Geological Microseismic Fracture Mapping – Methodologies for Improved Interpretations Based on Seismology and Geologic Context

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Summary

The results of microseismic monitoring of hydraulic fracture treatments are significantly more valuable when a high-confidence interpretation of results can be done. The most common approach is to look for trends, or directions, along which microseismic events line up that would indicate the direction of induced fractures. This type of interpretation is more difficult when the signal is low or when the events appear to define multiple directions. Analysis of geologic structures in the area of the reservoir can provide useful information to support or eliminate interpretations of apparent trends as stimulated fractures, as well as provide an explanation for fracture trends that deviate from the expected orientation from the in-situ stress directions. In some cases, structural geology observed at the surface can be extrapolated to the subsurface to aid the interpretation. When seismic reflection scale horizon and fault interpretations are available, they can be used to infer that smaller scale faults and fractures of similar orientation may have been activated at the wellbore. Inversion of seismic source mechanisms for microseismic events provides the most well-constrained parameters to describe the failure mechanisms of the hydraulic fracture treatment, and by combining this information with the geologic context a better understanding of the reservoir rock behavior during the stimulation treatment can be developed. In this paper, examples will be presented that describe interpretations of microseismic monitoring results based on geologic context and confirmed by source mechanism inversions.

Introduction

When microseismicity indicates a hydraulic fracturing result that deviates from the expected tensile fracture orientation that would form parallel to the maximum compressive stress directions, pre-existing fractures and faults could be responsible. Existing fracture planes favorably oriented for shear will fail at lower stresses than are required to create new fractures. Geologic mapping and regional to local in-situ stress information will allow informed interpretation of the resulting microseismicity patterns as well as providing predictive capability for fracturing patterns of treatments in subsequent area wells and production planning. The impact of the in-situ stress field on a natural fracture or a fault will be controlled by its orientation relative to that stress field. Examining the relationship of available stress data to existing regional structures can provide clues to explain whether or not natural fractures were activated as opposed to new fractures being created. While it is risky to infer that faulting and other geologic structures that are visible on the surface in the area of a treatment well are indicators of the subsurface structure, in some cases surface features do serve as reliable indicators of the important structural features in the subsurface. The answer to the question of whether a new fracture was created or an existing fracture was activated has different implications for the responsible failure mechanisms. With the application of surface arrays and broad areal coverage buried arrays, failure mechanisms along fracture planes can be determined, providing the orientation of the fault or fracture plane as well as the direction of slip, and information on the possible tensile portion of the failure mechanism. Source mechanism analyses that we have constructed from surface or near surface arrays confirms such structural correspondence as outlined in the following case studies.

Theory and/or Method

Microseismic monitoring surface arrays provide imaging coverage over the entire stimulated volume of a treatment well. Because the span of areal coverage for the many channels receiving event signals covers a large area, it is possible to analyze the first P-wave particle motion changes across the array and identify a fault plane associated with that motion (Figure 1). For nearly vertical faults, the first motions across the array will have zero P-wave amplitude radiated along a line parallel to a fault, and array stations will detect positive or negative motion on either side of an array. This method of analysis is done with surface based vertical component geophones and does not require the use of 3 component geophones. The integration of this result with information about the structural style in the area and the background stress tensor (if known) will allow identification of the displacement on the fault as normal or reverse dip-slip without the need do a full source mechanism inversion.

