Effects of noise and horizontal transverse isotropy on geophone orientation analysis

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Abstract

Using synthetic data generated from a simple layer-cake geological model, the effects of signal to noise ratio, source-receiver offset and receiver depth were determined to have an effect on this geophone orientation analysis. A signal to noise ratio of 1 or better was generally found to produce mean orientation angles within 0.5° of the true value. It was also found that increasing offset and decreasing receiver depth both improve the accuracy of azimuth calculations.

The effects of horizontal transverse isotropy (HTI) were also examined, under the assumption of weak anisotropy. A model was created using $\varepsilon = 0.1$ and $\delta = 0.025$, resulting in a maximum polarization angle deviation of 6.45°. Using this model, values for apparent polarization deviation were found for various source locations; these values produced distinct trends depending on the orientation of the source-well plane. The results of this study show that HTI media should be taken into consideration when undertaking orientation calibration for buried microseismic arrays or geophones used in vertical seismic profiles.

Introduction

In order to determine the orientation of borehole geophones, a controlled experiment is generally performed, using known source locations. The goal of this study will be to examine the combined effects of noise, receiver depth and source offset on the accuracy of a known geophone orientation. Figure 1 shows a sample shot gather of the synthetic data used. Additionally, the effects of horizontal transverse isotropy (HTI) will be considered, including the effects on a modelled survey (Figure 2).

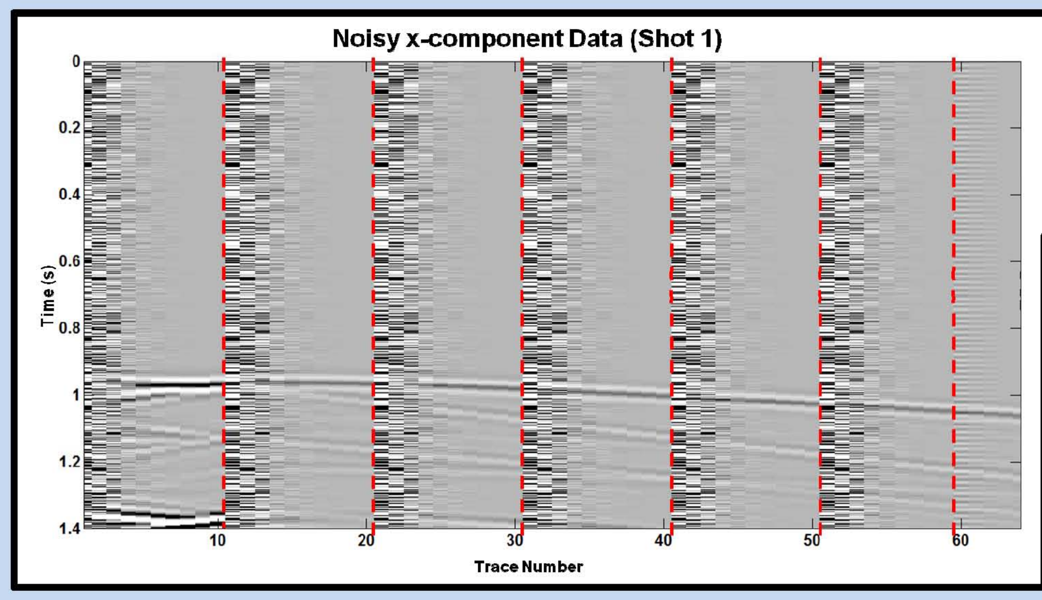

FIG. 1. Example shot gather for noise experiment.

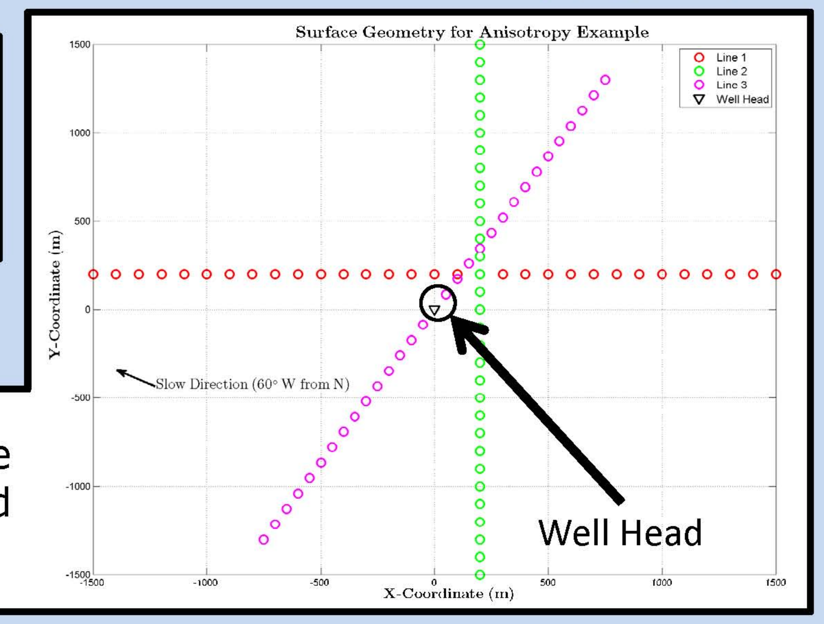

FIG. 2. Surface geometry modelled for HTI analysis.

