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Focal Mechanism Analysis of a Multi-lateral Completion in the Horn River Basin

Paige Snelling*, Cameron Wilson, MicroSeismic Inc., Calgary, AB, Canada
psnelling@microseismic.com

Neil Taylor, Michael de Groot, Encana Corporation, Calgary, AB, Canada
and
KyuBum Hwang, KOGAS Canada Ltd., Calgary, AB, Canada

Summary

Rock failure during hydraulic fracturing can be difficult to describe using microseismic event locations alone. Source mechanism inversion of events monitored with a large-aperture, shallow buried array can shed light on the failure process. Inversion was performed for events generated during completion on a multi-lateral pad in the Muskwa and Evie shales in the Horn River Basin. Three groups of event source mechanisms with distinctly different failure modes are found. The degree of non-double-couple component of source mechanisms varies for each formation, suggesting that rock failure in the Muskwa is driven by hydraulic fracturing, whereas the Evie experiences structurally-controlled failure.

Introduction

The process of rock failure during hydraulic fracturing is complex. Shear failures caused by double-couple force occur at the fracture tip while more complex non-double-couple source mechanisms can result from fluid injection (Sileny, 2009). Microseismic monitoring is essential for understanding this kind of rock behavior which can vary laterally with geology. The types of rock failure modes can be identified through source mechanisms. They provide insights into the factors (e.g., state of the stress) that drive the failure process during stimulation.

Method

P-wave amplitudes are used to invert the moment tensor using the least-square method (Williams-Stroud et al., 2010). *A-prior* source location information is needed to perform this inversion. This inversion technique also requires adequate station coverage on the focal sphere, as well as first motion picks with reasonable SNR. The wide azimuth, high fold, large aperture geometry of the buried array allows for consistent microseismic mapping under the entire array (Zhang et al., 2011) and robust moment tensor solutions (Williams-Stroud et al., 2010, Wessels et al., 2011).

Data

A subsurface buried array was deployed over a 7-well pad in the Horn River Basin to monitor a 201-stage completion over a 70 day period in 2012. The target formations with the shale package include the Muskwa Member and the Evie Members of the Horn River Formation. These are overlain by the relatively ductile shales of the Fort Simpson Formation. The array consists of 69 new stations and 29 existing stations from a previous monitoring project on a nearby pad. The sensors were cemented into boreholes at a depth of 30 m to ensure optimal coupling with the ground and to reduce cultural noise. Known faults are mapped on the pad trending N to NE with a prominent fault trending NNE across the pad.

During the monitoring period, over 11,200 events were detected and located. They are mostly confined to the target zones. The shallowest event occurred in the Fort Simpson shale at a local depth of 2100 m. Hypocentral mislocation is on the order of 10 m laterally and 20 m vertically as determined from velocity calibration using perforations. Based on reasonable signal-to-noise ratios (SNR), P-arrival amplitudes of 273 events were used to obtain source mechanisms on three Evie and three Muskwa wells.

Results and discussion

We use constrained DC solutions to group the selected focal mechanisms into three classes: strike-slip, vertical dip-slip, and reverse. Dip-slip (in blue) mechanisms occur where hydraulic fractures are observed (Figure 1), while strike-slip (in red) events take place near the mapped fault intersections (along the NNE trend) and along an undefined geological structure trending WNW. The events with reverse-faulting mechanisms (in green) are located mainly in one cluster at a fault junction, and above a cluster of strike-slip events.

