Identifying Fracture Patterns in Microseismic Data Sets

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ABSTRACT

Event clustering and principle component analysis are two processing algorithms that can aid in the interpretation of spatially and temporally distributed microseismic data sets. In the context of the petroleum field, reservoir injections, hydraulic fracture stimulations and other processes result in the generation of micro-earthquakes or microseismic events (M<0) associated with slip during the creation/activation of a fracture. Recently, monitoring of microseismic events has emerged as an effective method for determining a reservoir's response to these stimulation processes. Recording the arrival times of p and s waves and polarization direction with either a permanent or temporary array of sensors, the location of these events in the reservoir can be obtained. Relatively accurate event locations can be obtained from an optimized recording array, however, the uncertainty in arrival time picks and geological parameters generally result in a scattered image around the underlying fracture system. In this study we present the results obtained using principle component analysis and clustering algorithm applied to microseismic event locations acquired during a hydraulic fracture stimulation.

Dataset

During May of 1997, 863 high quality events were recorded during a hydraulic fracture-monitoring project located in the Cotton Valley Gas Field, East Texas (Walker et al, 1998). In nearby observation wells, arrays of sensors were deployed in order to record events as the hydraulic fracture was being performed. Initial locations, seen in Figure 1, show a general N81ºE trend. However, uncertainty in event p and s wave arrival time picking and velocity structure produce a scattered image.

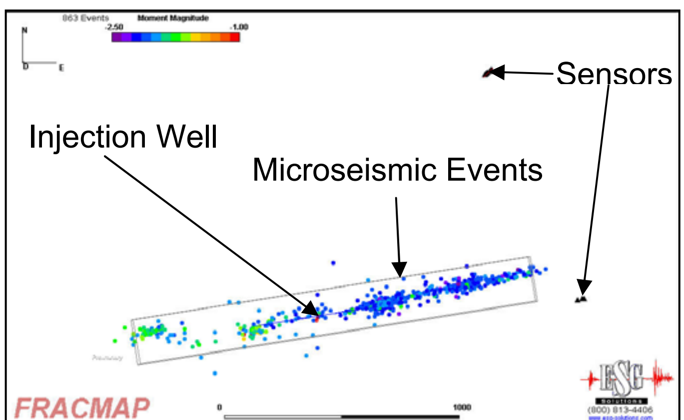

Figure 1: Microseismic events, scaled by moment magnitude, located from acquired waveforms during the hydraulic fracture monitoring project.

Data Clustering

A number of different approaches can be considered to improve the spatial distribution of located events. Collapsing and clustering algorithms have been applied to hydraulic fracturing and reservoir stimulation data to varying degrees of success (Fehler et al, 2001, Rutledge et al, 2003). Jones and Stewart (1997) proposed a method to try to remove spreading by random errors in which each event is moved towards the geometric centroid of all the events within its error extents. The method considers that if one event is located within another's error ellipse then it is feasible that the events were generated along the same failure plane. Moving the event towards the geometric centroid of the two events may condense the events around the causative geologic structure. Additionally, each event is constrained to remain within the extents of its original error ellipse to avoid over clustering. The clustering algorithm requires a good estimate of the error ellipse and in this case, error for each event was calculated considering p- and s-wave arrival times, hodogram orientations and velocity model uncertainty. An average value for error in north 77.5 ft (23.6 m), east 37.6 ft (11.5 m) and depth 40.9 ft (12.5 m) were used for all events in the clustering algorithm.

