. The Zoeppritz equation was then used to perform the model using offsets from 0-45 degrees. The results can be seen in figure 5. From the synthetic seismic model we can see that this interbedded zone is not a simple single reflection event. By changing the frequency and wavelength of the source wavelet the thin bed interval may be resolvable.

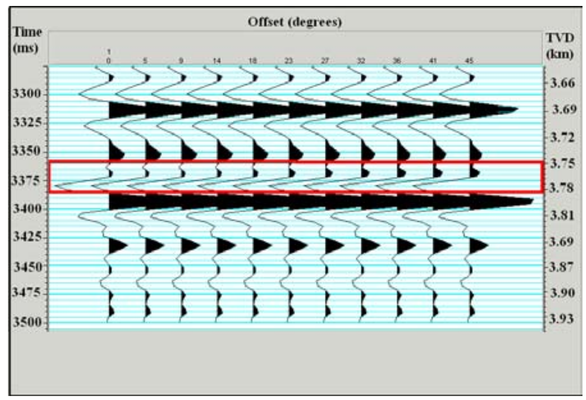

Figure 5: Synthetic seismic response generated with Zoeppritz approximation and, a 30Hz Ricker wavelet to a maximum of 45 degree offset. The equation assumes brine saturation and the red box corresponds to the lowest depth interval on the well log (3.75 to 3.78 km).

To further investigate this issue, one dimensional models of the turbidite intervals were run and a composite reflection coefficient was generated for the deepest interval (3.75 to 3.78 km) for three frequencies (15 Hz, 30 Hz and 60 Hz, in red, blue and black respectively. The results can be seen in figure 6.

The interpretation of finely bedded turbidite sequences may be more complicated, since seismic waves will be scattered by fluctuations in velocity and density throughout the section. The observed response will then be a superposition of waves reflected by the various sand and shale intervals, not an individual wave reflected by a single boundary between two welded half spaces, the model assumed by conventional AVO equations. However, the complete response can be modeled using propagator matrix methods (Aki & Richards, 2002). Because this approach enforces all of the required boundary conditions at each interface between the numerous layers, the solution includes all wave propagation phenomena and is not restricted by any assumptions of weak contrasts in material properties or near vertical propagation. This composite reflection coefficient includes the superposition, or "tuning", of all waves reverberating in the model layer (Gibson, 2004). As an example, we show the results of computing the P-wave composite reflection coefficient for

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the 3.75 to 3.78 km interval in figure 4. The total unit thickness, 0.03 km, is relatively thin compared to a wavelength for frequencies typical of surface seismic data, so reflections from it will be comprised of a single tuned event and it is reasonable to characterize it using the single value of the composite reflection coefficient. Because the reflecting zone has a finite thickness, this coefficient is frequency dependent (Fig. 6). As frequency increases from 15 to 60 Hz, the magnitude of the reflected signal increases, and the rate of decrease with increasing angle of incidence also changes. This suggests that conventional AVO parameters such as the gradient of the amplitude as a function of the squared sine of incident angle will be sensitive to frequency.

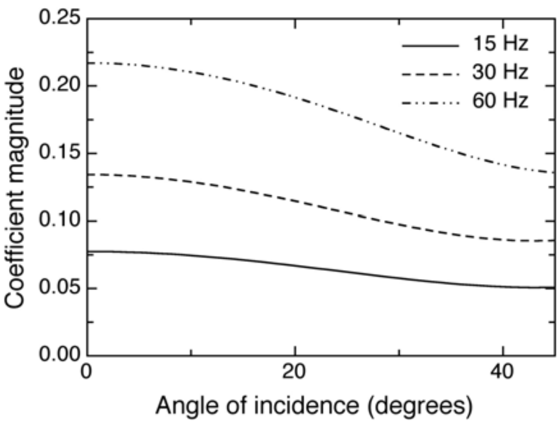

Figure 6: Composite reflection coefficient generated for interval (3.75 to 3.78 km) for three frequencies (15 Hz, 30 Hz and 60 Hz, in red, blue and black respectively.

Conclusions

Deep-water outcrop analogues help better predict frequency and occurrence of turbidite sequences when combined with well log and seismic and DHI's. The combination of the geological study, which helps to identify depth intervals of interest, with the computed composite reflection coefficient provides some potentially important insights into seismic characterization of turbidite sequences. These predictions can help to improve the interpretation of Direct Hydrocarbon Indicators. Presence of turbidite features might be an alternative explanation for the occurrence of high amplitude seismic events, which may be misidentified as hydrocarbon indicators. In conclusion, the combination of the geological study, which helps to identify depth intervals of interest, with the computed composite reflection coefficient provides some potentially important insights into seismic characterization of turbidite sequences.

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EDITED REFERENCES

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