Elastic waveform inversion with multiple reflections for onshore unconventional reservoirs.

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Summary

Elastic waveform inversion (EWI) was employed in an onshore unconventional 3-D seismic survey with two objectives. The first objective was to understand the response of EWI to multiple reflections. The second objective was to investigate the improvement in imaging over the production prestack time migrated stack through the use of the EWI based compressional wave reflectivity when using primary reflections or primary and multiple reflections. The understanding of the EWI sensitivity to multiple reflections is very important for reservoir characterization, even when using low amplitude residual multiple reflections. Furthermore the possibility of using EWI compressional wave reflectivity computed using both primary and multiple reflections removes to a great degree the stratigraphic and structural interpretation uncertainties resulting from multiple reflections.

Introduction

For the development of unconventional reservoirs, high quality imaging and accurate rock property estimation are necessary. The presence of multiple reflections can do damage to seismic inversion results and hence impact negatively the rock property estimation. In the present study, we studied EWI in two cases. In the first case the multiple reflections were very highly attenuated. In the second case, the multiple reflections were included in the seismic inversion along with the primary reflections.

In this case study, we show that the difference in EWI results between including and not including multiple reflections is very small. In addition, we demonstrate that the post-migration EWI when including multiple reflections generates a P-wave reflectivity imaging result that is much better than the conventional prestack time imaging stack.

Method

The geology of the study area is comprised of vertically heterogeneous distal to proximal marine shelf successions of marl, limestone, and organic rich calcareous mudstone 'unconventional' reservoirs. Shelf architecture during deposition controls lateral stratigraphic heterogeneities internal to the unconventional reservoirs. Determining the distribution of clay, calcite, quartz, and organic material within the reservoir is critical to optimization of lateral position, production performance, and sweet spot delineation within the play fairway.

The land 3-D seismic data used in this study is a subset of a larger survey and includes 119,723 Vibroseis shots and 51,221 receiver positions. The 3-D seismic data acquisition was wide azimuth and had maximum offsets of approximately 20,000 feet. The seismic bandwidth was 3-95 Hz and the CDP bin spacing in the inline and crossline spacing were 41.25 feet and 82.5 feet respectively. The raw field shot gathers were first geometry checked and a spherical divergence correction was applied with a picked brute velocity. The first arrival traveltimes were then picked on the data set and subsequently inverted with a non-linear tomography from topography. The tomography traveltime RMS error was 9.6 ms. After the traveltime tomography, tomostatics were applied, and then the following processing steps were applied: a) minimum phase conversion, b) CMP gather denoising, c) surface consistent deconvolution with 220 ms operator and 24 ms gap, d) two passes of velocity analysis at 0.5 x 0.5 mile spacing, e) a proprietary seismic scaling, f) three passes of reflection residual statics and finally g) migration velocity picking for migration velocity analysis. The prestack time migration residual moveout correction was then applied.
The resulting time imaging result was of high quality and correlated to the well log synthetic seismogram used in this study with a 0.80 correlation coefficient.

Elastic waveform inversion theory was developed in the late 1990s and early 2000s (Roy, et al., 2004), with several case studies published in Lau, et. al (2007), Hilliard, Vassiliou (2010), and Vassiliou et al. (2017). The elastic waveform inversion is wave equation based and is applied directly to PSTM gathers with NMO removed and it requires only a single wavelet. Furthermore both primary and multiple reflections can be modeled within the elastic waveform framework. It has been repeatedly demonstrated that elastic waveform inversion yields superior results to other seismic inversion methods.

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Examples

The EWI case study was conducted on a 20 square mile subset area of the USA onshore 3-D survey. The inputs to both the EWI were the prestack time migrated gathers, the picked seismic horizons and two of the several wells available in this area. The remaining wells were used as blind wells for the seismic inversion test.

The post-migration EWI uses the prestack time migrated gathers after NMO correction removal and a Ricker wavelet with peak frequency of 40 Hz. In order to compare the accuracy of the elastic waveform inversion in the presence of multiple reflection, we employed two data sets. The first data set has multiple reflection denoising applied to it. The second data set has no multiple reflection denoising applied to it. The gathers with multiple reflection denoising are shown in Figure 1a, the gathers with no multiple reflection denoising are shown in Figure 1b, the prestack time migrated stack is shown in Figure 1c.

The results from the EWI on a blind well are shown in Figures 2a and 2b for the P-wave velocity estimation, 3a and 3b for the S-wave velocity estimation and 4a and 4b for the bulk density estimation. For each of the elastic parameters Vp, Vs, Rho the first of the two figures correspond to the primary only reflection elastic waveform, while the second figure corresponds to the primary and multiple reflection elastic waveform inversion. The production prestack time migrated stack, the P-wave reflectivity with the primary reflections only and the P-wave reflectivity with the primary and multiple reflections are shown from the left to the right in Figure 5.

The comparison of the EWI results between a) using primary reflections only and b) using both primary and multiple reflections shows very small differences, practically negligible for rock property estimation. As a consequence, the difference of the EWI generated compressional wave reflectivity using as input either primary reflections only; or both primary and multiple reflections is very small as well. The comparison between any of the two EWI compressional wave reflectivity volumes with the production generated prestack time migrated stack, shows the clear superiority of the EWI P-reflectivity volume. Hence, the EWI compressional wave reflectivity volume computed using both primary and multiple reflections as input can be used instead of the production prestack time migration stack for decidedly better stratigraphic and structural imaging.

