# Nisku Multiple Attenuation with Interpolation and Sparsity: A Case Study

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## Summary

Exploration and development of the Nisku and Blueridge in West Central Alberta is challenging because these zones are deep, underlie thick coal sequences, and are contaminated with short period multiples. The advent of high resolution sparse Radon Transform multiple attenuation techniques allows us to examine the multiple issue. The Blueridge zone was found to be contaminated by multiples with a variety of small move-outs. The Radon Transform requires well sampled, regular gathers, as input. This can typically only be achieved in land data by borrowing traces from neighboring cmp locations (superbinning) over a significant area. We became concerned that this superbinning might limit the resolution of the transform through a structural smearing effect. We performed 5D interpolation prior to multiple attenuation to eliminate the need for superbinning and reduce the potential effect of smearing on the Radon Transform. Our processing flow resulted in an improved interpretation of the Nisku and Blueridge reservoirs relative to legacy processing flows. A significant improvement was gained from the aggressive AVO compliant noise attenuation and resolution enhancement that all our reprocessing efforts benefitted from. The interpolation-sparse Radon Transform approach produced superior Tau-p spaces, but the dominant cause for this appears to be an improvement in gather fold and signal to noise ratio as a result of the interpolation.

## Introduction: The Nisku and Blueridge Formations

The Nisku Formation in the Deep Basin area commonly consists of thick reefal carbonate that grows on the Bigoray / Lobstick platform. The reefs can grow up to 75m thick, and have porosities over 10%. The equivalent off reef material consists of tight, fine grained, open marine carbonates. The Blueridge carbonate overlays the Nisku. Blueridge reservoir locally develops in dolomitized grainstone shoals, which may be related to the underlying Nisku reefal development. The Blueridge reservoir is typically less than 8 meters thick. The Blueridge reservoir is challenging to image seismically because it is thin and is affected by the more dominant Nisku reef response. Figure 1 depicts the Nisku and Blueridge stratigraphy. The Blueridge porosity is completely removed on the right half of the model. The amplitudes at the Blueridge level are low, and the variations due to the change in porosity are minor.

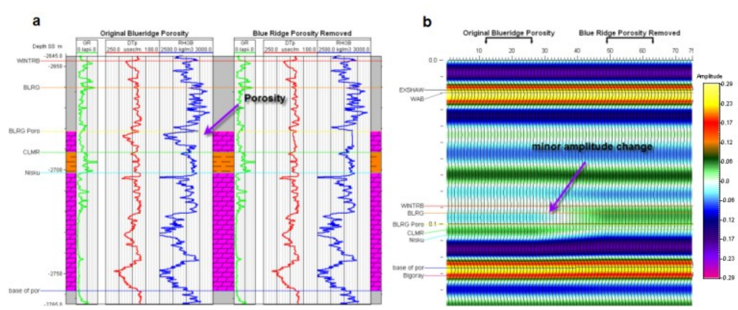



Figure 1: the Nisku and Blueridge formations. Figure 1a depicts the stratigraphy with and without Blueridge porosity. Figure 1b illustrates a simple normal incidence seismic model. Changes in amplitude associated with the Blueridge porosity are visible but minor.

The Blueridge can produce at economic rates over significant areas, and is an attractive target in the area. As Figure 1 indicates, delineation of the Blueridge reservoir is expected to be challenging due to the small amplitudes observed from modeled changes in reservoir quality. Figure 2 shows the original (legacy) processed seismic line from a 3D seismic survey. This line goes through a well that encountered Blueridge porosity and a thick Nisku reef. The amplitudes at the Blueridge level are clearly much too high, and are an indication of multiple contamination.

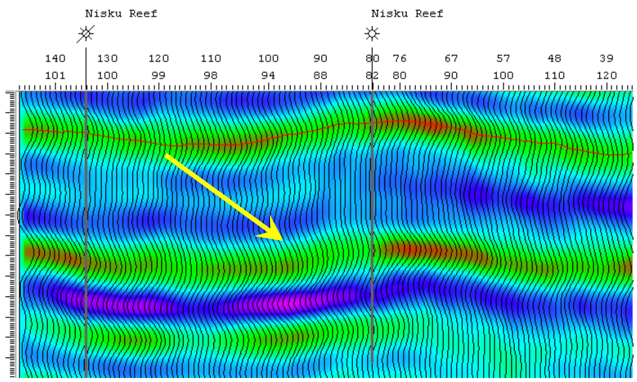



Figure 2: original (legacy) seismic line through a Nisku reef and Blueridge porosity. The amplitudes at the Blueridge level (yellow arrow) are much higher than expected from modeling.

