3-D Subsalt AVO

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Summary

AVO technologies were applied extensively in the Gulf of Mexico to evaluate primarily bright spots. These analyses were routinely performed on Z-D seismic data where the technique met with considerable success. However, as the prospect inventories dwindled, the success rate declined. Remembering that we drill our best leads first, it is only to be expected that the risk associated with these prospects would be higher - even with advanced technologies. It is probably for this reason that the application of AVO technology went through a hiatus. Today, time domain 3-D AVO is used in many areas of the world. FM the complex imaging areas of the Subsalt Trend, another advancement was needed. The combination of 3-D PreSDM and 3-D AVO is that advancement. Depth domain 3-D AVO is now possible (Figure 1).

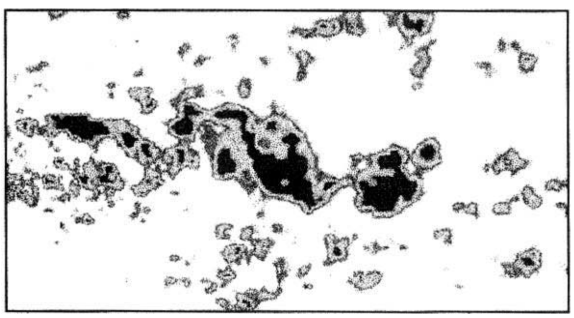

Fig 1. Mapped horizon of an amplitude and AVO anomaly below 1500 meters of salt. Event is mapped from 3-D depth domain prestack depth migrated seismic data.

Introduction

Seismic amplitudes have long been known to be related to hydrocarbon accumulation. However, bright spots are not risk free. Rarely is the exploration risk higher than in the Gulf of Mexico Subsalt Trend. Factors contributing to the risk include complex imaging problems, poor signal-to-noise ratio and pressure and temperature anomalies. In the Subsalt Trend the question becomes, what are the key factors involved in understanding seismic amplitudes?

Recent subsalt discoveries in the Ship Shoal South area have proven the hydrocarbon source and seal (trap) integrity leaving the geologic questions of reservoir size and quality the key elements. To reduce risk in the subsalt trend, the seismic technologies that are needed are 3-D PreStack Depth Migration (3-D PreSDM) to delineate structrue, including subtle faulting, and 3-D Amplitude Versus Offset (3-D AVO) to measure reservoir heterogeneity.

3-D reflector continuity enhancement

Amplitude extractions along mapped horizons are used to understand the contrast in rock properties at the interpreted interface. Modem 3-D PreSDM processing does an excellent job of correctly positioning subsalt reflectors. Yet, there are zones where complex tectonics, poor spatial sampling and migration operator noise cause extreme difficulty in mapping stratigraphically significant events (Figure 2). These events must be mapped precisely for seismic amplitude and AVO measurements to be meaningful.

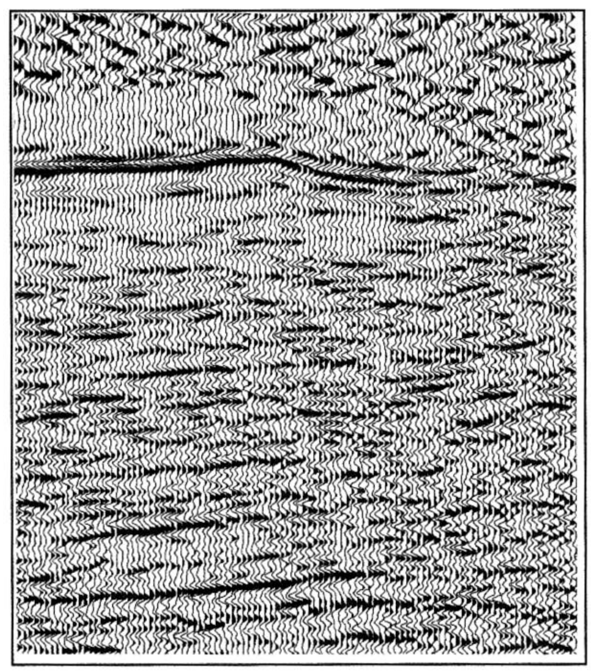

Fig. 2. Conventional 3-D PreSDM below salt

3-D reflectivity continuity enhancement provides a vastly improved look at the subsalt reflectors. The signal-to-noise ratio is improved while migration operator noise is eliminated allowing investigation of the so-called salt withdrawal suture zones and the difficult to image areas such as beneath the edges of salt (Figure 3).

