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Merge of two seismic AVO inversions: Montney example

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Summary

A 3D simultaneous AVO inversion was carried out to help characterize the reservoir properties of the Montney Formation. This case study showcases seismic data challenges caused by surface conditions that significantly affected the quality of the 3D seismic survey. Given the large spatial variations in frequency and amplitudes observed in the seismic data, a different methodology was applied to overcome these challenges. It consisted of treating the quantitative interpretation study as two separate inversions. Each subarea was analyzed individually rather than hampering the quality of one side of the study to match the other one with substantially lower amplitudes and frequencies. The final inversion results were seamlessly merged using a frequency-based mask approach and workflow. The combination of two seismic inversion volumes seemed to be an acceptable alternative when dealing with strong spatial differences in seismic data that can be easily identified.

Introduction

A challenging AVO inversion project was carried out targeting the Montney Formation. The limited well control and the challenges observed in the seismic data caused by surface conditions persuaded us to take a different approach when inverting seismic reflections into elastic properties such as acoustic Impedance (AI), P-wave and S-wave velocity ratio (Vp/Vs), and density. Preconditioning seismic data is a critical step to achieving accurate predictions of elastic properties (Mills et al, 2021). In this case study, after testing different preconditioning techniques, an alternative workflow was applied.

Large spatial variations in frequency content and amplitudes were noticeable throughout the seismic survey. Figure 1 shows a map view of the zone of interest where these differences in amplitude and frequency are clearly identifiable.

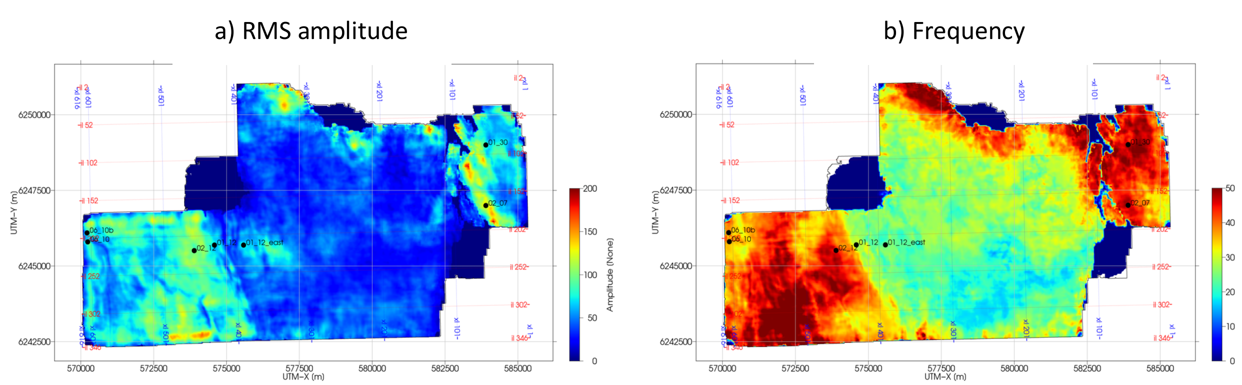

Figure 1 Map view at zone of interest. a) RMS amplitude, b) mean frequency.

The western side of the survey has higher frequencies and amplitudes compared to the centre area of the survey. When examining the amplitude spectra of the eight angle-stacks generated from the pre-stack depth migrated (PSDM) gathers converted to time, similar behaviour is observed (Figure 2). There is a strong difference in the shape of the spectra, amplitude levels, and frequency content between the western and the central section of the seismic survey.

