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 $\epsilon = 0.1$ 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 1a 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).

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 1.28° to 2.69°, 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 $\delta$ and $\epsilon$. Figure 4 shows a contour plot of these values, given a range of $0.15 \leq \delta \leq 0.15, 0 \leq \epsilon \leq 0.35$. Values indicate that $\epsilon$ has a more noticeable effect on the maximum deviation than does $\delta$, 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 6a 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 6b). In fact, the relationship appears very similar to that seen in Figure 7, the angle difference over a full 360° cycle.

Conclusions
- Even given $\delta$ within 0.05, deviations in geophone orientation angle can exceed 5° for values of $\epsilon$ as small as 0.05.
- A model created using $\epsilon = 0.1$ and $\delta = 0.025$ shows 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.

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

<table>
<thead>
<tr>
<th>Signal to Noise Ratio</th>
<th>Mean</th>
<th>Standard Deviation (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>90.00</td>
<td>1.28</td>
</tr>
<tr>
<td>0.5</td>
<td>90.00</td>
<td>2.69</td>
</tr>
<tr>
<td>0.25</td>
<td>90.00</td>
<td>4.53</td>
</tr>
<tr>
<td>0.15</td>
<td>90.00</td>
<td>6.45</td>
</tr>
</tbody>
</table>

Table 2. Parameters used for HTI model.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta$</td>
<td>0.025</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>0.1</td>
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<tr>
<td>$\nu_s$</td>
<td>3000 m/s</td>
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</tbody>
</table>

References

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