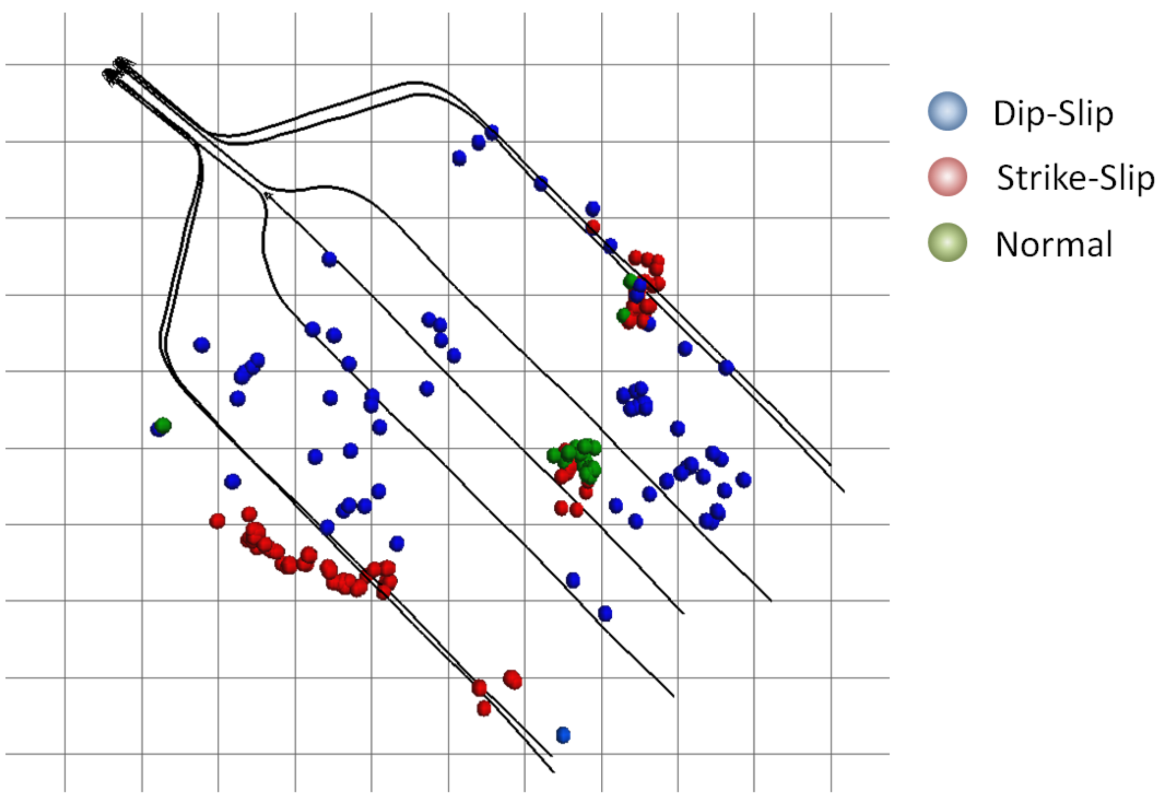

Figure 1: Plan view of picked events. Events are coloured by mechanism class: Strike-slip (red), dip-slip along a vertical plane (blue) and reverse (green).

The derived full moment tensors can be further decomposed into the components of double-couple (DC), compensated linear vector dipole (CLVD) and isotropic (ISO). We compare the ratio between these components to infer the type of failure modes, such as shear slip, tensile cracking (either opening or closing), or volumetric change. Decompositions of the events' full moment tensors are displayed using ternary diagrams and the Hudson source-type diagram (Hudson et al., 1989). Ternary diagrams represent the percentage of DC, CLVD, and ISO components of each event with a 100% vertex and the corresponding 0% base. The Hudson diagram is an equal area representation of the constant-volume and volumetric components of events (Hudson et al., 1989).

The ternary diagram shows the majority of the events have a high degree of DC component, while other events have a significant degree of CLVD component as well as minor volumetric component. The elevated DC component can be an indication that the rock failure is triggered and predominated by tectonic stress, whereas a high CLVD component indicates a tensile cracking mode involving either opening or closure (Figures 2 and 3). We also see distinct patterns when examining the constrained mechanism classifications and by shale zone (Figures 3 and 4). For example, strike-slip events tend to have a high degree of DC components while the dip-slip events have a significant CLVD component; the reverse-faulting population also has a higher CLVD component. A high degree of CLVD component for both dip-slip and reverse faulting events suggest a possible tensile cracking mode (Figure 3). In terms of the association with a target shale zone, the Evie events have a high DC component (Figure 4). Events from the Muskwa wells generally contain a more significant CLVD component.

