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Velocity model calibration effects on microseismic locations

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Summary

Accurate microseismic event locations are critical for microseismic monitoring, since they form the basis for interpretation of stimulated regions of an unconventional reservoir during a hydraulic fracture treatment. Calculated event locations depend on the velocity model, which in general is not well known. In this paper, we use finite-difference synthetic seismograms to assess the importance of seismic anisotropy (weak transverse isotropy, up to 20%, with a vertical symmetry axis) for microseismic event location uncertainty. Using a velocity model based on the Barnett Shale, we consider systematic position errors that arise when the velocity model is assumed to be isotropic. In particular, the starting model uses the correct vertical isotropic velocities and is adjusted to fit arrival times from a single calibration point (e.g., a perforation shot or string shot). As expected, we find systematic location errors. In areas where strong anisotropy is known to occur, it is important to incorporate anisotropy into the hypocentre location method.

Introduction

Accurate microseismic event locations are the basic requirements from a microseismic monitoring survey to interpret the stimulated regions of an unconventional reservoir during a hydraulic fracture treatment. The accuracy of microseismic event locations depend on the accuracy of arrival time picking and velocity model, the source-receiver geometry and the suitability of the location estimation technique (Ge and Kaiser, 1992; Maxwell, 2009). The velocity model, in general, is not well known and is calibrated locally using the arrival time picks from a single perforation shot for improved microseismic event locations.

In this paper, we use finite-difference synthetic seismograms to evaluate the significance of vertical transverse isotropy (VTI) for microseismic event location uncertainty. We use a velocity model based on the Barnett Shale (Maxwell, 2009) and consider systematic position errors that arise when the velocity model is assumed to be isotropic.

Method

We generate synthetic seismogram using finite-difference modeling for the Barnet Shale model (Maxwell, 2009), which is used as initial isotropic model. Figure 1 shows the initial isotropic model with a low velocity shale layer surrounded by high velocity layers. Sources are distributed in the offset range (200 – 400m). Receivers are positioned as a vertical array at 0m offset and in a depth range (2377 – 2432m), with inter-receiver spacing of ~6m. We relocate all the sources using the exhaustive grid search algorithm to validate the microseismic event location algorithm accuracy.

We, then, generate synthetic seismograms for velocity model with different levels of VTI in shale layer. The anisotropy parameters are considered in the range of 0-20% (weak anisotropy). In Thomsen parameters, $\gamma = 0.2$ represents 20% anisotropy and $\varepsilon = 0.9\gamma$, which in the case of missing data is a reasonable assumption (Erwemi et al., 2010). The arrival times are picked on the synthetic seismograms. We obtain a calibrated (best-fitted) velocity model using a synthetic seismogram, which is generated with a velocity model having 10% VTI in shale layer. The microseismic events are located using both the initial isotropic and the calibrated (best-fitted) velocity models.

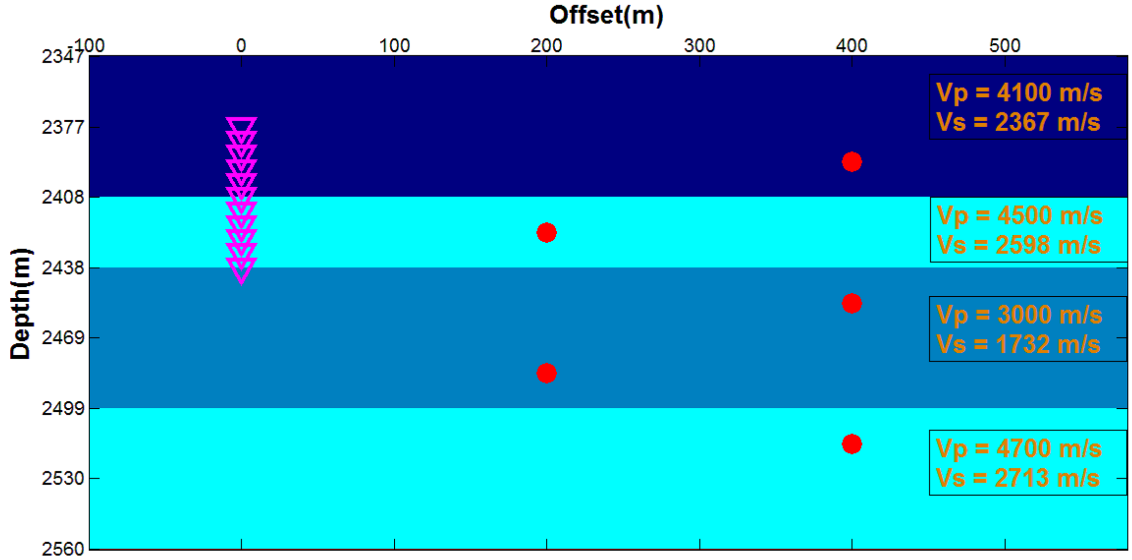

Figure 1: Input velocity model (from Maxwell, 2009). Receivers are displayed as inverted triangles (magenta color). Sources are shown as dots (red color).