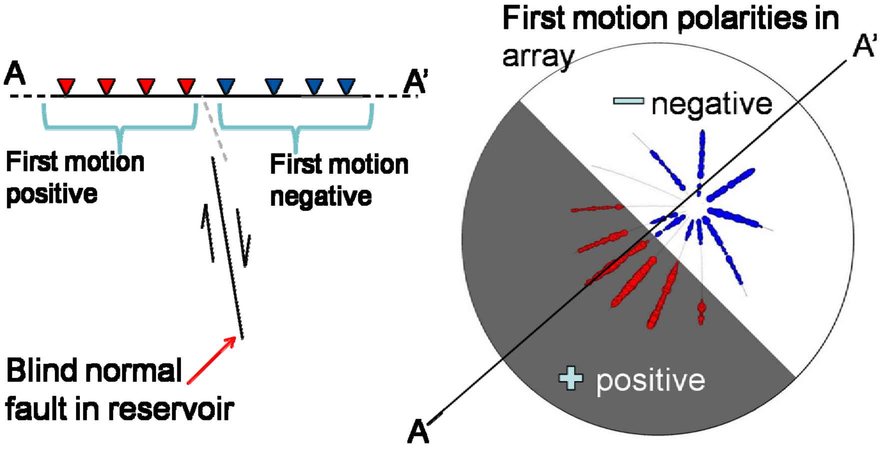

Figure 1. Example surface-based microseismic geophone array configuration. The asymmetric layout of the receiver pattern optimizes signal for a horizontal well deviated to the southwest.

Examples

In a case where a series of strong events outline two intersecting trends about 30 degrees apart, it is clear that the treatment fluid found and reactivated two nearby fault planes (Figure 2). The manner in which the fault planes slipped is not obvious from the geometry, but by integrating the geologic information with the wellbore measurements, the complete nature of the failure mechanisms and fault interactions was determined. For events defining a 120 azimuth trend, a fault plane was identified that parallels that 120 azimuth, which indicates that the first motions of the seismic energy P-waves to the geophones in the array above were positive on one side of this nodal line and negative on the other side. This type of response cancome from dip slip on a steeply dipping fault in the subsurface. The events that define the east-west trend did not have this kind of first motion of P-waves. The interpretation of the microseismic events is reactivation and possibly extension of an east-west oriented fault in strike-slip motion and as it grew, it intersected a southeasterly striking fault so that normal dip-slip motion occurred on it. The interpretation is consistent with the anisotropy measurements in the wellbore that identified maximum horizontal stress parallel to the strike of the normal dip-slip fault.

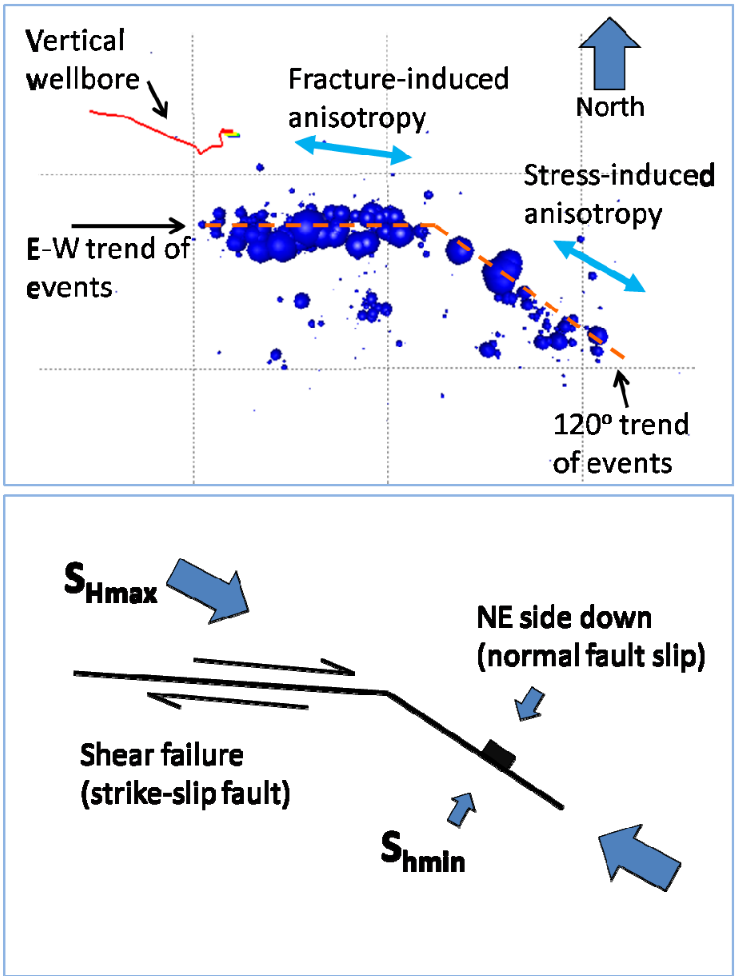

Figure 2. Failure mechanisms of two interacting faults reactivated by hydraulic fracture stimulation.

