Application of elastic prestack waveform inversion to acoustically transparent Cretaceous age gas sands

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Summary

Seismic identification of gas charged reservoir quality sandstone is very difficult when the acoustic impedance contrast between the reservoir and non-reservoir rocks is close to zero. This is the situation with many Cretaceous sandstones in the northern part of the Western Canadian Sedimentary Basin in Alberta, Canada. Well log crossplots show that gas charged reservoirs and bounding shales and siltstones have very similar acoustic (P- wave) impedance. However gas charged reservoirs always have significantly lower Poisson's ratios and Vp/Vs ratios than non-reservoir rock. A robust elastic prestack waveform inversion is necessary to generate accurate Poisson's ratio volumes which can identify the thin gas sands.

Over the last few years we have seen an increasing application of elastic prestack waveform inversion to both marine and land data. One reason for the increasing application is due to significantly more computational capacity available. Another reason is the substantially improved optimization algorithms currently employed in the prestack waveform inversion.

In this paper we report on a successful case study of the application of prestack waveform inversion to map thin gas charged sandstones.

Introduction

A 3-D seismic survey originally shot in 1999 was purchased by Samson in 2007. The survey had a bin size of 30 by 60 meters and nominal maximum offsets of 4740 meters. The survey covered an area of 180 square kilometers under which 30 wells had been drilled to the formations of interest based on well control alone. The economic results of many of the previous wells were marginal so the decision was made to buy and reprocess the survey in an attempt to map the prospective sandstones.

The target interval is Lower Cretaceous sand, silt and shale deposited in continental to marine environments and currently found at depths of 2300 – 2800 meters. Many of the reservoirs were deposited in a deltaic environment in which thick coals were also deposited. These coals generate the largest amplitudes of the seismic volume. Seismic modeling and interpretation of the PSTM volume showed that post stack amplitude was not effective at identifying the sandstone reservoirs. Well logs and elastic modeling indicated that a Poisson's ratio volume would give the best chance of identifying reservoirs.

Elastic prestack waveform inversion generates accurate elastic parameters P-wave velocity, S-wave velocity and density. Byproducts of the inversion are the Poisson's ratio and the P-wave and S-wave impedances.

The prestack waveform method was chosen for the elastic inversion because it has several advantages compared to angle stack inversion methods. Some of these advantages are related to the use of the complete gather after reverse NMO correction, use of the interval velocity field, and use of a very smooth starting model related to the migration velocity field. Unlike many other methods of elastic inversion, there is no NMO stretch on the far offsets and the low frequency part of the inversion comes directly from the PSTM velocities instead of well control or picked time horizons.

Processing and Prestack waveform inversion

The 3-D land data covering the zone of interest was re-processed from field tapes. The following processing sequence was employed after geometry application, bad trace editing and spherical divergence correction:

- Refraction statics
- Surface consistent deconvolution and amplitude balancing
- Velocity analysis
- Residual statics
- Velocity analysis and residual second pass
- Zero-phasing
- Prestack time migration
- Prestack time migrated gather denoising.

The prestack migrated gather denoising is an essential step prior to the use of the prestack waveform inversion. It substantially attenuates the migration artifacts, coherent noise and other events which would otherwise impede the prestack waveform inversion (Lionel, et at. 2005).

The prestack waveform inversion is applied after prestack time migration where the 1-D local model assumption per each CDP gather is reasonable. The reflectivity method of Kennet (1983) is used for forward modeling. The Frechet derivatives are computed in a similar fashion to Randall (1989). The optimization objective function in the prestack waveform inversion method is composed of both a data misfit part and a regularization part. The optimization is iterative for each separate CDP gather. The computation of the regularization parameter is done through the Engl discrepancy principle as it has been applied in Roy et al., (2004) and Lau et al. (2007).

Interpretation

An example well log from the area is shown in Fig. 1. The reservoirs are readily identified by the low values on the Poisson's ratio log. Intervals with Poisson's ratio < 0.2 are highlighted in orange. Figure 2 shows this effect in cross plot space of Poisson's ratio vs. density. Pay zones are highlighted by larger squares. All pay intervals have Poisson's ratio < 0.2.

The Poisson's ratio volume was the primary volume used for interpretation. Existing high productivity wells correlated well to low Poisson's ratios at the appropriate interval. Figure 3 shows a line from the Poisson's ratio volume through a productive well and a non-productive well from one of the target formations. The productive interval is shown by the orange anomaly (low Poisson's ratio value) at about 1.5 sec.