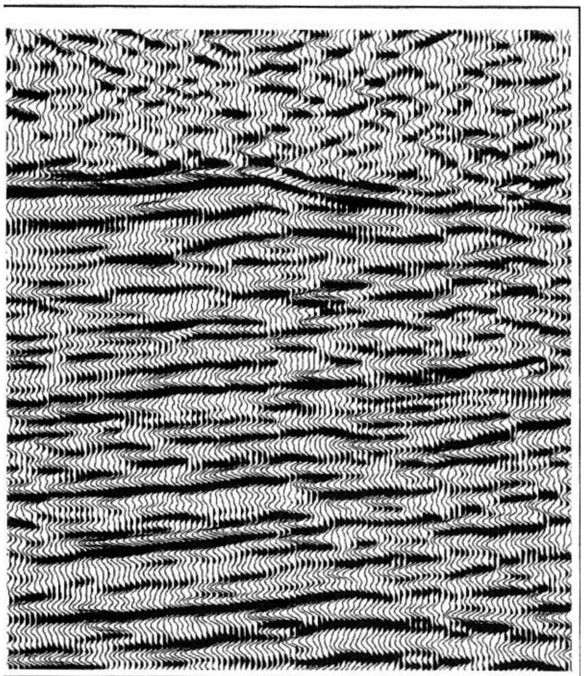

Fig. 3. Enhanced 3-D PreSDM below salt

Horizons are mapped with much greater confidence from the 3-D reflector continuity enhanced data volume. The mapped horizons are copied on to the true amplitude and AVO data volumes allowing the extraction of amplitude and AVO maps at the prospective horizon. These maps thereby represent rock property contrasts at geologically consistent horizons (Figure 4).

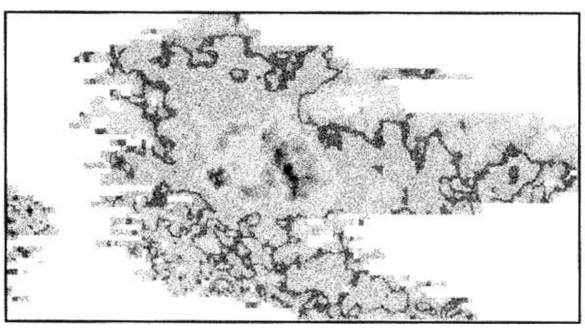

Fig. 4. Mapped horizon of an amplitude anomaly below 1500 meters of salt. Event is mapped from full volume 3-D depth domain prestack depth migrated seismic data.

Subsalt rock properties

The rock properties in the Golf of Mexico Subsalt Trend are strongly influenced by abnormally high pore pressure end low formation temperature making amplitude interpretations somewhat ambiguous without additional information (Figures 5,6).

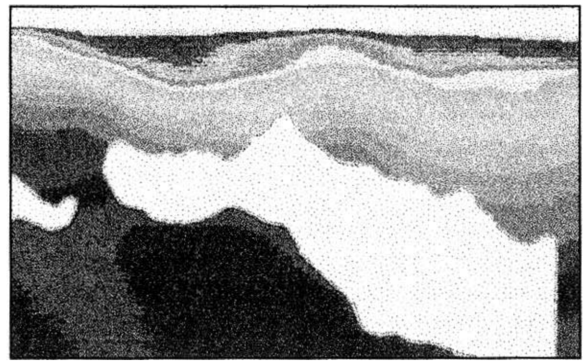

Fig. 5. North-South profile through 3-D pore pressure volume showing pressure anomalies above and below salt. Profile intersects Mahogany #l well.

