

# Geophysics and Shale Gas: Examples from Western Canada and Beyond

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## Summary

Lockstep with increased North American and global shale gas activity over the last decade have been advances in technology and operational efficiency, primarily in completion and stimulation engineering. More recently there have also been advances in geological and geophysical characterization of these 'resource plays'. Currently, there is much interest in integrated geological, petrophysical, geomechanical and geophysical workflows for shale gas characterization, with different degrees of scientific sophistication evident amongst different operating and service companies.

In this paper we present a case study from an active shale gas play in the Triassic age Montney Formation, Western Canada, which integrates surface seismic amplitude and elastic property volumes with petrophysical data and micro-seismic monitoring results. We also look at edge detection volumes as possible indicators of fracture intensity from the Montney Formation and within other basins from North America. The integration of reflection seismic data and appropriate attributes brings more geophysical rigor to a traditionally engineering dominated play type.

## Introduction

Integrated workflows for shale gas reservoirs have received increased attention following the step changes achieved in operational efficiency over the last decade. Du et al. (2009) presented such a workflow for the Barnett Shale play in Texas; however, a crucial link missing in their workflow was analysis and inversion of pre-stack seismic data. In Western Canada the majority of major leaseholders in the Horn River Basin and those exploiting the Montney Formation are utilising pre-stack amplitude variation with offset (AVO) inversion data to assist in well placement and field development planning.

It is known from well log analysis that the ratio of compressional to shear sonic velocities ( $V_p/V_s$ ) is a good indicator of sand-shale or quartz-clay ratios in shales and/or tight siltstones (Figure 1). Qualitatively and empirically, an increased sand-shale ratio correlates to increased porosity, lower breakdown pressures for stimulation, and enhanced relative production (Camron et al., 2007). AVO inversion of 3D seismic data allows for the creation of  $V_p/V_s$  (or Poisson's ratio and/or  $\lambda$ - $\mu$ - $\rho$ ) volumes and maps of the reservoir interval that can be utilised for exploration and field development, which reflect the reservoir quality based broadly on the sand-shale ratio. Inversion data and other attributes derived from pre- or post-stack seismic data require corroboration from independent sources to confirm its utility. Data that can provide such calibration for these seismic based properties includes log data, micro-imaging data, production log data, production data, and micro-seismic monitoring data.

For the geophysicist, mapping major structures and looking for closure becomes less imperative in shale gas, where in-situ permeabilities are typically sufficiently low that there is no mobile gas. However, with the prospect of providing pre-drill data to high-grade potential well locations, the geophysicist can provide significant uplift to the asset team. Geophysicists can also help identify subtle structural trends using seismic attributes sensitive to discontinuities and reflector geometry.

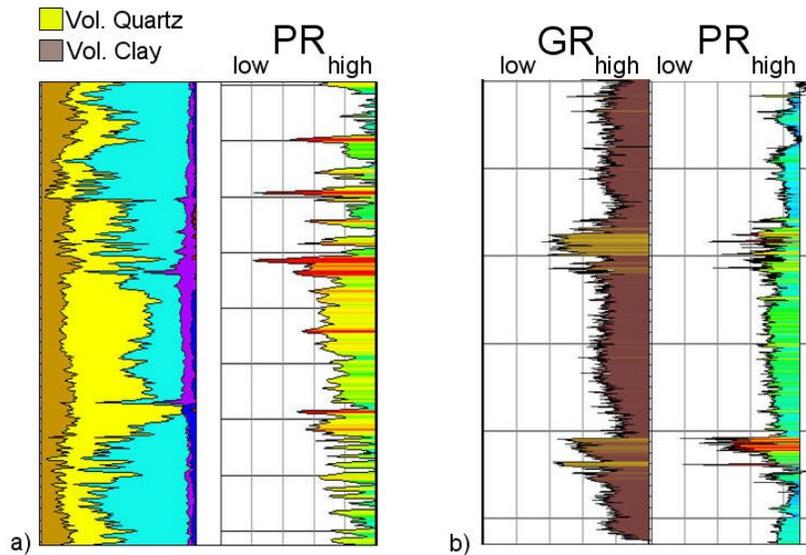


Figure 1: Log data that illustrate the correlation between low  $V_p/V_s$  ratio and/or Poisson's Ratio (PR) with increased sand-shale content, from a) a Western Canadian shale gas play, and b) a South Texas tight gas play where low gamma ray (GR) is taken as a proxy for increased quartz content.

