[GC]Microseismic Data from Hydraulic Fracturing Can Locate Faults*

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General Statement

Microseismic technology is crucial these days for understanding reservoirs and planning development programs:

- Borehole microseismic is used to monitor seismic activity generated during hydraulic fracturing.

- The displacement of rock along a shear wave is referred to as a fault, and the energy released by such a movement propagates as a seismic wave; a measure of this energy within the domain of microseismic technology is referred to as magnitude.

- The magnitude values of the recorded microseismic events are proportional to the size of the surface and the displacement involved in faulting. Assuming that surfaces and displacements associated with preexisting faults are bigger than those of hydraulically induced fractures, during hydraulic stimulation the registered higher magnitudes should characterize fault reactivation.

Magnitude is usually one of the parameters derived from borehole microseismic measurements. Additionally, microseismic recording sensors only detect microseismic events occurring within a certain radius from them – usually no more than a few thousand feet.

One way to quantify this phenomenon is with a Magnitude vs. Distance Plot (MDP). This plot shows the relationship between the energy associated with a particular event and its distance from the monitor well. The MDP is a useful analysis tool in microseismic interpretation for all the information it summarizes on a simple graphic display.

Events with a combination of highest magnitude and highest distance away from the monitor well define the maximum detection distance, which can be used to plan the maximum distance for monitor well placement in future jobs. The rest of the recorded events populate the middle upper left portion of the MDP graph, forming a quasi-triangular pattern. The presence of faults in the subsurface – and their reactivation during hydraulic stimulation – thus becomes noticeable on MDPs, because magnitudes of events associated with fault reactivation are usually higher than the rest.

Example

We use the Magnitude vs. Distance Plot (MDP) to discern fault reactivation in this microseismic monitoring exercise, performed real-time during hydraulic fracturing operations. In Figure 1, the higher magnitudes' events associated with possible reactivated faults are highlighted by a dotted blue circle. When implementing the hydraulic stimulation no surface seismic data was available – and subsurface geologic maps, built solely on sparse well information, did not foresee the possibility of a fault in the area. This encouraging geologic model also supported the drilling and stimulation of the treatment well.

More than a year after the stimulation of the well associated with Figure 1, newly available 3-D reflection seismic data provided a better image of the subsurface near the well. Unfortunately, due to resolution limitations, the broadband frequency data from this 3-D reflection seismic survey does not provide unequivocal evidence for the presence of a fault. By coupling the 3-D seismic data with the microseismic events interpreted as the response of fault reactivation, however, we infer the presence of a fault in the seismic image.

In Figure 2 we show sections with and without the microseismic events. The overlay of microseismic events on the 3-D seismic vertical section suggests the presence of an antithetic fault in the subsurface and its possible reactivation due to hydraulic fracture stimulation. The microseismic event set aligned very well in the direction of the interpreted fault plane.

By computing similarity on the 3-D seismic volume and extracting a surface slice from seismic data at the zone of interest, we interpret the presence of a fault crossing the path of the treatment well. The good correlation between microseismic event lineaments and the extrapolation of similarity trends provides further evidence supporting our hypothesis of fault reactivation due to the hydraulic fracturing treatment – which we illustrate in Figure 3.

Figure 3 also shows that the azimuth of the event cloud associated with the fault reactivation is different from the azimuth inferred from previous stimulation stages. This characteristic, solely based on microseismic event location, provides another tool to derive subsurface geological information not generally emphasized.

We suggest that in the absence of additional supporting data, an azimuth change observed from microseismic sets – coupled with anomalously high magnitudes for the same events – could be interpreted as an indication of fault reactivation. Moreover, when integrated with treatment pressure information, these microseismic observations could be used in the decision-making process of changing a predesign treatment job – and could significantly reduce completion costs.

Conclusions

The example presented here serves to validate and support the use of microseismic-derived MDPs as a tool to identify fault reactivation in the absence of additional subsurface data. Moreover, when combined with other independent measurements, MDPs could unequivocally characterize the reactivation of a fault based on higher amplitudes and possible azimuth changes.

We also show that 3-D seismic is a powerful tool to mitigate drilling and completion risks as those encountered when faults are not anticipated along the well path. Availability of 3-D seismic data beforehand could have improved well placement and possibly resulted in lower completion costs and better well performance.

