Comparison of angle stack and prestack waveform inversion: U.S. onshore Gulf Coast

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Summary

Redevelopment of old fields in the U.S. onshore Gulf Coast requires identifying reservoir compartments and inter-well connectivity, as well as verification of fluid content in undrilled areas. New drill locations are mainly attic locations in water drive reservoirs and reservoir compartments that were not penetrated by existing wells. Seismic inversion can be used as another tool to de-risk drill locations and improve pre-drill reserve estimates. Seismic inversion allows estimating elastic parameters directly without having to interpret phase reversals or other complicated AVO response characteristics. Poisson ratio is the best discriminator for fluid content in the study area based on well log evaluation and fluid substitution modeling

An angle stack based inversion was done to see if a Poisson ratio volume could assist in evaluating and finding drill locations. Numerous low Poisson ratio anomalies were identified, but most tied into wet sands in existing wells. It was determined that this method was not reliable enough. A full waveform prestack inversion was then completed and this method seems to be more stable and reliable when tied into existing well control.

Introduction

Oil and gas production in the study area is from Upper Miocene age sediments in both normal pressured and geopressured environments. AVO class II and III is the dominant hydrocarbon signature. Reservoirs depths range from 2000-20,000 feet.

The 3D survey was acquired in 1995 with far offsets to 19980 feet with an average of 30 fold. The data set is a Kirchoff prestack time migration done in 2006. A continuous velocity analysis every CMP was used to generate a 3D velocity volume.

The key well has a full log suite from 3500-14550 feet that includes compressional velocity, shear velocity (dipole sonic), and density. This well was used in both inversions to determine the wavelet and the well to seismic amplitude scaling. A synthetic seismogram at the key well location was used to verify the well tie and a wavelet was extracted at the key well location.

Angle Stack Inversion

The inversion inputs:

- 6 angle stacks – 2-9, 9-16, 16-23, 23-30, 30-37, and 37-44 degrees
- Compressional velocity (Vp) background model generated by smoothing the continuous seismic velocity analysis volume.
- Shear velocity (Vs) background computed by Vs=0.778*Vp-3120 (m/sec)
- Density background model provided by third party using continuous velocity analysis and well control.
- Wavelet estimation for each angle stack

Inversion workflow:

1. CMP gather conditioning (TVF+ trim statics + AGC)
2. Log calibration and wavelet estimation
3. Simultaneous AVO relative inversion
4. Generate low frequency model
5. Simultaneous absolute AVO inversion

Inversion outputs:

- Acoustic Impedance, Poisson ratio, and Density volumes

Flattening the seismic gathers was a serious issue. Trim statics were necessary to try and flatten the prestack time migrated gathers. The results were still not perfectly flat and ultimately we believe this is the primary reason the inversion results were unreliable.

Prestack Waveform Inversion

The inversion inputs:

- Denoised prestack time migrated gathers with NMO removed
- Compressional velocity (Vp) background model used the continuous seismic velocity analysis volume.
- Shear background model computed from Vs= 0.8*Vp-1.0 (km/sec)
- Density background model (Rho) computed by Rho=2.1+(0.368*(Vp-2.88) (g/cc)

Outputs from the inversion:

- Vp, Vs, and Density volumes
- Impedance and Poisson ratio volumes were computed from the three output volumes.

Comparison of angle stack and prestack waveform inversion

Comparisons of the two techniques

There are some significant theoretical and practical differences between the prestack waveform inversion and the angle stack inversion (Roy et al. 2004; Roberts, et al. 2005). The prestack waveform inverts for two-way traveltime, waveform and phase. First, prestack waveform inversion is applied directly on prestack time migrated gathers with NMO correction removed. Second, the prestack wavefom inversion does not have a requirement for the migrated gathers to be flat and also there are no issues with far offset stretch. Furthermore prestack waveform inversion works well with gathers in class II AVO environment with reverse polarity. Third, prestack waveform inversion can work with only primary reflections or with both primary and multiple reflections. Fourth, there is only one wavelet used in the prestack waveform inversion.

A trace was extracted from each inversion output volume and compared to the filtered well log data at the key well location. Since this was where the wavelet and scaling was estimated one might expect a good tie between the inversion estimates and the well logs. Compressional velocity (Vp), shear velocity (Vs), density (Rho), acoustic impedance (AI), and shear impedance (SI) are overlaid and compared. In all cases the prestack waveform inversion was a better estimator. Both methods did not reproduce velocity inversions. This is probably due the background model being derived from stacking velocities. The prestack inversion underestimates the true values in the pay sand but is proportional and more stable. The density from the angle stack inversion is unusable.

