Towards application of nonlinear time-lapse AVO to the Pouce Coupe data set

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Introduction

A time-lapse survey makes an important monitoring contribution to the production of hydrocarbons around the world by measuring the changes in the behavior of a reservoir over time (Lumley 2001). There is a strongly nonlinear relationship between P-wave velocity changes and pressure changes in a reservoir during production (Landrø 2001). This is suggestive that large local variations in seismic parameters, leading to non-negligible AVO nonlinearity, are possible. A framework has been formulated to model linear and nonlinear elastic time-lapse difference AVO ($\Delta R_{PP}(\theta)$) for P-P sections (Jabbari and Innanen 2013). The framework is a series expansion in orders of physical change or baseline interface contrast and time-lapse changes. In the present study in conjunction with Talisman Energy Inc., a time-lapse data set acquired during hydraulic fracture stimulations of two horizontal wells in the Montney Shale at Pouce Coupe Field, Alberta, Canada has been used to compare our theoretical linear and nonlinear difference data AVO with real data.

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 (Aki and Richards 2002). The difference data reflection coefficients between the baseline and monitor survey is then calculated as:

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

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

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

More details can be found in Jabbari and Innanen (2013).

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.

Pouce Coupe time-lapse, Multicomponent Seismic Data continued

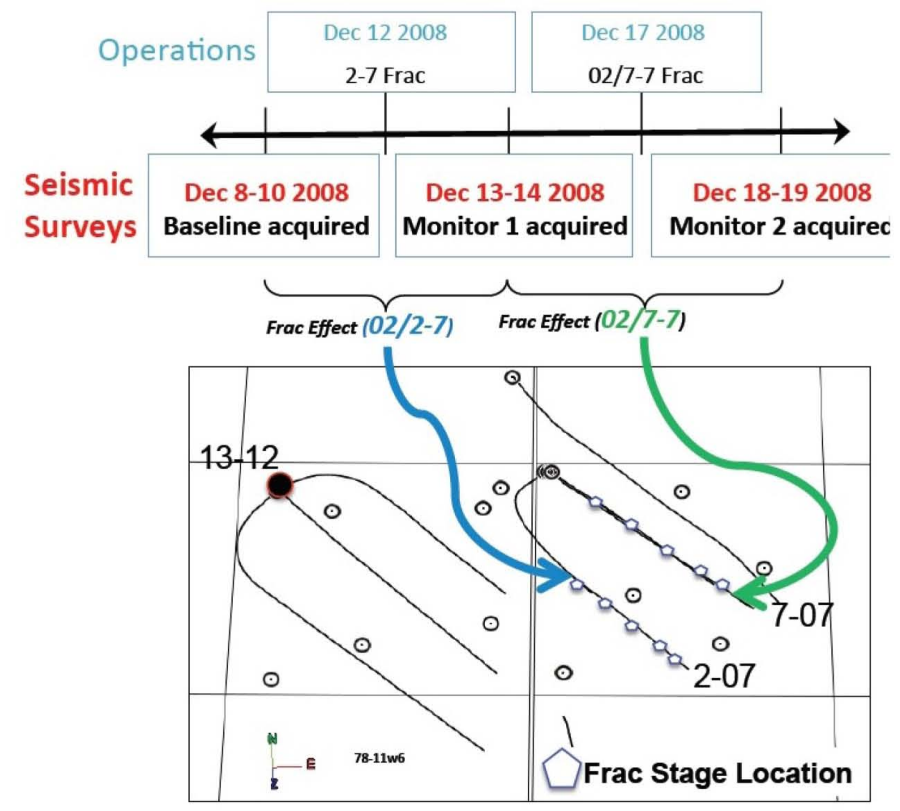

Figure 2: Pouce Coupe time-lapse seismic and field operations timeline. Two horizontal wells hydraulically stimulated (2-07 well and 7-07 well) and the location of the vertical shear sonic log (13-12 well). Modified from Atkinson (2010).

