En-Echelon Fracture Growth Behaviour Associated with Hydraulic Fracture Stimulations as Determined from Stress-Strain Analyses of Microseismicity

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Introduction

Seismic moment tensor inversion analyses of microseismic events provide an opportunity to assess the components of failure for individual events and the spatial and temporal stress-strain conditions under which that failure occurred, and the effective volume of perturbation. By assuming that failures occur in a relatively stable underlying stress field, the misfit between individual principal strain axes (pressure and tension, or P and T respectively) can then be further evaluated to obtain the principal stress orientations within a target volume. This derived state of stress defines the background regime to which the events are responding and, for the case of hydraulic fracture stimulations, the effective conditions related to fracture development.

Strain Axes

In this paper, we use the individual strain axes (P, T) as determined by seismic moment tensor inversion analysis to obtain a three dimensional strain distribution based on a linearly interpolated 'nearest neighbourhood' statistical approach. The rate of deformation or strain rate was then calculated for the effective volume and corresponding time interval. As shown in figures 1 and 2, the general trend in P and T axes suggests that the stimulation has led to local variations in the relative strain distribution. The T axes (figure 1) map the maximum direction of strain outlining a complicated deformation pattern with regions in tension and compression. The general non-uniformity of the strain shows that the treatment has altered the in-situ strain regime. Similarly, the P axes (figure 2), indicate the minimum direction of strain rate and also display a highly heterogeneous strain field.

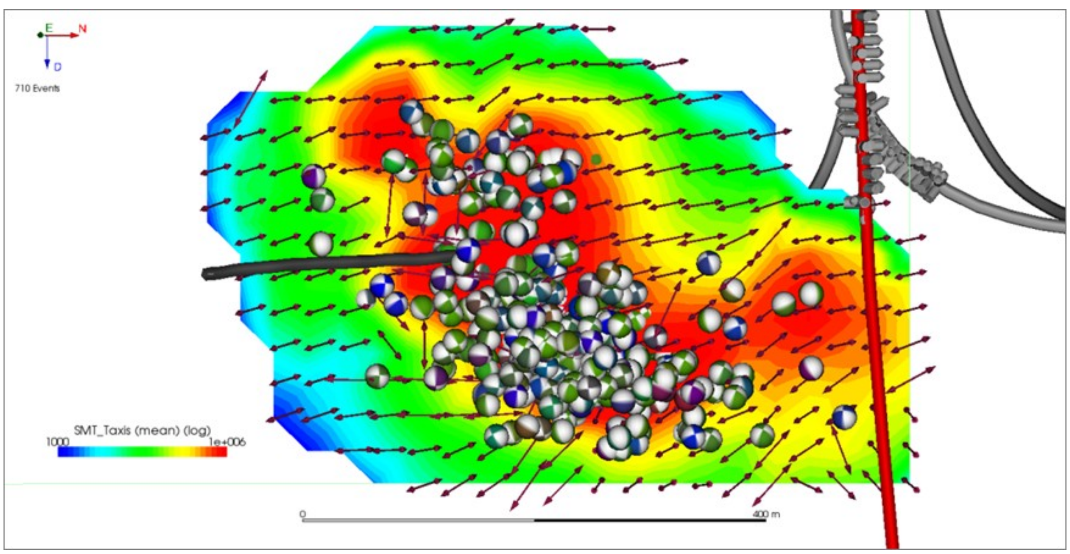


Figure 1: The T axes (shown above) map the maximum direction of strain as determined from the moment tensor data.

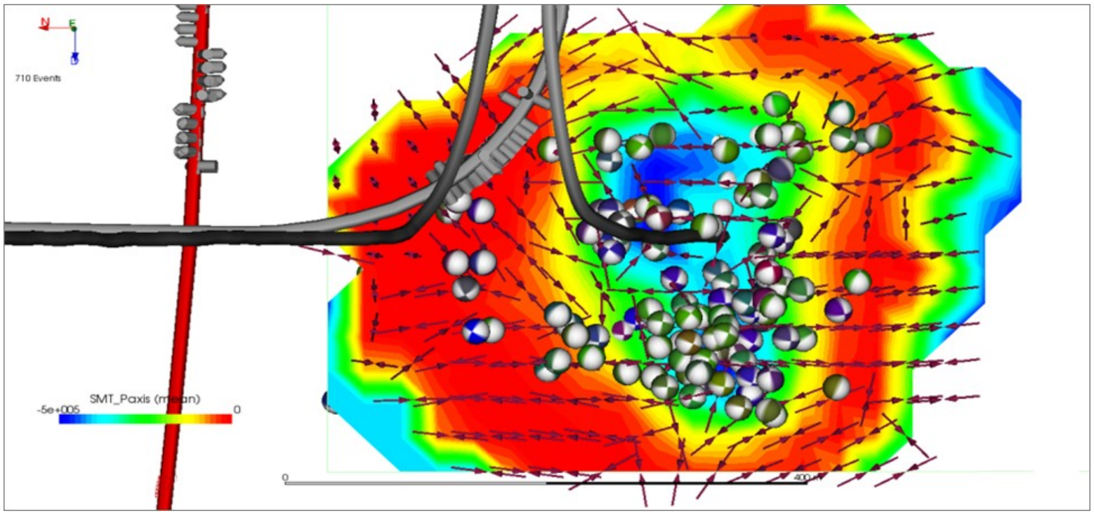


Figure 2: The P axes (shown above) map the minimum direction of strain rate.

