Are Key Technological Changes of the Last Three Years Enough to Warrant Reprocessing? Interpolation and AVO Inversion for the Nisku at Brazeau*

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Abstract

This case study shows the value of reprocessing a recent 3D seismic survey for AVO inversion as applied to a Nisku carbonate play. An important element of this work is the fact that this particular 3D has been the subject of a previously published AVO case study on the Nisku. As such, we have an excellent control study to compare against our new method. The key to our new method and the improvements we demonstrate is an interpolation process. By performing 5D minimum weighted norm interpolation prior to the PSTM, the wavefield is better sampled leading to superior migration and AVO results. In order to support these assertions AVO attributes and analyses are compared between the original and reprocessed results. Validation is carried out using the current, improved, well control in the area.

Introduction

Pelletier and Gunderson (2005) published a thoughtful, petrophysically driven, work on AVO Inversion for a Nisku target in the Brazeau area. They attempted to discriminate low impedance basinal Cynthia shales from porous Nisku Reefs using AVO inversion on a 3D seismic survey. Their AVO Inversion techniques followed a rationale derived from petrophysical analysis of Lamé's parameters from wireline data in the area. The work appeared to be successful in that it seemed to identify four known reefal wells, and identified two new prospects. There were no basinal wells available on the 3D survey at that time. We use the modifier "appeared" simply because the amount of drilling control remained statistically insufficient for greater confidence. In the time since that paper, 10 new wells have become available, and several new technologies have been adapted to improve the veracity of AVO Inversion products. Of particular interest is the fact that Pelletier and Gunderson's analysis was performed on CDP gathers rather than image gathers. Since then, new 5D amplitude preserving interpolation algorithms have become available. These interpolation algorithms can minimize migration artifacts allowing us to improve our AVO estimates. This paper compares the AVO analysis based on the original and reprocessed flow including interpolation and PSTM. We will utilize the new drilling data to help us objectively quantify the improvements to be gained by using our interpolation migration method of AVO analysis, and discuss whether these new improvements add enough value to warrant reprocessing of even recently analyzed data.

A Solution for the Non-Uniqueness of the Nisku Reef to the Cynthia Shale

Exploration for gas bearing Nisku reefs in the Brazeau area represents a classic challenge for seismic lithologic prediction. The basinal Cynthia member is stratigraphically equivalent to the Nisku reefal carbonates. When the Cynthia member is sufficiently argillaceous, it has a strong gamma ray response, a low rigidity, and may appear very similar to the porous Nisku reef on conventional stacked seismic. In this case, our challenge would be the separation of higher rigidity, lower Lambda*Rho reef from lower rigidity shale - a classic carbonate AVO Inversion problem. The Cynthia member can also be more calcareous as well, which would represent a different problem seismically. In such a case, wireline data would see less of gamma ray response, and the rigidity would be higher - potentially higher than the reefal facies. Figure 1 represents these facies differences as measured by wireline logs.

Pelletier and Gunderson (2005) focused more on the calcareous element of the basinal response. With further drilling since their publication, we have been able to sample the potential lithologic outcomes more completely, and can address a wider range of reefal and basinal possibilities. Table 1 represents the rock properties we would expect from the key end members we wish to represent.

Figure 2a is a Lambda*Rho versus Mu*Rho cross plot from Pelletier and Gunderson (2005). As stated earlier, critical sampling of the argillaceous basin was not available at the time of that publication, and the facies was therefore not fully represented. In Figure 2b we illustrate a Lambda*Rho versus Mu*Rho cross plot calculated from currently available wireline logs on or near the 3D. In this case, we used data points from three reefal wells and an argillaceous basinal well that discriminates the lower rigidity we expect from that facies. The augmented petrophysical sampling that is currently available should improve our ability to discriminate facies in cross plot spaces estimated from the 3D seismic.