## Theory: Combining Two Recent Technological Advances

The Radon Transform is a common method to perform multiple attenuation of short period multiples. This transform typically uses parabolas or hyperbolas as its basis function when used for multiple attenuation. Thorson and Claerbout (1985) and Hampson (1986) both solved the Radon transform based on the following underdetermined system of equations:

$$Lm = d,$$

where *d* is the data, *m* are the data model weights in the Radon domain, and *L* is the basis function operator. Both approaches combat non-uniqueness through the use of constraints, with the former method using sparse constraints in a computationally intensive scheme and the latter using non-sparse constraints in a computationally efficient scheme. Sacchi and Ulrych (1995) emphasized that this solution was non-unique and poorly resolved due to limitations in all surface seismic experiments, and they proposed the use of computationally efficient sparsity constraints to mitigate these problems. Cary (1998), Ng and Perz (2004), and others developed this idea commercially and implemented it for both parabolic and hyperbolic applications that could be solved in either the time or frequency domain (Sacchi, 2009). The use of sparsity constraints is now common in high resolution Radon Transforms, and these modern transforms are now widely accepted as superior to previous moveout based methods, especially when supplemented with interactive graphical tools for time and space variant Radon mute definition.

Land 3D seismic data is typically poorly sampled. Liu and Sacchi (2004) proposed a Minimum Weighted Norm Interpolation (MWNI) method to improve the sampling of the data. Sacchi and Liu (2005) went on to demonstrate that the interpolation would preserve offset characteristics in the data. Trad (2007) extended the method to 5 dimensions. Hunt et al (2008) showed that the 5D interpolation method allowed for improved AVO analysis on imaged gathers. In this last case, the interpolator is enabling an improvement via a reduction in migration noise due to poor sampling.

The Radon Transform requires regular, well sampled gathers as input. In land 3D applications, this is achieved via the borrowing of data from adjacent cmp bin locations (superbinning). The superbinning process borrows from as large an area as required to fill in the missing data. Large superbinning areas may smear geological information in the gathers. The 5D MWNI is a more sophisticated method for regularizing data. The interpolation method may be a better way to regularize the data prior to the Radon Transform since it has been shown (Hunt et al 2008) to introduce less smear than superbinning. Combining MWNI with the Sparse Radon Transform should produce Tau-p spaces with the greatest resolution.

## Method

We evaluate the proposed method by comparison with a series of seismic results designed to control or isolated the experiment. The comparative reprocessing products all have the same aggressive AVO compliant noise attenuation and resolution enhancement as a starting point, and are all improvements over the legacy processing result of Figure 2. The comparison also includes versions of the seismic with an alternative method of regularization as well as Tau-p mutes that vary with observed changes in resolution. The alternative method of regularization is the industry standard superbinning discussed earlier. The Tau-p mutes are picked in two ways: a mild mute picked on the superbinning Radon Transform Tau-p space, and a more aggressive mute picked on the interpolated Radon Transform Tau-p space. Our controlled experiment will also include a multiple attenuation produced using a less sparse implementation of the Radon Transform. Table 1, below, summarizes the experiment.

| Starting point | Regularization | Radon Transform | Tau-p mute |
|---|---|---|---|
| original (legacy) processing | none | none | none |
| final noise attenuated gathers | none | none | none |
| final noise attenuated gathers | superbinning | Radon Transform | mild mute |
| final noise attenuated gathers | superbinning | Sparse Radon Transform | mild mute |
| final noise attenuated gathers | superbinning | Sparse Radon Transform | aggressive mute |
| final noise attenuated gathers | interpolation | Sparse Radon Transform | mild mute |
| final noise attenuated gathers | interpolation | Sparse Radon Transform | aggressive mute |

Table 1: variations in multiple attenuation approaches

## Results

Figure 3 shows actual production gathers and forward Radon Transforms (Tau-p spaces) at one cmp location for the Sparse Radon Transform and the Sparse Radon Transform with MWNI. The version with the MWNI is more resolved at the Blueridge level. Based on these Tau-p spaces, the mild and aggressive mutes were designed. The mild mute cuts multiples with a far offset moveout of 22ms, and is time invariant. The harsh mute cuts down to 7ms moveout in the zone of interest, but varies surgically in time, and cuts multiples at 22ms elsewhere. The aggressive mute could only be defined using the Tau-p space from the MWNI and Sparse Radon Transform. Figure 3 illustrates two differences in the data gathers: first, the MWNI gather has a higher signal to noise ratio, and second, there is a potential structural error in the superbinned gather that is depicted in 3a by a yellow circle. Investigation of the superbinning operation revealed that there was very little spatial borrowing for this particular gather, making the apparent bump more likely caused by noise than structural smearing. The higher signal to noise ratio in the MWNI gather of Figure 3b is thus of greater significance, and has several potential causes. The first potential cause is noise attenuation in the MWNI algorithm itself. Although MWNI is not specifically a noise attenuator, the algorithm does remove some noise. The second cause for the higher signal to noise ratio is the higher fold of the MWNI gathers, which are stacked across azimuths in this production run. As multiple attenuation is considered to be an azimuth independent operation, this stacking for the purposes of Tau-p modelling and multiple design would seem to be reasonable. The MWNI created more than 6 times the input data, and typically led to about 4 times the fold in the gathers input to multiple attenuation. This example illustrates the superior appearance of the Tau-p space in the MWNI data is caused by the better quality of the gather, rather than by the theoretical possibility that the MWNI gathers endure less structural smearing than superbinning. In general, either effect could be important, depending on changes in overall data quality or structural characteristics of the area.

