Analysis of time-lapse difference AVO with the Pouce Coupe field data

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Introduction

Time-lapse seismology is a cost-effective approach for monitoring the changes in the fluid saturation and pressure over a period of time in a reservoir. In a time-lapse seismic, multiple seismic surveys are acquired at different time intervals and then compared to see reservoir changes (Landro 2001). A multicomponent time-lapse seismic data set was acquired during hydraulic fracturing of two horizontal wells in the unconventional Montney Reservoir at Pouce Coupe Field in the Peace River area by Talisman Energy Inc. In the present study, in conjunction with Talisman Energy Inc., the Pouce Coupe time-lapse data set, is used to validate the theoretical linear and nonlinear time-lapse AVO difference derived by Jabbari et al. (2015).

Theory

The amplitudes of reflected P-wave striking on the boundary of a planar interface between two elastic media, incident medium (cap rock) and reservoir with rock properties V_{P0}, V_{S0}, ρ_0, V_{PBL}, V_{SBL}, ρ_{BL} as in baseline survey and V_{Pm}, V_{Sm}, ρ_m as in the monitor survey, are calculated. Setting boundary conditions in the problem leads to Zoeppritz equations which can be rearranged in a matrix form (Keys, 1989, Aki and Richards 2002). The reflection coefficient difference between the Baseline and Monitor surveys is then calculated as:

$$\Delta R_{PP}(\theta) = R^m_{PP}(\theta) - R^b_{PP}(\theta) \qquad (1)$$

$\Delta R_{PP}(\theta)$ is then expanded in order of physical change or baseline interface contrast and time-lapse changes (changes in V_P, V_S, ρ) and $\sin^2\theta$.

$$\Delta R_{PP}(\theta) = \Delta R^{(1)}_{PP}(\theta) + \Delta R^{(2)}_{PP}(\theta) + \Delta R^{(3)}_{PP}(\theta) + ... \qquad (2)$$

More details can be found in Jabbari et al. (2015).

Pouce Coupe time-lapse, Multicomponent Seismic Data

4D time-lapse, multicomponent seismic surveys were acquired by Talisman Energy Inc. at the Pouce Coupe Field which is located on the border of Alberta and British Columbia in the Peace River area . The target formation in these seismic acquisitions was Triassic Montney Shale reservoir (Figure 1).

Figure 1: Pouce Coupe Field on the border of Alberta and British Columbia, Source: Birchcliff Energy November 2013.

For economic production, enhanced permeability pathways of natural and induced fractures are required due to the tight nature of the Montney (Davies 1997). Figure 2 shows vertical and horizontal wells with fracture operations and the timeline of the baseline and monitor surveys. Seismic data was recorded by CGGVeritas on a patch grid of about 5 km^2. The bin size is 50 m $\times$ 100 m (patch is twice bigger in E-W direction). A result of the survey design was uniform 360° azimuth for different offset distribution (340-3011m). The processing flow includes statics, prestack noise attenuation, surface consistent deconvolution, CMP (common mid point) stacking, FK (frequency enhancement) filter, radon multiple, normal 2-term moveout, and Azimuth Detection and Rotation (RADAR) and was completed by Sensor Geophysical Ltd.