Results

Figure 2 shows the horizontal component of the synthetic seismogram for a source point (offset = 400m, depth = 2515m). The waveforms are almost similar. There is, however, a slight time shift in the arrivals (microseismic events are arriving earlier with increasing anisotropy). Figure 3 shows the located microseismic events using the isotropic velocity model without calibration. The red dots in Figure 3 show the correct microseismic locations. There exist notable systematic variations in the microseismic event locations. The general trend is the microseismic events clustering towards the geophones away from their true positions. This suggests that the velocity model requires calibration, which is normally performed by minimizing the errors between observed and modeled travel times using a known source position. However, this calibration is only local and may result in improved microseismic locations near the vicinity of the calibration point. Figure 4 shows the microseismic locations using the calibrated velocity model. The microseismic source positions near the calibration shot are improved. However, the use of locally calibrated model introduces huge errors in other positions, especially the event from the top layer. This is due to the velocity adjustment during calibration process with an isotropic ray-tracer. As suggested by Warpinski et al., (2009), an anisotropic ray-tracer should be used in the velocity model calibration and building look-up table process for improved microseismic locations.

Conclusions

Accurate velocity model is critical for obtaining reliable interpretations of stimulated regions of an unconventional reservoir during a hydraulic fracture treatment. Correct incorporation of anisotropy parameters into the velocity model is important. The velocity model calibration, with a single calibration shot and an isotropic ray-tracer, may improve the microseismic locations in the vicinity of the calibration shot but it can also introduce significant errors in the surrounding microseismic event locations. It is, therefore, recommended to use anisotropic ray-tracer in the velocity model calibration and building look-up table process for accurate microseismic locations.

Acknowledgements

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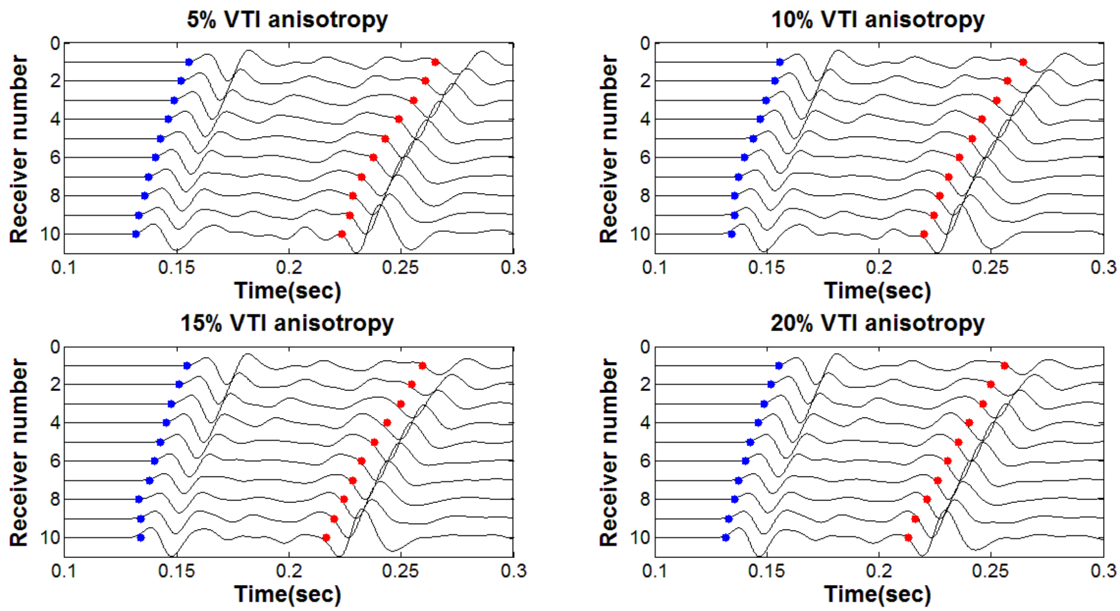

Figure 2: Horizontal component of synthetic data for velocity models with different percentage of VTI in the shale layer. P and S-wave arrival time are picked (blue and red dots respectively).

