The Effect of Microseismic Array Configuration on the Determination of Hydraulic Fracture Parameters

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Introduction

The distribution of microseismicity induced by hydraulic fracturing and other injection programs is frequently used to confirm and calibrate models of hydraulic fracturing. The length, height, and azimuth of the cloud of event locations are the first-order parameters that an engineer would use to assess the efficiency of the treatment. Often, these microseismic events are recorded with sub-optimally distributed downhole sensor arrays, this has implications for the observed distributions. In fact, the majority of microseismic monitoring programs utilize just one toolstring. This lack of coverage introduces potential artefacts due to both an uneven coverage of the treatment area and a restriction that both P and S waves need to be seen in order for the event to be reliably located (utilizing standard processing approaches). The more well-distributed the arrays are around the seismicity, the more accurate the events will be located. We shall present the results of reprocessing a cluster of events from a steam injection program originally located with 3 downhole arrays. We relocate the events after having removed one of each of the arrays and then relocate the events again based on only single toolstring locations. Comparing the various distributions with the 3-array solution, taken to be "ground truth", will allow us to assess the effect of having compromised array configurations on the observed seismicity and address questions regarding monitoring effectiveness, frac geometry, and symmetry.

Data

Over 400 events, shown in figure 1, comprise the three-array solutions of the event distribution recorded from a steam injection. The events cluster around the treatment well (blue) in a relatively confined distribution; about 200 ft long, 50 ft wide and 150 ft high, and delineate the region responding to the steam treatment. Each of the toolstrings received signal for these events due to the good azimuthal coverage, the locations are highly accurate since the location algorithm uses the traveltime information from the P- and S-wave picks as well as hodograms to arrive at a location. In addition the very wide aperture for the array, nearly 700 ft, results are very well-constrained in depth. Starting with the 3-well array we decimate the arrays and examine all possible subsets of the arrays, and relocate the events. The distributions of these sub-arrays are used to examine the effect of decimating the array coverage on the final distribution of events that could lead to differences in the interpretation of the data (if the changes in the distributions are sufficiently extreme).

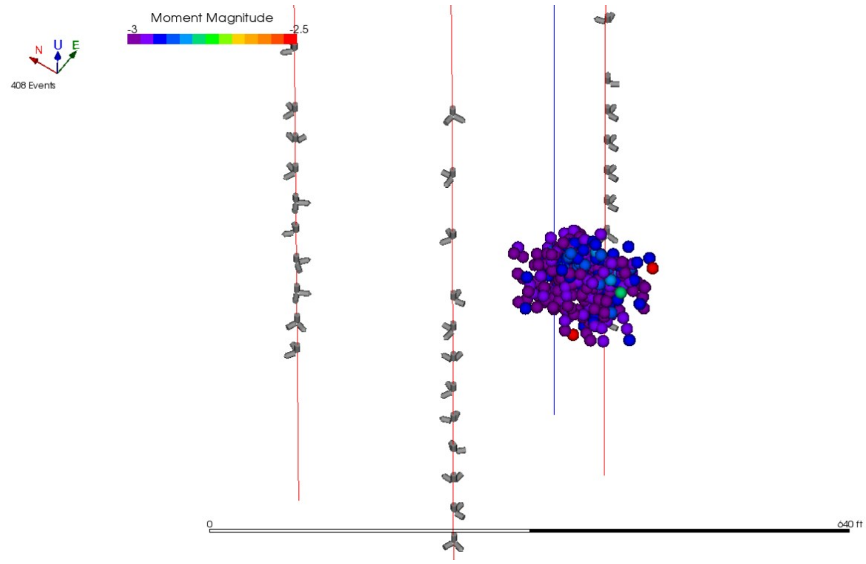

***Figure 1.** The distribution of 408 events located from three toolstrings*

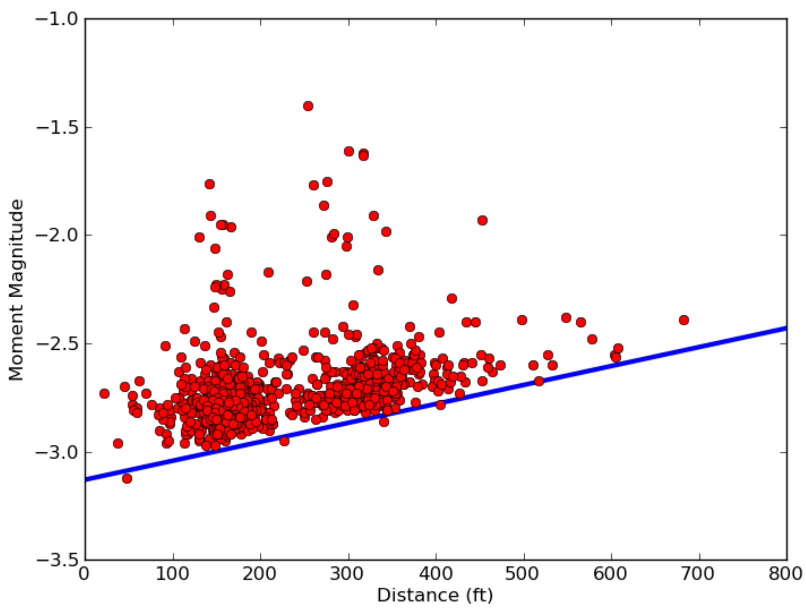

***Figure 2.** The magnitude-distance relationship for 1023 events in and around the cluster shown in figure 1. The blue line defined the minimum detectable magnitude as a function of distance.*