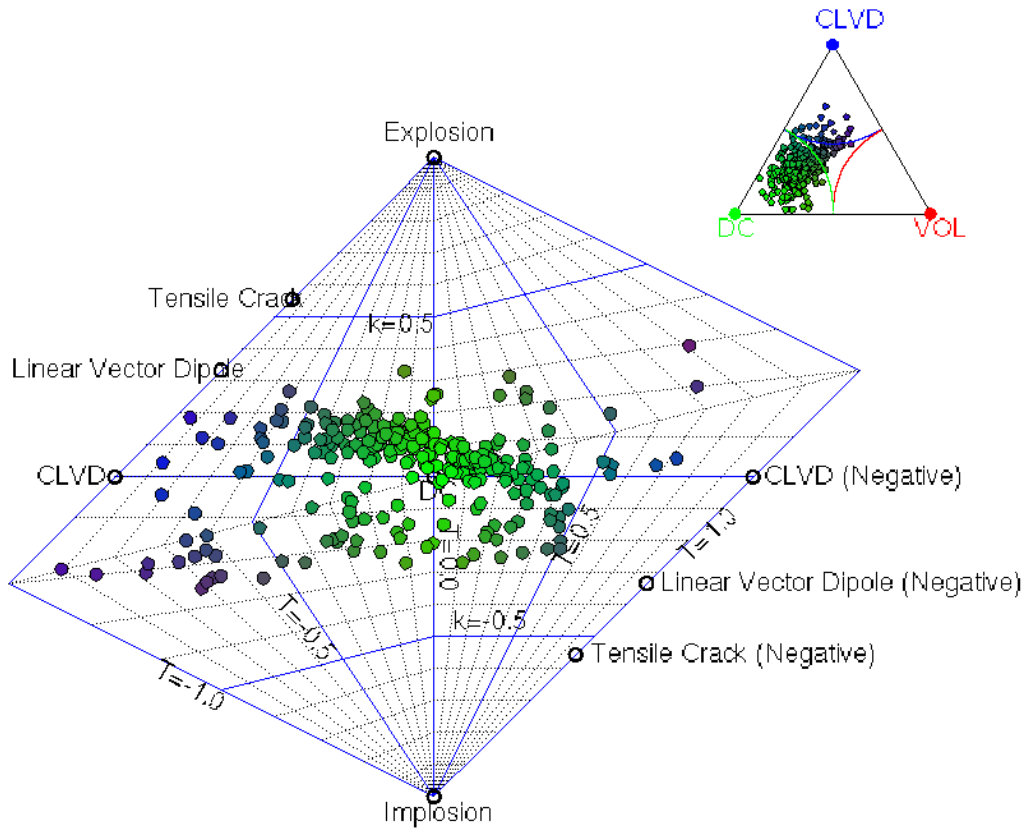

Figure 2: Hudson plot and ternary diagram showing all 273 events.

From the high degree of CLVD component in the Muskwa, it can be inferred that stimulations in this zone are induced by pore pressure changes during hydraulic fracture. The higher DC component in the Evie reflects the high number of strike-slip events. While hydraulic fractures do occur in the Evie, (they are observed to extend from the wellbore in the same orientation as completions in the Muskwa above), the behaviour of rock failure in this formation appears to be dominated by pre-existing geologic structure. These rock failures may be triggered by stress changes rather than directly induced by changes in pore pressure.

