Surface microseismic monitoring of slick-water and nitrogen fracture stimulations, Arkoma Basin, Oklahoma

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Summary

Surface based microseismic monitoring was done to assess the effectiveness of slick-water and nitrogen fracture stimulations in a horizontal well with a 3500' lateral drilled in the Arkoma Basin of Oklahoma. Water production from this shale as well as the located events from the microseismic monitoring suggested the fracs were not contained and contacted foreign water. The observed distribution of microseismic events suggested that planar fractures were created with varying complexity. The azimuths of the produced trends suggested that a strong influence from the pre-existing natural fractures directed the induced fractures. A direct comparison of the slick-water treatment to the nitrogen treatment revealed multiple advantages with the latter, such as more in-zone events, more energy per event, and more complexity in resulting fractures.

Introduction

The area monitored is located in the Arkoma Basin of Oklahoma, an area where the basin tectonics are inactive, but the weather is not. The surface array used to perform the surface monitoring of the slick-water and nitrogen treatments was designed to locate induced microseismic events by beamforming. The array consisted of 1078 stations of 12 geophones laid out in a radial pattern around the treatment well (Figure1). Although the treatments were two months apart, the array geometry was identical with the exception of removal of 11 stations from the array during the nitrogen treatment. The geophones were buried to a depth of one foot to maximize the signal to noise ratio by reducing the interference of the frequent seasonal rainfall. Cultural sources of noise such as traffic and inherent pad noises were taken into account by surface array design and seismic processing.

Fracture Stimulation Monitoring

Seismic data was recorded over the entire array for the duration of both treatments. 25 hours of data were recorded and processed. Microseismic events induced by the hydraulic fracturing were located by a beamforming process, essentially a one-way depth migration. As with any migration process, an accurate velocity model is critical to success.

A constant velocity model was calculated for each treatment using the perforation shots as sources for calibration events. By taking a measurement of the arrival times across the array and plotting them against the distance between receivers a velocity estimate from the well depth to the surface was derived. The derived velocities were consistent with RMS velocities calculated from a sonic log of the well bore. Receiver statics were then calculated from the perforation shot arrivals and used to complete the calibration of the model. Using the calibrated model, the events corresponding to the perforation shots located to within 50 feet of their measured location in the well bore.

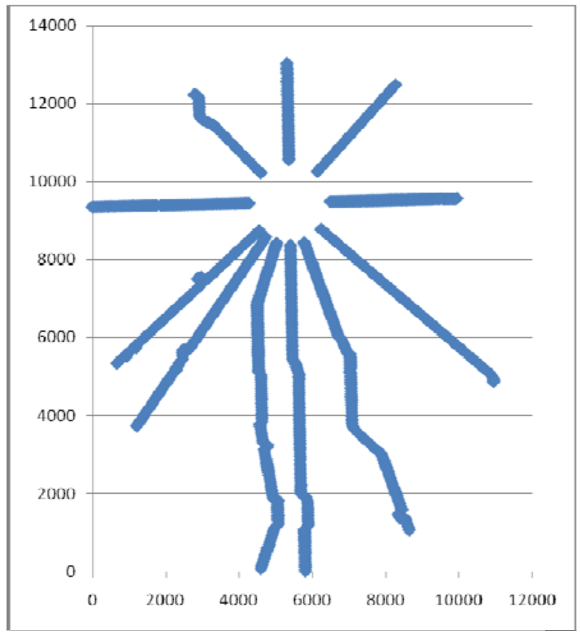

Figure 1: Plan view of the array. Axis units are in feet.

Slick-Water Versus Nitrogen

The lateral was treated in two ways: the toe portion of the lateral was stimulated with a slick-water frac consisting of 8 stages while the heel portion of the lateral was treated with a nitrogen frac consisting of 4 stages.

