Seismic Imaging through Outcropping Carbonates: An Example from the Canadian Rocky Mountains

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We investigated a seismic time processing procedure that provides an optimum dataset for advanced depth imaging. A processing flow is introduced with the aim of improving the imaging on a 2D crooked seismic line through outcropping Carbonates in the Rocky Mountains. The results of the major approaches on statics, signal to noise ratio enhancement and migration are illustrated.

Seismic Data Description

The seismic line in this study was acquired in the Canadian Rocky Mountains (Figure 1). This crooked 2D line is about 22 Km in length and was shot with a split-spread array using a dynamite source. The topographic range is about 1400 meters. The receiver interval is 10 meters, the nominal fold is 60 and far offset is 4030 meters. A typical unprocessed shot located on outcropping carbonates is shown in Figure 2.

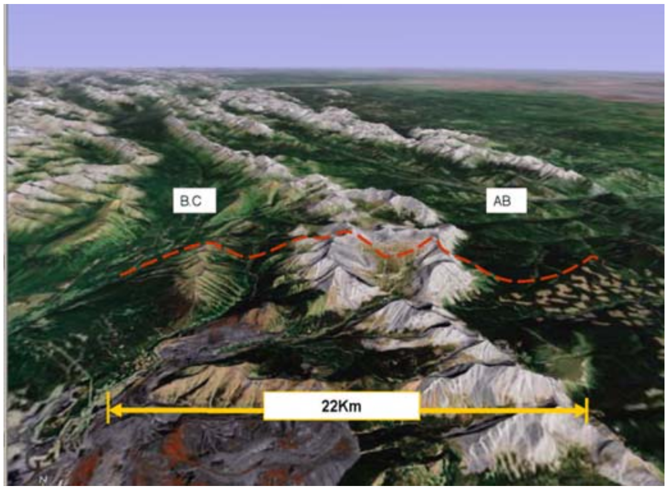

Figure 1. View showing the 2D line (courtesy Google Earth).

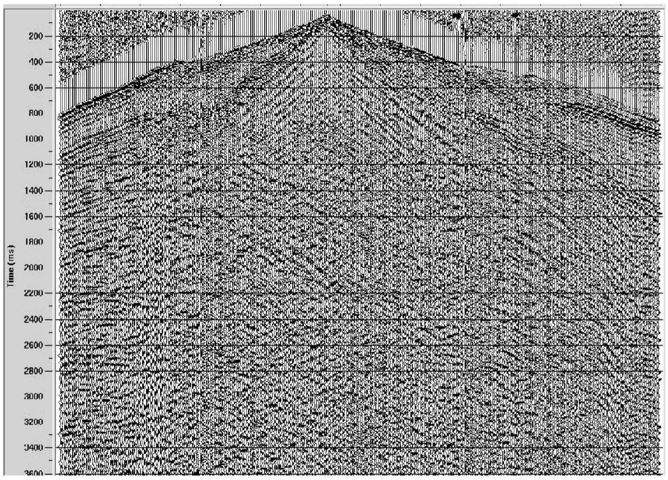

Figure 2. Shot gather recorded for shot located on outcropping carbonates at surface.

Time Processing

This seismic line was time-processed using ProMAX software; the final processing flow shown in Figure 3 was developed based on results from number of tests. The potential goal for the reprocessing was to optimize the dataset for advanced pre-stack depth imaging (PSDM).