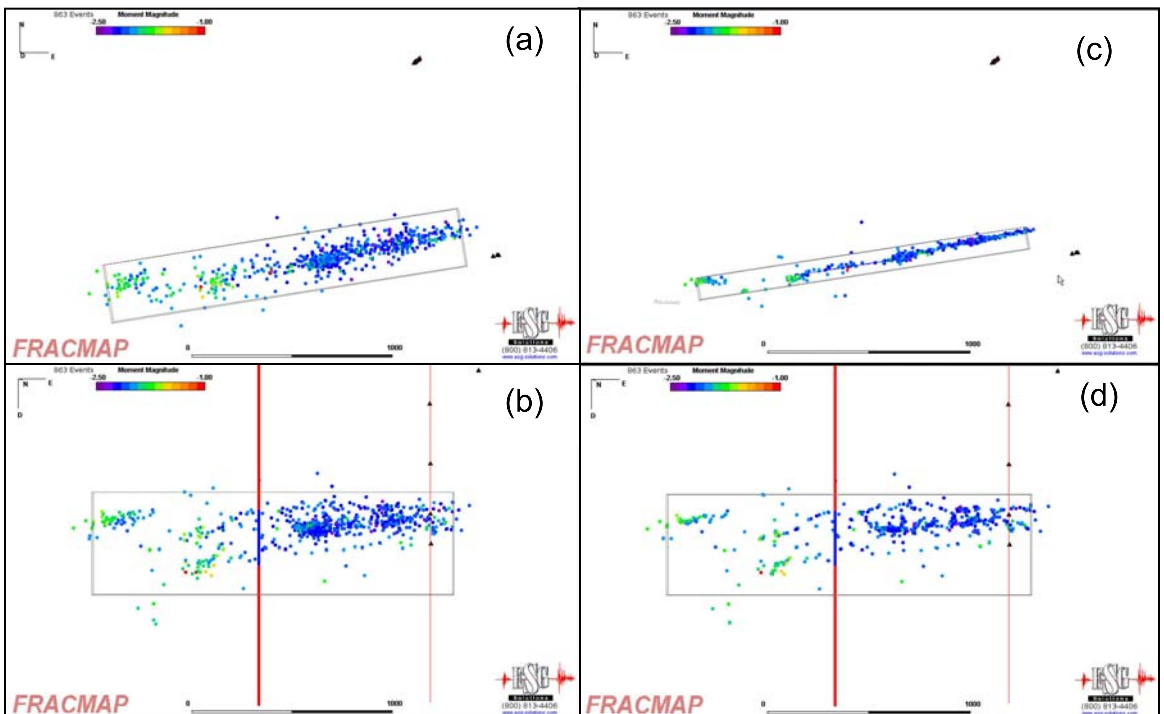

Figure 2: Original data set in Plan (a) and Depth (b) view. Clustered data set in Plan (c) and Depth (d) view. The perforation zone is represented in blue on the treatment well.

Figure 2 shows a comparison of the original data set (a,b) and the data set after clustering (c,d). The trend of the events is retained and the events define a thin vertical fracture typical of hydraulic fractures performed in deep wells. Furthermore, in longitudinal depth view (b,d) the clustering algorithm has condensed the events showing that the hydraulically induced fracture is dominantly within the upper portion of the perforation zone.

Principle Component Analysis

In this paper we also examine the potential for defining the fracture networks responsible for generation of events through a principle component analysis (PCA). Previous work (Posades et al. (1993), Urbancic et al, 1993) used principle component analysis to determine the orientation of fault planes from locations of earthquakes and mining induced seismicity. With principle component analysis, it is assumed that events that occur close together in space and time are inherently related to some geological structure. Considering event location uncertainty, this technique can be applied to statistically derive orientations of the fault planes. Comparison of these planes in a spatial and temporal sense can potentially provide insight into the growth and orientation of the hydraulically induced fracture. The method considers an event and all events within a sphere centered at the first event. The sphere radius is determined from an understanding of the size of the causative geologic structures and error associated with event location. Eigenvectors and eigenvalues, representing the orientation of the major axes of the PCA ellipse are calculated, with the maximum eigenvalue/ eigenvector corresponding to the fracture orientation as a function of time.

Principle component analysis results calculated from the unclustered and cluster data set are displayed in Figure 3. Derived azimuths in both cases show a general trend of N80-90°E, but with considerable variation for the unclustered data set compared to the clustered events.