In a second case study presented here, the complex fracture network illuminated by the microseismicity of a stimulation treatment can be used to define upper bounds of fracture length, as well as their height and dip (Figure 3.). Comparison of the event trends with the subsurface structure indicates that the microseismicity has reactivated existing structures. The largest events line up parallel to the strike of major faults indentified in the subsurface in the interpreted seismic horizons. The largest events form a trend parallel to the faults with orientation closest to the maximum horizontal stress direction, and a secondary trend of weaker events appears to form at an angle to the first trend. Both orientations are present in the subsurface, and the results are interpreted to have reactivated existing faults and fractures. The strong microseismic events define a trend at an angle approximately 25 degrees from the fault trend. If the effective stress in the reservoir is east-northeast (roughly sub-parallel) to the faults, then faults in this orientation may be expected to be presently critically stressed, meaning they are in an orientation that is likely to slip (Zoback, 2007). Source mechanism inversions done for this data set confirm predominantly dip-slip normal fault displacement on the fault planes oriented approximately 80^{o} azimuth. This is consistent with the predominant maximum horizontal stresses in the area.

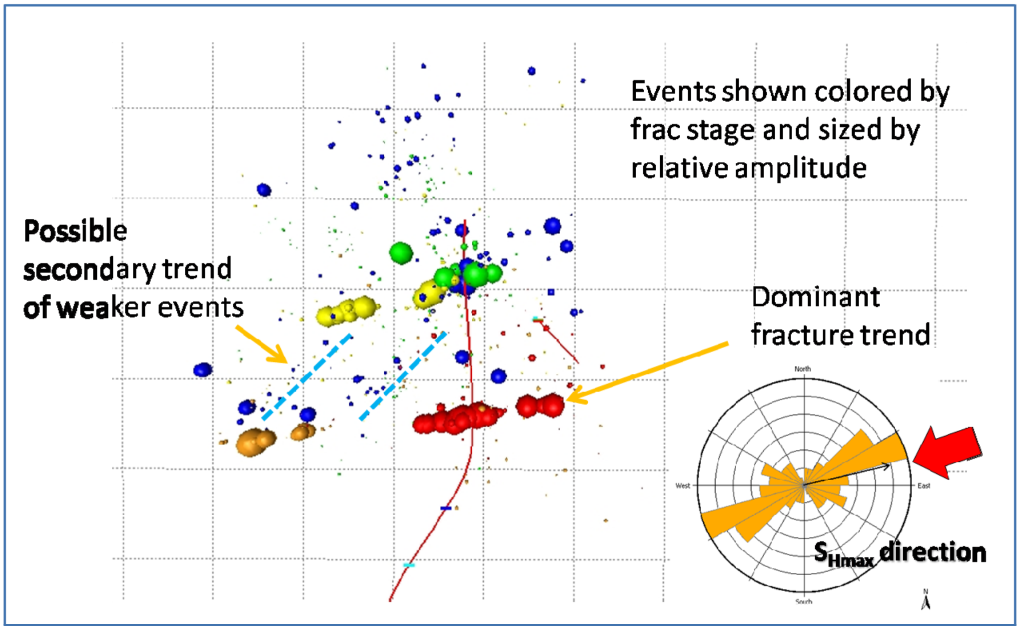

Figure 3. Microseismic monitoring result with some stages showing better defined trends than others. The trends are parallel to major faults mapped nearby in the subsurface. The failure mechanisms for the events are consistent with normal dip-slip motion along such faults.

Conclusions

Combining structural geology analysis with source mechanism solutions for microseismic events provides a high-confidence approach to fracture mapping interpretations of microseismic monitoring results. We show that integration of data from different types of data sources, including geologic mapping, World Stress Map Project data (Heidbach et al, 2008), sonic logs from wellbores, and seismic interpretation converge to support the same interpretation from the different analytic methods. Characterization of the sub-regional geologic setting identifies potential important structural features that may influence the hydraulic fracture treatment. The broad aerial coverage of data acquired using a surface-based microseismic array or a shallow buried array provide the necessary information to derive source mechanism solutions for the induced microseismic events. Within the geologic context, an unambiguous choice of failure mechanism fault plane can then be defined the microseismic events, so that a full characterization of fault and fracture interactions, can be done, including identification of new versus reactivated fractures.

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References

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