Utilizing b-values and Fractal Dimension for Characterizing Hydraulic Fracture Complexity

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Introduction

The application of microseimic monitoring to characterizing hydraulic fracture stimulations has, in many ways, become routine for the petroleum industry. Typically, the analyses are focused on obtaining event locations and their magnitudes, and performing a spatial and temporal analysis with respect to the treatment interval and ascribed treatment parameters. Based on these analyses, completion engineers can interpret the effectiveness of the stimulation program and work towards designing optimal well placement for the field. Current approaches focus on the utilization of single well multi-level multi-component array based monitoring. Such approaches restrict our ability to utilize advanced processing approaches, such as moment tensor analysis due to non-uniqueness in the solutions. However, by evaluating waveform characteristics, based on single array monitoring, information on fracture complexity and its effect on the rock can be obtained by assessing spatial and temporal variations in frequency magnitude distribution parameters (occurrence rate of seismic activity and b-values) and associated fractal dimension.

The b-value

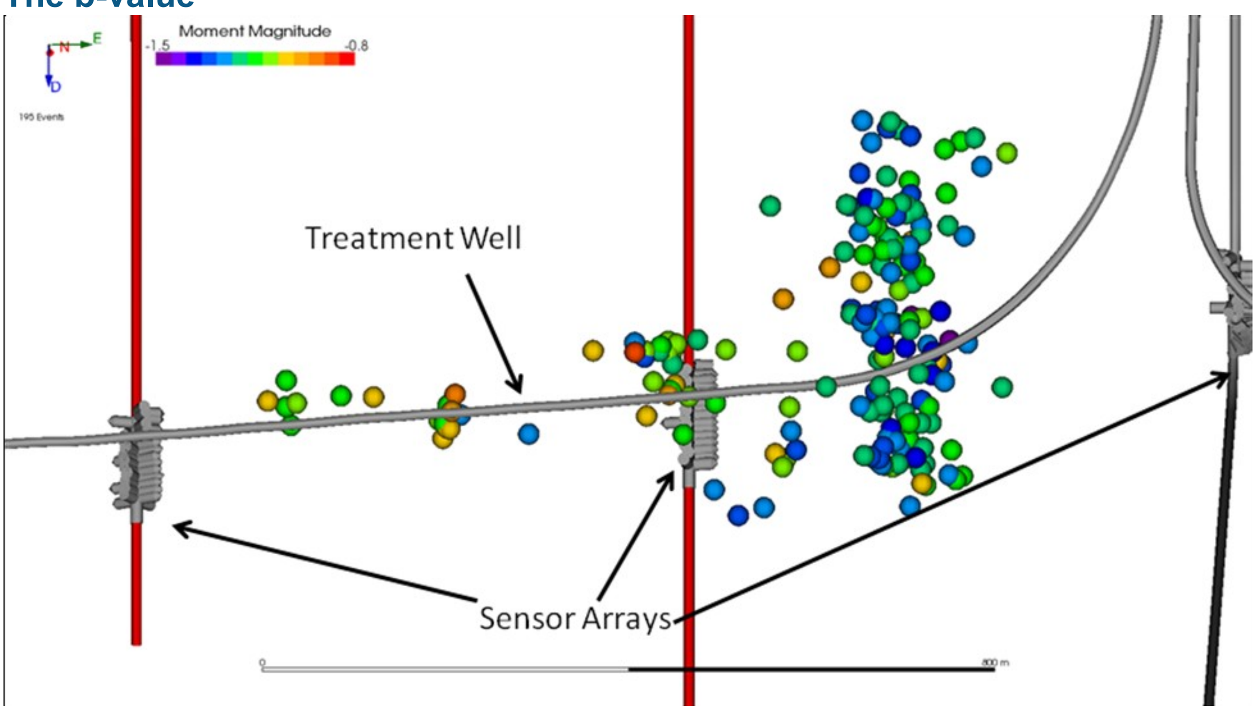

Figure 1. Distribution of events associated with stimulation in a horizontal treatment well (grey) utilizing a single array.