Discussion

In the noise experiment, geophone orientation azimuths were found for every receiver, and the results were plotted against source-receiver horizontal offset; values calculated from the noise-free synthetic data are also shown for comparison (Figure 3). Quantitative analysis (Table 1) reveals that the standard deviation at a signal to noise ratio of 1 ranges from 1.24°-7.69°, whereas a signal to noise ratio of 0.5 produces standard deviations as high as 22.2°. Furthermore, Table 1 demonstrates that increasing receiver depth is well correlated with higher angle scatter.

The maximum angle difference due to HTI was computed for a range of values of δ and ε. Figure 4 shows a contour plot of these values, given on a range of $-0.15 \leq \delta \leq 0.15$, $0 \leq \varepsilon \leq 0.35$. Values indicate that ε has a more noticeable effect on the maximum deviation than does δ, and that the deviation produced can reach values that are quite large. In the modelled case, the anisotropic axis of symmetry was chosen to be at an azimuth 60° west of north, perpendicular to the azimuth of Line 3; other parameters are shown in Table 2, and a sample wavefront is shown in Figure 6. Figure 5a shows the difference between the phase and group angles calculated using the modelled survey, as a function of source-receiver offset. In the context of this study, this is effectively the deviation that will be produced for a noise-free geophone orientation calibration. Note that each line follows a distinctly different trend. On the other hand, if we examine the orientation angle deviation as a function of source-receiver azimuth, the pattern seen is more consistent between lines (Figure 5b). In fact, the relationship appears very similar to that seen in Figure 7, the angle difference over a full 360° cycle.

Results

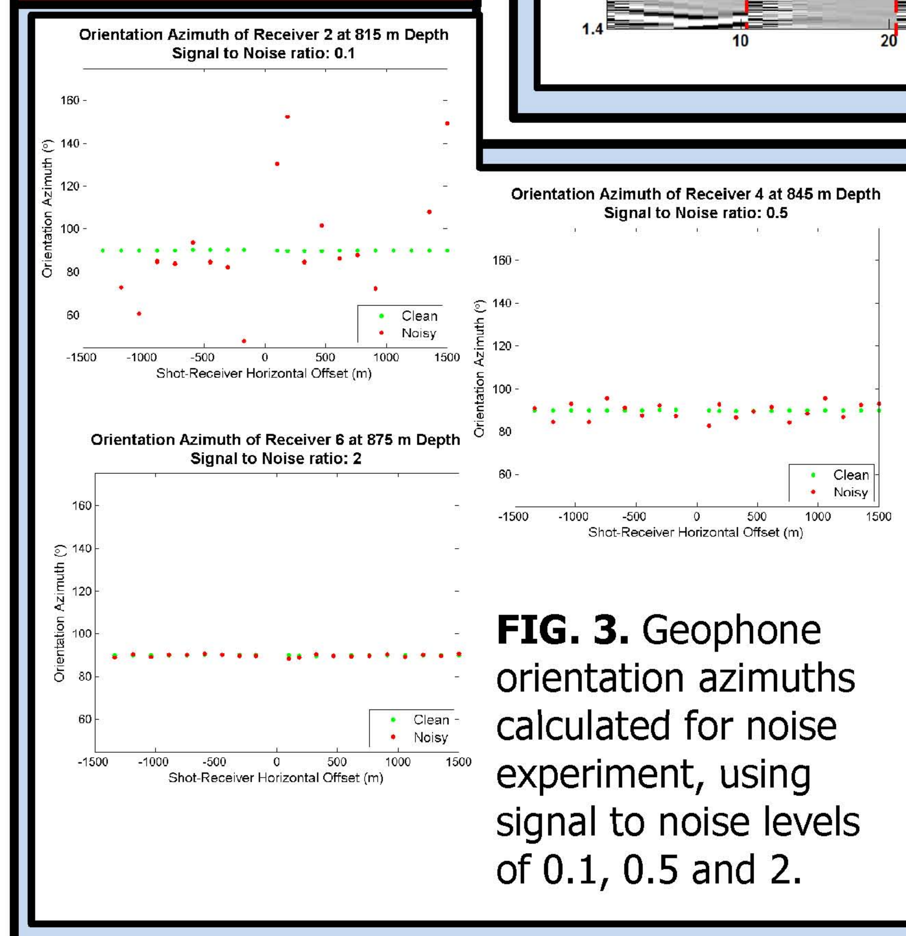

FIG. 3. Geophone orientation azimuths calculated for noise experiment, using signal to noise levels of 0.1, 0.5 and 2.

