P-wave and S-wave near-surface characterization in Northeast British Columbia (NEBC)

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Summary

A seismic survey in NEBC was acquired using shear (SH) and compressional (P) sources and 3-component geophones. First break arrivals were picked in both data sets and refraction analysis was used to calculate the depth and velocity of the layers that were detected with the offset of 1500 m used during the acquisition. The objective of the project was to gather all the required information in order to elucidate the near surface P and S-wave velocity-depth structure. This model will help in the processing of a 3D/3C seismic survey that will be acquired in this area, and to provide constraints on registration of PP and PS volumes.

From the P-wave data, one refractor was detected and the presence of a channel was confirmed to the east end of the line. The depth of this refractor ranges from 140 m to ~230 m at the channel. The average velocity for the first layer is 1950 m/s and for the second layer is 2800 m/s. From the S-wave data a different model was determined, with two refractors detected to the west and only one refractor to the east. The depth of the first refractor is ~70 m and the second ~140 m; to the east the refractor detected is at ~180 m. The S-velocity for the first layer is 350 m/s to 420 m/s, and 650 m/s to 800 m/s for the second layer to the west and 1400 m/s for the third layer. Finally static correction times were computed. For SH data the static corrections range from -150 ms to -250 ms and for the P data, values range from 15 ms to -15 ms are obtained. A comparison with the generalized linear inversion (GLI) method was also made.

Introduction

Shear and compressional data have been used before for near surface characterization in order to calculate static corrections (Al Dulaijan, 2008; Martin, 2002; Parry and Lawton, 1993). Static corrections are used in the processing of reflection seismic data to remove the effects of variable low velocities in the shallow weathered layer and the effects of elevation. The problem caused by statics is more severe in areas with glacial sediments due to their irregular thicknesses, which is the case in a large part of western Canada (Lawton, 1990) and also in Northeast British Columbia.

The main objective of this study was to obtain accurate depth and velocities in order to have a detailed description of the near-surface properties. For this report, only an east-west segment from the seismic survey was used for the analysis. This section comprised 220 shots. Two datasets were used; the vertical data (P) which was the result of P-wave source recorded on the vertical component and the shear data (S) which was the result of the shear vibrator on one of the horizontal components of the geophone. The shear vibrator was polarized transverse to the seismic line, so as a result the first-arrival data used were acquired from the transverse component. Rotation of the raw data was performed to transform it into the radial and transverse components; the field orientation of the H_1 component of the geophones was zero degrees (magnetic north). After rotation of the data, the first break arrivals were picked and these values were exported for the plus-minus analysis. Two methodologies were used: Manual calculation with Excel spreadsheets and software developed to automate the plus-minus analysis. Depth and velocities were obtained and from them static corrections were calculated for source and receiver components.

Plus-Minus time analysis method

The plus-minus time analysis method (Hagedoorn, 1959; Dufour, 1996) is useful for both depth and velocity determination. The basis of the plus-minus time analysis method lies in the traveltime reciprocity: The traveltime from source to receiver is the same as from receiver to source if they are interchanged. The plus-times are used to give the traveltime from the surface to the refractor while the refractor velocity is estimated from the minus times. The plus-time (T^+_D) is defined as the sum of the traveltimes from two sources located on either side of a receiver minus the reciprocal time from shot to shot. The minus-time (T^-_D) is calculated by subtracting the times from the two sources located on either side of a receiver minus the reciprocal time.

To use this method, enough spread should be recorded in both directions, at least covering the whole distance between the sources. A window of analysis is defined between the two crossover points (from the forward and reverse curves, X_f and X_r, respectively). Inside this window, the plus-time value at each receiver can be evaluated with the following expression (A and D represent sources)

$$T^+_D = T_{AD} + T_{HD} - T_{AH} \quad (1)$$

The minus-time at a receiver D is

$$T^-_D = T_{AD} - T_{HD} - T_{AH} \quad (2)$$

Expressions to calculate depth can be obtained from the plus time analysis and velocities to the refractors are generated from the minus time analysis.

P-wave data analysis

The results of velocity and depth analysis are shown in Figure 1, showing a simple 2-layer result.