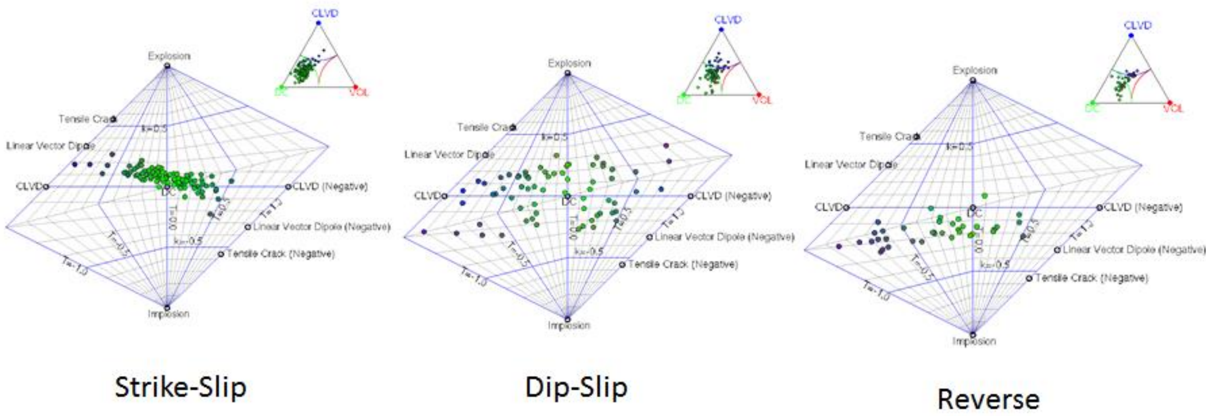

Figure 3: Hudson plots and corresponding ternary diagrams for strike-slip, vertical dip-slip and reverse mechanisms.

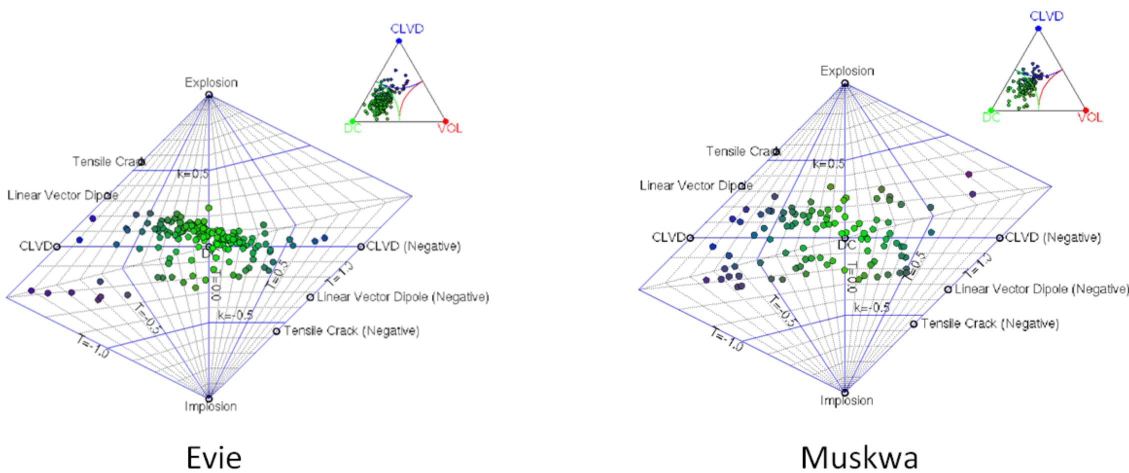

Figure 4: Hudson plots and corresponding ternary diagrams for events associated with Evie and Muskwa wells.

Conclusion

Focal mechanism inversion was performed for 273 events recorded with a near-surface array over a multi-lateral pad in the Horn River Basin. Decomposition of the moment tensor into DC, CLVD and ISO components demonstrates that strike-slip events are dominated by a high DC component. Dip-slip mechanisms contain a higher proportion of CLVD and ISO components. Following this separation, events associated with completions on wells in the Evie are dominated by DC failure because of the predominance of strike-slip mechanisms in this zone. Events associated with Muskwa completions contain a higher CLVD component, indicating that rock failure in this zone is associated with tensile cracking during hydraulic fracturing.

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