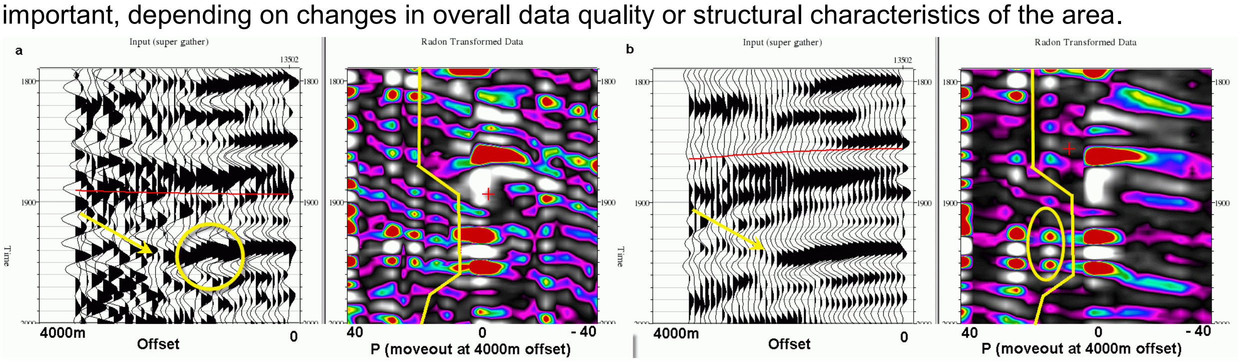
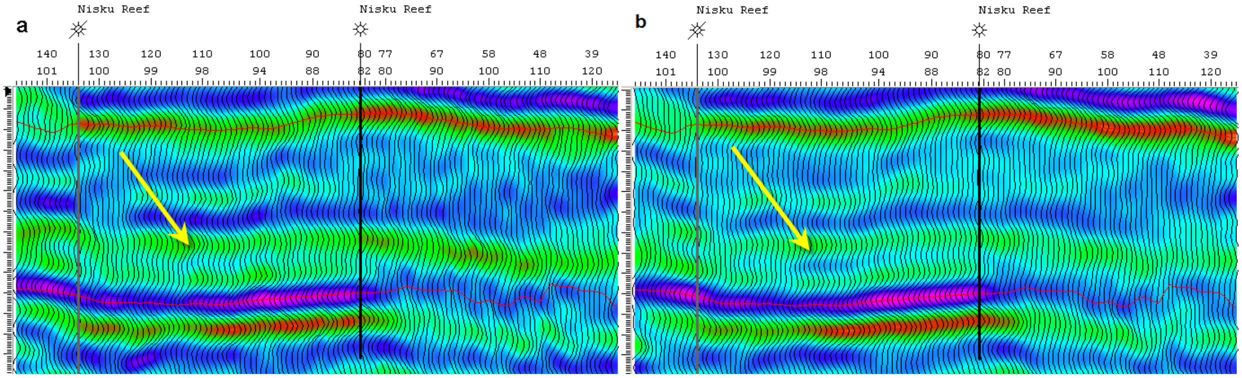



Figure 3: gather and Tau-p space (respectively) from (a) the Sparse Radon Transform, and (b) Sparse Radon Transform with MWNI. The Blueridge level is identified with a yellow arrow. The harsh mute is a shown in yellow.

Multiple attenuation was performed using these mutes. Figure 4 shows the comparison of our base control result (second version in Table 1) and the MWNI plus sparse Radon Transform multiple attenuation using the harsh mute. The stack response at the Blueridge level has changed significantly in both cases when compared to the legacy product of Figure 2, with the multiple attenuated version matching the model result of Figure 1 most closely. In the talk, we will show comparisons between all the control product versions, and evaluate the improvements in each via quantitative analysis at well ties.




Figures 4: Reprocessing results (a) control reprocessing result, and (b) the full reprocessing as well as MWNI, and sparse Radon Transform with the aggressive mute. The Blueridge level is identified with a yellow arrow.

## Conclusions

Aggressive reprocessing with AVO compliant noise attenuation and resolution enhancement improved the data at the Nisku and Blueridge level as compared to the legacy result. The multiple attenuation also had an additional clear, and significant affect on the stack response. The combination of MWNI and the sparse Radon Transform produced the most stable, resolved, Tau-p space at many of the cmp locations we observed. This better resolution allowed us to consider a more aggressive mute in Tau-p. The interpolation produced cleaner, higher signal to noise gathers partly due to an increase in fold. This increase in data quality may be a more important reason than the concerns over structural smearing that the interpolation-sparse Radon Transform Tau-P space had the best resolution. In general, it may be practically difficult to know which cause for the improvement may be most important to the results. Regardless of our certainties over dominant causes, the MWNI and sparse Radon Transform was shown to yield a result that was superior for production processing and interpretation.

## Acknowledgements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