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Understanding Hydraulic Fracture Growth by Mapping Source Failure Mechanisms

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Summary

Microseismicity recorded utilizing two optimally placed mutli-level downhole triaxial geophone arrays was analyzed to characterize fracture growth related to a hydraulic fracture stimulation in North-Eastern British Columbia. A total of 81 microseismic events with clear P, Sv, Sh first motion arrivals and good signal to noise ratio (> 3:1) were detected. Of these, Seismic Moment Tensor Inversion (SMTI) was carried out for a subset of 29 events with good focal sphere coverage. Our analysis suggests that the majority of the events consisted of significant volumetric components of failure although a shear component of failure was generally present. Additionally, spatial analysis of the failure mechanisms showed that as the hydraulic fracture propagated from the perforation zone the mechanism of failure also changed. In regions close to the treatment zone the event failures were predominantly volumetric whereas as distance increased the failures were more shear-like. The distribution of failure planes suggested that a complex mesh-like pattern of cross-faults in the direction of the maximum horizontal stress was responsible for the observed fracture growth. Based on these analyses, further consideration is given to developing a model of hydraulic fracture development that can be used to characterize the effective fracture volume and identify potential means for re-stimulation of previously treated wells.

Introduction

Microseismic monitoring has become a common tool for evaluating the effectiveness of hydraulic fracture stimulations. Typically, a single downhole multi-level 3C geophone array is utilized to detect and locate microseismic events. However, due to geometric array constraints, there are limited opportunities for conducting advanced post-acquisition processing associated with these data. In this study, data collected from two downhole multilevel monitoring arrays is used to invert for the general failure components of microseismic events (Seismic Moment Tensor Inversion – SMTI) and provide robust source parameters for events associated with a hydraulic fracture treatment. The goals of this study are to analyze the complex fracturing process during the treatment, identify mechanisms of failure, understanding the dynamics of the fracturing process and identifying which events recorded during monitoring will likely contribute to production.

Results

A total of 81 microseismic events with clear P, Sv, Sh first motion arrivals and good signal to noise ratio (> 3:1) were detected on multiple geophone levels on both arrays during this stimulation . Of these, a subset of 29 events had good focal sphere coverage thereby allowing for Seismic Moment Tensor Inversion (SMTI) to be determined. Based on SMTI analysis, the majority of the events had a Double Couple (shearing) component of failure, however, most of the failures were associated with a complex fracture process rather than a simple 'fault-slip' type mechanism (Figure 1, Figure 2).

Spatial analysis of the relative double couple component of failure characterized regions with larger shear (double-couple - DC) failure at distance from the perforation interval and regions of non-shear (isotropic) failure adjacent to the injection point. Temporally, the events outlined the relative fracture growth where events occurring at the "fracture front" tended to be primarily shear in failure. Conversely, events occurring behind the "fracture front" tended to be primarily isotropic (non-shear) failures, representing the opening of fractures (Figure 3). The DC components identified potential planes of failure suggesting that fracture growth was precipitated through an en echelon network of fractures, with the isotropic failures contributing to the volume most likely to result in production. Inherently, this volume also experienced the highest levels of seismic deformation (Figure 4).