Analyzing the data

Seismic data was recorded by CGGVeritas on a patch grid of about 5 km^2 (Figure 3). 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, CDP (common depth 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. (Grossman 2013).

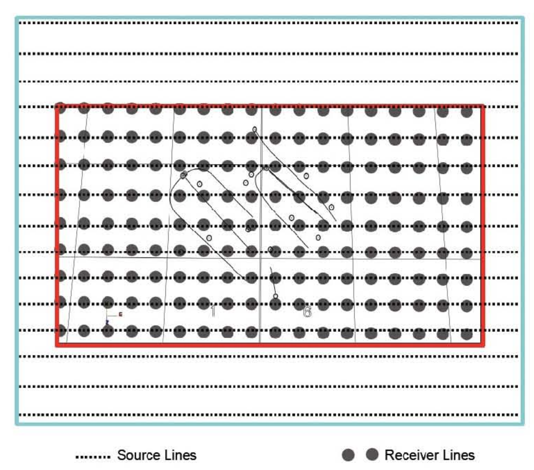

Figure 3: Pouce Coupe time-lapse, multicomponent seismic survey acquisition layout. Resulting 1.6 km $\times$ 3 km patch centered over horizontal wells 2-07 and 7-07. Modified from Atkinson (2010).

The well tie of the P-wave is done using a statistically extracted wavelet and the acquired sonic logs at the vertical well 09-07-078W6 (Figure 4).

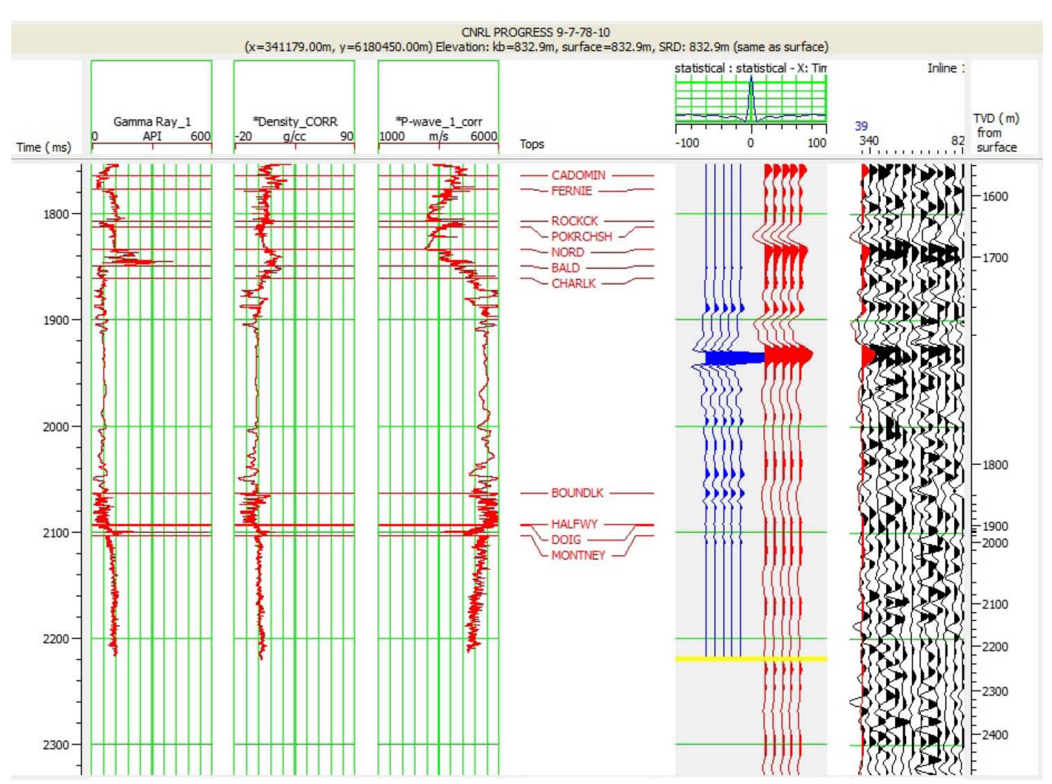

Figure 4: Vertical well tie with the baseline P-wave seismic.