It is clear that accurate estimates of Mu*Rho are key in order to carry out the necessary discrimination. Lambda*Rho is also important, but is subject to smaller experimental error than the estimate of Mu*Rho. This is a consequence of the fact that Mu*Rho is calculated solely from the Simpedance reflectivity (Goodway, 2001) which has larger uncertainty in the presence of noise than the P-impedance reflectivity (Downton and Lines, 2001). By interpolating and then prestack migrating the seismic data, the signal-to-noise level is improved. This is a result of the better sampling of the wavefield prior to the migration, resulting in less migration artifacts and noise. Pelletier and Gunderson's work was carried out on CDP gathers at a time when this kind of interpolation migration flow was not available. We will evaluate how much of an improvement comes from using the new method over the old by comparing the original Pelletier and Gunderson AVO attributes to the same attributes extracted using our new method. Validation will be carried out using the current, improved, well control in the area.

Theory and/or Method

Fractional elastic parameters such as the compressional (R_p) and shear reflectivity (R_s) may be estimated from the prestack seismic data by AVO Inversion such as the two-term Gidlow et al. (1992) equation $R(\theta) = R_p \sec^2\theta - 8R_s\gamma^2\sin^2\theta$ where θ is the average angle of incidence and γ is the average S-wave / P-wave velocity ratio. Inversion of R_p and R_s to compressional and shear impedance estimates is followed by algebraic manipulation to Lambda*Rho and Mu*Rho as in Goodway (2001). As shown in Table 1 and Figure 2, Lambda Rho, Mu*Rho, and the ratio of Lambda*Rho divided by Mu*Rho (LMR ratio) are key attributes for discriminating the various reefal and basinal facies of the Nisku.

Unfortunately, all of these parameters are notoriously difficult to estimate with the fidelity and resolution necessary to be useful on many stratigraphic prospects. Li, Downton, and Xu (2007) describe the crucial challenges involved in successfully estimating the elastic parameters. Those challenges include the need to attain migrated (or imaged) gathers that have sufficient resolution and high signal to noise ratios. In this example, the structural deformation appears to be significant enough to require that AVO be performed on pre-stack imaged gathers. The nominal source and receiver line spacing of this 3D survey is 600m, and the data is noisy and bandlimited to about 55Hz. This acquisition geometry was not sampled sufficiently fine enough so that the wavefield would constructively and destructively interfere to image all the reflectors with a good S/N ratio.

The particular interpolation used in this paper is based on Minimum Weighted Norm Interpolation (Liu and Sacchi, 2004; Trad, 2007). The 5D interpolation is performed by solving a large inverse problem. In this case, the desired model is the super-sampled seismic dataset, the data is the original seismic dataset, and the linear model is the sampling operator. The resultant supersampled seismic data contains data for every possible in-line, cross-line, offset, and azimuth combination. In practice, this creates so much data that it becomes impossible to deal with, so the algorithm only outputs a representative subset of this. In this case, we output twice as many shot and receiver lines as the original geometry thus preserving the original geometry and data as a subset of the new volume. As the original data is preserved it is easy to verify that the original AVO trend is preserved. Further note that the minimum norm constraint applied in the spatial frequency domain tends to ensure that the amplitude changes slowly in all four spatial dimensions including offset and azimuth while honoring the original data.

Figure 3 is an Ostrander gather taken at an argillaceous basinal well location. As Pelletier and Gunderson used super-binned CDP gathers for their AVO analysis, we illustrate a CDP gather in Figure 3a versus a super-binned CDP gather in Figure 3b. Our new method is illustrated by comparison with a PSTM gather in Figure 3c and the interpolated PSTM we advocate in Figure 3d. It is clear that the interpolated results have a superior S/N ratio. This is due to the higher fold in the non-migrated examples. In the case of the interpolated PSTM gathers, better sampling of the wavefield results in less migration noise. Note all the gathers shown have been partial offset stacked with the same offset binning so that the figures may be easily compared.