Decimation

To quantify the effect of decimating the array configuration on the event distribution, we assess the distributions for the increase in scatter of event locations and any changes in orientation or positioning away from the treatment well. The dimension of the inferred fractured zone is considered by determining the surface that contains 90% of the events (event density). In addition, we track the events individually, always referencing to the 3-array hypocentres to assess any systematic trends in mislocations.

The detectability and location quality of the events are controlled by the proximity to the sensor array. As the wavefront expands away from the event, the signal amplitudes decrease geometrically and anelastically, until the background noise levels begin to dominate. To answer the question of whether an event is detectable or not, we consider both the distance it needs to propagate to the array and the magnitude of the signal. Plots of magnitude versus distance, like in figure 2, show that there is a very clear minimum threshold magnitude that increases linearly with distance. Far from the sensor well, low magnitude events may be occurring but go undetected. Reducing the array coverage biases the distribution toward the sensor wells where lower magnitude events will be detected. In practice, a magnitude threshold is employed to homogenize the datasets by removing these low-magnitude seisms (representing a dataset representative of the population). For the single-well case, the situation is exacerbated by for the single-well scenario by the requirement that both P and S waves need to be observed to reliably locate the data. For these cases, we see that not only will some events go unobserved due to their low magnitudes, but those that are detected will only have one phase and therefore be unlocatable using standard waveform – hodogram type analyses.

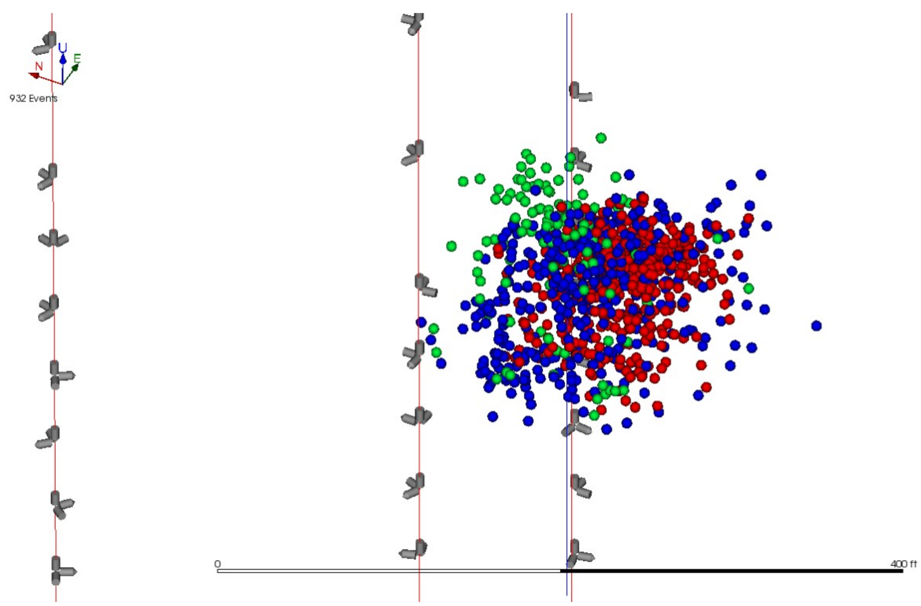

Figure 3. *Comparison of event locations, shown in figure 1 , when located with all 3 arrays (red), 2 arrays (blue), and just the closest sensor array (green).*

In figure 3, we present a comparison of the event distributions from the events in figure 1 located with just one array (in green), for two arrays (in blue) and the original distribution in red. The scatter of the events increases with the removal of sensor arrays; since the additional arrays bring more independent constraints on the solution, this increase in scatter can be attributed to the an increased reliance on noisier hodogram data to obtain the event location . Although there are as many events located with the two arrays as there are with all three, three quarters of the events were not locatable with the single well solutions due to the lack of both P and S waves on this array.

Decimation of sensors is accomplished by removing levels within the same toolstrings and comparing the effects of removing levels from the sensor arrays against progressive removal of toolstrings.

Conclusion

Good coverage of the treatment area with geophones increases the accuracy of the event locations. The independent constraints on the hypocentres when the events are observed from different azimuths stabilize the inversion for event locations and lessen the reliance on noisier hodogram data. Stable solutions for single-phase data are obtainable when the distribution is observed from multiple arrays but single toolstrings cannot reliably locate an event if only one P or one S wave is registered. Additionally, good coverage of the treatment avoids the natural biasing of events toward the observation well due to low threshold of the magnitude-distance plots. Multiple sensor arrays are ideal for accurate locations of hypocentres.