Acknowledgments

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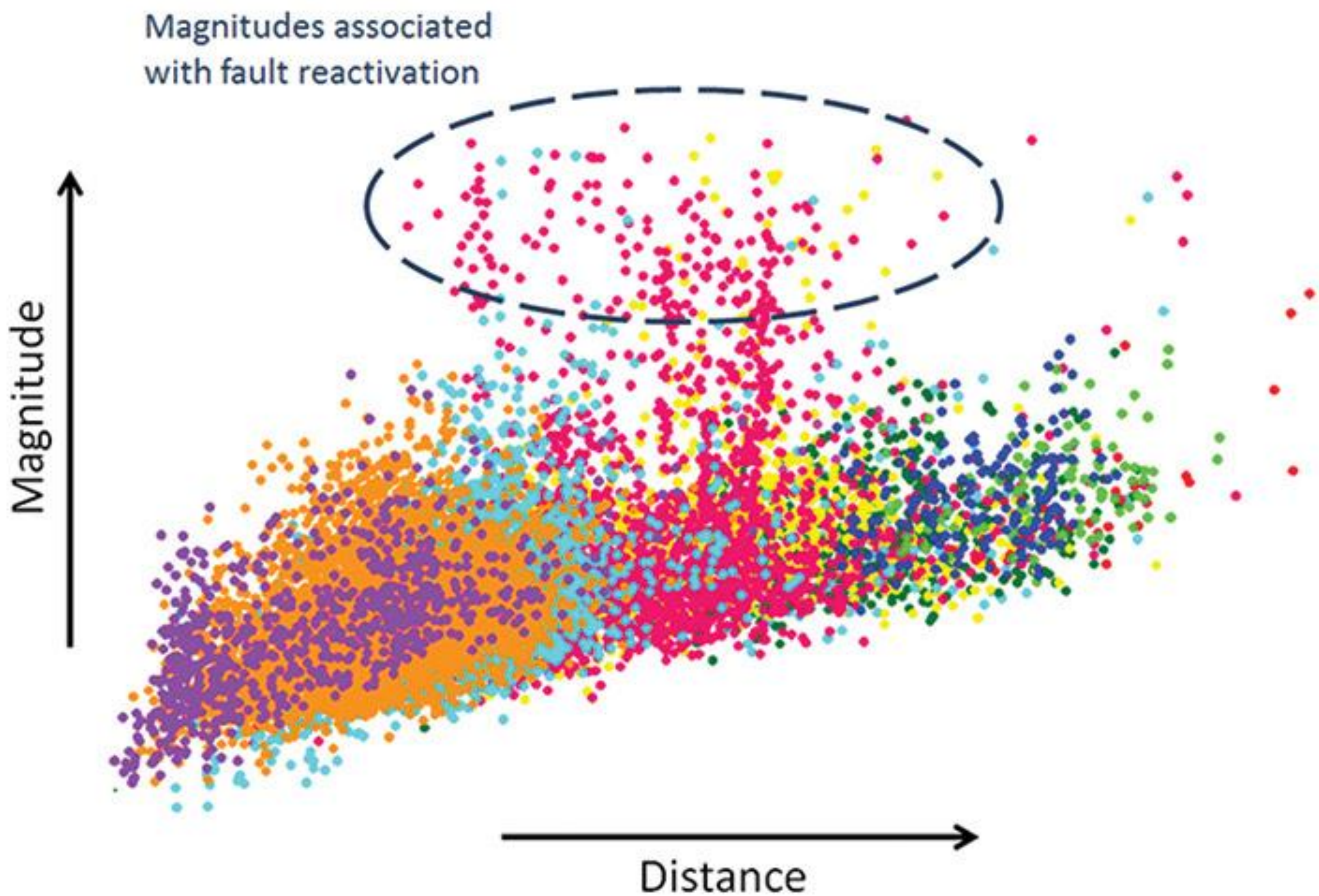

Figure 1. Magnitude vs. distance plot from a multi-stage hydraulic stimulation job monitored from a borehole for microseismic activity. Different colors represent event sets from different stages. Most of the stages generate microseismic events that predictably populate the graph (i.e. lower magnitude events can be detected near to the monitor well, while farther away from the monitor well only relatively higher magnitude events can be detected). Stages yellow, cyan, and especially red suggest fault reactivation due to their higher magnitude, as compared to magnitudes from other stages. Magnitude and distance increase respectively in the direction of the arrows.