Conclusion

The difference of the post-migration prestack elastic waveform inversion when including primary reflections, versus when using both primary and multiple reflections is negligible. Additionally, the EWI compressional wave reflectivity computed using both primary and multiple reflections has wider seismic bandwidth and higher spatial resolution than the conventional PSTM stack. As a result, the primary and multiple reflection input based EWI compressional wave reflectivity volume can be used for seismic interpretation instead of the production prestack time migrated stack.

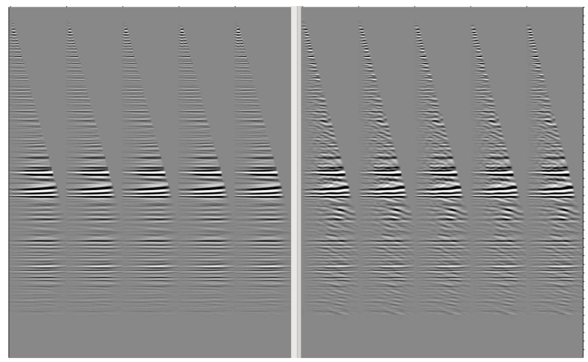


Figure 1a and 1b. Prestack time migrated gathers with denoised multiple reflections on the left and no denoising on the right.

Seismic imaging

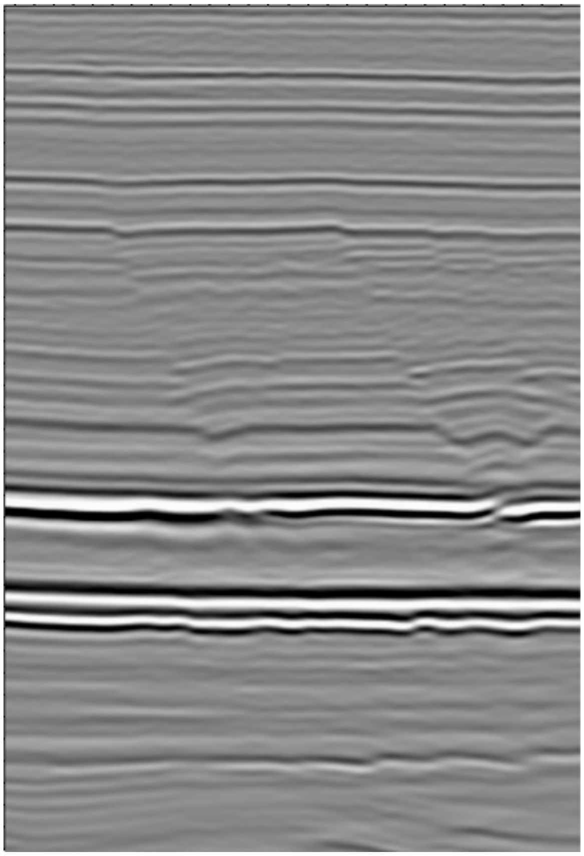
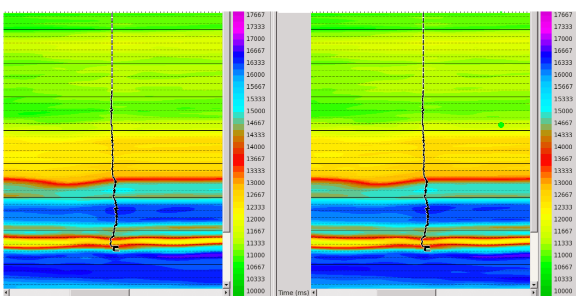
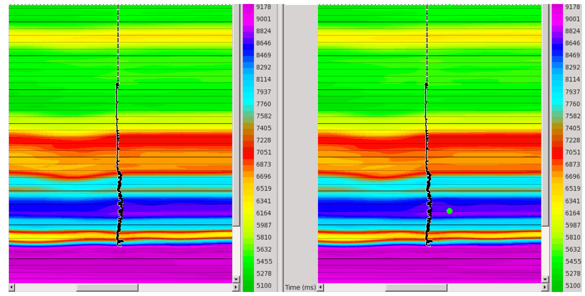


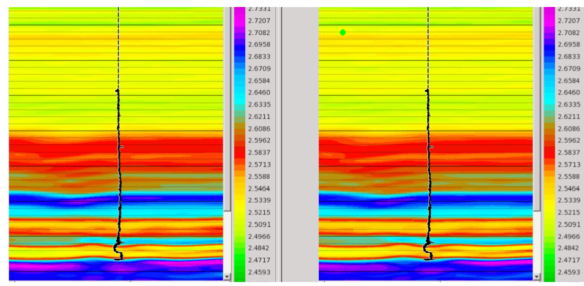
Figure 1c. Prestack time migrated stack.



Figures 2a and 2b. Comparison of EWI P-wave velocity inversion with only primary reflections (left) and also with primary and multiple reflections (right).



Figures 3a and 3b. Comparison of EWI S-wave velocity inversion with primary reflections only (left) and with primary and multiple reflections (right.)



Figures 4a and 4b. Comparison of EWI bulk density inversion with primary reflections only (left) and with primary and multiple reflections (right.)

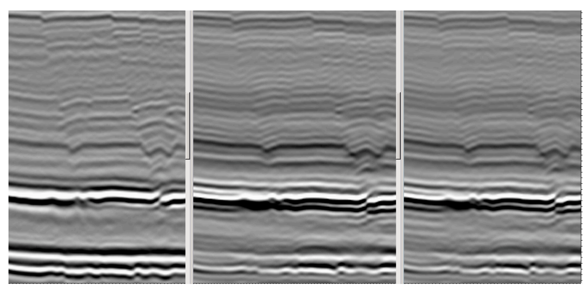


Figure 5. From the left to the right: Production prestack time migrated stack, P-wave reflectivity with primary reflections only and P-wave reflectivity with primary and multiple reflections