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AVO in Oman: Ticking another box in the exploration process

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Summary

*Gregg and Bukowski (2000) advised "If at first you don't succeed, try something unconventional." Their paper goes on to discuss the success of **A**mplitude **V**ersus **O**ffset on an onshore USA gas field complex. Since its introduction to the industry in the mid 1980's AVO has continued to enjoy growth as a tool for hydrocarbon exploration and development across the globe. However, it is still in its infancy within the world's primary oil patch – the Arabian Gulf. Here most hydrocarbon reserves are found within the carbonate sequences of the Cretaceous, and older. This study focuses on more recent rocks, offshore Oman in what is prognosed to be a clastic environment. Within this wildcat area of the Gulf of Oman all aspects of prospect generation linked to exploration process, including AVO studies, are required to minimize exploration risk. Our paper summarizes the approach taken and observations made in one of those aspects, pre-drill AVO analysis. The study ranks as one of the world's largest pure AVO studies, covering approximately 2000 sqkm of 3D marine seismic data and it reveals an encouraging overlap of positive AVO anomalies with leads generated by the interpreters.*

Introduction

The study area comprises the Sohar basin in Gulf of Oman. The Sohar Basin is bounded to the southwest by the Oman Mountains, to the northeast by the Makran Accretionary Prism (SW directed thrust zone) and to the northwest by the Musandam platform as in Figure 1.

The seismic dataset used for AVO studies from the study area comprises of approximately 2000 sqkm of 60-fold 3D PSTM seismic with offsets up to 6275m, which amounts to over 5.5 terabytes of data. Main targets range from 1000 - 2000ms TWT but deeper events have also been analyzed. The data exist as uncorrected CDP gathers and were NMO corrected using velocities supplied by the processors. Various data conditioning techniques were investigated, such as super-gathering and residual moveout correction but the improvement of signal to noise was negligible compared to data management complexities.

In this paper we present the methodology and the results of the AVO study carried out as part of the exploration process.

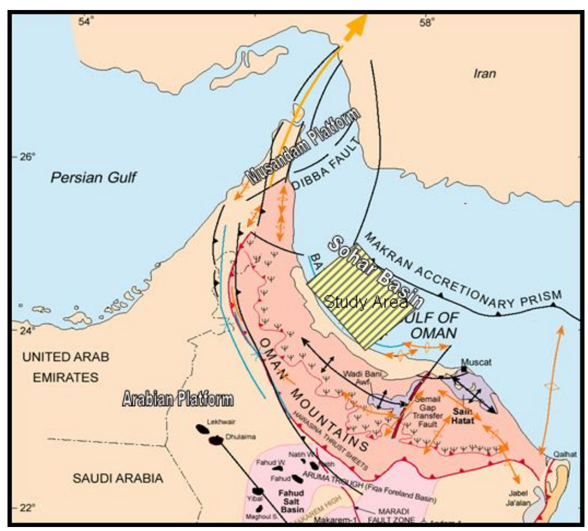

Figure1. Location map of study area

Geological Setting

The Sohar basin is developed as the eastern trailing Oman margin following the obduction of the Semail Ophiolite onto the north eastern margin of the Arabian Platform .This tectonic event created the initial configuration of the Oman Mountains in the Late Cretaceous. Sedimentation began in the Sohar Basin in the Campanian.

Initial coarse clastics were shed from the Oman Mountains into the deep basins gradually filling the basin, initiating the development of Eocene carbonate shelf. Massive faulting along the inner shelf margin at the end of the Eocene caused episodic gravity sliding of huge masses of the Paleocene-Eocene section downslope into the basin. This created a large evacuation cavity, into which enormous volumes of Middle Oligocene-Lower Miocene clastics were funnelled from the once again uplifted Oman Mountains. Clastics sedimentation continued through Miocene-Pliocene period & is marked by a significant erosional (subaquous) boundary at the base of it. Mio-Plio coarser clastic sediments were drained down the basin mainly through wadi system, fault scraps and slope gullies & is a major exploration target under appropriate strati-structural entrapment configuration. 3D seismic volume based amplitude/sweetness stratal slices through Miocene-Pliocene section shows presence of coarser sediment fairways on shelf along major fault systems. Subsequently, sediments were reworked & transported down basin bypassing the slope as turbidite aprons. AVO studies were taken up for these sands as potential exploration targets.