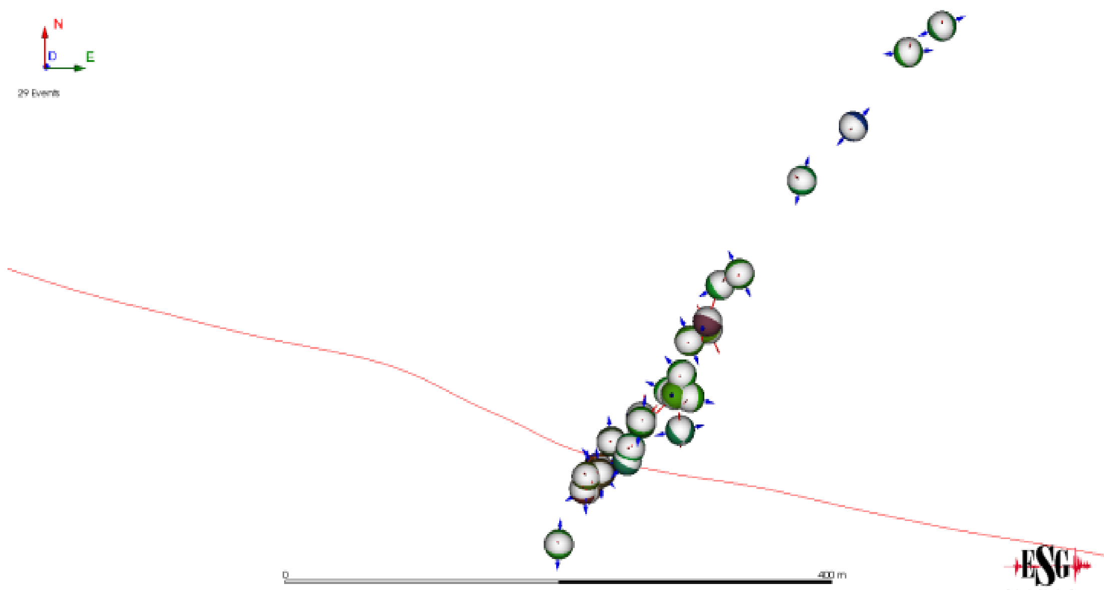

Figure 1: Plan view of the events analyzed in this study. Treatmernt well is as indicated in red. For the purposes of visualization traditional "beach-ball" diagrams are used based on a colour scaling with the coefficients of the Isotropic-CLVDVector Dipole)-DC decomposition. In this case each of three coefficients absolute value vary between 0 and 1 and are mapped onto RGB (Red, Green, Blue)

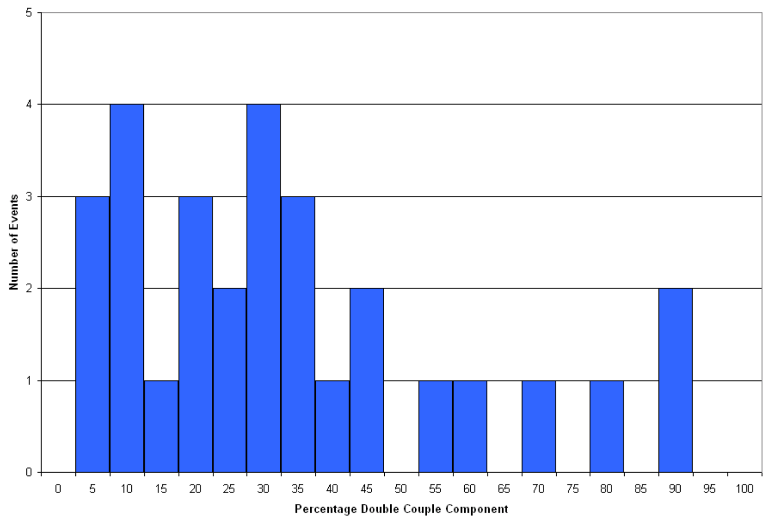

Figure 2: Histogram of the relative percentage of double component failure indicating that the majority of events had significant non-shear components of failure (<50% DC).

