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Shallow VSP Survey using a Small Vibrator Source

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Summary

A shallow VSP survey was conducted in the Rothney Test Well using an EnviroVibe surface source and a downhole clamping 3C geophone in the well. The goal was to evaluate VSPs for imaging thin-bed stratigraphy in the near-surface environment. Two offset VSPs were obtained with the vibrator located 15m and 30m south of the wellhead. The vertical component data were subjected to wavefield separation to remove down-going P-wave and S-wave events, as well as other up-going and down-going low-velocity events. The residual up-going P-wave reflections were mapped using a simplified VSP/CDP procedure. The reflections on the resulting reflectivity maps corresponded closely to the near-surface stratigraphy of the Paskapoo formation as identified by sonic velocity, resistivity, and natural gamma-ray logs. The project confirmed that the EnviroVibe vibrator used in near-surface VSP surveys produces enough high-frequency energy to be effective for imaging relatively thin stratigraphy in the upper 100m.

Introduction

Two vertical seismic profiles (VSPs) were acquired in the Rothney Test Well using the U of C EnviroVibe as a source and a downhole clamping 3C geophone as a receiver. The well is located on Rothney Astrophysical Observatory property near Priddis, Alberta, at the eastern edge of the Rocky Mountain foothills in the triangle zone. It has a total depth of about 125m and is protected from collapse by 100-mm-ID PVC casing. The well encounters about 3m of unconsolidated overburden (tills, glaciolacustrine sediments, and alluvium), and then goes through interbedded sandstones and shales of the Tertiary Paskapoo formation. This formation is the largest single source of groundwater in the Canadian Prairies, supplying more than 100,000 wells in Alberta (Grasby, 2006). Shallow VSPs can contribute to understanding its near-surface hydrogeological characteristics.

Acquisition

The two VSPs were recorded with the vibrator offset 15m and 30m south of the wellhead. In both cases, the downhole 3C geophone was placed at depths ranging from 5m to 90m with half-metre intervals. The vibrator was driven with frequencies linearly swept from 20Hz to 200Hz. The sweep length was 10 seconds, and the listen time was 11 seconds. Digitization, correlation, and recording were done with a 24-channel Geometrics Geode and a Panasonic CF-30 portable computer. The sampling time was 0.5 ms. Figure 1 shows 3C seismograms for the 15m and 30m offset VSPs. Bandpass filtering by an Ormsby filter with corners at 40-50-200-300Hz and AGC have been applied to the seismic traces before display.

The traces have observable energy above 100Hz. The downhole geophone has no azimuth control, so the two horizontal component labels merely indicate two orthogonal orientations. Phase reversals at some depths for the horizontal components were corrected in later processing.