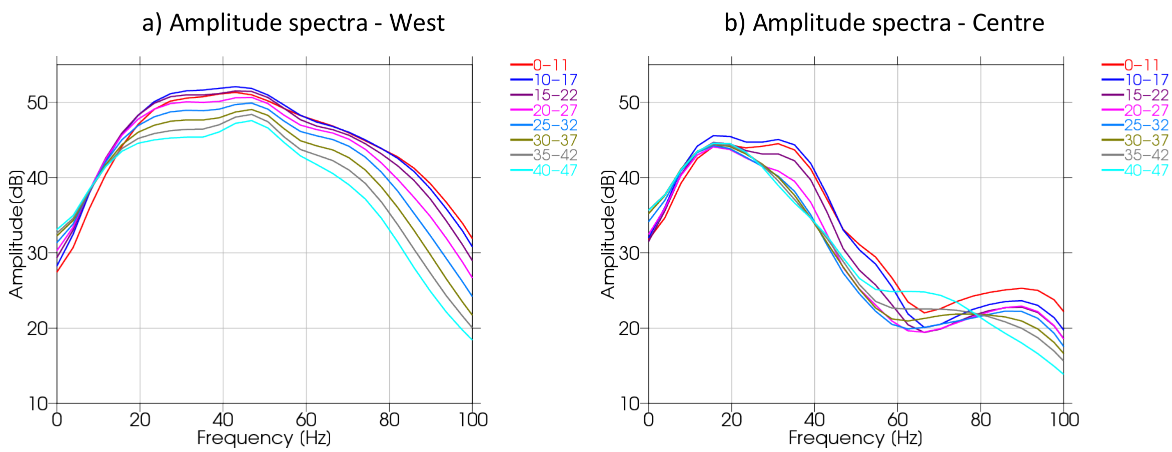

Figure 2 Amplitude spectra of each angle-stack prior to seismic conditioning: a) west section, b) center section.

The following sections describe the main preconditioning steps applied to the raw PSDM seismic gathers converted to time, followed by the AVO inversion results obtained after treating each section of the survey independently and seamlessly combining the two inversion results with a mask based on the mean frequencies.

Seismic preconditioning

Radon de-multiple and residual moveout (RMO) corrections were analyzed to remove multiple energy and slightly flatten the gathers as part of the pre-conditioning tests performed on the pre-stack depth migrated gathers.

A parabolic tau-p radon de-multiple was tested with varying maximum moveout times to determine the most appropriate mute (Hampson, 1986). The radon analysis was compared to the initial inversion tests to see if the inversion itself was sufficient as a de-multiple filter. However, it was decided that a mild radon mute was needed to remove the larger moveout multiples.

To flatten the gathers in a velocity consistent manner, a residual moveout correction method was applied. The algorithm is based on automatic, continuous velocity RMO correction by iterative correlation of CMP gather intercept and gradient (Swan, 2001). This technique is AVO friendly, has limited user bias and generates an updated continuous high-frequency velocity model. After the radon de-multiple and RMO correction, an additional and harsher radon de-multiple step was applied to the seismic gathers to remove any remaining multiple energy in the data.

A visual inspection of the corrected offset gathers showed a broad-angle coverage with generally uniform data quality from 0 to 47 degrees. Using the seismic velocities, the offset gathers were stacked into 8 partial angle-stacks. Based on the RMS and interval velocities used to compute the angle-stacks. The purpose of this angle range stacking is to have sufficiently small angle bands to improve the subsequent inversion flow, while maintaining sufficient fold and signal in each angle sub-stack.

Furthermore, FXY deconvolution, lowpass filters and seismic event alignment were applied to the angle stacks to improve the overall signal to noise in the data and to correct for any additional residual NMO misalignments. This alignment of the angle-stacks used an iterative seismic warping algorithm that locally optimizes the angle-stack cross-correlation coefficient by applying a smooth varying displacement field while preserving the amplitudes.

The potential improvements from all the pre-conditioning steps were verified by extracting wavelets and running inversion tests around wells and areas of interest before selecting the final parameters.

Results and discussion

A simultaneous AVO inversion algorithm based on Aki-Richard's (1980) linearized Zoeppritz approximation is applied to invert partial stacks directly for acoustic impedance, Vp/Vs, and density. In addition to the preconditioned seismic data, the input to the simultaneous AVO inversion consists of a wavelet for each partial stack and a low-frequency model for each property to be inverted for. 3D low-frequency models of acoustic impedance, Vp/Vs and density are constructed by extrapolating well log data calibrated to the seismic, throughout the seismic volume along the available horizons. Several low-frequency models were generated combining a set of well logs and different filters. After testing the models in the full cube inversion, a two-well low-frequency model was selected (one from the higher amplitude and frequency western area and the other from the deficient central zone) to be used in the final inversion. An angle range of 0-42 degrees and a signal-to-noise ratio volume combining seismic energy and seismic coherency measurements were used to weight each angle-stack spatially in the inversion.

