Microseismic Event Locations Uncertainity and Acquisition Geometry

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Summary

Microseismic event location position uncertainty is one of the most critical aspects of passive seismic. These locations form the basis of interpretation of simulated rock volume. In order to have confidence on simulated rock volume calculation, it is important to understand the origin of position uncertainty in microseismic event locations. Uncertainties in microseismic event location arise due to several factors, including inaccurate velocity model, random errors associated with P and S wave arrival time picking and receiver configuration. In this study we investigate event location uncertainties for various receiver configurations.

Introduction

Microseismic monitoring is a valuable tool to evaluate the performance of simulation treatment of unconventional reservoir. It involves placement of three-component geophones in borehole or on surface, to detect and record small earthquakes. Effectiveness of microseismic monitoring is defined by increase of production as a result of fractures conductivity. Different algorithms are applied to locate events using compressional (P-wave) and shear (S-wave) wave arrivals. These locations can be associated with new fractures or activation of pre-existing fractures. Microseismic event locations can be used to image the growth of the fracture network to help assist in optimization of hydrocarbon production, well placement in the field undergoing steam injection.

Accurate microseismic locations are key product of monitoring survey to correctly interpret the simulated region of unconventional reservoir. The accuracy of the microseismic event locations depends on 1) precision of arrival time picking [*Kocon and van der Baan*, 2012], 2) velocity model [*Maxwell*, 2009] and 3) source-receiver geometry [*Eisner et al.*, 2010]. In this paper we present an analysis to illustrate the effect of acquisition geometry and source receiver distance on event locations uncertainty.

Location Uncertainty

To evaluate different acquisition geometries commonly used in microseismic monitoring, it is important to quantify the location uncertainties in the model. The simplest way of locating microseismic events is by grid search algorithm. In grid search algorithm, each grid point is defined by E(x, y, z, θ, and t) where t is the theoretical travel time difference between P and S and x,y and z are the northing, easting and depth of the potential source location. The grid point with the smallest residual value is considered to be the most likely location. In this case the residual value is defined as

$$PD = exp^{-\frac{1}{2}\left(\sum_{i=1}^{N}\frac{wi(t_{cal}-t_{obs})^2}{\sigma_t}+\sum_{i=1}^{N}\frac{Li(\sin(\theta)_{cal}-\sin(\theta)_{obs})^2}{\sigma_z}\right)}.$$

Where *i* is the number of receivers ranging from 1 to *n*, w_i is the weighting factor based on the S/N ratio of each receiver,L_i is the weighting factor for the azimuth defined as the linearity L_i, estimated from the polarization analysis mentioned above. As explained above σ_t is the uncertainty in the S-P travel time picks, σ_z is the uncertainty in azimuth calculation which is affected by the P wave travel time picks. *PD* is the probability density of hypocenter location; highest probability is linked to minimum misfit in the observed and theoretical S-P travel time and source azimuth.

To evaluate event location uncertainty, synthetic microseismic dataset is generated for deviated, vertical and horizontal boreholes using a 1D velocity model. Each borehole contains ten, 3C geophones. Table 1 shows the receiver coordinates for all three cases. This source-receiver geometry is based on a real recording configuration used for a steam injection experiment. Next we compute the theoretical back azimuths and P and S arrival times using 1D velocity model for each receiver configurations.

Vertical Borehole			Horizontal Borehole			Deviated Borehole		
X(m)	Y(m)	Z(m)	X(m)	Y(m)	Z(m)	X(m)	Y(m)	Z(m)
1200	1200	350	1200	1200	350	1200	1200	350
1200	1200	360	1190	1210	350	1190	1210	360
1200	1200	370	1180	1220	350	1180	1220	370
1200	1200	380	1170	1230	350	1170	1230	380
1200	1200	390	1160	1240	350	1160	1240	390
1200	1200	400	1150	1250	350	1150	1250	400
1200	1200	410	1140	1260	350	1140	1260	410
1200	1200	420	1130	1270	350	1130	1270	420
1200	1200	430	1120	1280	350	1120	1280	430
1200	1200	440	1110	1290	350	1110	1290	440

Table 1:Geophone coordinates for all three receiver configurations, where X, Y and Z corresponds to easting, northing and true vertical depth respectively.

For this study true back azimuths and S-P travel times are used as observed quantities. The linearity *Li* and weight factor *wi* in equation 1 are set to one for all three cases. Now we discuss results for three considered well orientations.

Uncertainty space and acquisition geometry

We use the above mentioned algorithm to analyze the size of uncertainty space (number of cells with greater than 99% probability in 3D grid) associated with different borehole geometries, and its variation with source-receiver distance. For this purpose we generated three synthetic events at different distances from the receiver. Event 1, 2 and 3 are located at 100,200 and 400m from the receiver array respectively.

Uncertainty plots for vertical, horizontal and deviated borehole for three events are shown in Figure 1. Figure 1(top) shows the variation in the uncertainty space with increasing source-receiver distance for a vertical borehole. Comparing the uncertainty plots for the vertical borehole to horizontal and deviated boreholes for event 1, the size of the uncertainty space (figure 1, left column) is found to be significantly larger (500%) for the vertical borehole, although this is compensated by a slightly smaller azimuthal uncertainty (not shown). Likewise for event 2 and 3, uncertainty space is still largest for vertical borehole 120% and 30% respectively. A, moderate difference is found between the horizontal and deviated borehole uncertainty space. Thoroughly comparing the variation in the uncertainty space with distance reveals that the increase in the uncertainty space for a horizontal borehole is 30 to 100% greater than for a deviated borehole (Figure 1, center and right column).