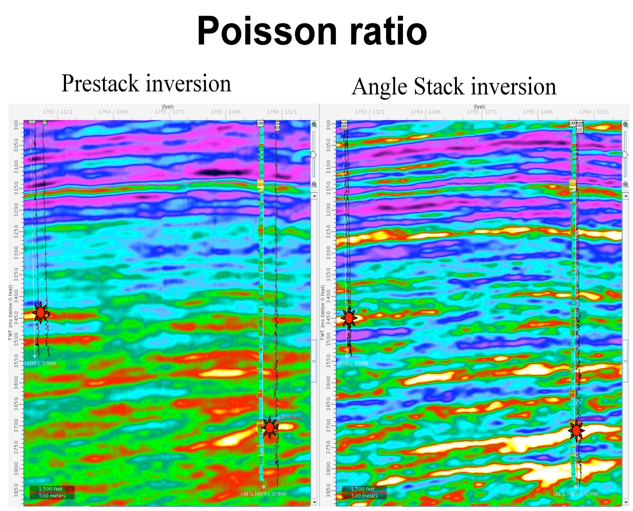
An inspection of one of the false anomalies on the angle stack inversion indicates the misalignment of the seismic events on the gather as the probable cause in an incorrect Poisson ratio calculation. The amplitude versus angle plots show a large difference in the intercept and gradient calculations due to the misalignment. This misalignment was very small, but had a big impact on the inversion result.

A comparison of using cut-offs to detect anomalies as geobodies is compared for each inversion result. As expected, the angle stack inversion shows hundreds of anomalies where the prestack waveform inversion is a better match in areas of known production. An example of a horizon based geobody extraction using cut-offs for a particular reservoir sand displays anomalies downdip of known wet wells in the angle stack volume, where the prestack inversion matches the gas/water contact much better.

Conclusions

Both inversion methods utilized the same well for wavelet estimation and scaling as well as using the stacking velocity volume as a basis for the background model. The angle stack method required 6 restricted range angle stacks where the prestack inversion utilized the prestack time migrated gathers with NMO removed. The prestack inversion benefited from denoising the gathers prior to inversion while the angle stack method used more traditional processing for noise reduction (radon transform). The use of 6 different wavelets in the angle stack inversion may have impacted the reliability of the results.

Both data sets exhibit low Poisson ratios at known pay sands. The prestack waveform inversion is more stable and matches the key well in both known and wet sands. The angle stack inversion also shows pay anomalies in wet sands. The prestack waveform inversion underestimates the true Poisson ratio in pay sands, but is stable enough that cut-offs can be used to detect hydrocarbon bearing sands. The density estimation from the angle stack inversion is unusable.



(a) (b)

Figure 1. Poisson Ratio inversion results
(a) Prestack waveform inversion; (b) Angle stack inversion; Note multiple low Poisson Ratio anomalies in (b) that are not present in (a).

Comparison of angle stack and prestack waveform inversion

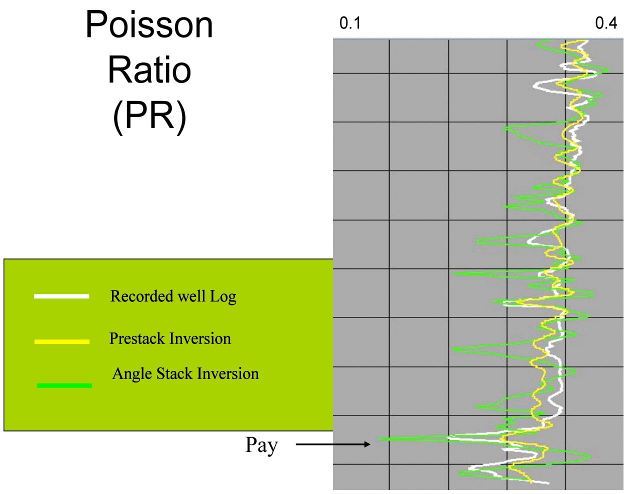


Figure 2. Poisson Ratio inversion results at key well. Note the overall good match of the prestack inversion and the multiple low Poisson ratio anomalies on the angle stack inversion result.

