Geophone orientation azimuth consistency case studies

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3D borehole study, Lousana

Abstract

Geophone orientation azimuths were found analytically from 3D walkaway VSP data acquired near Lousana, Alberta. This dataset was divided based on source-well azimuth into bins with centers trending 0°-180°, 45°-225°, 90°-270° and 135°-315°; the standard deviation in orientation azimuth was found to be 5.24° using all azimuths, and 1.28°, 0.66°, 1.07° and 2.77° respectively when binned. The mean angle calculated for each receiver did not appear to have any dependence on source-well azimuth, suggesting flat, isotropic geology near the well. Finally, the orientation angles for the 3D walkaway analysis were also calculated using a linear regression analysis of trace hodograms. Results showed that mean angles calculated using this method differed from the analytic method by less than 1° on average, but that the analytic method produced less scatter.

Survey Parameters

The 3D walkaway consisted of 249 source locations with a maximum offset of 3255 m (Figure 1). Dynamite was used as a source, and the VSP array consisted of 16 receivers. An example of a common shot gather is shown in Figure 2. The dataset was divided into 4 bins based on the source-well azimuth; bin centers were lines trending at 0°-180°, 45°-225°, 90°-270° and 135°-315°.

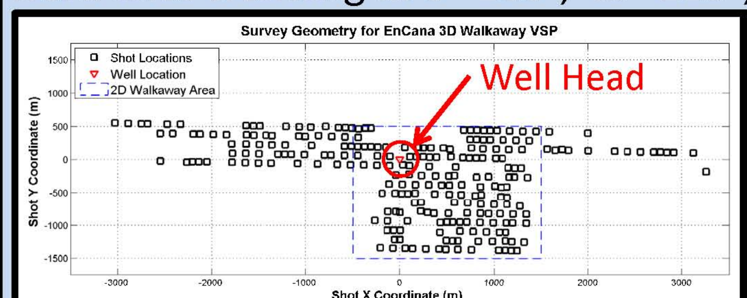

FIG. 1. Surface geometry for 3D VSP.

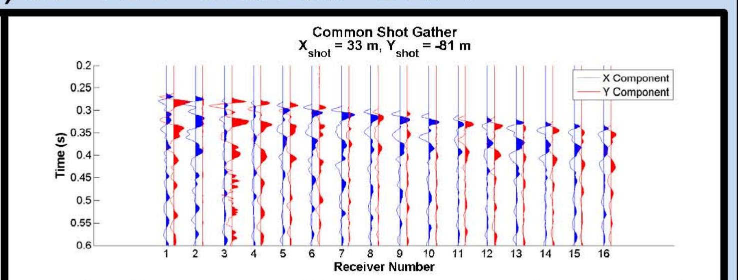

FIG. 2. Near-offset shot gather for 3D VSP showing horizontal components.

Discussion

Figure 3 shows orientation azimuths calculated using the analytic method, plotted against offset. Table 1 summarises the differences between the two methods using unbinned data.

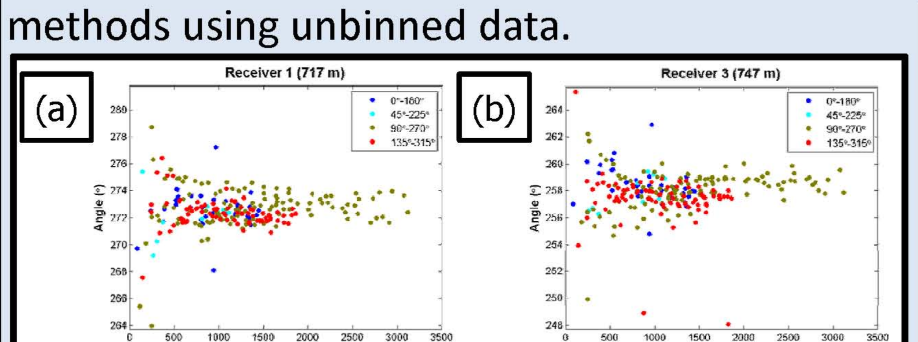

FIG. 3. Orientation azimuths for receivers 1 (a) and 3 (b) of 3D VSP.

Table 1. Difference in orientation statistics between analytic and regression methods using 3D VSP.

Receiver	Mean	Std. Dev
1	0.01	-0.13
2	-0.21	0.20
3	-0.22	-0.14
4	-0.21	0.62
5	-0.19	-0.55
6	-0.04	-0.18
7	0.37	-0.22
8	0.22	-1.23
9	0.04	0.04
10	0.40	-1.20
11	0.53	-3.90
12	-0.08	0.10
13	0.24	0.29
14	0.07	0.08
15	0.33	-0.73
16	0.27	-1.65
Average	0.21	0.70

Conclusions

- Geophone orientation angles were found using the DiSiena analytic method. The standard deviation was 5.24° using all azimuths, and became 1.28°, 0.66°, 1.07° and 2.77° when the data were binned into centers of 0°-180°, 45°-225°, 90°-270° and 135°-315° respectively.
- Geophone orientation angles were also found using a linear regression, or hodogram, method. The standard deviation was 5.83° for all azimuths, and 4.05°, 0.90°, 1.16° and 2.96° for binned data.
- Absolute difference in mean angles between the two methods averaged 0.21° for all azimuths, and 0.79°, 0.34°, 0.11° and 0.23° for binned data.