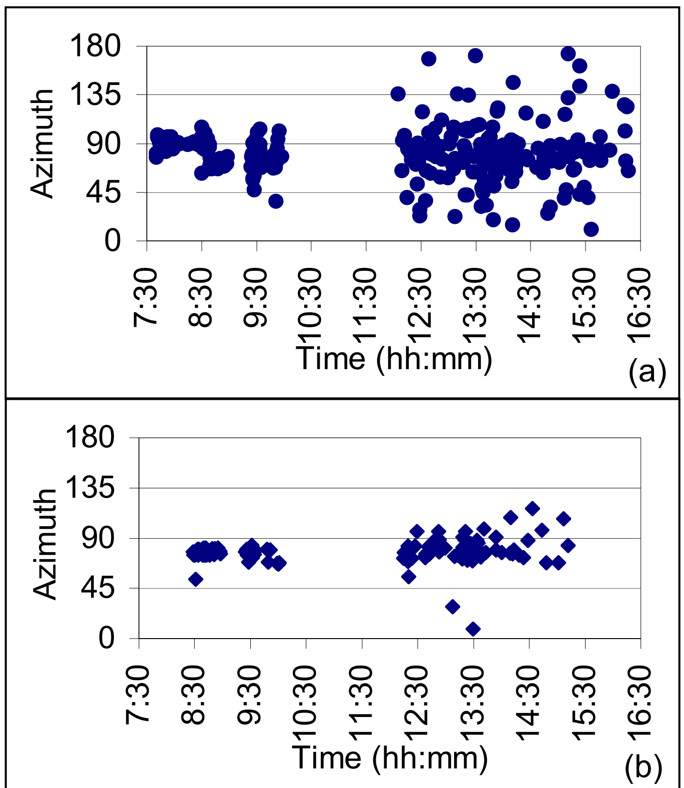

Figure 3: Results of principle component analysis on (a) original data set and (b) clustered data set.

Conclusions

In the context of the Cotton Valley hydraulic fracture, event clustering and principle component analysis reinforce conclusions based on the primary analysis of the data set. Event clustering shows that the hydraulic fracture is near vertical with an azimuth of N81ºE. Further analysis of the original and clustered data sets using principle component analysis shows that the orientation of planes related to microseismic events in space and time have the same general N80ºE trend. Clustering algorithms and principle component analysis provide clear images of the causative geological structures and allow for their integration into seismic sections and geo-databases to improve our understanding of reservoir fracture structure and fluid movement.

References:

Fehler, M., Jupe, A., Asanuma, H. More Than Cloud: New Techniques for Characterizing Reservoir Structure Using Induced Seismicity. The Leading Edge, Vol. 20. Issue 3, March 2001, Pages 324-328.

Jones, R.H., Stewart, R.C., A method for determining significant structures in a cloud of earthquakes, Journal of Geophysical Research, Vol 102, No B4, Pages 8245-8254, 1997.

Posadas, A.M., Vidal, F., de Migual, F., Alguacil, G., Pena, J., Ibanez. J.M., and Morales, J., Spatial-Temporal Analysis of a Seismic Series Using the Principal Components Method: The Antequera Series, Spain, 1989, Journal of Geophysical Research, Vol 98, No. B2, pages 1923-1932, 1993.

Rutledge, J.T., Phillips, W.S., Hydraulic Stimulation of Natural Fractures as Revealed by Induced Microearthquakes, Carthage Cotton Valley Gas Field, East Texas. Geophysics Vol 68. No.2 March-April, 2003) pages 441-452.

Urbancic, T.I., Trifu, C.I., Young, R.P., Microseismicity derived fault planes and their relationship to focal mechanism, stress inversions, and geologic data. Geophysical Research Letters. Vol 20, No 22, Pages 2475-2478, 1993.

Walker, R.N., Zinno, R.J., Gibson, J.B., Urbancic, T.I., Rutledge, J., Carthage Cotton Valley Fracture Imaging Project – Imaging Methodology and Implications, SPE Annual Technical Conference, 1998. pages 599 – 612.