Methodology

Many AVO analyses are based around the Intercept (A) and Gradient (B) AVO attributes. The process of this attribute generation involves the transform from offset to angle domain. The attributes are subsequently calculated using Wiggin's representation (1983) of the Aki-Richards equation (1980):

$$R(\theta) = A + B \sin^2\theta + C\sin^2\theta\tan^2\theta \qquad (1)$$

To perform reliable fluid and lithology identification angles in excess of 25° are preferred. Historically a simple linear assumption has often been applied to calculate the slope (Gradient attribute – B) and the Intercept (attribute – A). However, this survey has data up to 60°, which allows the application of the full 3-term equation for Intercept, Gradient and the Curvature (C) term from equation (1). The high angles are possible because of the shallow targets and low velocity overburden.

A major risk in AVO analyses of wildcat areas is the inability to calibrate observed responses against those modeled using well data and AVO theory. There are no guarantees that two hydrocarbon accumulations will yield the same seismic response. Similarly there are no guarantees that two different processing companies will provide identical CDP gathers with the same raw data. Two wells exist in the block but were (a) outside of the 3D volume and (b) did not contain any acoustic log data. Therefore an assumption had to be made. The majority of hydrocarbon-associated AVO effects documented in the literature fall in to Class II and Class III categories of Rutherford & Williams (1989) classification system, i.e. a small or large negative reflection coefficient increasing in magnitude with offset. The assumption made was that it is likely that any hydrocarbons would yield a similar Class II or III response.

A multi-tiered approach was used to locate and analyze any AVO anomaly in the volume. Class II and III responses have a positive product (AxB) for Intercept and Gradient. Events that dim with offset will appear as a negative AxB. Once positive anomalies were located they then were vetted to eliminate a number of artifacts that may result in false positives. From the CDP gathers background noise, residual moveout and multiples can be discounted by inspection. The gathers will not, however, give any indication of NMO stretch or they can mask tuning effects. The next step was therefore to analyze the uncorrected gathers. Picking the event of interest on the uncorrected gathers and showing the amplitudes revealing any variation due to NMO stretch. Analysis of the event and those immediately above and below was carried out to check for tuning. Figures 2 and 3 show two apparent positive AVO effects in NMO corrected and uncorrected states. The deeper is the result of stretch while the shallower can be considered real.

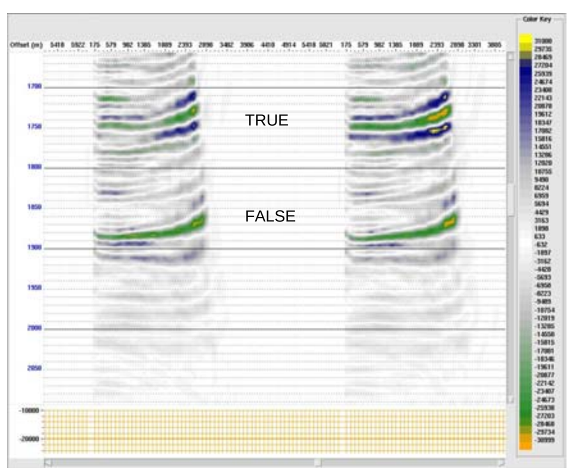

Figure 2. NMO corrected gathers

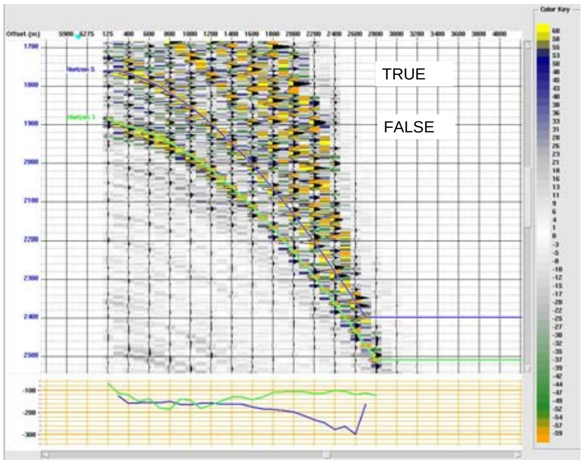

Figure 3. Uncorrected gather

Anomalies were mapped on the AxB volume and viewed in 2D (plan) and 3D to assess continuity and synergy with the interpreter's areas of interest. Cross plotting was also used to investigate the lateral and areal extent of anomalies found. This took the form of the standard Intercept versus Gradient plot and the selection of zones within the targeted Classes.

