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Hydraulic Fracturing Operation Monitoring Using Sparse Surface Networks

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SUMMARY

In certain shale or carbonated reservoirs, seismicity associated with Hydraulic Fracturing (HF) or Enhanced Oil Recovery (EOR) techniques can be detected and characterized by sparse surface networks of high-quality three-component instruments. Here we provide pilot project examples of surface seismic networks, initially deployed for induced seismic monitoring, generating rich data sets in the Duvernay and Montney shale plays in western Canada.

In particular, we show that in environments with favourable surface noise levels, high in-situ stress regime, low anelastic attenuation and shallow depth reservoirs, such networks can detect seismic events down to magnitude -1.0 within the stimulated volume along with induced seismicity on proximate faults.

Introduction

In certain shale or carbonated reservoirs, seismicity associated with Hydraulic Fracturing (HF) or Enhanced Oil Recovery (EOR) techniques can be detected and characterized by sparse surface networks of high-quality three-component instruments. Here we provide pilot project examples of surface seismic networks, initially deployed for induced seismic monitoring, generating rich data sets in the Duvernay and Montney shale plays in western Canada.

In particular, we show that in environments with favourable surface noise levels, high in-situ stress regime, low anelastic attenuation and shallow depth reservoirs, such networks can detect seismic events down to magnitude -1.0 within the stimulated volume along with induced seismicity on proximate faults.

We utilize three-component detection of compressional and shear waves along with waveform template matching event detection techniques to lower the magnitude of completeness and maximize the recorded event catalogue. By locating events using 3D velocity data, grid-search and relative location techniques, the precision and clustering of solutions is optimized for first-pass evaluation of stimulated volume boundaries and delineation of activated geological structures. Furthermore, use of high-quality instruments, including broadband seismometers, allows for unsaturated estimates of event magnitude across the full range of detections, leading to unbiased analysis of magnitude-frequency distributions (b-values) and cumulative radiated seismic energy.

For larger magnitude events with sufficient signal to noise ratio, displacement spectral fitting is used to compute source parameters. Larger magnitude events also allow for individual or composite fault plane solutions to be derived and used to perform principal stress axes inversion as well as determine fracture plane orientations. Although surface noise typically interferes with detection of events below magnitude -1.0, spatiotemporal correlations between events above -1.0 and treatment parameters (stage time/location, treatment pressure, slurry rate, proppant volume, etc) can provide operators with metrics to assist with assessing the effectiveness of each frac stage. Consequently, sparse surface networks of high-quality seismic instruments can generate rich and informative data sets that make them a scalable, practical and cost-effective reservoir monitoring option.

Case Study

A network consisting of six high quality seismic stations was deployed for 2 months to monitor hydraulic fracture operations on four lateral wells. Each station was equipped by three-component 20s seismometers. The lateral wells were at depth of 2.0 to 2.3 km. Data was processed in real-time with a traffic light system in place for higher magnitude events.

A rich catalog of over 1100 events was generated using standard STAl/LTA and template matching techniques. Events were located using a grid search method and 3D velocity model built from 3D reflection seismic, VSP and sonic logs. Event locations were refined using relative relocation by minimizing travel time differences between suitable co-located event pairs (Figure 1). This resulted in improved focus of event clusters associated with various stages. It is worth noting that 98% of the events were recorded during frac stages and no events were recorded 2 weeks prior to and 1 month following the completion of the operations by the same network.

Events with sufficient signal to noise ratio were selected for fault plane solutions derived from P and SH first-motion polarities. Take-off angle and azimuth uncertainty based on median location uncertainty were incorporated into fault plane solutions for individual events to better constrain them.

Inversion of fault plane solutions revealed maximum horizontal stress (S_{Hmax}) orientation consistent with operator-supplied well breakout data. Stress inversion also indicated that vertical stress (σ_v) is lower than the two horizontal stresses (Figure 2). Stress inversion results, fracture plane orientations and the timing of the recorded events suggest that the majority of recorded events are associated with reactivation of pre-existing fractures. This is in good agreement with the treatment data analysis. Further analysis and interpretation work is ongoing in cooperation with the operator.