Due to the distinct seismic character observed across the survey with varying frequency content and amplitude levels, two individual inversion runs were performed using different wavelets tailored to each subarea target. Then, a mask based on the mean frequency at each sample of the volume was built to seamlessly blend the inversion results obtained with each set of parameters. Figure 3 illustrate the acoustic impedance and Vp/Vs results before (a, c) and after (b, d) the merge. A random line across the survey including the available 3 wells located on the western section of the volume, shows a smooth transition from west (left) to east (right) after the merge.

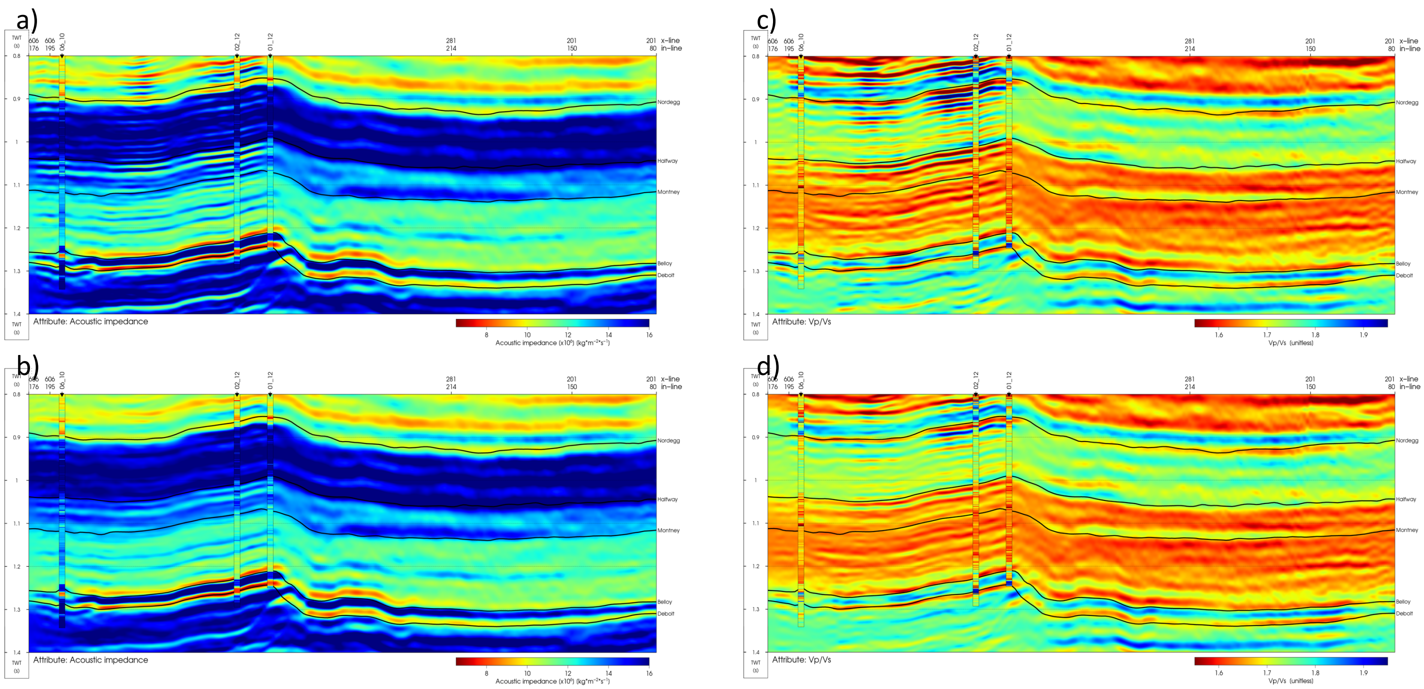

Figure 3 Acoustic impedance and Vp/Vs results before (a, c) and after (b, d) the merge of two volumes.

Conclusions

Performing quantitative interpretation studies can be very difficult when encountering large spatial variations in the seismic data. This case study is a good example of one of the many obstacles encountered when working with land data. Given these challenges, a different approach was taken to overcome the spatial variations in frequency and amplitude. Rather than hampering down the high frequency and high amplitude section of the volume, two different inversions were completed for each spatial subarea zone. Then, the two inversion volumes were seamlessly merged using a frequency-based mask. This relatively straightforward method seems to be a plausible alternative when dealing with large differences across a given survey.

Acknowledgements

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