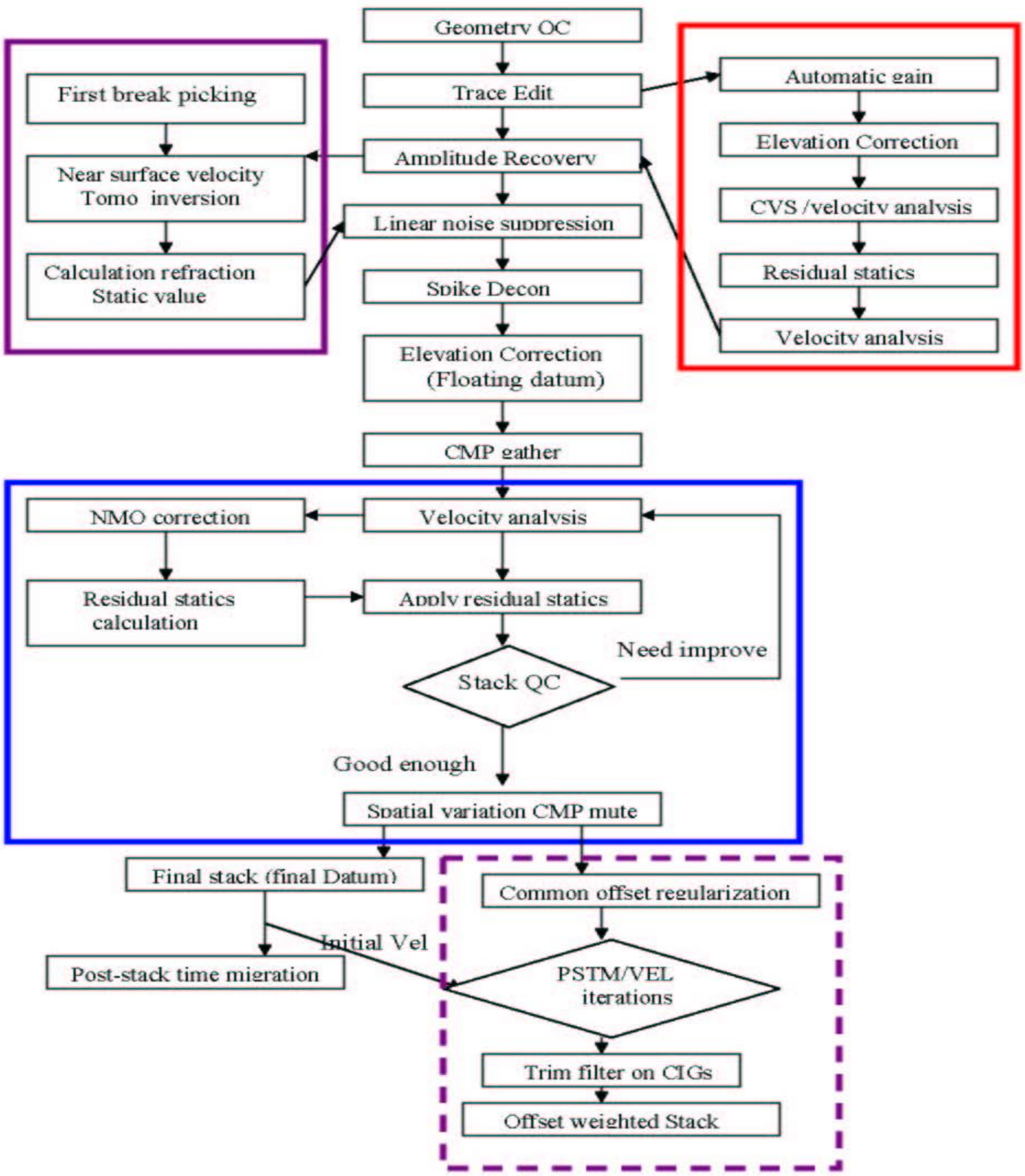

Figure 3. Processing flowchart. In the red box, the initial processing was conducted to define elevation correction parameters and a proper stacking velocity on the purpose of quality control. Secondly (in the solid purple box), smoothed first break picks were transferred to GLI3D and used to build a near surface model using tomographic inversion which was applied to remove weathering statics. Thirdly, linear noise attenuation with spatially-varying parameters was implemented to enhance S/N. Then, a number of iterations of velocity analysis and residual statics following the elevation correction (the blue box) were performed to resolve effects of short-wavelength statics. Finally (the dashed purple box), after iterations of common offset pre-stack time migration (PSTM), residual velocity analysis and non-surface consistent statics were used on common image gathers (CIGs) to generate the final PSTM stacked section with weighted offset stack.