Geophone azimuth consistency, Violet Grove

Abstract

Raw borehole geophone data, taken from a 3-line walkaway vertical seismic profile (VSP) acquired in the Pembina oil field in Alberta, was examined for orientation azimuth consistency. Data were recorded using a 16-level VSP tool placed at three different levels in a deviated well. An algorithm was developed that compensated for the added complexities of a deviated well. Orientation azimuths, using all three lines, had an average standard deviation of 4.39°; consistency was poorest for the mid-level tool position, and best for the shallow-level tool position. Most interestingly, orientation azimuths calculated using sources from Line 1 were, on average, 3.7° higher than Line 2 and 3.0° higher than Line 6. This was judged to be related to geological properties of the area, particularly azimuthal anisotropy.

Methods

Consider an observation well that has an arbitrary deviation (Figure 4). We can define a plane that is perpendicular to the well at any receiver. We must choose a useful coordinate system for this plane; for this study, the new "pseudo" x and y axes are defined as

$$\hat{x}' = \begin{bmatrix} -\sin\phi_w \\ \cos\phi_w \\ 0 \end{bmatrix} \quad (1) \qquad \text{and} \qquad \hat{y}' = \begin{bmatrix} -\cos\theta_w \cos\phi_w \\ -\cos\theta_w \sin\phi_w \\ \sin\theta_w \end{bmatrix} \quad (2)$$

where θ_w is the well inclination angle and ϕ_w is the horizontal direction of the well relative to the positive x-axis. Finally, we must project the source coordinates onto the plane defined above.

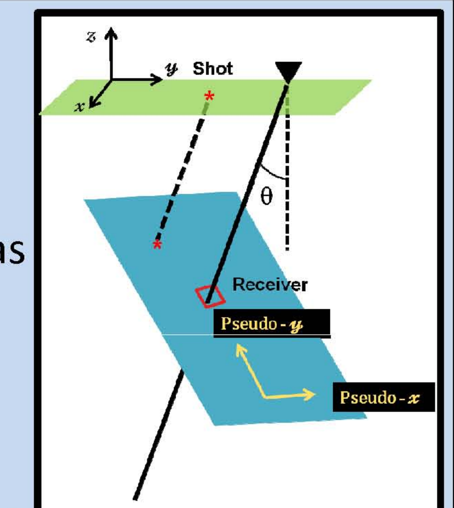

FIG. 4. Schematic of pseudo x and y axes.

Discussion

Receiver orientation azimuths between the x-component (H1) and pseudo y-axis were calculated for each line. These angles were then plotted against source pseudo offset (Figure 5); on average, Line 1 calculated an angle 3.7° higher than Line 2 and 3.0° higher than Line 6. Figure 6 directly shows the differences in the mean orientation azimuths of each line.

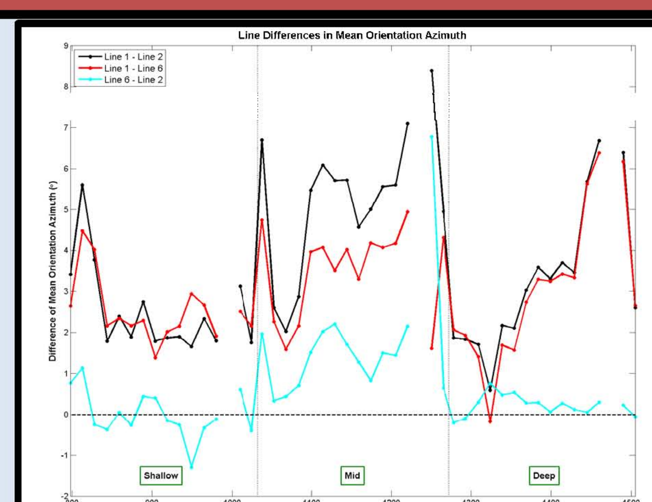

FIG. 6. Differences in mean orientation azimuth for each geophone level of Violet Grove VSP.

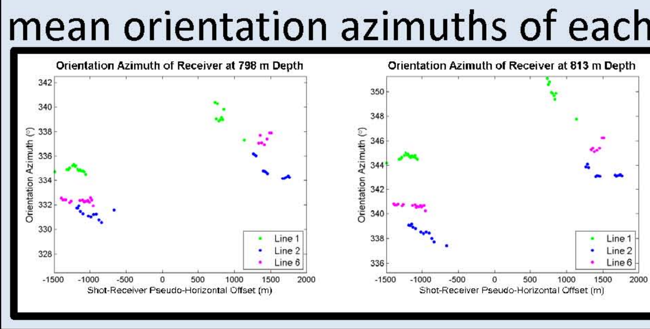

FIG. 5. Orientation azimuths for receivers at levels 1 and 2 for Violet Grove VSP.