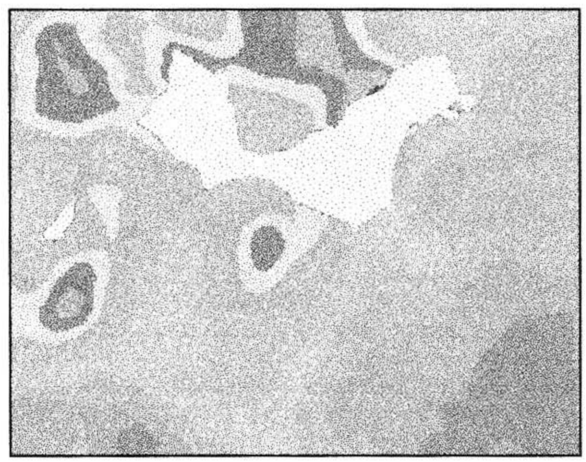

Fig. 6. Iso-depth map through 3-D pore pressure volume showing spatial variability of pore pressure.

AVO provides an additional dimension to amplitude analysis allowing the interpreter to better discriminate pay filled reservoir quality rocks from non-reservoir racks. Half-space AVO modeling indicates that en average shale-over-brine send should exhibit a decrease in absolute amplitude-versus-offset while similar models for pay tilled reservoir rocks should exhibit a mild increase in absolute amplitude-versus-offset.

The models are consistent with observations from 3-D depth domain AVO from 3-D PreSDM seismic date at the Mahogany discovery location in Ship Shoal South Addition block 349. In these data, the Phillips #1 well encountered low resistivity oil pay. The P-sand reservoir interval is responsible for the amplitude anomaly at 4400 meters depth

Sidetrack #3 from the Phillips #1 well location also encountered pay sands while the #2 sidetrack tested an (interpreted) unproductive, down-thrown interval at the P-sand depth.

Variations in AVO response are clearly seen in the seismic data (Figures 7, 8). Additionally, the character of the P-sand bright spot changes as a function of offset supporting the interpretation of a complex system of submarine fans and over-bank deposits. The seismic response changes with offset because of the rock properties contrast, the interaction of thin reflectors (AVO tuning) and variations in water saturation and clay volume.

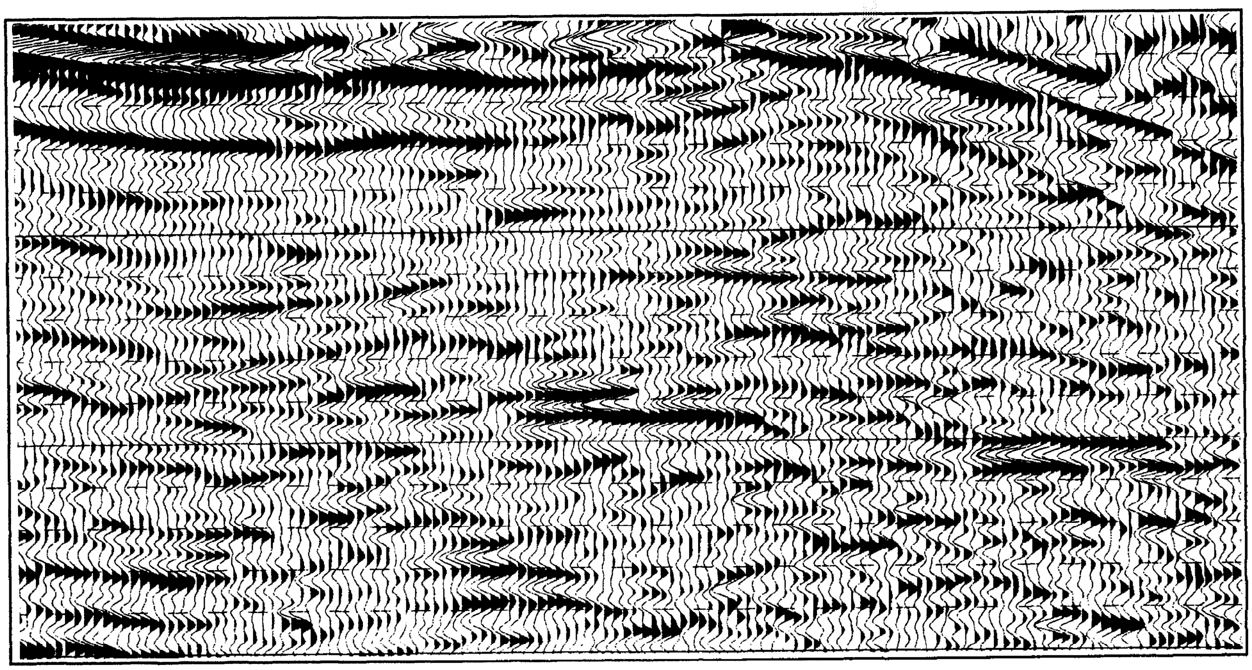

Fig. 7. North-South normal incidence profile through Mahogany #1.