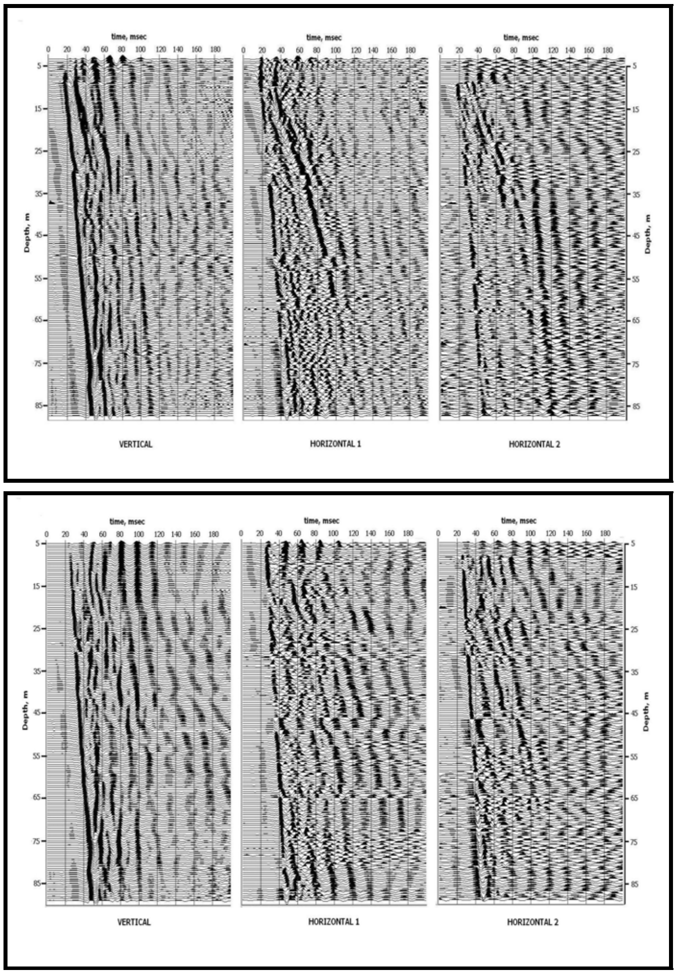

Figure 1: VSP field seismograms for source offsets of 15m (top) and 30m (bottom).

Wavefield separation

The data were processed to yield VSP/CDP maps of P-wave reflections (Miong, 2008). Figure 2 is an example of wavefield separation. Figure 2a shows the raw vertical component seismograms for the 15m-offset VSP. Median filtering was used to isolate the down-going first arrivals and other events with similar down-going velocities.

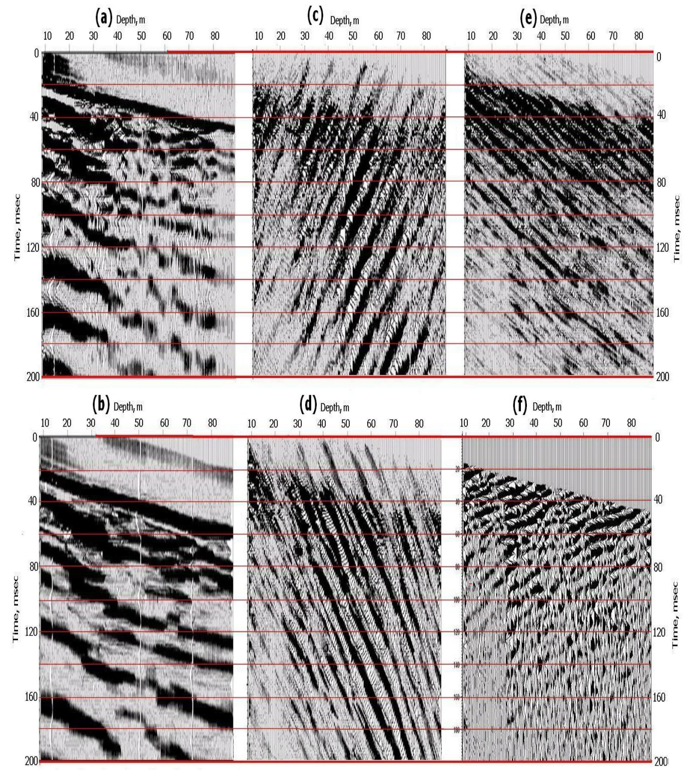

Figure 2: (a) Raw field seismograms; (b) down-going P waves; (c) and (d) down- and up-going low-velocity waves; (e) down-going S waves; (f) residual up-going P waves.

The resulting wavefield (Figure 2b) was then subtracted from the total wavefield, leaving a difference wavefield. On the difference wavefield, prominent up-going and down-going low-velocity waves were isolated by further median filtering. These low-velocity waves (Figures 2c and 2d) were subtracted from the first difference wavefield, resulting in a second difference wavefield. On the second difference wavefield, median filtering was applied once again to obtain the down-going shear wavefield shown on Figure 2e. The down-going shear waves were subtracted from the second difference wavefield, yielding the final residual wavefield shown on Figure 2f. The residual wavefield consists of mostly up-going reflected P waves. We then applied deconvolution to whiten the reflections, gain compensation to correct for spherical divergence, and NMO correction to flatten the reflections on Figure 2f.

