Resolving Prospective Pay Zones Through Interpretation and Simultaneous Inversion of Spectrally-Broadened Seismic Data; Comparison of Conventional and High-Resolution Seismic Impedance Inversion of the Olmos tight sand

G. Porfiri (Swift Energy), X.E. Refunjol* (Swift Energy) & J.P. Castagna (The University of Houston)

Introduction

In South Texas, tight gas sandstone reservoirs in the Olmos Formation are prospective. Unfortunately, detecting and mapping the lateral continuity of reservoir quality Olmos sands is limited by the fact that prospective pay zones are commonly below conventional seismic resolution. Thus, spectral broadening is potentially valuable if it can be shown to be useful in this area. This paper describes seismic interpretation and simultaneous inversion results of an original and a spectrally-broadened high-resolution seismic dataset across the South Texas Olmos tight sand. The incorporation of high-resolution seismic data addresses the lack of enough vertical resolution to image thin beds within the Olmos productive zone. This high-resolution seismic data results from the application of the sparse-layer inversion method (Zhang and Castagna; 2011) to the original pre-stack seismic data. The method is unbiased against thin beds and thus allows the detection and resolution of thin beds below tuning thickness. In this study, we find that inverted, low P-impedance intervals in the Olmos are correlated to high production values; therefore, low P-impedance zone recognition is essential for productive-prone zone identification. High-resolution seismic data allowed the identification of additional reflectors in the Olmos productive zone that were below seismic resolution on the original data.

High-Resolution Seismic Data and Analysis

The study area comprises ~ 32 sq mi (83 sq km) region in South Texas. The study dataset includes full-azimuth, full-offset 3-D seismic gathers with a sample interval of 3 ms and an offset of 26,000 ft (7925 m) (80 degrees angle offset), an RMS velocity model, and four wells with a suite of digital well logs. Angles from 4 to 46 degrees were retained after gather conditioning. Four gas and/or oil producing wells in the database have P-wave, S-wave, gamma ray, and density logs. Three out of the four wells are horizontal wells and the logs interpreted in this work correspond to the vertical pilot well. Two wells are producing from the Olmos Formation.

On the original seismic data, the vertical resolution is 20 ms, which corresponds to a ~100 ft (30 m) tuning thickness (based on formation velocity). Therefore, the Olmos HPZ zone (107 ft/ 32.5 m maximum thickness) is at about seismic resolution. However, the thin beds within the Olmos high-porosity interval cannot be resolved on the seismic.

To improve seismic resolution, a sparse-layer inversion method developed by Zhang and Castagna (2011) was applied. Said method uses *a priori* information and spectral decomposition to improve the resolution, but does not directly utilize well logs in a starting model. Thin beds below tuning thickness (i.e. maximum constructive interference that occurs when the bed thickness reaches one quarter of the wavelength at dominant frequency (Kallweit and Wood, 1982; Brown, 2004)) can be imaged by inverting the frequency spectra for layer thickness using complex spectral analysis.

The process was applied to five different partial angle stacks. As a result, high-resolution pre-stack seismic data containing five traces was obtained (12°, 20°, 27°, 35°, and 42° angle traces).
compare these high resolution results with the original seismic data the workflow used was: 1) generation of post-stack seismic volume from the high-resolution pre-stack data; 2) re-sample the original seismic data so the volumes will have the same sample rate; 3) extract a statistical wavelet from the re-sampled original seismic data; 4) perform sparse-layer inversion to invert for reflectivity and convolve with a desired wavelet; and 5) apply an equal amplitude scalar to both post-stack volumes, since the amplitudes of the original and high resolution data were not balanced. This was followed by a visual comparison of both volumes.

Due to the higher level of detail the horizons had to be re-interpreted on the high-resolution seismic data. The maximum peak-to-trough amplitude occurs at 10 ms (TWT), when using a velocity model this translates to ~ 50 ft (15 m) of tuning thickness. The high resolution process thus doubles the original data resolution. The frequency spectrum of high-resolution seismic shows that much higher frequencies were added to the seismic when compared to the original. Consequently, two additional horizons are interpreted within the Olmos HPZ (Figure 1). These were the top and base of Olmos HPZ thin layers separated by shale breaks that could not be seen on the original seismic. This represents an important advantage since it could aid in the productive interval identification.

Figure 1. Two more horizons can be interpreted in the high-resolution seismic besides Top and Base of the HPZ. Blue represents positive seismic amplitudes and red negative seismic amplitudes.

Simultaneous Inversion and Analysis

Simultaneous inversion is one of the pre-stack seismic inversion processes in which lithologic volumes (P-impedance, S-impedance, and density) are created simultaneously. The method is based in three assumptions: 1) linearized approximation for reflectivity holds, 2) the Aki-Richards equation gives the reflectivity as a function of angle, and 3) there is, to first order, a linear relationship between P-impedance and both S-impedance and density (Gardner’s relationship: Δδ/δ=(1/4)(ΔVp/Vp), and Castagna’s equation: Vs=(Vp-1360)/1.16). Hampson-Russell software uses the AVO Equation (Fatti et al. 1994) that considers the P-reflectivity, S-reflectivity, a geometric factor (that includes the different incidence angles of the gather), and density reflectivity (Hampson and Russell, 2005).
The principal issue of this method is that the seismic input is band-limited. A time domain bandpass filter is applied to interpolated well logs to obtain the missing low frequencies in the original seismic, and the result is the “initial guess”. Then, by several iterations, using the conjugate gradient method, with the original seismic data, the generated inverted trace will contain the low frequencies and the original frequency spectra of the input seismic.
Figure 2. Original P-Impedance (top) and high resolution P-Impedance (bottom) lines across two control wells and corresponding P-Impedance Vatmin extractions between Olmos 2 and 3 horizons. Note the change in the anomaly distribution towards Southwest.

The analysis of the high-resolution seismic inversion shows that P-impedance decreases towards the South Southwest region (Figure 2). Low P-impedance trends can be recognized in that area. Cross-section along the wells shows low values within the HPZ. The impedance range is 24,000-29,000 (ft/s)*(g/cc), with lower values (less than 25,500 (ft/s)*(g/cc)) at OL-2. At OL-1, a new P-impedance anomaly can be identified (Figure 2).

Figure 2). The low impedance values correspond to the deeper thin layer identified on the high-resolution seismic. Thus, the high resolution process reveals prospective productive locations that are not apparent on a conventional seismic inversion.

Conclusions

The sparse-layer high-resolution seismic vertical resolution is double that of the original seismic data based on frequency bandwidth; this is verified by well ties. This allowed the interpretation of additional horizons within the interval of interest in the high-resolution seismic data.

Horizon extraction comparison between original vs. high-resolution inverted P-impedance of the HPZ shows different anomaly distribution in the Southwest region. A productive well, previously not associated with an impedance anomaly, is seen to consist of thin pays that were not previously resolved, but can be mapped on the high resolution data. Using the additional interpreted horizons allowed the localization of that low p-impedance layer within the HPZ.

We conclude that high-resolution seismic inversion may allow better definition of productive zones in the Olmos formation.

Acknowledgements

The authors would like to thank Dr. Bruce Moriarty and Dr. Robert Stewart for their invaluable time and contributions. The authors would also like to express their thanks to Swift Energy for their support, Global Geophysical for kindly granting permission to display this dataset, as well as Lumina Geophysical for processing the high resolution data used in this investigation.

References