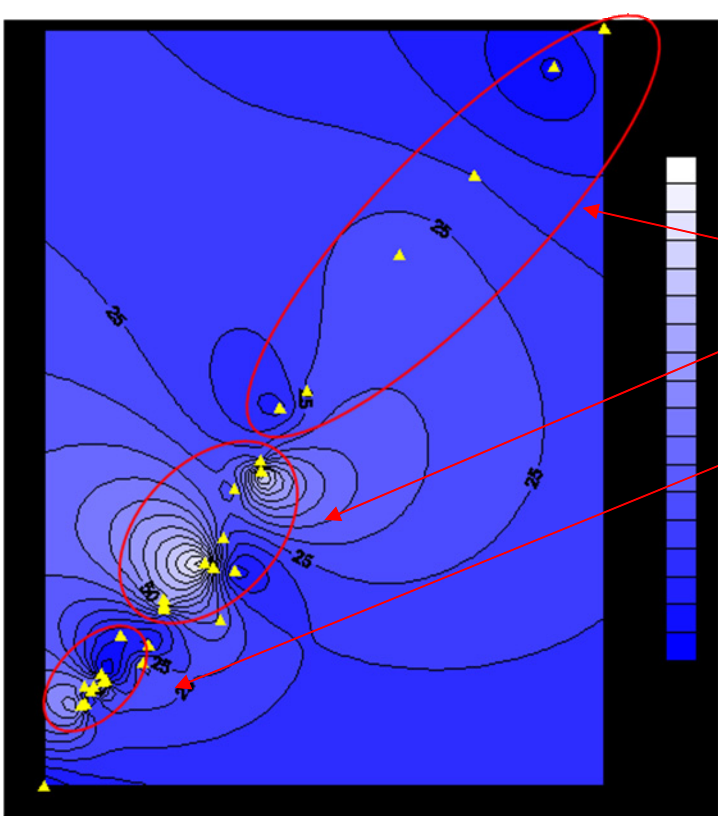

Figure 3: Spatial distribution of the relative DC component of failure overlain by the event distribution (triangles). Perforation interval is at the bottom left corner of the diagram.

Events occurring at a distance from the perforation zones have a large CLVD component of failure.

As the fracture propagates from the perforations the failures are mostly Double Couple failures.

Most events near the perforation zone have large ISO (Isotropic) components of failure.

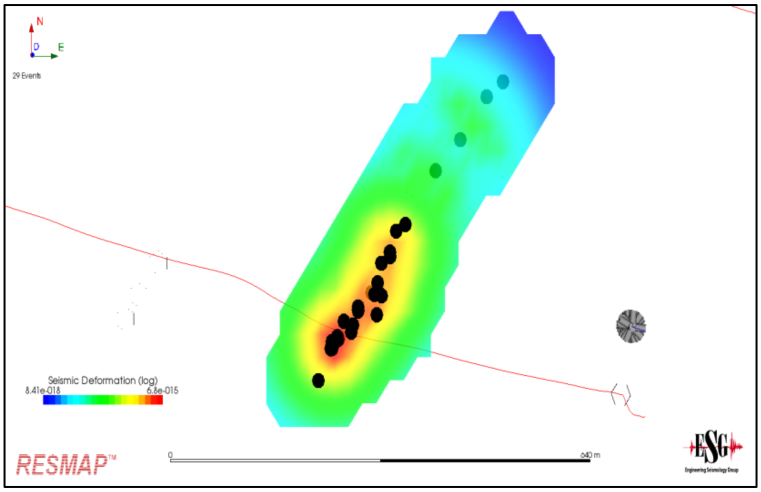

Figure 4: Spatial distribution of seismic deformation in plan view. Region of highest seismic deformation coincides with the region with the distribution of events with large isotropic components of failure.

Conclusions

Moment tensor inversion was carried out on 29 events recorded on two downhole monitoring arrays associated with a hydraulic fracture treatment. The majority of the SMTI solutions suggested that a simple 'fault-slip' type mechanism of failure was insufficient to describe the failure process, rather each event was comprised of isotropic, deviatoric and double couple components of failure. Spatial analysis of these failure mechanisms indicated that as the fracture propagated into formation it was propelled predominantly by a DC fracture front whereas events occurring near perforations were comprised predominantly of isotropic type failures associated with an en echelon network of fractures. Using these techniques we were able to effectively visualize an "Effective Fracture Volume", rather than simply assuming that the entire fractured volume is contributing to production, as defined by the spatial extent in event distribution.

Acknowledgements

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