Stress Field and Fault Orientation

By considering the ensemble of P and T axes from the treatment, as shown in figure 3, the principal strain axes were inverted for the underlying principal stress axes. In this example, the stimulation appears resulted in maximum and intermediate stress axes flipped with respect to the regional stress field. Based on observed strain conditions for individual events, two potential planes of fracturing or failure are possible. By assuming that the events occurred under the calculated stress field conditions, we derived the likely orientation of the failure thereby resolving any orientation ambiguity. In the provided example (figure 4a), primary and secondary fractures were identified, both suggesting that failure was moderately dipping north to northwest fractures.

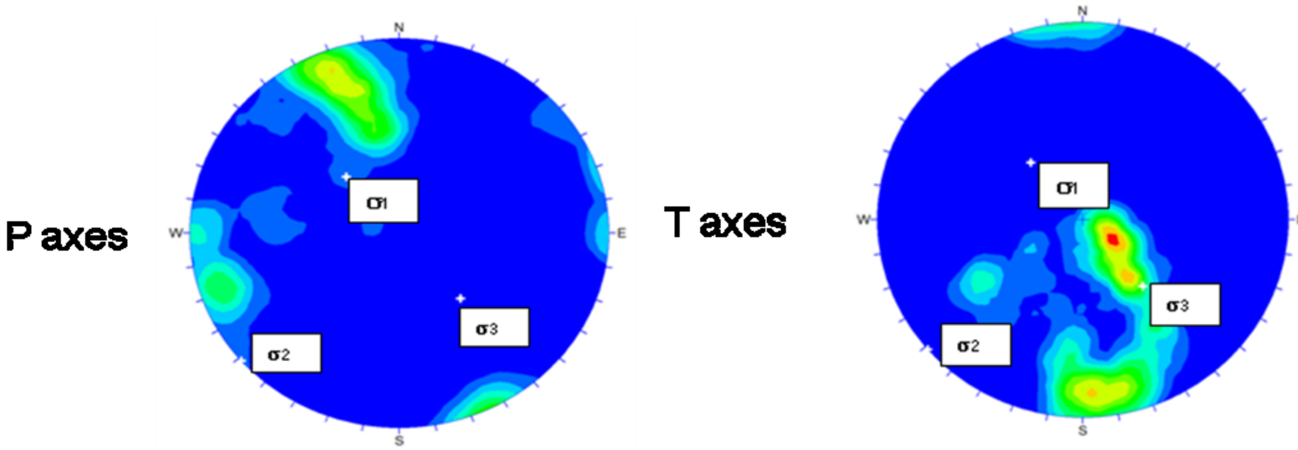
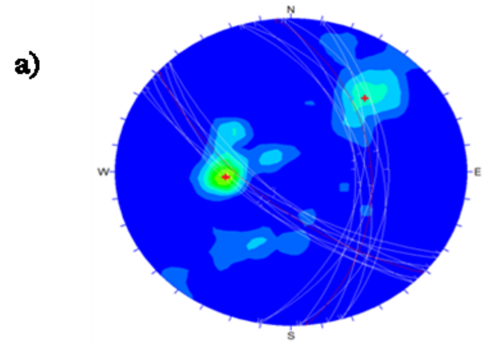


Figure 3: The P and T axes of each moment tensor are used to constrain the state of the stress in the area of the stimulation.



	Strike	Dip
Primary	355	41
Secondary	130	65

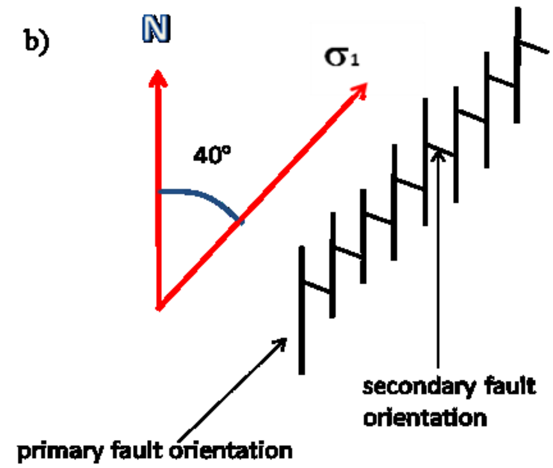


Figure 4: a) Based on the obtained underlying stress field, the likely orientation of failure orientation from individual events is shown along with their poles (to the planes). b) Postulated fracture growth model- as shown, the failures fall into two sub-orthogonal families and the fracture growth can be accommodated by an en-echelon fracture network.

Interpretation

Based on these orientations, we propose that fracture growth and development was related to an en-echelon collection of identified primary and secondary fractures along the maximum shear stress direction (figure 4b). This and similar analyses provides an opportunity to investigate the potential for assessing the effectiveness of different injection scenarios and their influence on the surrounding rock.