Using Converted Waves to Detect a Morrow Sandstone Reservoir

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Summary

Morrow sandstone reservoirs are often transparent to compressional waves, but can be recognized with pure shear waves (Blott, 1999). In the spring of 1999, a high resolution, 3D-3C seismic survey was acquired to characterize a Morrow valley-fill sandstone reservoir. The results of this study show that by using multicomponent seismic data, we were able to characterize the producing reservoir and provide crucial information for field development.

Introduction

Morrow valley-fill sandstone reservoirs in Oklahoma, Kansas, Colorado, and Texas have been a very elusive exploration target. Traditional compressional wave (P-wave) seismic methods often fail to image these relatively thin, discontinuous sandstone bodies. One of the main reasons for this lack of success is the low P-wave impedance contrast between the Morrow sandstones and the encasing Morrow shale. However, the shear impedance contrast is often many times greater than the compressional impedance contrast. Seismic methods that measure the shear response may be able to exploit this difference. The purpose of this study was to determine if high resolution 3D – 3C seismic could locate and characterize a Morrow sandstone reservoir at the Eva South field, located in Texas County, Oklahoma.

Geologic Setting

Eva South is located in the Oklahoma Panhandle, in the far northwest corner of the Anadarko basin. The reservoir at Eva South is an incised valley-fill sandstone, located at depths between 5500 and 5600 feet below ground level. The channel has a known width of one-half mile and a know length of about one mile. The reservoir sandstone ranges in thickness from zero to forty feet. Nearly two million barrels have been produced since the field's discovery in 1960 (Miller, 2000). A secondary waterflood was initiated in 1993.

Seismic Data

A 4.25 square mile 3D seismic survey was acquired for Ensign Oil and Gas in the spring of 1999. The survey was designed for optimal P-wave acquisition. Three-component geophones were deployed to recover mode-converted shear waves (PS-waves) along with the traditional compressional wave data. A vibratory source was used, with a 14 to 128 Hz sweep. Bin size for the survey was 82.5 X 82.5 feet.

Modeling the Seismic Response

Modeling studies show that imaging the Morrow sandstone with compressional seismic methods is nearly impossible. However, the reservoir can be imaged with converted waves. Figure 1 shows a reflectivity vs. offset cross plot for a single shale over sandstone interface. At near offsets, the P-wave reflectivity is nearly zero, and reverses polarity to a moderate trough at far offsets. The converted wave reflectivity is much stronger. For typical converted wave stacking angles of 25 to 35 degrees, the converted wave reflectivity is expected to produce a moderate reflection coefficient of about 0.1. For this survey, the maximum usable source to receiver offsets are about 6500 feet. This corresponds to intercept angles of approximately 30 degrees for P-waves and 37 degrees for PS-waves.

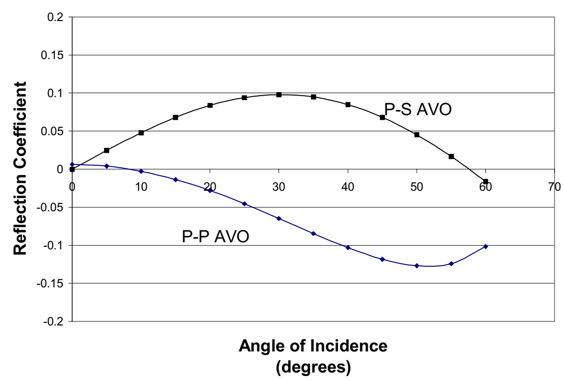

Figure 1. Compressional and converted wave AVO curves. Note the very weak P-wave amplitude at small angles of incidence and the moderate PS-wave amplitude at larger angles. Converted waves are often stacked in the 25 to 35 degree range

Since the reservoir at Eva South is relatively thin, it is important to model the seismic response in the presence of tuning. Synthetic modeling has shown that for thicker reservoirs, on the order of 100 feet, converted waves vividly image the sandstone while compressional waves fail to produce any significant reflection. The average reservoir thickness at Eva South is only about 30 feet. Figure 2 displays the correlation between P-wave and PS-wave synthetic seismograms for this case. As expected, the Morrow sandstone is invisible to P-waves, but a strong reflection is produced on the converted wave synthetic. Unfortunately, the top and bottom of the 30 foot thick sandstone is not resolved accurately. Synthetic models were also created for the case of zero sandstone. In this case the P-wave response showed almost no change from the 30 foot sand model, while the PS-wave response shows a significant decrease in the amplitude of the corresponding peak. By modeling different thickness' of the reservoir, we were able to develop a relation between the thickness of the Morrow sandstone and the amplitude of the seismic response.