Microseismic results from the monitoring of the treatments showed fracture events extending as far as 300 feet (+/- 50 feet) above the target interval for both treatments. However, the nitrogen treatment produced only six events that extended a maximum of 40 feet into the lower, water bearing formation; whereas the slick-water treatment produces over 150 events that extended as much as 320 feet into the lower, water bearing formation (Figure 2).

A direct comparison of the relative amplitudes from each treatment was performed which revealed that the energy released by the nitrogen treatment was over 13 times higher than that of the slick-water.

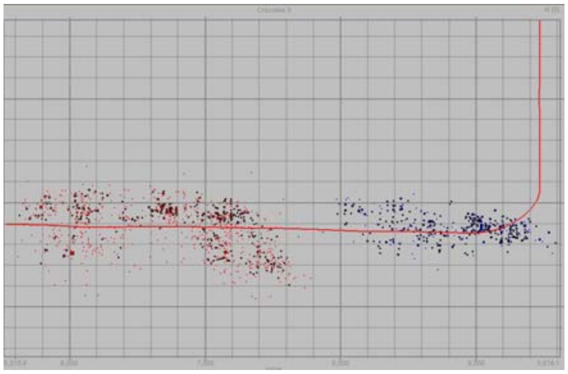

Figure 2: 2D depth view showing vertical extent of both treatments. Slick-water shown in red, nitrogen shown in blue. The grid is 200ft^2.

Planar to Complex

While some stages activated multiple trends and some trends were created by multiple stages, an examination of the entire dataset shows that both treatments produced planar trends of low complexity as well as areas of dispersed distribution interpreted as complex fracture networks. The nitrogen treatment resulted in more events in complex networks as opposed to the majority of the events produced by the slick-water treatment aligned into concentrated planar features that correlated with the natural fracture directions logged in the pilot well (Figure 3).

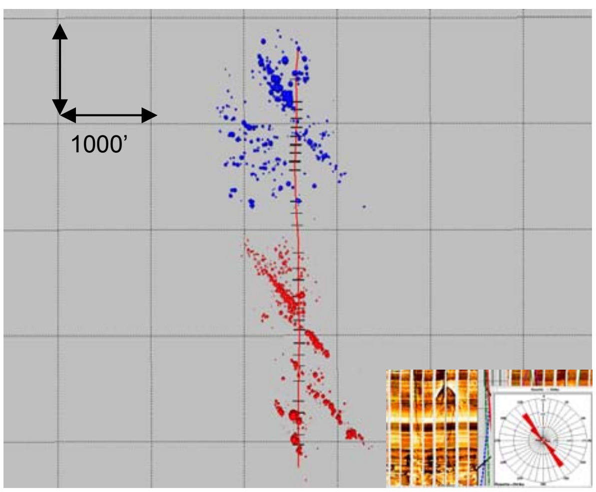

Figure 3: Map view of the results from surface monitoring. All events sized by relative amplitude. Red events are slick-water, blue events are nitrogen. Rose diagram and FMI log imposed.

Conclusions

- The induced fractures seen with the microseismic events are interpreted to have gone out of zone both above and below the shale which matches the most recent models of frac behavior for this well. Water production from the well also suggests the fracs went out of zone which is supported by the microseismic monitoring results (Figure 4).
- The nitrogen treatment produced numerous events interpreted as complex fracture systems as well as large planar features with low complexity. The slick-water treatment produced mainly large planar features with low complexity (Figure 3).
- The relative amplitudes of the two treatments were compared and showed the nitrogen produced events that were 13 times larger than those produced by the slick-water.
- Both treatments produced fractures trending perpendicular to the orientation of the maximum horizontal compressive stress near the Arkoma Basin. The orientation of many of the event trends match known natural fractures orientations from FMI, and the surface orientation of fractures from hyper-spectral satellite imagery.