Table 1. Geophone orientation statistics for noise experiment. Correct orientation is 90°.

Signal to Noise: 0.1	Depth (m)	815	965	1115	1265	1415	1565
	Mean (°)	85.04	85.27	75.29	72.66	86.81	79.83
	St. Dev (°)	33.92	38.87	43.20	54.53	61.37	65.36
Signal to Noise: 0.2	Depth (m)	830	980	1130	1280	1430	1580
	Mean (°)	91.78	93.62	105.72	104.29	104.81	113.63
	St. Dev (°)	14.06	30.12	36.60	27.62	34.66	41.19
Signal to Noise: 0.5	Depth (m)	845	995	1145	1295	1445	1595
	Mean (°)	89.59	90.54	89.60	90.20	99.42	91.07
	St. Dev (°)	3.94	4.93	19.43	9.47	22.20	22.00
Signal to Noise: 1	Depth (m)	860	1010	1160	1310	1460	1610
	Mean (°)	89.67	89.55	90.34	89.99	90.59	89.67
	St. Dev (°)	1.24	1.75	2.88	5.82	5.35	7.69
Signal to Noise: 2	Depth (m)	875	1025	1175	1325	1475	1625
	Mean (°)	89.85	89.70	90.07	89.65	91.65	92.68
	St. Dev (°)	0.66	1.47	1.32	1.37	11.63	10.36

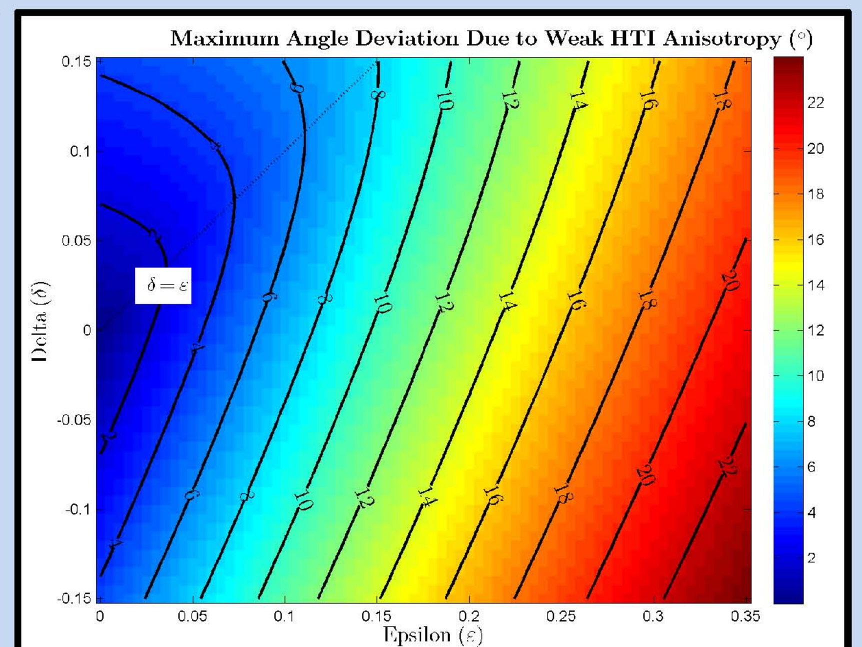

FIG. 4. Maximum geophone orientation deviation as a function of δ and ε.