A variety of attributes were applied to the Poisson's ratio volume to help image the thin (5 to 15 meters) productive sands including spectral decomposition and wavelet correlation mapping. Three different Cretaceous pay intervals were mapped and three of the best anomalies were targeted for drilling during the 2008 winter drilling season. All wells are currently producing from at least one of the targeted intervals.

Conclusions

Elastic prestack waveform inversion is an effective process for generating accurate elastic parameters P-wave velocity, S-wave velocity, and density. From these volumes a Poisson's ratio volume can be calculated. Low Poisson's ratio is a better discriminator of a porous gas saturated reservoir than any of the other parameters. Drilling of three wells in the Lower Cretaceous of northern Alberta proved that the Poisson's ratio volume can be used to image gas charged sandstones that are not visible on stacked seismic data.

This method can be applied to other situations where the acoustic impedance of the reservoir rock is very similar to that of the non-reservoir rock and productive gas sands cannot be identified on stack data.

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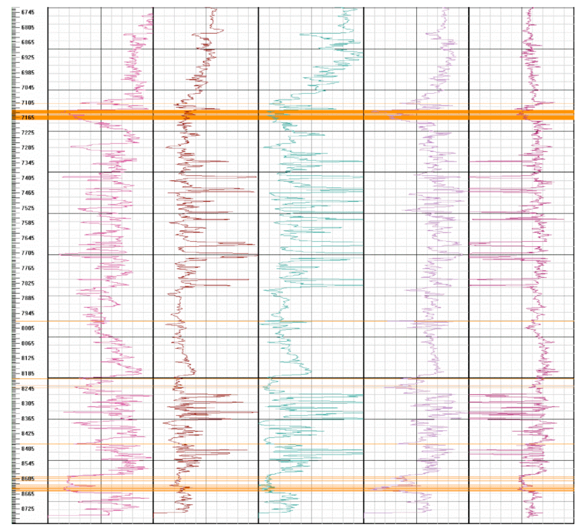

Figure 1. Well logs through formations of interest from left to right are Gamma Ray, P Slowness, S Slowness, Poisson's ratio, and Density. Zones with Poisson's ratio less than 0.2 are highlighted in orange. This well produces from the shallow thick orange zone.

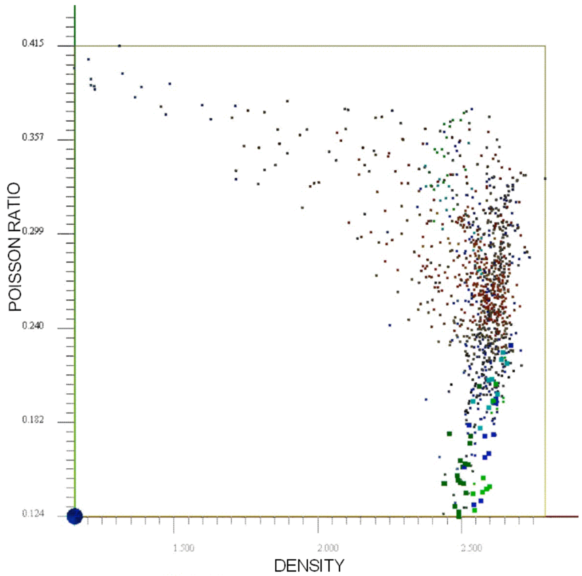

Figure 2. Crossplot of Poisson's ratio (y) and Density (x) from well logs. Productive sandstones are shown as larger squares. Most producing zones have Poisson's ratio < 0.2.

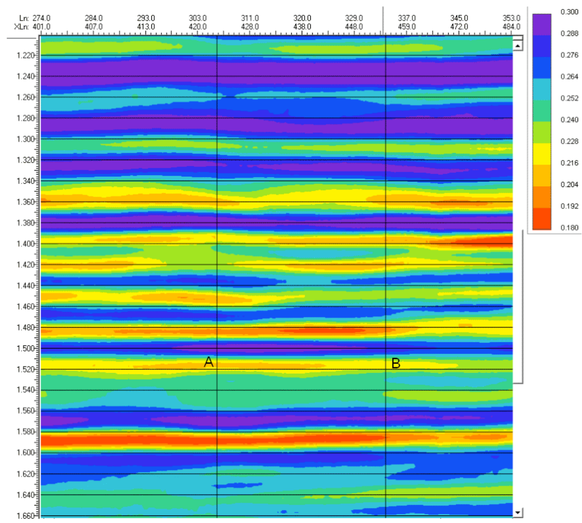

Figure 3. Poisson's ratio section through a productive well (A) and non-productive well (B). Productive interval is at 1.52 sec. Lower Poisson's ratio values are orange and red.