Test Procedure: Quantifying Well Lithologic Information and Comparing to 3D AVO Attributes

The 3D that we used for this test had some 14 Nisku penetrations. Of key importance is the fact that three of the Nisku penetrations are basinal, and one penetration is a tight reef. Each of these wells is given a lithology code as defined in Table 1. We have Pelletier and Gunderson's Lamé parameter attributes from their original work, and we have the new Lamé attributes extracted from the same 3D with our new interpolation migration technique. We compare the quality of these results in several ways:

1. The correlation coefficient of (chiefly) the LMR Ratio and (secondarily) the other Lamé parameters to the lithology code that we give to each well on the 3D. This objective, quantifiable measure will be key to making our conclusions.
2. Comparison of cross plots of LMR Ratio versus Mu*Rho and Lambda*Rho versus Mu*Rho applied to a map view. We will compare how the well (lithologies) plot in this cross plot space and determine an accuracy of lithologic prediction in these spaces.
3. We will also comment qualitatively on how the shape and scatter appear in the cross plot domains. Noise or error in the estimation process should contribute to greater scatter of the Mu*Rho axis in particular.

4. Our ability to integrate the geologic model of reef building into the final maps will also be commented upon.

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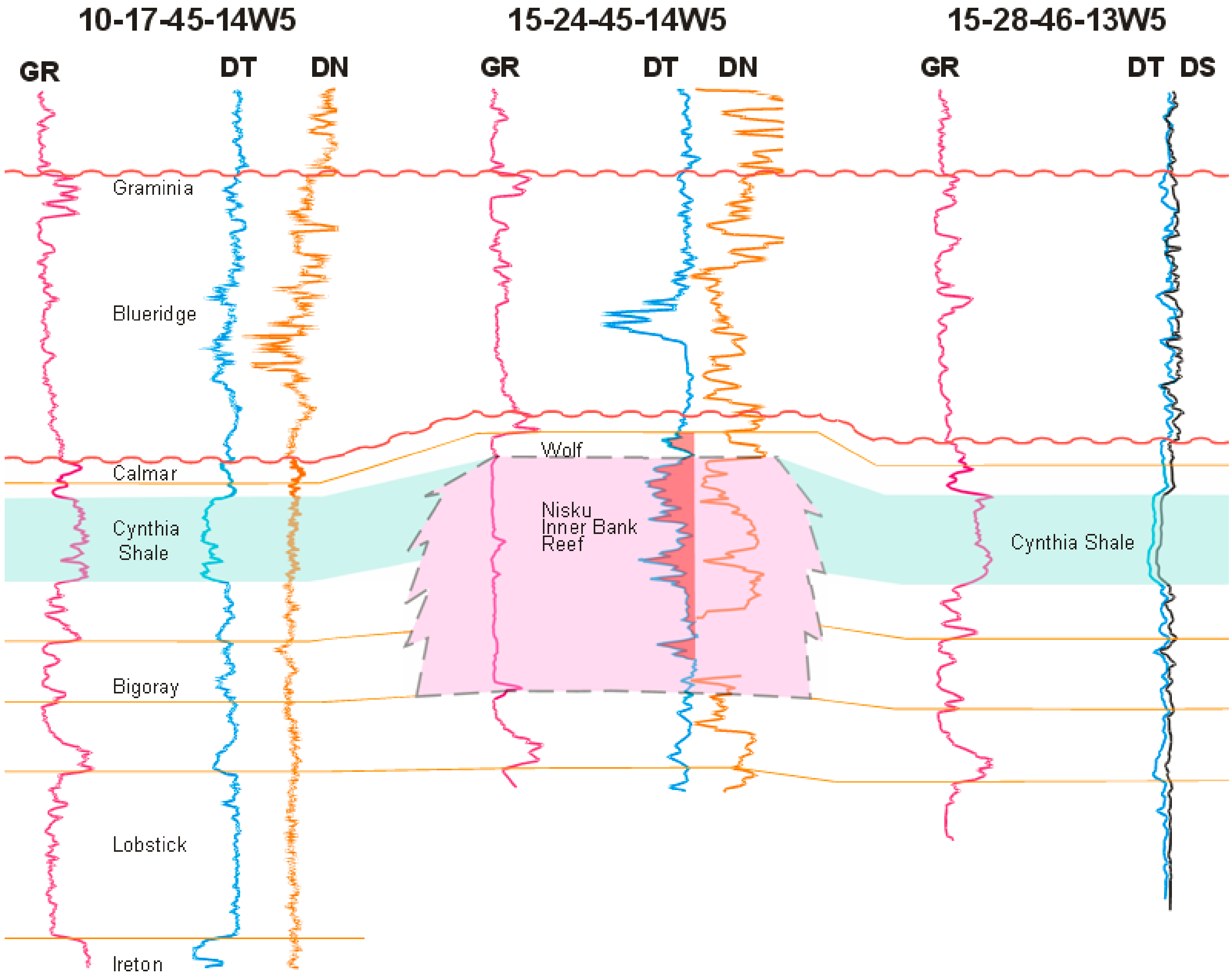