Pouce Coupe time-lapse, Multicomponent Seismic Data continued

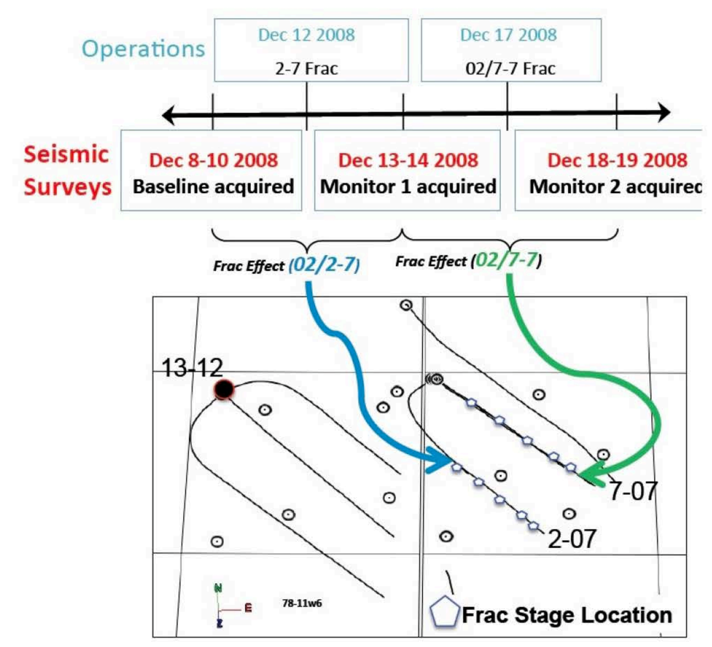

Figure 2: Pouce Coupe time-lapse seismic and field operations timeline. Two horizontal wells hydraulically stimulated (2-07 well and 7-07 well) and the location of the vertical shear sonic log (13-12 well). Modified from Atkinson (2010).

Methodology

A synthetic seismogram was generated using a wavelet extracted from the horizontal well, 102-02-07-078-10W6, and reflectivity derived from P-wave sonic and density logs. The S-wave log is calculated using Castagna's Equation with parameters of $V_S = 0.8619 V_P - 1172$ m/s. This synthetic seismic trace is aligned to the seismic section at the well location to relate horizon tops with specific reflections on the seismic section (Figure 3).

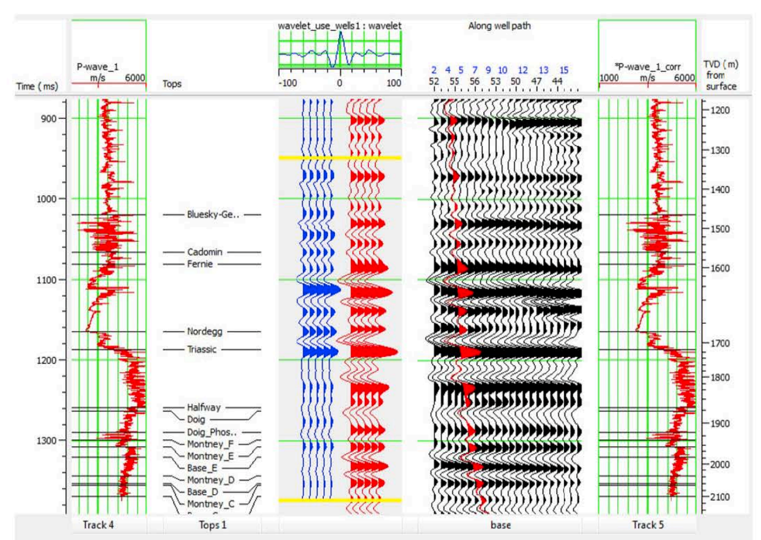

Figure 3: Vertical well tie with Baseline P-wave seismic.

The synthetic trace has been used to estimate the depth of different horizons, specially the target horizon, the tops of Montney C and D (Figure 4). The same method can be used to interpret the seismic data for the Monitor seismic sections. As all log data were acquired at the time of the Baseline survey and before inducing the fractures, the synthetic logs for the Monitor survey are modeled by simulating the parameters in the systematic changes during the fracture operations.

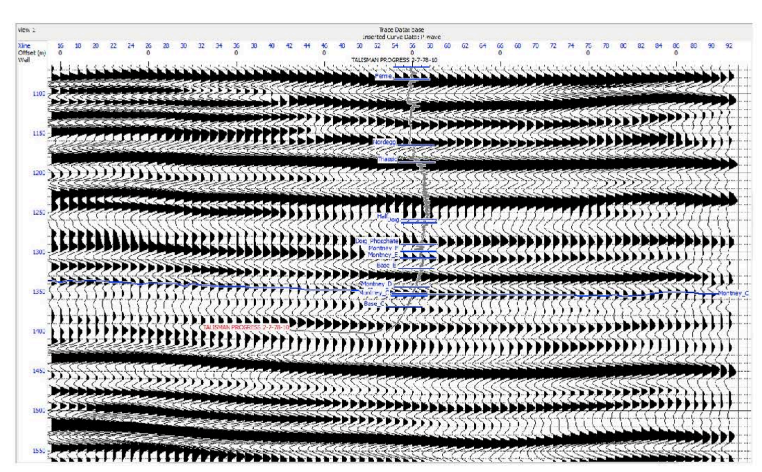

Figure 4: Estimating the horizon times on the seismic section by tying synthetic in Figure 3 to the Baseline seismic data.