Conclusions

- Orientation azimuths, using all three lines, had an average standard deviation of 4.39°.
- Orientation azimuth consistency was poorest for the mid-level tool position (6.70°), and best for the shallow-level tool position (2.74°).
- Orientation azimuth values calculated using sources from Line 1 were, on average, 3.7° higher than Line 2 and 3.0° higher than Line 6. This could be related to geological properties of the area, such as azimuthal anisotropy.

Borehole geophone calibration experiment

Abstract

Using an Envirovibe vibrator source, calculated geophone orientation azimuths for an 18-level tool were examined in order to determine the effects of stacking and correlation on orientation analysis. Sweeps were 20 s long, and their range was either 10-80 Hz or 10-200 Hz. Using all data points, uncorrelated traces produced standard deviation in the azimuths of 7.90° prior to stacking, and 3.74° after stacking; for correlated traces this was 5.84° prior to stacking and 5.54° after stacking. When the data were split into the separate sweep frequencies, it was found that the higher frequency sweep resulted in less scatter for correlated data, while having little effect on the uncorrelated data. The best statistics were obtained using uncorrelated stacked traces, using shots recorded with the 10-200 Hz sweep, giving a standard deviation of 3.62°. While this is an acceptable amount of scatter, it will still produce errors in offset of more than 6%. It is suggested that the number of shot points should be increased in order to obtain better precision.

Survey Parameters

For this experiment, seismic data was acquired using vibroseis in early 2011. Three lines were recorded (Table 2); Line 1 trended southwest (along the well trajectory), Line 2 trended south and Line 3 trended east. Two types of sweeps were examined in this study, 10-80 Hz and 10-200 Hz; in both cases, the sweep length was 20 s long. A raw, correlated, shot record is shown in Figure 7.

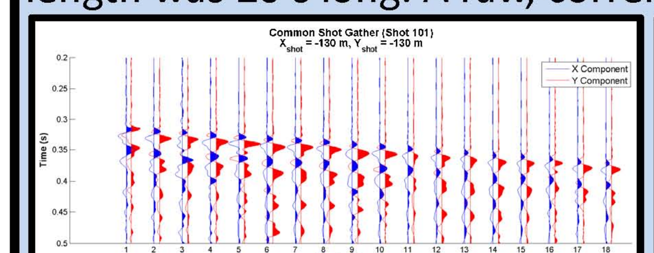

FIG. 7. Calibration shot gather showing horizontal components.

Table 2. Summary of acquisition parameters for the calibration experiment.

Line	Number of Shot Locations	Sweeps Used	Minimum Offset from Well (m)	Maximum Offset from Well (m)
1	7	10-80 Hz, 10-200 Hz	183.8	1688.0
2	2	10-80 Hz	1137.1	1499.3
3	2	10-80 Hz, 10-200 Hz	1140.1	1499.5

Discussion

Angle calculations, plotted against pseudo offset, are shown in Figure 8. Line 1 is shown in magenta, Line 2 in green, Line 3 in blue; shots from the 10-80 Hz sweep are shown as squares and those from the 10-200 Hz sweep are shown as crosses.

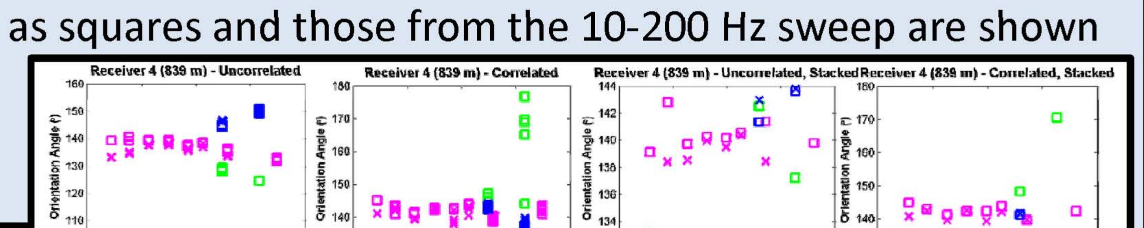

FIG. 8. Orientation azimuth for receiver 4 of calibration experiment plotted against pseudo offset.

Conclusions

- The standard deviation in geophone orientation azimuth calculations of uncorrelated traces was 7.90° for unstacked data and 3.74° for stacked data. For correlated traces, this became 5.84° for unstacked data and 5.54° for stacked data.
- The 10-200 Hz sweep produced better orientation azimuth calculations than the 10-80 Hz sweep for correlated data; sweep frequency had little effect on the uncorrelated data.
- It was determined that, in this experiment, uncorrelated, stacked data produced results with the least amount of scatter in geophone orientation azimuth.
- The best results showed a standard deviation of 3.62°. Increasing the number of shot points, especially at farther offsets, should be considered in order to improve this number.

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