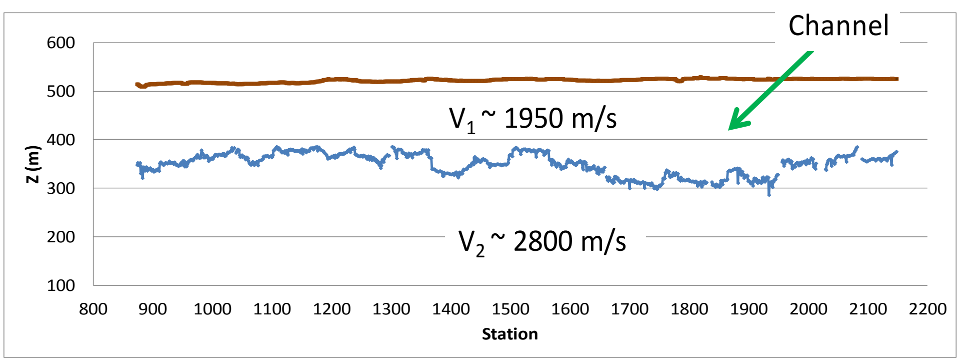

Figure 1. Cross-section obtained by using the plus-minus time analysis method on P-wave data.

S-wave data analysis

The results for velocities and depths deduced from the analysis of the S-wave data are shown in figure 2. The S-wave structure is more complex than the P-wave structure, with 3 layers present in the western portion of the line, and only 2 layers in the eastern part, including a broad channel.

Datum receiver correction times were calculated for the P-wave and SH-wave near-surface models obtained previously and the results are shown in figure 3.

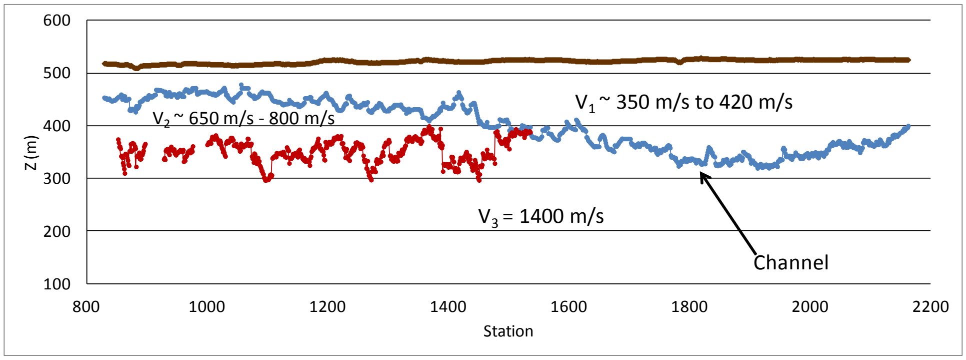

Figure 2. Cross-section obtained by using the plus-minus time analysis method on S-wave data.

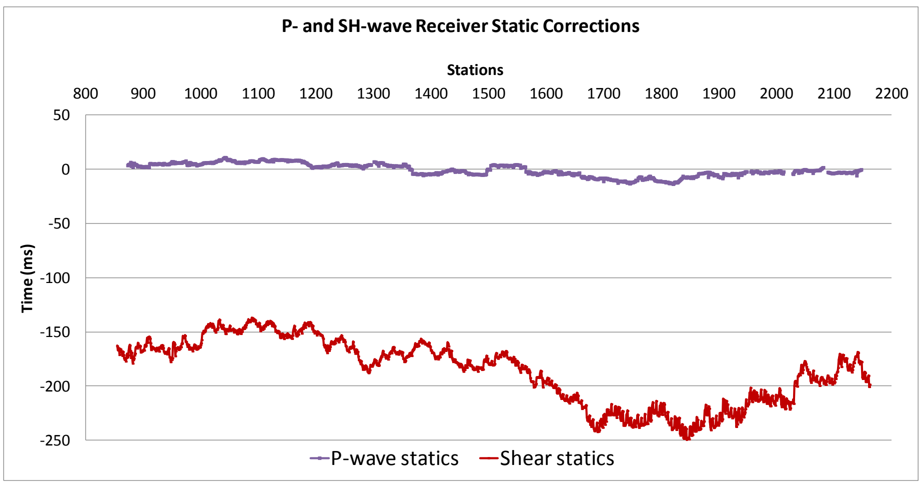

Figure 3. Datum receiver static corrections for P-wave data and SH-wave data.