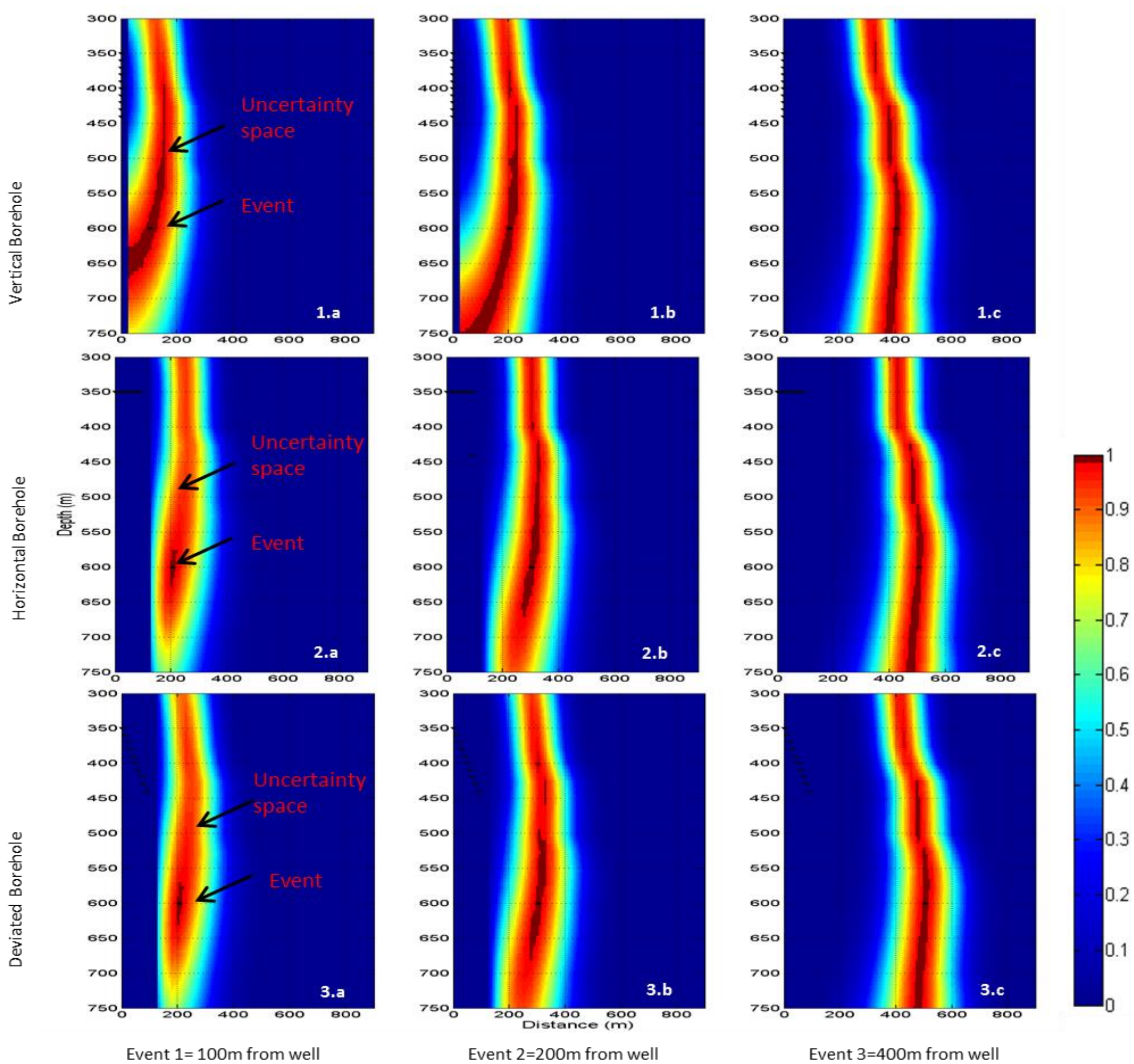

Figure 1: Combined time and azimuth residuals indicating the uncertainity space for vertical (top)), horizontal (center), and deviated (bottom) boreholes. Left to right: Events 1—3. Colors: normalized likelihood (red=1, blue=0).

The uncertainty space for all three geometries is found to be similar when events are further than 600-700 meter from the observation well (the spread in geophones is 90m here). Comparison of the uncertainty plots favors thus deviated borehole geometries over horizontal and vertical borehole geometry, when events are expected to occur within 700 meter radius of the observation well, due to the better azimuthal and depth coverage of the geophones in a deviated borehole.

Conclusion

It has been demonstrated in this study with the help of synthetic microseismic dataset that event location uncertainty is minimum for deviated borehole geometry. Because deviated borehole configuration has advantage of wider azimuthal geophone coverage than a vertical borehole configuration and a better depth constraint than horizontal boreholes.

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Reference

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