In this study, we examine microseismicity recorded during a hydraulic fracture stimulation in a shale formation (figure 1). Event moment magnitudes -1.1 to -0.9 were used to determine frequency-magnitude distribution (FMD) parameters that describe the log-linear relationship between the number of events and their magnitudes (Gutenburg and Richter, 1944; (figure 2). The FMD is characterized by two parameters, the seismic activity level, which is the number of events with magnitudes greater than a preset reference magnitude per unit time-space volume, and b-values, which represents the slope of the recurrence graph and describes the relative relationship between the number of smaller to larger events. Spatial-temporal variations in b-values and seismic activity level were obtained at every point of a given space-time grid by incorporating nearest neighbourhood estimates of the probability density function of a predefined event size at that space-time position. The complexity of the fracture process was also elucidated by the b-value through the calculation of the fracture dimension, d, by the equation d = 2b. In general, a b=1 is representative of failure associated with a planer surface, whereas a value of b = 1.5 is more characteristic of failures associated with a three-dimensional distribution or network of fractures. It has been speculated that the presence of fluid as related to magmatic intrusions results in b-values of 2 or a fractal dimension of 4.

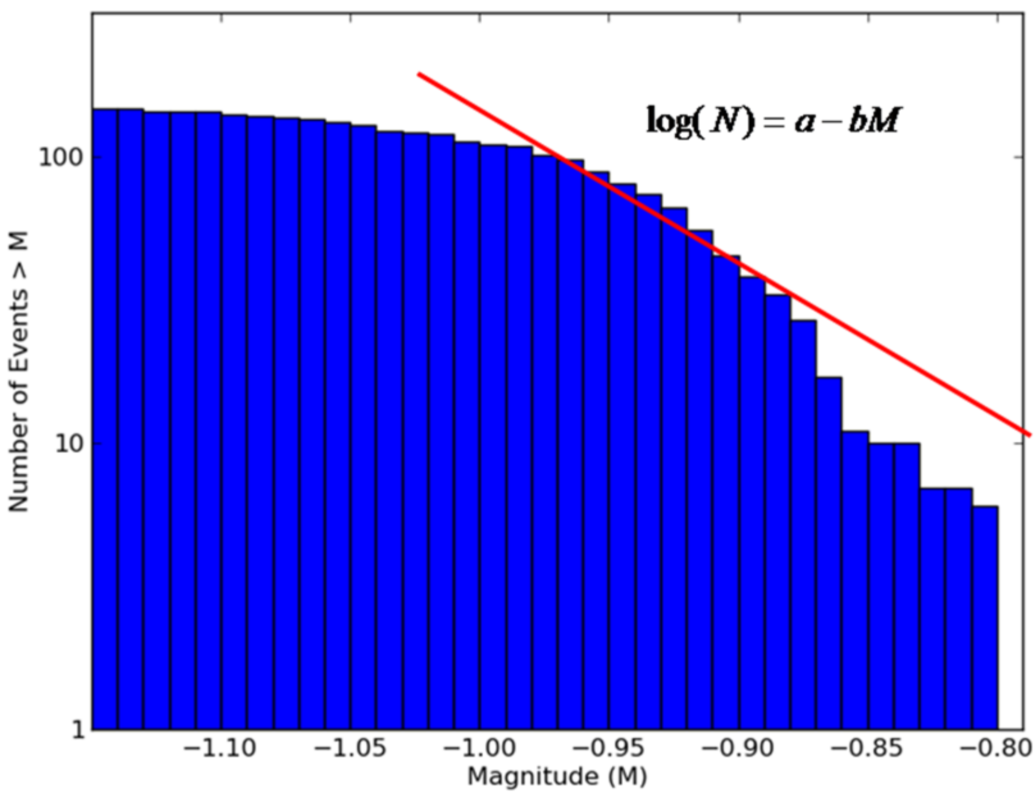

Figure 2. The frequency-magnitude distribution for the events in Figure 1. The b-value is calculated from the slope of the linear part of the FMD.