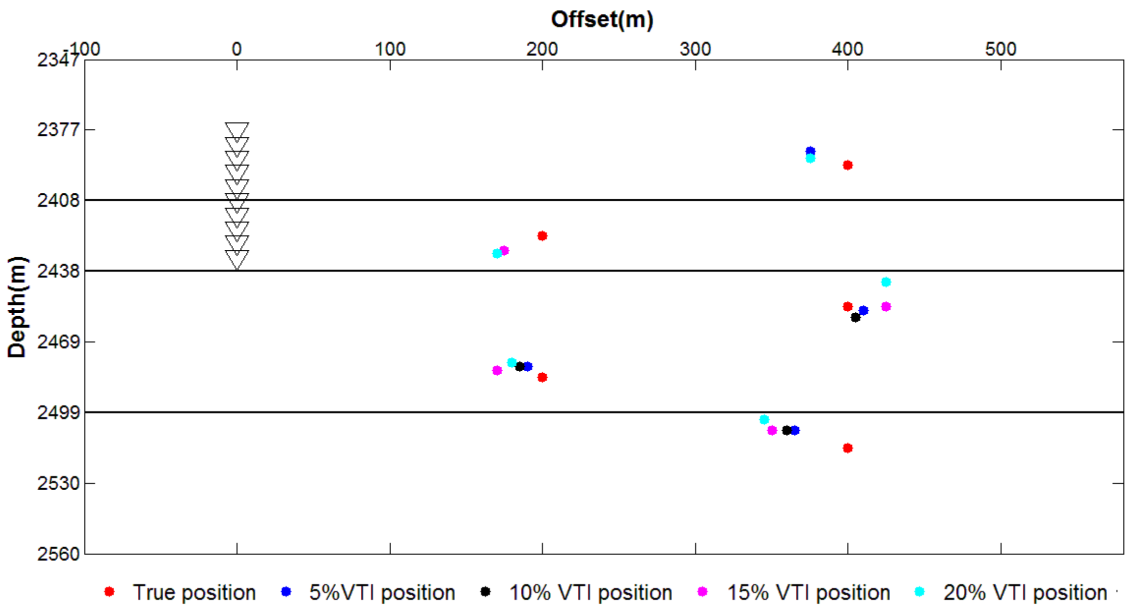

Figure 3: Microseismic positions of synthetic data with different percentage of VTI in the shale layers. The isotropic model is used for microseismic event locations.

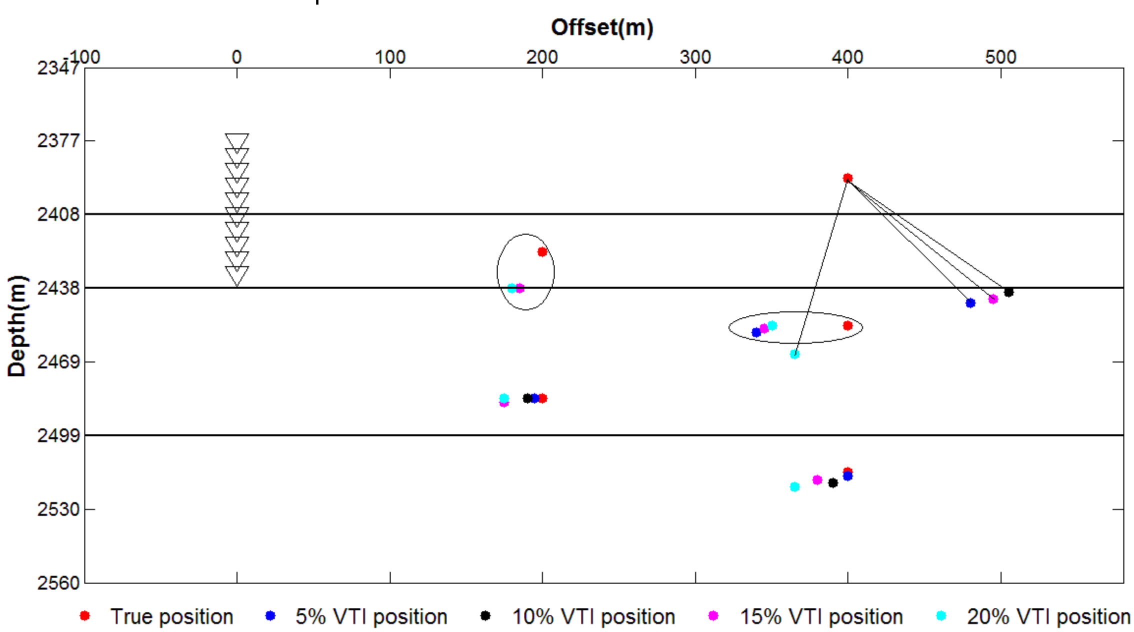

Figure 4: Microseismic locations of synthetic data with different percentage of VTI in the shale layers. The synthetic seismogram (offset = 400m, depth = 2515m) obtained from velocity model with 10% VTI in shale layer is used to calibrate the velocity model.