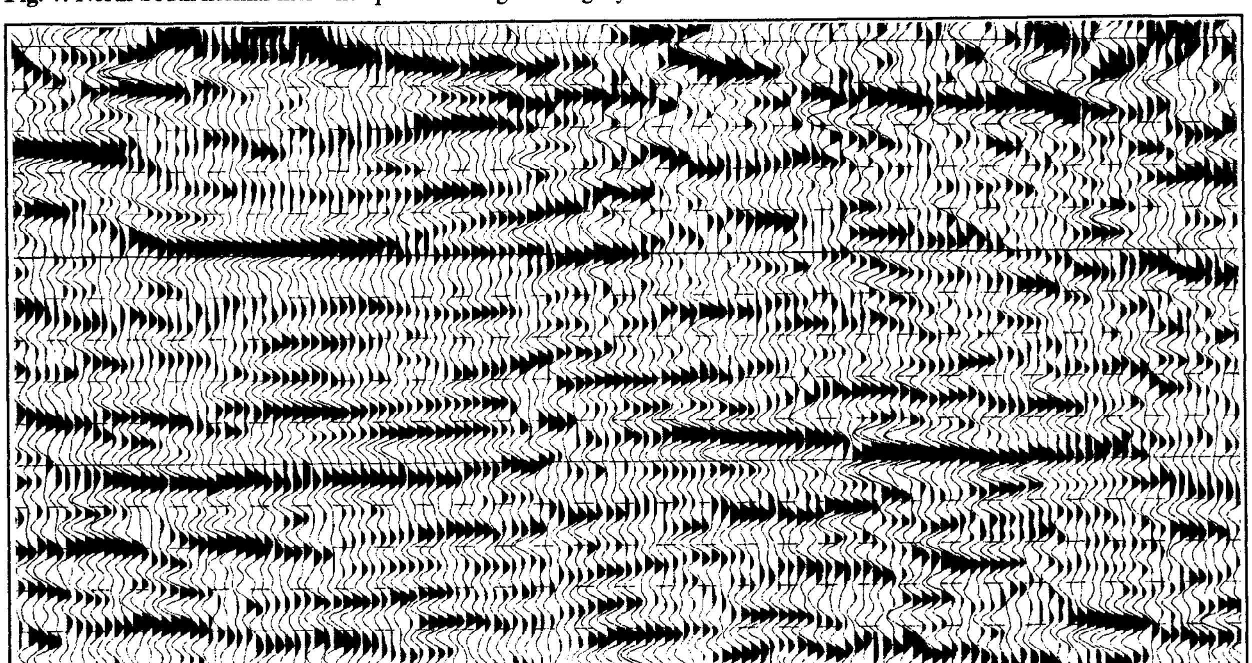

Fig. 8. North-South oblique incidence profile through Mahogany #1.

Depth domain 3-D AVO

Many methods of investigation have been employed in AVO analysis. Techniques range from visual interpretation of common midpoint gathers (CMPs) to three-parameter AVO inversion. The applicability of each method seems to be most closely coupled to the exploration question being asked and the overall quality of the available seismic data. Only within the past few years has the quality of 3-D PreSDM seismic data reached the level where 3-D depth domain AVO analyses below salt are possible (Figure 1).

Conclusions

Yet, from this complexity two simple interpretations emerge.

- AVO anomalies are associated with hydrocarbons.

- The quality of reservoir rock in the Gulf of Mexico Subsalt Trend may be predicted by 3-D depth domain AVO plan-view analysis.

Acknowledgments

The authors wish to thank Diamond Geoscience Research Corporation and Diamond Geophysical Service Corporation for the permission to publish this paper.

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