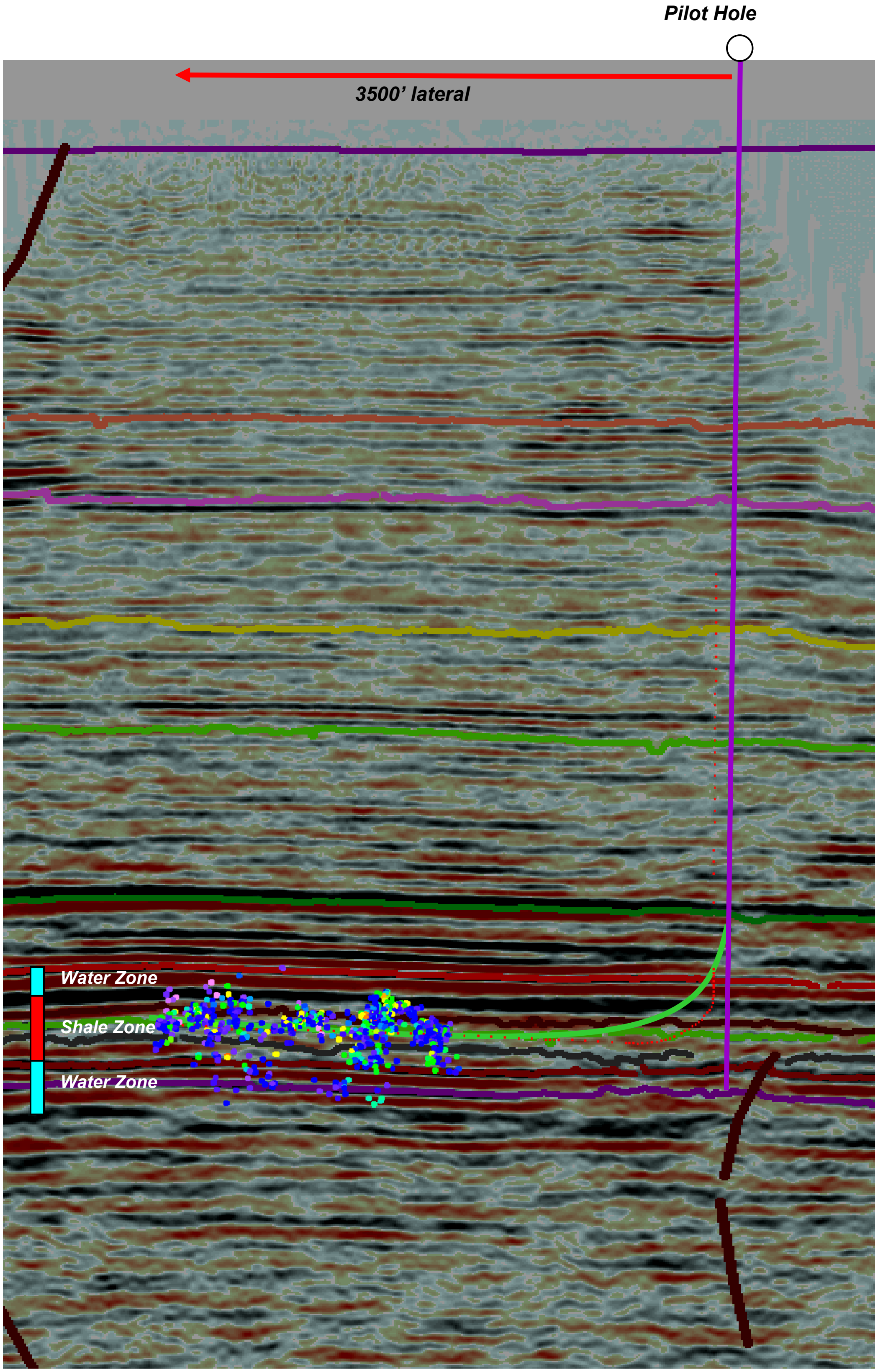

Figure 4: 2D Seismic Line with Micro-seismic Events from Slick-water Stages 1-8

EDITED REFERENCES
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REFERENCES
None