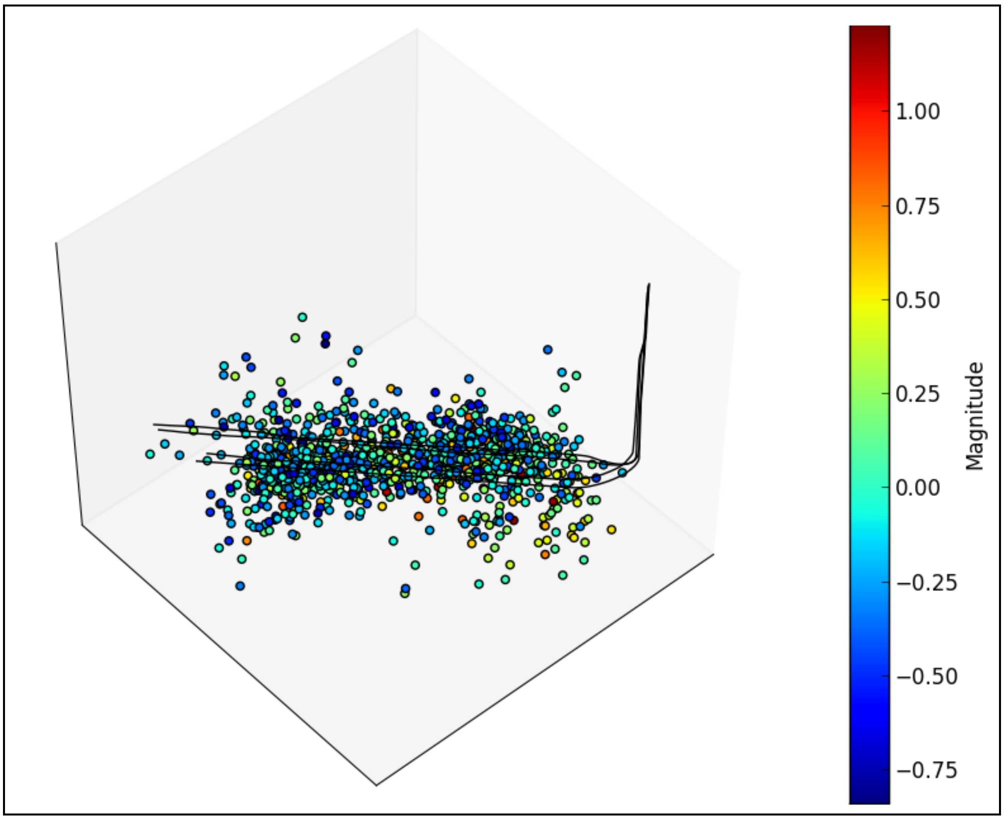

Figure 1 *Passive seismic events detected during the stimulation of four horizontal treatment wells colour coded by magnitude*

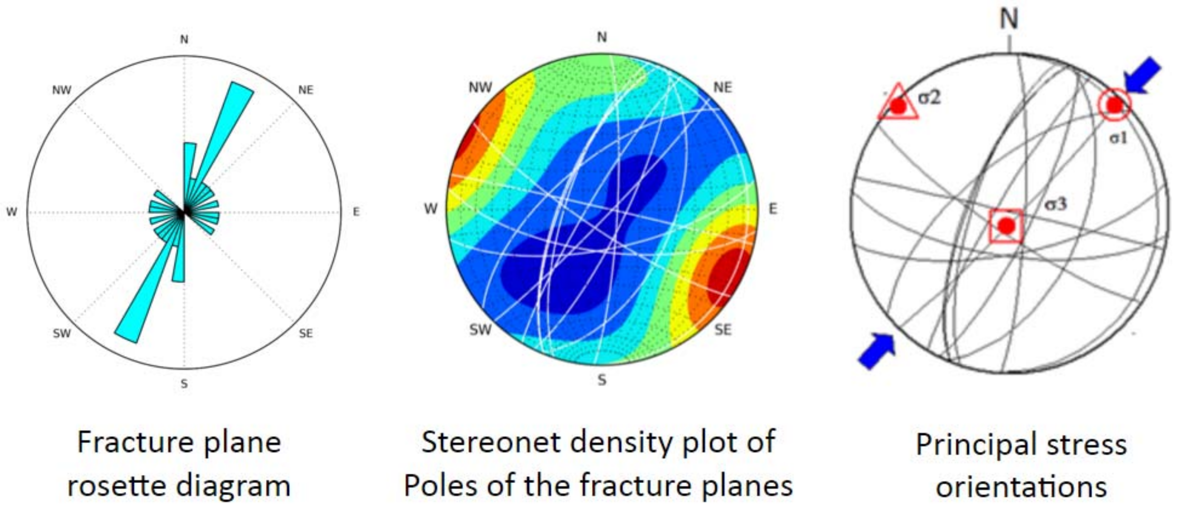

Figure 2 *Rosette diagrams of fracture planes and stereonet density plots of their respective poles show that the majority of them are sub-vertical with NNE-SSW strike orientation. Inversion of fault plane solution reveals that the maximum horizontal stress (S_{Hmax}) orientation is 44^{o} to the north.*

Conclusions

Using a sparse six-station surface array of high quality instruments during a 22-25 stage 4-well completion operation approximately 1200 events were located. Refined event locations show tight event clustering around the wellbores adjacent to perforations with no fault lineaments or out of zone clusters. Almost all of the events are recorded within the frack stages with no seismicity prior to or after operations. Results of this study confirm the presence of high natural fracture density with complex slip orientations. Estimated relative stress magnitudes indicate vertical stress is lower or equal to horizontal stresses. Fracture planes for the largest events are consistent with the direction of S_{Hmax} which in turn is consistent with the regional stress field. While noting that further analysis and interpretation work is ongoing, the results to date indicate that sparse surface networks can, under right conditions, assist in the evaluation of the effectiveness of hydraulic fracture operations at a fraction of the cost of traditional microseismic monitoring.

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