Observations

Seismic data quality over the area is generally good. File header information indicated Radon demultiple had been applied. Investigations in to data conditioning, while improving the coherence of the AVO attributes, did not change the extent of positive product values. Figures 4 and 5 show CDP gathers and the Product attribute used in the analysis. Processes investigated include supergather (rolling common offset stack) and residual moveout correction, using time varying trim statics.

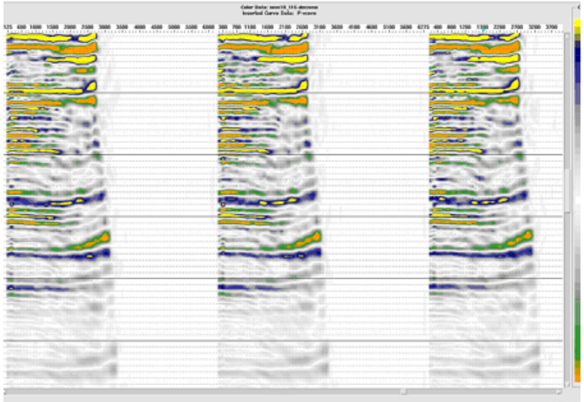
Figure 4. Raw CDP gathers

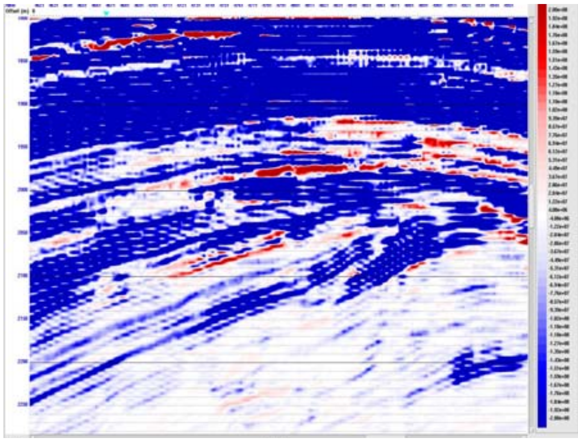
Figure 5. Raw AVO Product attribute

A total of 12 leads were generated by the interpreters, Figure 6. The interpretation was carried out simultaneously with the AVO aspect and thus allowed both parties to focus on a common goal. Using the method described above seismic data were analyzed on a 10 line increment and anomalies mapped. The subsequent maps, when compare to those produced by the interpreters reveal a high correlation. Ranking was carried out based on the strength of the AVO effect and its areal extent. Figure 6 shows a map of the anomalies in X-Y (UTM) space with time to anomaly shown in colour together with the areas of interest highlighted by the interpreters. Three significant leads are proposed for consideration together with other prospect generation features normally reviewed during the process of exploration.

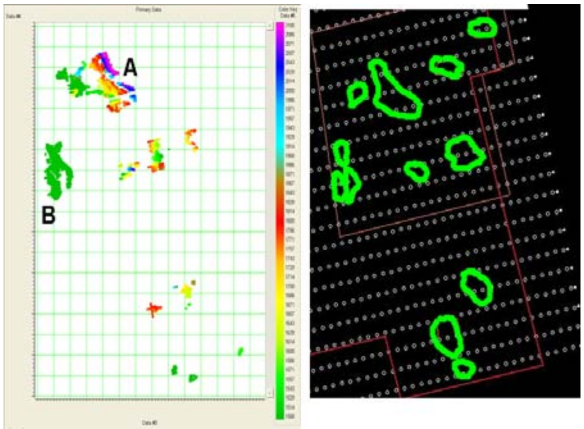

Figure 6. Comparison of anomaly coverage with interpreter's zones of interest.

Of the leads identified two stand out in terms of size, marked as A and B in Figure 6. Good Class III type responses are associated with these leads, together with structural closure highlighted in Figure 6. The full three-term generation enables the computation of other attributes such as the change of p-wave, s-wave and density ($\Delta Vp/Vp$, $\Delta Vs/Vs$ and $\Delta\rho/\rho$, respectively). The typical attribute response while crossing a shale/hydrocarbon sand interface is a drop in p-wave and density with an increase in s-wave values. The observations around leads A and B display these responses as seen in Figures 7 and 8.