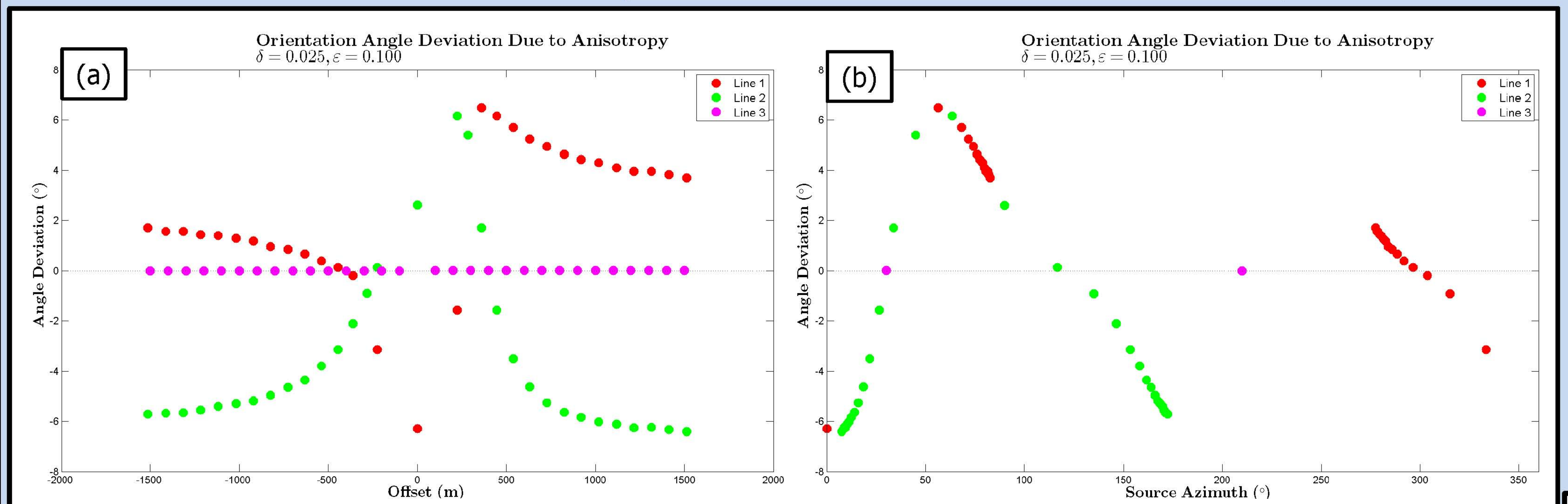

FIG. 5. Geophone orientation deviation due to anisotropy vs. source-receiver offset (a) and source-receiver azimuth (b). Line 1 is shown in red, Line 2 is shown in green, and Line 3 is shown in magenta.

Table 2. Parameters used for HTI model.

Parameter	Value
δ	0.025
ε	0.1
v_0	3000 m/s

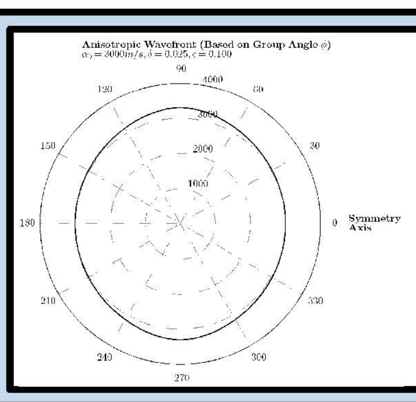

FIG. 6. Anisotropic wavefront as a function of group angle, using parameters shown in Table 2.

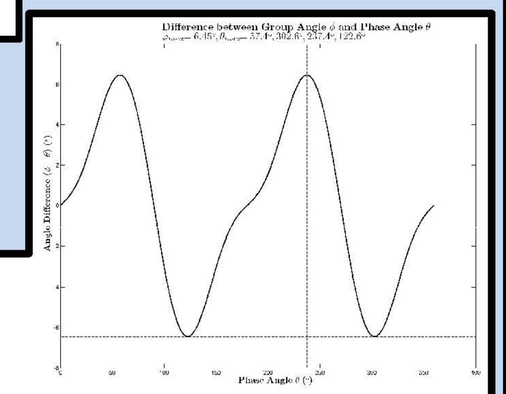

FIG. 7. Geophone orientation deviation as a function of phase angle (δ=0.025, ε=0.1).

Conclusions

- The calculation of geophone orientation azimuths is dependent on signal to noise ratio, source-receiver offset and receiver depth.
- A signal to noise ratio of 1-2 seems to be the minimum required for statistically reliable azimuth calculations; these calculations generally produced a mean within 0.5° of the receiver's true orientation.
- Larger source-receiver offsets produce more accurate azimuth calculations.
- Deeper receivers result in less accurate azimuth calculations.
- Even given δ within ± 0.05, deviations in geophone orientation angle can exceed 5° for values of e as small as 0.05.
- A model created using $\varepsilon = 0.1$ and $\delta = 0.025$ showed a maximum difference in phase and group angle of 6.45°.
- The effect of anisotropy on geophone orientation angle is difficult to interpret when examined as a function of source-receiver offset; however, it produces a much more consistent trend when examined as a function of source-receiver azimuth.
- The results of this study show that neglecting anisotropy in geophone orientation calibration analyses can introduce significant error.

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