Examples

In figure 3, the distribution in b-values reveals how the magnitude distribution varies over the study area. The b-values generally vary over a wide range from 0.5 to 2 depending on position relative to the treatment well. In all appearances, b-values tended towards b=2 at the extremities of the stimulated zone, suggesting that fracture growth occurred through a three-dimensional network of fractures influenced by the presence of fluids (d = 4). Within the fracture zone, the b-values appear to be closer to one, suggesting that there may have been a simplification occurring during the injection of the fracturing process, resulting in slippage along a single zone of weakness or plane or along a predominant orientation.

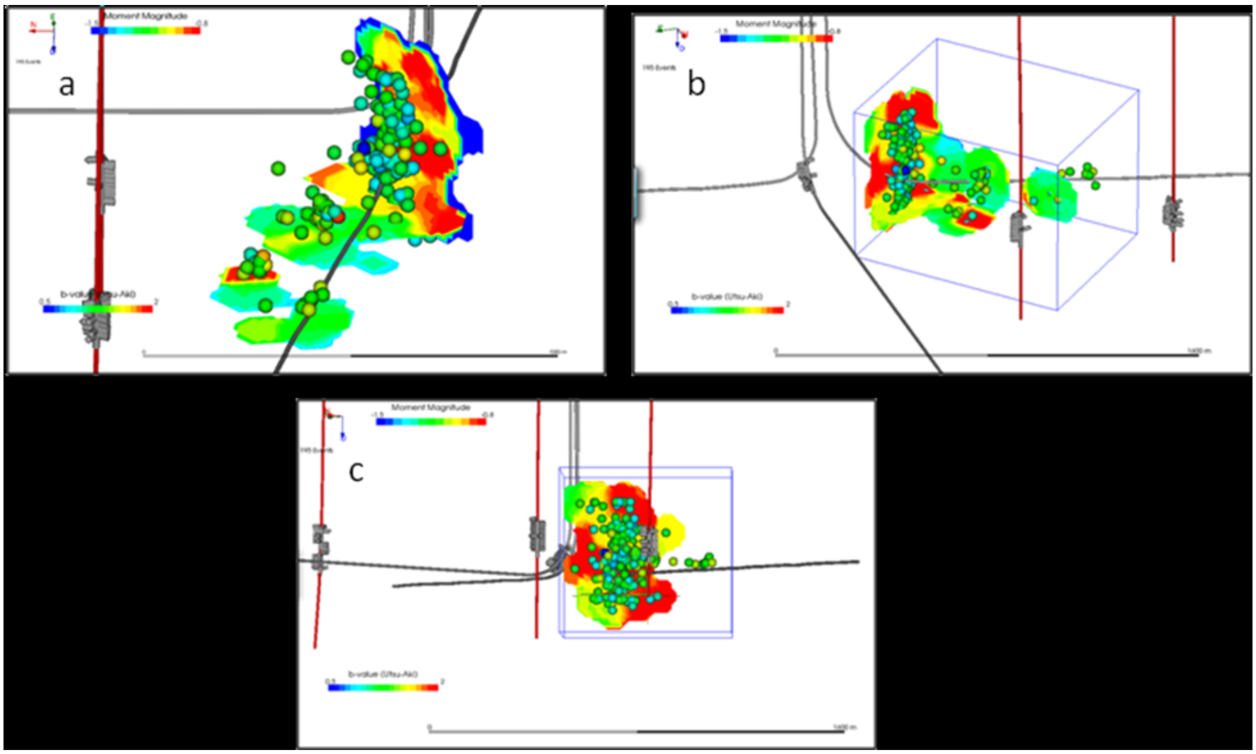

Figure 3 The b-value field for the dataset. a) view one, b) view 2, c) view 3.

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Conclusions

Based on these observations, we can speculate that the spatial and temporal variations in FMD parameters in this study are indicative of differences in failure complexity leading to the development of the hydraulic fracture. Further, we suggest that the fracture can be separated into distinct regions based on their FMD parameters; failures in a predominant or single orientation close to the treatment well, and along multiple orientations at the extremities of the fracture zone. These FMD related features represents a fracture development that appears to be highly dependent on the timing and proppant materials used in the injections, as well as the pre-treatment geologic structural conditions. Further our results suggest that utilizing FMD and fractal dimension can provide an alternative approach to providing additional information about a stimulation when monitoring configurations are not conducive to multi-well multi-array recording.