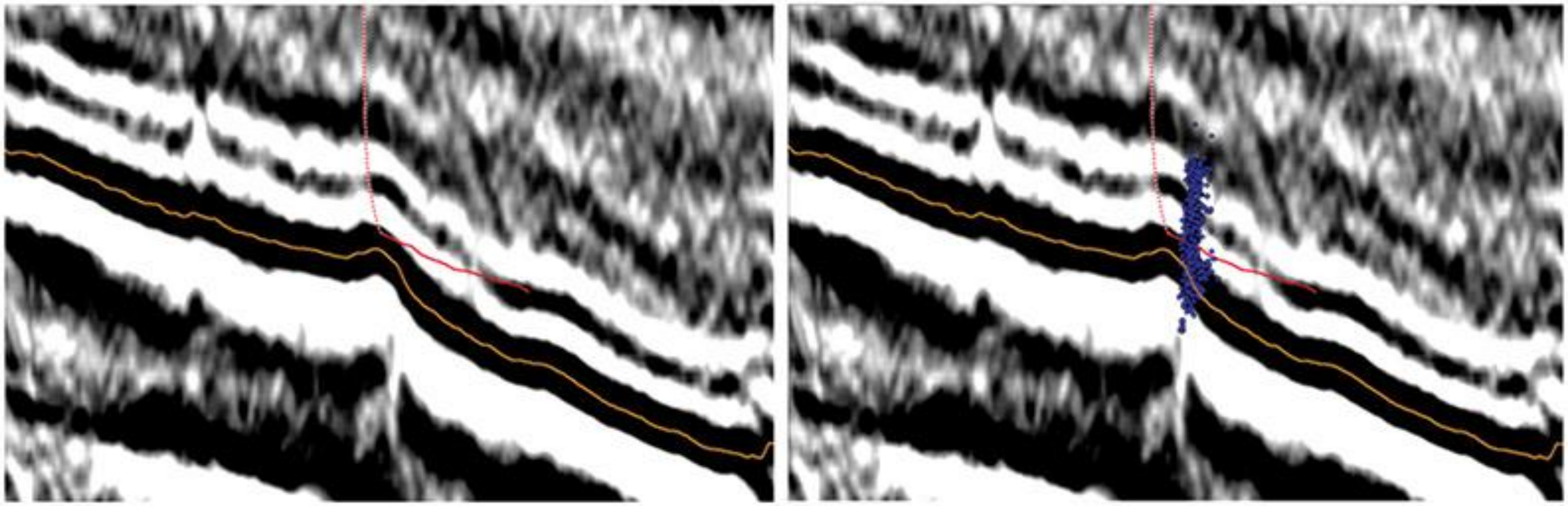

Figure 2. (a) Vertical seismic section parallel to the azimuth of a treatment well monitored for microseismic activity (courtesy of Seitel Inc.); (b) Same seismic line overlaid by microseismic events from a stage interpreted as associated with a fault reactivation. Microseismic events align very well and depict the trace for an antithetic normal fault verging opposite to the inclination of the reflectors, beds and horizontal well.

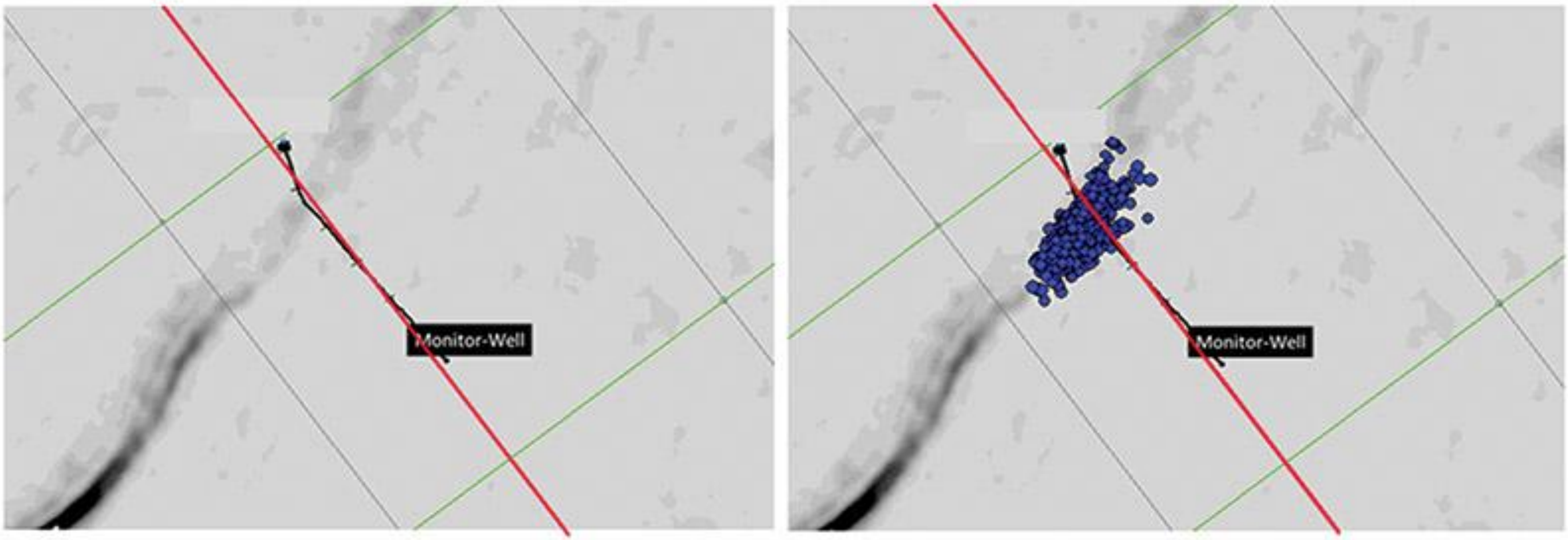

Figure 3. Similarity horizon slice extracted along the stimulated zone of interest monitored for microseismic activity. (The original seismic data used as input into the similarity algorithm is the property of Seitel Inc.) Highly similar data is colored in grey shades while areas with low similarity values are tinted black. Microseismic events from the hydraulic stimulation stage believed to have reactivated a fault are aligned very well with a similarity anomaly that also represents a fault system trace. The treatment well is shown for reference purposes. The red line labeled A-A' represents the direction and length of the line shown in Figure 2.