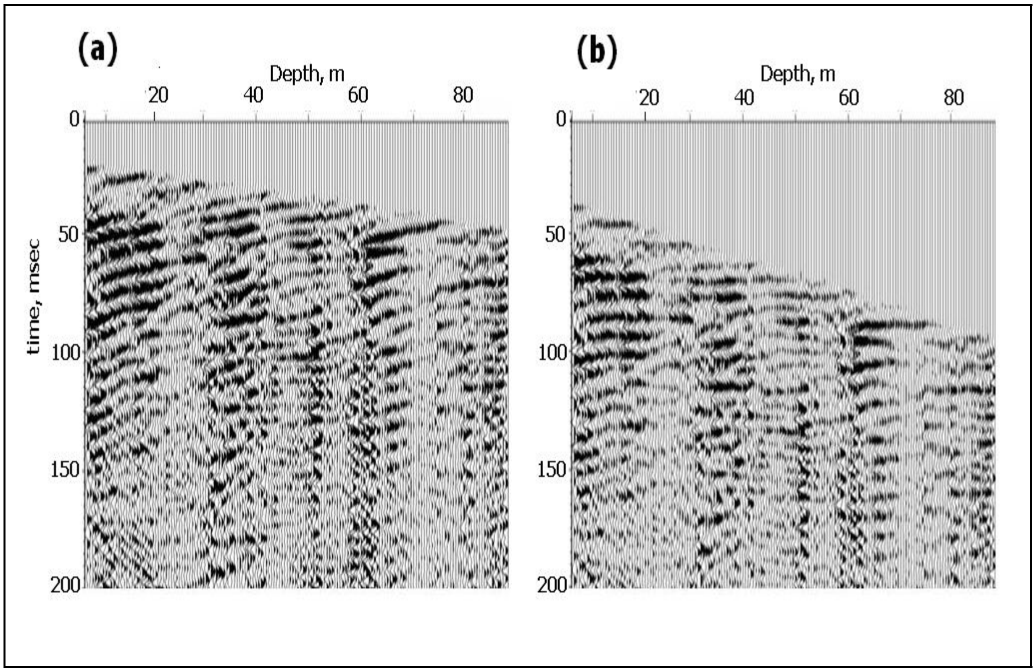

Figure 3: Up-going reflected P wavefield: (a) deconvolved and compensated for spherical divergence; (b) after NMO correction. The reflections are mostly flattened after NMO correction.

VSP/CDP mapping

The P-wave reflections after deconvolution, gain compensation, and flattening are shown on Figure 3. Reflectivity images were then created from the NMO-corrected reflections by VSP/CDP mapping. These reflectivity images show the lateral spatial coverage of the offset VSP surveys. Standard procedure for offset VSP/CDP mapping involves ray-tracing through a P-wave velocity model to locate reflection points. However, approximate mapping methods such as those described by Stewart (1991) and Gulati et al. (1997) can also be used. The offset x_B of the reflection point from the well for a P-wave arrival over a homogeneous single-layered earth is given by Gulati et al. (1997):

$$x_B = \frac{x}{2}\left[\frac{vt_v - 2z}{vt_v - z}\right], \qquad (1)$$

where x, v, t_v, z, are the source-receiver offset, constant velocity of the homogeneous single-layered medium, normal incidence time of reflection, and depth of the receiver respectively. This equation is valid for a single-layered earth, but it can be adapted to a multilayered earth simply by substituting the RMS stacking velocity v_{rms} in place of the constant velocity v (Gulati, 1998).

Results

Using the approximate method, final VSP/CDP images for both the 15m-offset and 30m-offset VSP data were produced. They are displayed on Figure 4, where we show the correlation of the VSP/CDP maps with resistivity, P-wave sonic velocity, and natural gamma-ray logs from the well. Also shown is the lithology and stratigraphy as interpreted qualitatively from the gamma-ray log. The time-to-depth conversion on the VSP/CDP maps was done by applying an RMS velocity of about 2.2 km/s to one-way travel time. We note on Figure 4 that most of the coherent reflections (marked by red lines) are located at or near shale-sandstone boundaries indicated by the resistivity and natural gamma-ray logs. The Paskapoo formation has very complex stratigraphy at shallow depths because of meandering sand channels that developed as fluvial deposits. It is encouraging and significant that the shallow VSPs were able to delineate shale-sandstone boundaries in this experiment, since fractured sandstones are often a source of groundwater.