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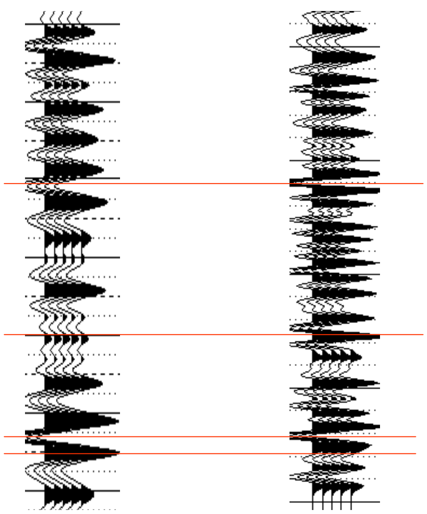

Figure 2. Converted wave (left) and compressional wave (right) synthetic seismograms. Note that the Morrow sandstone fails to produce a unique reflection on the compressional synthetic, while it appears as a strong peak on the converted wave synthetic.

Interpretation of the compressional wave data

Interpretation of the high-resolution seismic data provided new insights into the structural and stratigraphic complexity of the reservoir. P-wave coherency interpretation highlighted the presence of three major NE-SW trending faults, and numerous smaller faults. Recognition of these faults led to the realization that a regional stress direction, trending parallel to the faults, is influencing the quality of both the P-wave and PS-wave data. With this in mind, an azimuthal anisotropy investigation of the P-wave data was initiated. This study found that azimuthal anisotropy has considerable effects on determining proper static corrections and on the general imaging of both stacked data and AVO gathers. Azimuthal sectoring of the data aided in the interpretation.

Isochron mapping of the Morrow interval on the P-wave data accurately delineated the extent of the valley. Characterizing the actual valley-fill was more of a challenge. Since the reflection of the Morrow sandstone is such an offset dependent phenomenon, we believed that these offset limited volumes would provide some insight into the character of the valley-fill. Indeed, the investigation of the offset stacks showed that the AVO effect complicated the full stack image. Additionally, it was found that the near offset stacks provided a more consistent fold distribution over the majority of the survey. This helped us separate true anomalies from fold effects.

Interpretation of the converted wave data

A major challenge when working with converted wave data is to accurately correlate PS-wave reflections to their respective horizons. A converted wave synthetic seismogram was created to tie the data. This required inverting converted wave reflectivities and travel times (calculated from log data) into a new time series that could be input into standard synthetic modeling programs. The resulting synthetic seismogram correlates well with the PS-wave data.

The original converted wave data was reprocessed to enhance imaging. This effort focussed on compensating for shear wave birefringence and azimuthal anisotropy. The final volumes consist of migrated S1 and S2 data.

Amplitude extraction of the converted wave Morrow sandstone reflection aided in determining the location of valley-fill sandstone. Traveltime differences between the S1 and S2 reflections, as well as polarization directions of the converted wave data provided insight into the degree of fracturing within the reservoir. Vp/Vs ratios calculated from the P-wave and PS-wave isochrons were valuable in interpreting sand / shale ratios.

Conclusions

The high-resolution 3D-3C seismic survey was successfully used to determine the location of the Morrow incised valley and to characterize the valley-fill. In particular, the converted wave data provided crucial information for determining optimal reservoir development. Proper analysis of shear wave birefringence and azimuthal anisotropy was essential for accurate converted wave imaging.

References

Blott, J.E., Davis, T.L., and Benson, R.D., 1999, Morrow Sandstone Reservoir Characterization: A 3-D Multicomponent Success, The Leading Edge, March 1999, vol. 18, No. 3, pp 394 – 397

Miller, W.A., Wheeler, D.M. 2000, 3C-3D Seismic Characterization of the Eva South Morrow Sand Unit, Texas County, Oklahoma. 6th Annual RMAG-DGS 3D Seismic Symposium abstracts

Acknowledgments

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