The reflection data from the refraction line was processed and the migrated images were used to undertake PP-PS registration, assisted by the shallow Vp/Vs analysis from the refraction analysis. The result of this process is shown in figure 4 and interval Vp/Vs values from the seismic analysis matches closely the results from analysis of well-log data (shown on the left in this figure).

Discussion and conclusions

- Both depth sections, from compressional and shear data, show a channel that was also mapped from an airborne electromagnetic (EM) survey acquired in the area.

- The final model produced from the SH data shows three layers in the west part of the line and two layers to the east side of the profile. The presence of a channel is confirmed in the east side. The model obtained from the P-wave data shows only two layers, and the channel is also detected. The difference in model between the two wave modes is due to higher sensibility of shear waves to changes in velocities.

- The velocities obtained through the refraction analysis were used to calculate Vp/Vs for the near surface. High Vp/Vs values for the first layer were obtained, reaching values up to 6. For shallow layers, values of 3 to 4 are expected. This high value is due to high P-wave velocity relative to the low SH-wave velocity in the area. At greater depth, Vp/Vs generally are closer to values around 2. The results are comparable to the values obtained from well log data located in the same area.

- The receiver static corrections for the S-wave data gave significantly higher values than the static corrections times for the P-wave data as expected due to lower velocity of the SH-waves. The ratio goes from 10 to 16 (S to P static values).

- The main reflectors were interpreted in both PP and PS sections and interpretation of these sections enables event registration that generates interval Vp/Vs. This ratio was obtained with the information of interval times between the horizons of interest and matched closely the results from analysis of well log data.

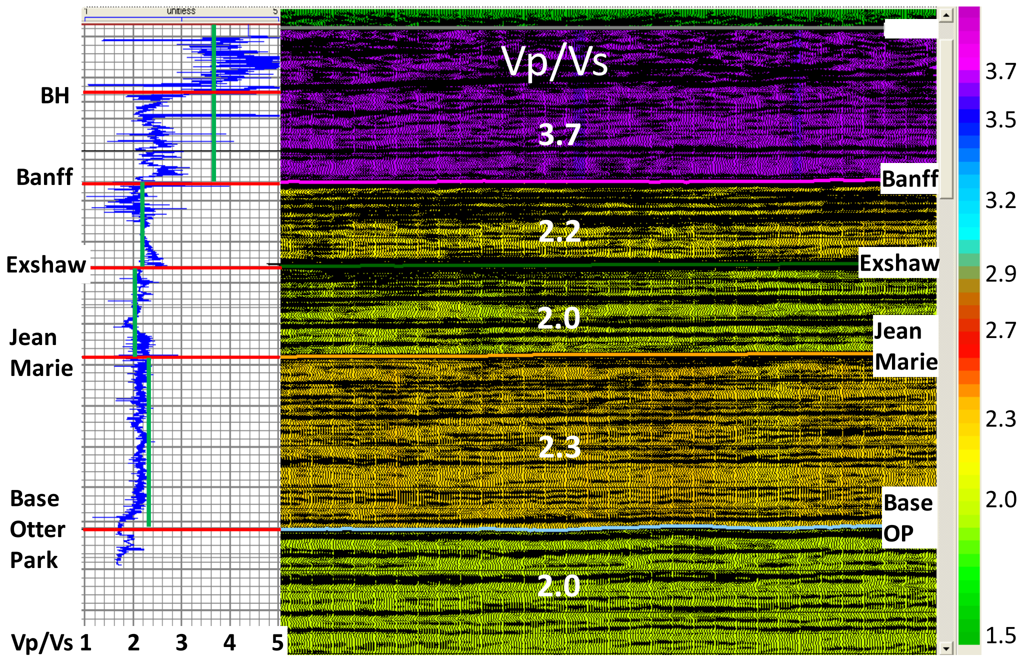

Figure 4. Vp/Vs after event registration. The ratio from the well log is overlapped to the left.

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