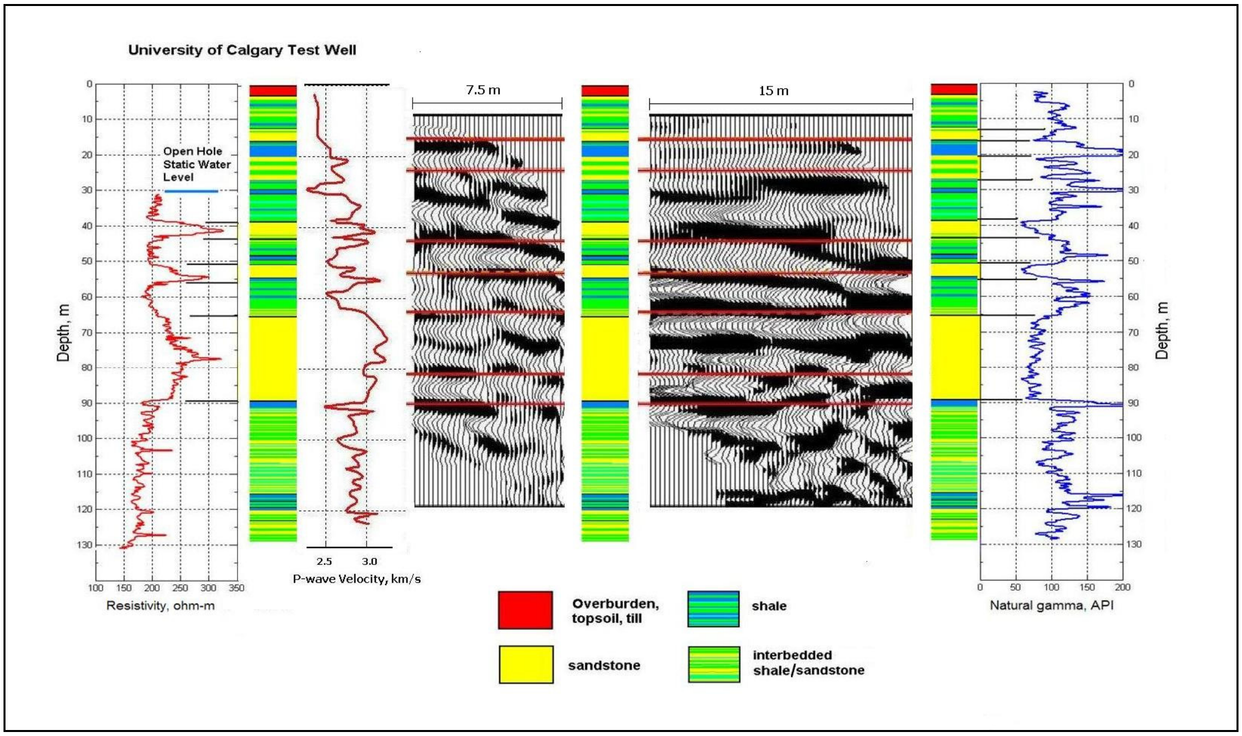

Figure 4: Correlation of the VSP/CDP maps with well logs and lithology (interpreted qualitatively from the natural-gamma ray log). The P-wave velocity log above 20m is not reliable due to poor coupling of the well casing to the formation.

Conclusions

The 3-C VSP survey in the Rothney Test Well using the EnviroVibe vibrator as a source and the analysis of the resulting field data proved to be very successful. Excellent quality seismograms, with significant energy at frequencies exceeding 100Hz, enabled us to apply sophisticated processing techniques that produced good-quality VSP reflection images. These images correlated reasonably well with the stratigraphy encountered in the borehole. We conclude that shallow VSPs can be effective and valuable for helping to characterize local geological and hydrogeological conditions in the Paskapoo formation. The velocity information and imaging quality of the hydrophone VSP data provide considerable promise for the technique's use in near-surface characterization (e.g., for groundwater exploration) and statics determination for related seismic processing.

Acknowledgements

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