Results

With three sets of the P-, S- wave velocities, and the density for the Formation above the reservoir or target, and the reservoir itself before and after the fracture, exact $\Delta R_{PP}(\theta)$ for the Baseline, Monitor, and their difference are calculated using the Zoeppritz equations (Figure 5 and 6).

Results continued

The red curve representing the time-lapse difference reflection coefficient is almost at zero for all offsets. The reason is because the reflection coefficient, R_{PP}, for the Baseline and Monitor surveys are almost identical. The seismic parameters, P-, S- wave velocities, and density for the reservoir Formation at the time of the Baseline survey relative to the Monitor survey are similar. This explains the similarity of reflection coefficient for the Baseline and Monitor surveys. Choosing another interface such as the base of the Doig or the base of the Montney E gives a higher contrast in the Baseline survey.

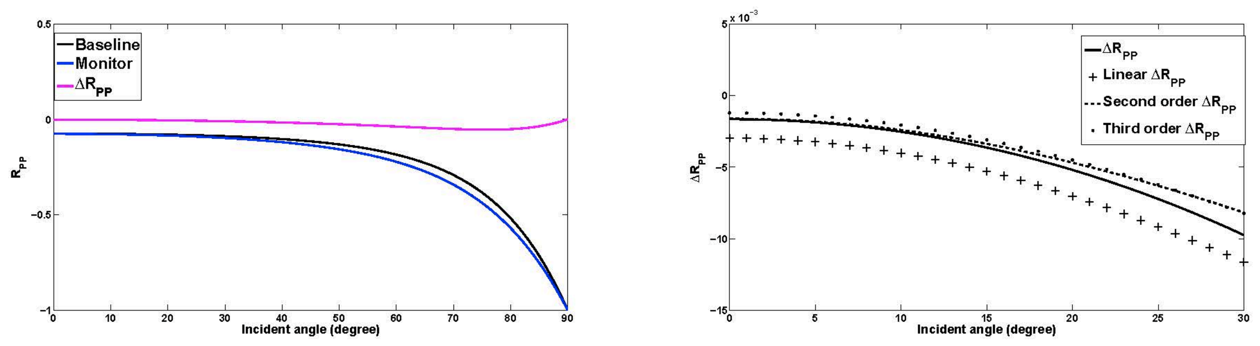

Figure 5: Left:$R_{PP}(\theta)$ for the Baseline (black) and Monitor (blue) surveys and for their difference (red), $\Delta R_{PP}(\theta)$, for Pouce Coupe data set. Right: $\Delta R_{PP}(\theta)$ for the exact (solid line), linear (+++), second (—), and third order (...) approximation for Pouce Coupe data set

Conclusions

An increase in pore pressure has been induced following hydraulic fracture operations in the unconventional Montney shale reservoir. This will affect seismic parameters including the compressional wave velocity. Jabbari et al. (2015) concluded that the higher order terms in time-lapse AVO represent corrections appropriate for large P-wave and S-wave velocity and density contrasts in the reservoir from the time of the Baseline survey to the time of the Monitor survey. The Pouce Coupe data set shows low contrast between the cap rock and reservoir in the Baseline survey and also lower contrast in time-lapse changes from time of the Baseline survey relative to the time of the Monitor survey. Therefore, linear approximation is good enough to approximate time-lapse difference for the Pouce Coupe data set for the top of the Montney C or Montney D layers as the reservoir interfaces. Because of the small time-lapse contrast, this data set is not an appropriate data set which can be used to evaluate the nonlinearity of time-lapse AVO difference results.

ACKNOWLEDGMENTS

The authors thank the sponsors of CREWES for continued support. This work was funded by CREWES industrial sponsors and NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 461179-13. Author 1 was also supported by a scholarship from the SEG Foundation. We also thank Talisman Energy Inc. part of Repsol Group for providing the data for this study, and CGG Hampson Russell software for AVO analyzing of data.

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