Figure 1. A stratigraphic cross section representing several key Nisku facies: a porous reef versus argillaceous or gamma ray "hot" basin. GR, DT, DS, and DN represent gamma ray, compressional slowness, shear slowness, and bulk density, respectively.

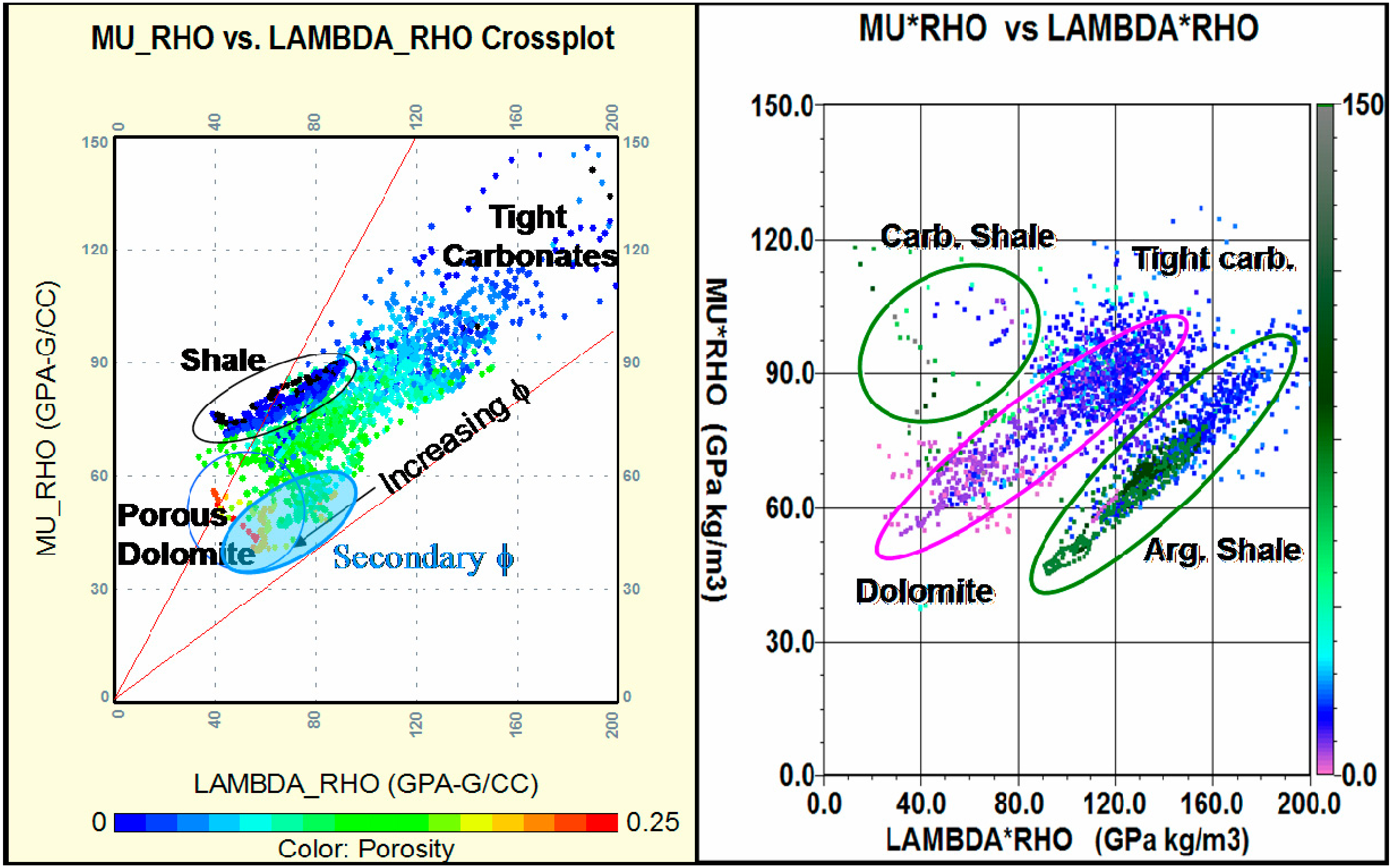

Figure 2. a) Old Lambda*Rho versus Mu*Rho cross plot from Pelletier and Gunderson (2005); b) new Lambda*Rho versus Mu*Rho cross plot. Each data point in Figure 2b is coloured according to its gamma ray value as illustrated by the colour bar on the right side of the figure.

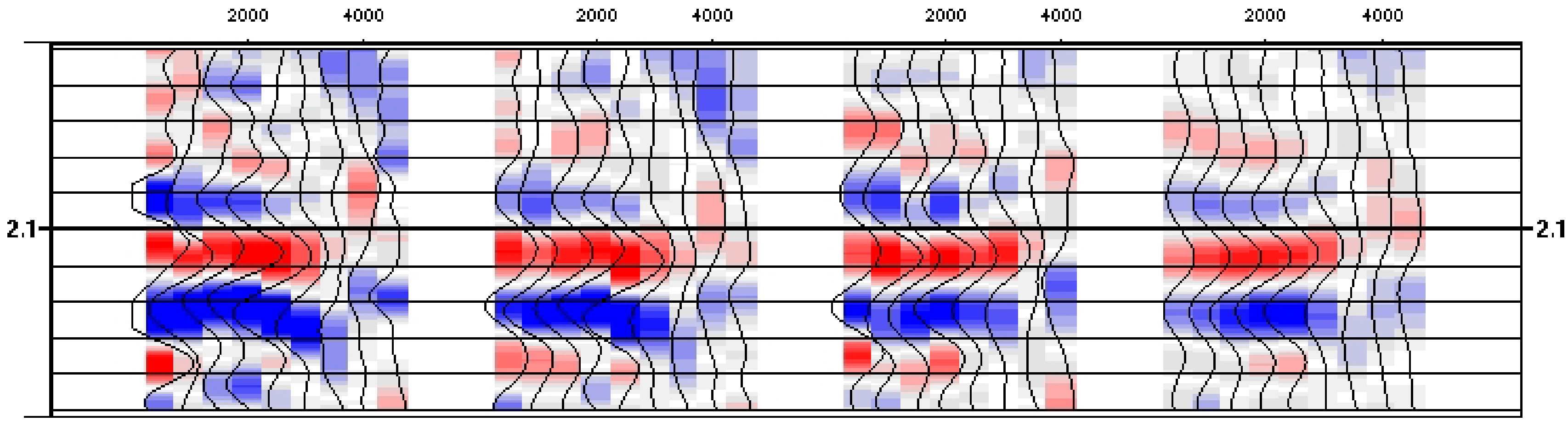

Figure 3. Ostrander gathers at the argillaceous basinal well 10-17. 3a is the 1x1 CDP gather; 3b is the 5x5 CDP gather such as was used by Pelletier and Gunderson (2005); 3c is a 1x1 PSTM gather; 3d is the interpolated PSTM gather without superbinning represents the new method. The Nisku zone is comprised of the trough (in blue) just above 2.1s, to the base Nisku peak (in red) which is just below 2.1s.

Lithology	Stack Response	Lambda Rho	Mu*Rho	LMR Ratio	Code
Porous dolomitic reef	strong	low	medium	low	1
Tight limestone reef	weak	high	high	medium	2
Calcareous basin	weak	High	high	medium	3
Argillaceous basin	strong	medium	low	high	4

Table 1. Key Nisku facies, quantified facies codes, and qualitative descriptions of their rock properties.