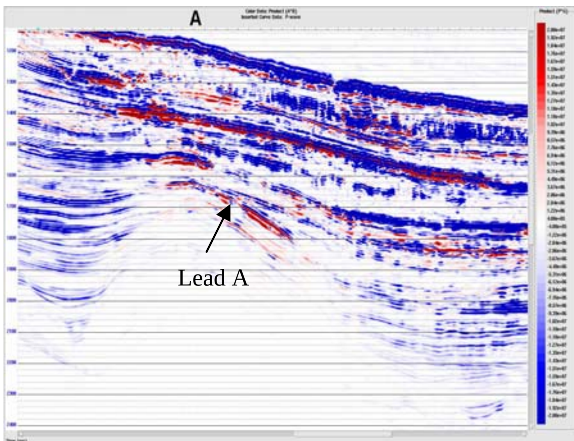

Figure 7. AxB attribute through lead A

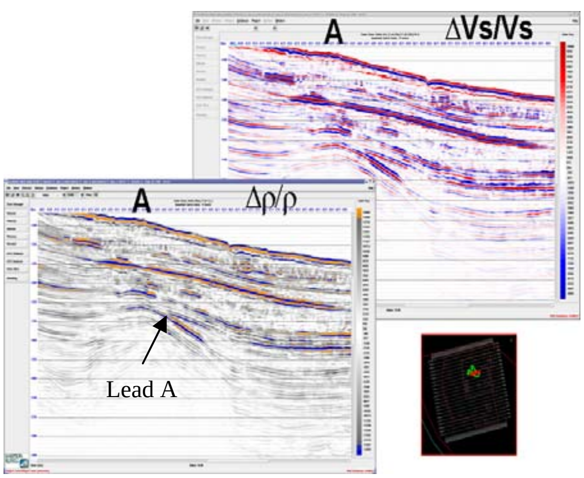

Figure 8. $\Delta Vs/Vs$ and $\Delta\rho/\rho$

The final interpretation process involved in the AVO analysis workflow is that of cross plot examination. Class III responses can also be characterized by points falling in the lower left quadrant of an Intercept versus Gradient crossplot, Figure 9. Highlighting points in this quadrant on a cross plot of points around lead A shows the continuity of the anomaly as well as conformance with structure, Figure10.

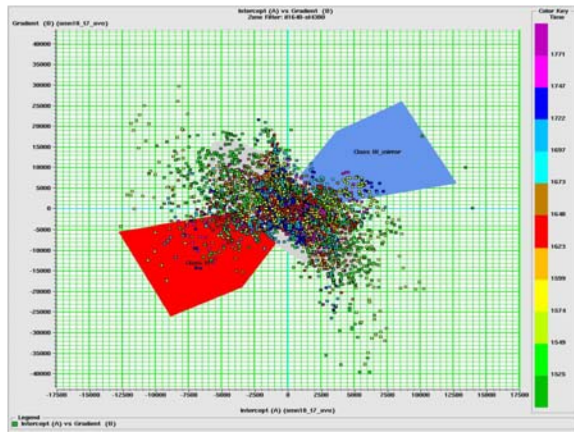

Figure 9. Cross plot of A versus B around Lead A

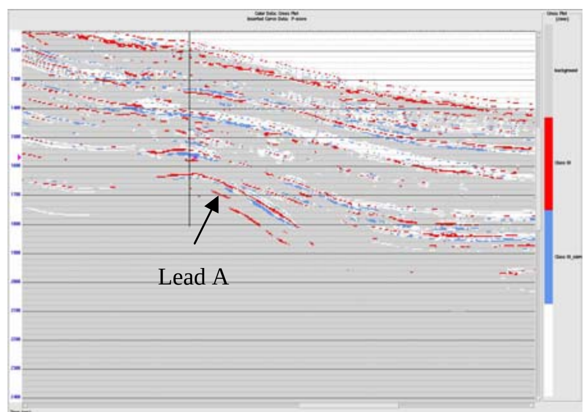

Figure 10. Section through lead A showing cross plot zones

Conclusion

The potential risk of this study is the lack of well data. Hydrocarbon accumulations can be associated with all Classes of AVO response. AVO Class II and III responses mapped here may relate to possible hydrocarbon charging, however it is not the full guarantee of hydrocarbon presence as many combination of lithologies may exhibit similar responses. However the authors still suggest the positives derived out of this detailed AVO studies as **'ticking another box in the exploration process'**. Post-well appraisal has been proposed as a next recommended step.

Acknowledgments

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