Analyzing the data continued

The AVO analyzing for the whole range of offsets and azimuths for the same well in the Montney formation is done using AVO gradient analysis (Figure 5).

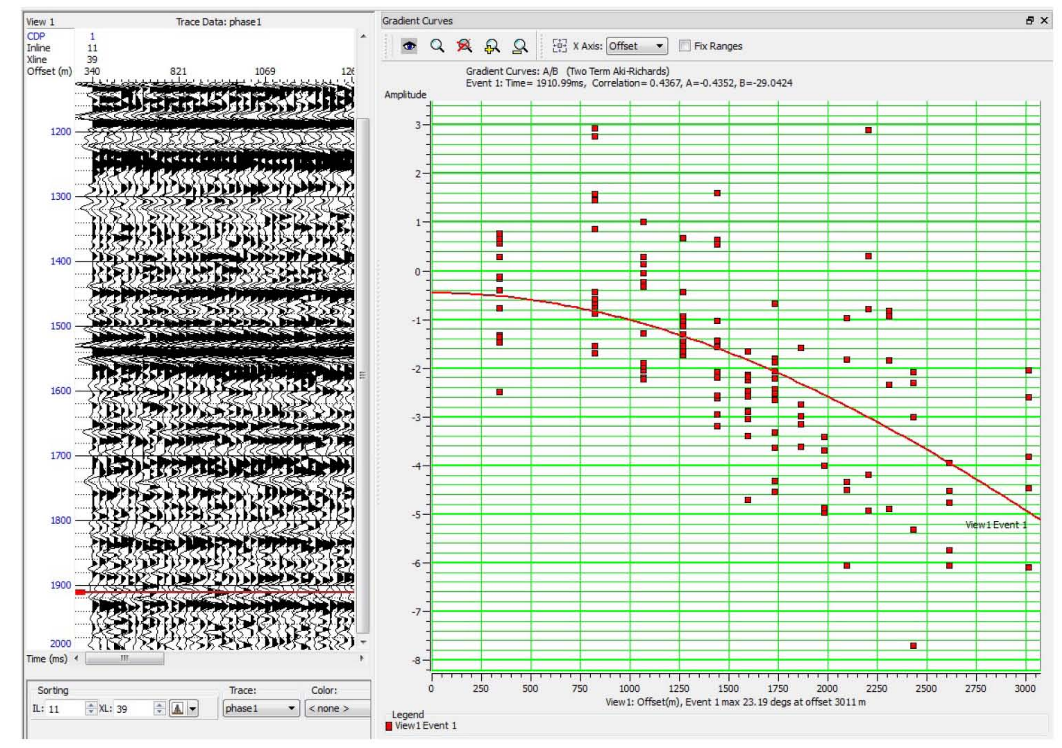

Figure 5: Amplitude versus offset for the Montney formation for offset and azimuth ranged from 340-3011m and 0°-360° respectively.

Plan forward

- Investigating nonlinearity of P-wave time-lapse changes by focusing our analysis in the vicinity of the induced fracture.
- Monitoring any converted wave time-lapse changes to model the hydraulic fracture stimulation.

Conclusions

An increase in pore pressure has been induced following the hydraulic fracture operations in the unconventional Montney shale reservoir. This will affect the seismic parameters including the compressional wave velocity. Due to the tight nature and low permeability of the Montney reservoir, the injection of fluid into the reservoir during the fracture operations will affect only the close vicinity of the fractures. For this reason, the change in P-wave velocity should be investigated in the vicinity of the hydraulic fractures in the horizontal wells. We have initiated the investigation and are analyzing methods to quantify the P-wave time-lapse difference AVO. Data analysis is still under review pending more well data information.

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