First Arrival Tomographic Inversion and Statics

Tomographic inversion based upon the inverted GLI model was executed to obtain a detailed near-surface velocity model for the long-wavelength statics calculation. A gentle smoothing approach was applied on first arrival picking before the inversion in order to minimize the picking errors and reduce the iteration times for a reliable inversion result. Based on computation time, sufficient sampling, and an optimal distribution of rays through each velocity grid cell, a grid spacing of 20 X 20 meters (double the receiver interval) was used for the construction of an initial tomographic velocity model. Finally, the long-wavelength static value was calculated by using the final near–surface velocity model with a carefully chosen a lateral smoother and replacement velocity for the surface layer.

Linear Noise Attenuation

Radial filters and FK filters were tested on shot gathers to enhance signal and attenuate linear noise. This linear noise has different apparent velocities and frequency bandwidth in different regions of this survey. Spatially varying parameters in FK filters were found to best suppress linear noise without destroying primary reflection events. Some residual linear noise were dealt with migration algorithms on either pre-stack gathers or post-stack.

Iteration of Velocity Analysis and Residual Statics

Optimum stacking velocities were picked using semblance analysis and constant velocity stack scans. The velocities were then used to create NMO-corrected gathers. A manually picked spatially varying mute function was applied to the NMO-corrected gathers instead of the automatic NMO stretch mute. Residual static values were then calculated on the NMO-corrected gathers by stack-power maximization that was especially effective in the poor signal-to-noise areas. To minimize the risk of cycle skip, two approaches were implemented during the iteration: Firstly, estimate the statics in lower frequency band (8-40 Hz) followed by the higher frequency (30-60 Hz); Secondly, residual statics were calculated with a small time-shift limitation initially, then a larger time-shift limitation (to a maximum of 100 ms) after progressive iterations .In order to check the processing effect of the residual statics application, receiver and shot gathers were investigated before and after residual statics corrections.

Pre-stack Time Migration (PSTM)

Regularization was applied to fill the missing traces on the single common-offset gather before PSTM. Pre-stack Kirchhoff time migration was conducted on the common-offset domain by using the post-stack migration velocity as an initial velocity. After a number of iterations of PSTM and imaging velocity analysis, a residual velocity was picked to refine the flatness of reflection events on the common image gathers. The final PSTM stacked section (Figure 4) was generated after the application of non-surface consistent statics (trim filter). This stacked section will be used to produce the initial geological interpretation for PSDM.

The processed gathers with all pre-migration procedures (except elevation correction) were then prepared for pre-stack depth migration (PSDM) from topography. The initial PSDM result produced by the Kirchhoff diffraction summation PSDM (Lawton 2005) shows the promising result in terms of a viable interpretation.

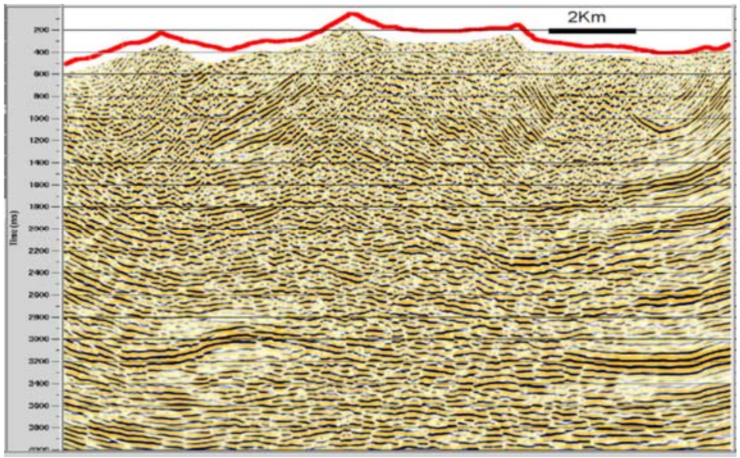

Figure 4. Final PSTM stacked section (red line indicates the elevation in time domain)

Summary

1. Tomographic inversion and statics based upon smoothed first arrival picks, and spatially varying smoothing parameters were effective in compensating for the effects of the laterally variable near-surface layer.

2. Spatially varying noise reduction processes were effective in improving the signal to noise ratio of gathers.

3. Multiple iterations of residual statics and stacking velocity analysis were effective in enhancing the signal to noise ratio and improving the continuity of reflections.

4. Pre-stack imaging from topography assisted in enhancing reflections within the carbonate-dominated region of the seismic line.

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