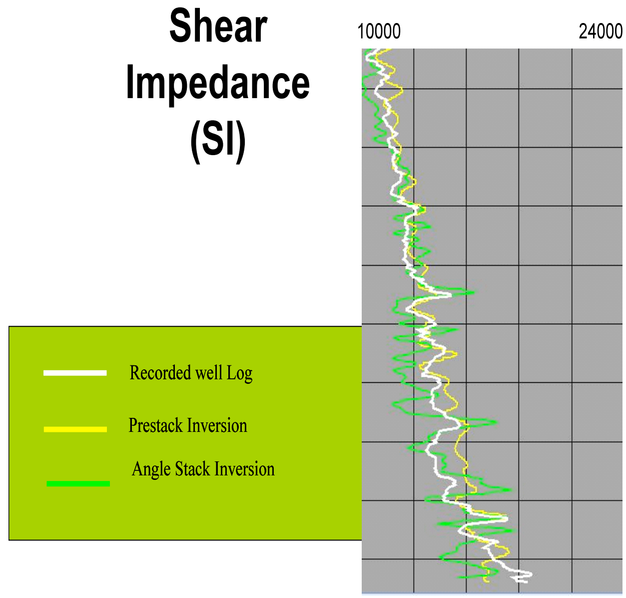


Figure 4. Shear Impedance at key well.

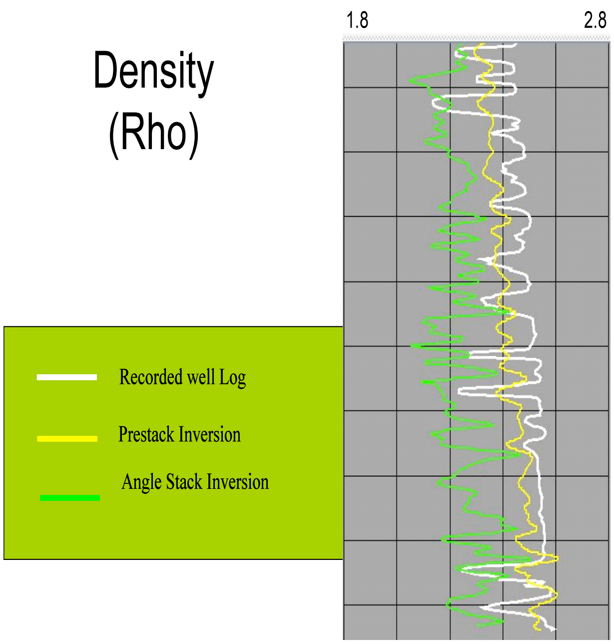


Figure 3. Density inversion results at key well. The angle stack inversion results are unusable while the prestack inversion results are much more stable.

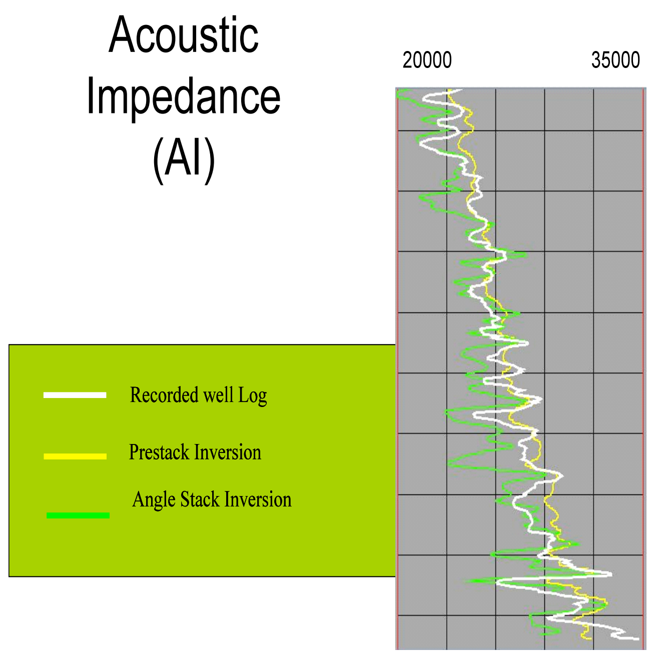


Figure 5. Acoustic Impedance results at key well.