High Fidelity Microseismic Monitoring

MagicMoment®

Microseismic Surface Monitoring
Source Mechanism Inversion

MagicMoment® is a proprietary technique developed by NanoSeis, which allows rapid determination of source mechanisms for microseismic events, regardless of the event size, and significantly enhances the accuracy of event locations.

The Value

The value of accurate determination of the source mechanism of microseismic events is undeniable (Baig and Urbancic, 2010). Figure 1 shows both the downhole data event locations (left) and the surface data source mechanism solutions (right) from a hydraulic fracture stage in the Bakken Formation of South Dakota. The strike of the source mechanisms for each event as determined by MagicMoment are shown as colored lines. While the distribution of the downhole events might be used to infer the orientation of the fractures, the scatter is also consistent with the uncertainty in the downhole event azimuths (Drew and White, 2008). The source mechanism solutions from the surface data make the orientations of the fractures obvious.

Figure 2 shows events from a hydraulic fracture stage in eastern Pennsylvania. A line connects each event to the central perforation point of that stage. Stage perforations are shown as colored diamonds, colored differently for each stage. The source mechanism has been independently determined for each event using MagicMoment. The location and orientation of the source mechanisms suggest that pumping of this stage has reactivated fractures from two previous stages.

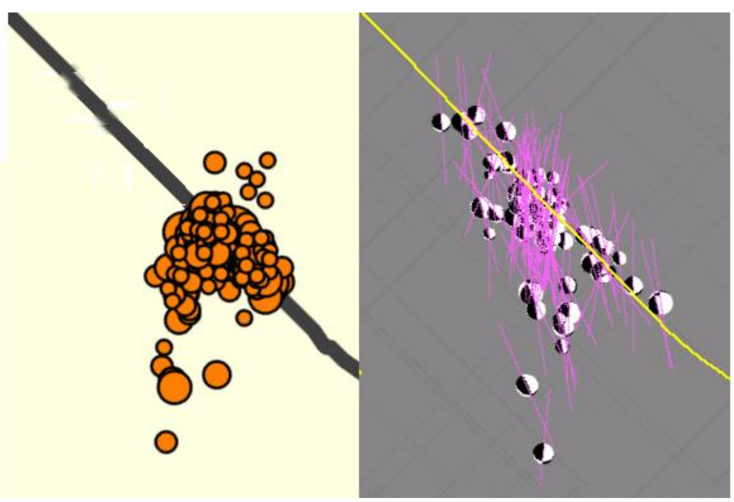

Figure 1. Downhole (left) and surface data solutions (right) from the Bakken.

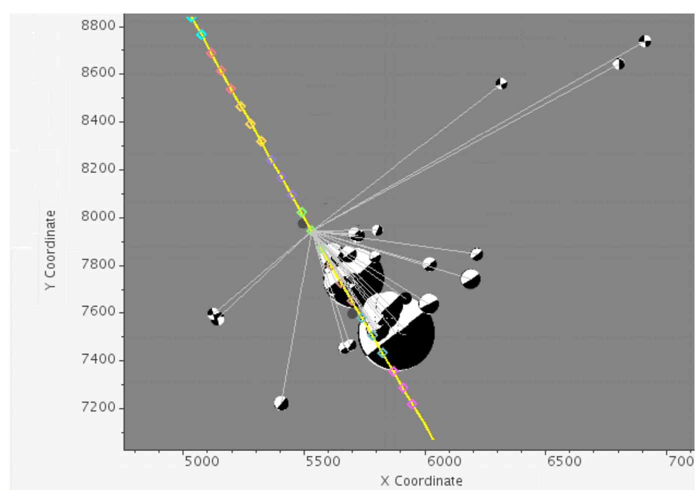

Figure 2. Events with a line connecting to the perf location.

The accuracy of the event locations in Figure 2 also benefits from the source mechanism determination. This issue is seldom discussed, but if the location of a surface microseismic event is not known then the source mechanism cannot be determined. Conversely, if the source mechanism is not known then the location cannot be determined accurately. The location accuracy determined from perf shots is misleading, because the source mechanism is known for perf shots. MagicMoment solves this problem by iterating on the location and the source mechanism. The solution is only accepted when the source mechanism and location converge, significantly enhancing the accuracy and integrity of results. MagicMoment's ability to determine the source mechanism for all event sizes avoids the bad practice of forcing the source mechanism of large events (typically magnitude > -1) when locating smaller events. The source mechanisms for large events and small events are often quite different, and forcing the source mechanism creates systematic location errors in the smaller events.