## Method

AVO techniques exploit relative changes in seismic reflection amplitudes at varying incident angles to quantify changes in elastic properties at reflection boundaries, which can provide information regarding lithological and fluid properties of the formations. Such techniques have been extensively and successfully applied in various types of plays and environments. In shale gas plays, AVO inversion is being used to map heterogeneity within the reservoir zones that are related to subtle changes in grain size and composition and porosity.

A critical step in AVO inversion is selection of wavelets for each of the angle or offset stacks that are used in the inversion. AVO inversion is a means of calibrating our seismic data with well log measurements, therefore it is critical to have at a minimum compressional sonic, shear sonic, and density logs. The shear data is necessary to define the angle dependent reflection coefficients. Figure 2 shows an extracted wavelet and associated synthetic at a well penetrating the Montney Formation in west-central Alberta.

Using the ISIS simultaneous inversion algorithm (based on the Aki and Richards (1980) approximation to the Zoeppritz equations) we inverted four angle stacks ( $0-12^\circ$ ,  $12-18^\circ$ ,  $18-25^\circ$ , and  $25-30^\circ$ ) for acoustic impedance,  $V_p/V_s$  ratio, and density. The angle ranges for the four angle stacks were selected to optimize the fold in each angle stack over the zone of interest. A standard quality control (QC) step for inversion volumes is to compare the predicted properties with log based properties, as illustrated in Figure 3.

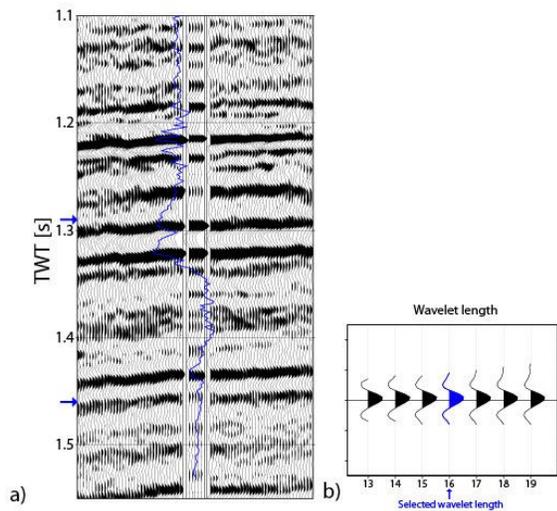


Figure 2: a) Synthetic seismogram based on the angle impedance well log (blue curve) inserted into seismic data from near angle stack, and b) a Suite of wavelets extracted over the zone of interest (defined by blue arrows) with varying length, the wavelet selected for inversion is highlighted in blue. A relatively simple wavelet is selected to minimize local noise contamination that is characterized by extensive side-lobes.

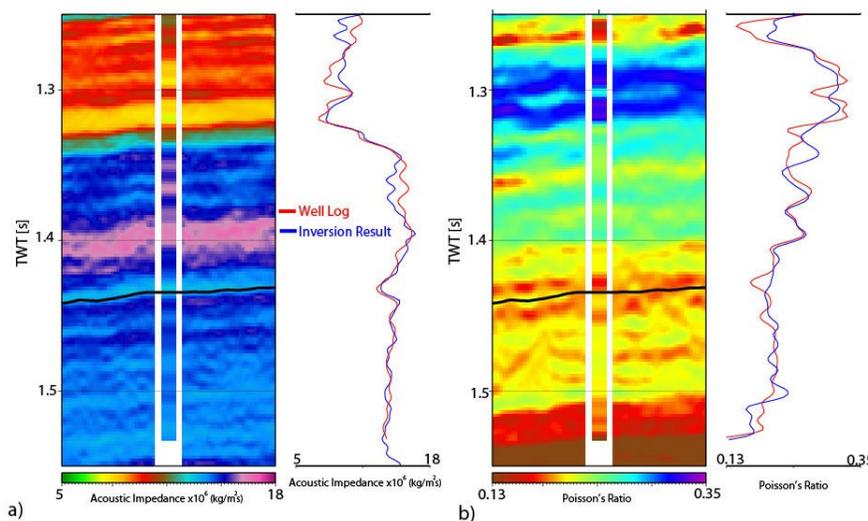


Figure 3: Pseudocolour a) acoustic impedance and, b) Poisson's ratio logs inserted into their respective inversion volumes. The zone of interest is illustrated by the bold dark horizon at ~1.425 s TWT.