The Method

The MagicMoment method is very simple – it compares the polarity and amplitude of a library of modeled source mechanisms to the observed polarities and amplitudes of each microseismic event, and finds the best match.

Solving for all moment tensor possibilities is a complex, compute intensive process. If the 6 independent components of the moment tensor are each varied by 5 percent during each step of the search, it would be necessary to test 4.75 billion modeled source mechanisms for each event, which is impractical. MagicMoment uses a library of source mechanisms that are most geologically reasonable for hydraulic fracturing, many of which involve shear and crack opening mechanisms, and uses a hierarchical search that effectively tests 167 million of the most likely source mechanisms. The MagicMoment source mechanism inversion runs in about 4 seconds for one event on an ordinary computer, and because of its speed it can be used in real-time field processing of thousands of channels of surface data.

Eaton and Forouhideh (2011), using a least-squares inversion approach based on P-wave or S-wave amplitudes, concluded that “Taken together with geometrical consideration, we found that a S/N > 10 is generally needed to obtain reliable inversion results for the full moment tensor under certain microseismic acquisition scenarios that include dual observation wells or surface star pattern”. MagicMoment overcomes this signal/noise limitation by using an imaging approach that does not require the P-wave or S-wave amplitude to be determined for any individual receiver.

Figure 3 shows prestack traces from a clear strike-slip event, after correction for the travel times (left panel). The polarity reversals from the radiation pattern are evident. The right panel shows the event in the image domain. The four lobes of the imaged event are an artifact of the lack of correction for the radiation pattern. The MagicMoment source mechanism solution for the event is shown as a “beachball”. See en.wikipedia.org/wiki/Focal_mechanism for more information on beachball displays.

Figure 4 shows the same event, but with noise added that is 20 times higher than the RMS level of each input trace. The event is no longer visible in the prestack traces. It is now a “sub-visible” event, although the lobes of the event are still visible in the image domain. The MagicMoment source mechanism solution for the event is shown as a beachball. The noise caused the solution to produce a slightly different dip, and with a small CLVD component, but the solutions are remarkably similar considering that in one case the event is so buried by noise that it is invisible in the prestack traces.

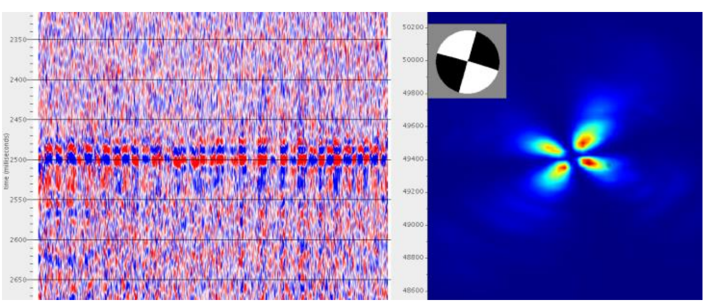

Figure 3. Prestack traces, image domain, and source mechanism for a strike-slip event.

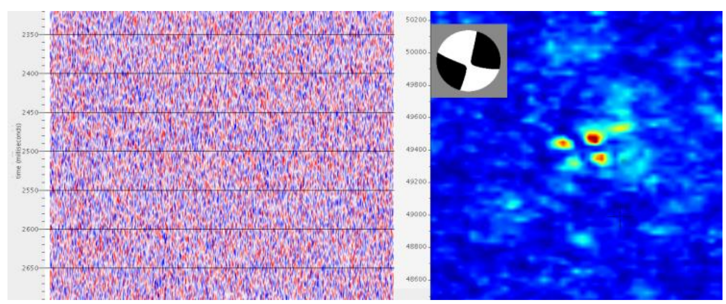

Figure 4. The same event with 20X noise added.

For more information please email Barry.Fish@NanoSeis.com or call +1 303 667-8547.

References

Baig, A., and T. Urbancic, 2010, “Microseismic moment tensors: A path to understanding frac growth”, The Leading Edge, 29, no. 3, pp 320-324.

Drew J., and R. White, 2008, “Microseismic event azimuth estimation: establishing a relationship between hogogram linearity and uncertainty in event azimuth”, SEG Las Vega 2008 Annual Meeting.

Eaton, D.W., and F. Forouhideh, 2011, “Solid angles and the impact of receiver-array geometry on microseismic moment-tensor inversion”, Geophysics, Vol. 76, No. 6, pp. 77-85.