The zone of interest in the area of this case study is in the Lower Doig and Upper Montney, an interval which averages around 40 to 50 metres in thickness. Although the thickness is relatively consistent throughout this area, the porosity development within the zone varies and illustrates the heterogeneity of the play. The porosity development is strongly correlated with an increase in quartz relative to clay minerals. Using mineral proportions calculated from standard triple-combo data, based on a proprietary shale gas model, we have calculated porosity-height ( $\phi$ -h) values at 12 well locations to allow us to correlate the inversion data to petrophysical data (Figure 4). We see that in general there is a good correlation between higher  $\phi$ -h values and lower Poisson's Ratio values.

Focusing more specifically on a sub-area allows us to correlate micro-seismic monitoring data, from a five-stage hydraulic fracture stimulation (frac), with the inversion data. It is clear from the microseismic data that stages 1 and 2 of the frac behaved very differently to stages 4 and 5 (Figure 5). We contend that this is primarily in response to changing reservoir properties along the length of the lateral and that the reservoir at the toe of the well has a higher Poisson's Ratio, reflecting higher clay content, and also lower tectonic stress (as estimated by amplitude variation with azimuth or seismic anisotropy analysis), which explains the poor fracture network development for stages 1 and 2.

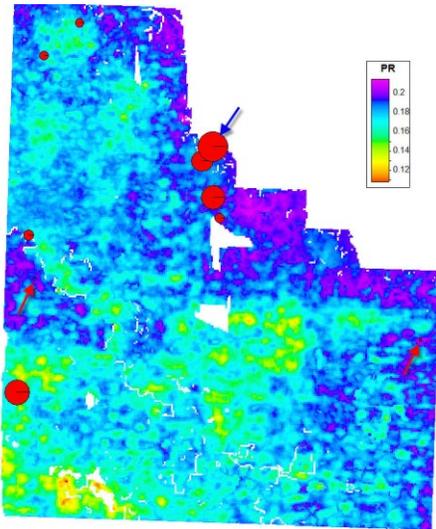


Figure 4. Map of median Poisson's Ratio value and porosity-height from 12 wells through the Lower Doig and Upper Montney. The red arrows highlight wells with very small porosity-height values and correspond in general to areas of higher Poisson's Ratio. The blue arrow highlights a well with a large porosity-height at the edge of the seismic data where the inversion is adversely affected by decreased fold.

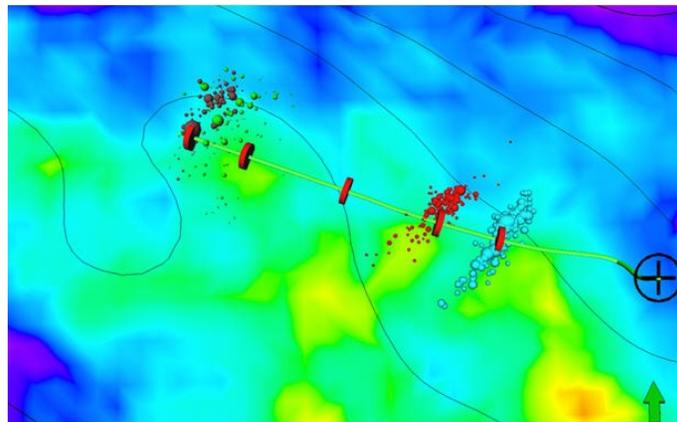


Figure 5. Micro-seismic monitoring data overlain with a Poisson's Ratio map from AVO inversion.

## Conclusions

Geophysics and specifically AVO inversion can bring significant uplift to shale gas reservoir characterization studies. Variations in  $V_p/V_s$  ratio can be used to investigate and understand heterogeneity in shale gas reservoirs related to facies variations and changes in grain size and mineralogy. The AVO results presented here are correlated to both petrophysical modeling results from 12 wells and micro-seismic monitoring data from a single well. The continuation of this workflow is to integrate production data and decline curve analysis with volumetrics predicted from reservoir models based on log data at well locations and AVO inversion data between the wells.

## Acknowledgements

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