Surface Based Microseismic Monitoring of a Hydraulic Fracture Well Stimulation in the Barnett Shale

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Summary

Microseismic monitoring of well stimulation by hydraulic fracturing is now an accepted technology. Most such monitoring is achieved with a downhole array of geophones located at or near the reservoir level in a nearby observation well. The need for an available observation well and the limited view such a well provides are impediments to the potential usefulness of the technology. The ability to monitor hydraulic fracture growth from the surface allows for larger array apertures and increases subsurface coverage with while maintaining reasonable resolution and detection limits. Stacking over a large number of stations effectively cancels the surface noise and enables seismic signal detection at levels that are comparable to downhole techniques. More importantly, the surface array is able to detect these comparable signals over a larger subsurface area and shed more light on the extent of the reservoir volume being stimulated.

Introduction

We present a comparison between surface based and downhole microseismic monitoring of the hydraulic fracture stimulation of the Burlington Resources operated well, C. W. “B” 19-H in Wise County, Texas. The seismic energy released by these hydraulic fracture induced earthquakes is typically too weak to be seen on a single station record at the surface. A dense array of geophones is used in order to build up the signal-to-noise ratio using a beam summation technique we refer to as Passive Seismic Emission Tomography or PSET®. Areas of concentrated energy are interpreted to represent the hypocenters of discrete microearthquakes. The objective of the experiment was to validate the observations by making surface passive seismic measurements concurrently with a downhole observation.

The Barnett is a low permeability, naturally fractured shale reservoir that requires fracture stimulation to facilitate production. Directional wells are horizontally drilled perpendicular to the prevailing maximum horizontal compressive stress direction (S_H) and are completed with a hydraulic fracture treatment. Hydraulic fractures are anticipated to propagate in the direction of S_H and intersect and interact with other naturally occurring fractures to form a complex network of connected fractures that enable greater reservoir drainage by enhancing permeability. It is important to diagnose the fracture system in order to optimize the hydraulic fracture treatment, calibrate the fracture model, provide insight on well placement and ultimately improve reservoir production performance.

Method

The surface seismometer array consisted of 97, 3-component stations arranged in a rectangular grid centered on the C. W. “B” 19-H well. All geophones were oriented 3 component seismometers with a natural frequency of 10 Hz. The array covered nearly 2 ½ square miles and was deployed over an area of 6000’ by 8000’ on a side. The inline spacing was 600’ and the crossline spacing was 800’. Near the toe of the well 24 stations were buried 10-18’ beneath the surface to test the efficacy of burying the stations to improve the S/N ratios and increase the recorded bandwidth.

The C.W. “B” 19-H well was hydraulically stimulated with a massive single stage completion. A series of perfs were made every 500’ along an uncemented liner. The treatment was delivered over an 8-hour period. Periodic sand slugs were introduced during the treatment to control leak off.

The passive surface seismic data were recorded continuously using a Sercel 408 system. Abutting 1 minute records were written to tape at 2ms sample rate. The array was live before during and after the pumping operation.

The data were analyzed using standard seismic data processing techniques. The traces were bandpass filtered and then balanced using a trace by trace AGC. The components were separated into horizontal and vertical component traces. Layered, 1D P- and S-wave velocity models were constructed using a dipole sonic log. The upper and lower portions of the velocity model were extrapolated using expected rock properties. The velocity model was then calibrated by focusing the energy from a small string shot at the heel of the well to the correct location.

A series of records were processed to examine the spatial and temporal distribution of acoustic emission energy. The energy for each cell in a 3D grid was calculated for a series of time periods of one second up to a minute. Horizontal and vertical component beam sum records were analyzed for areas of concentrated energy. The highest energy cells for each time period were plotted and animated to show the relationship between the onset of the activity and the surface pumping pressure.

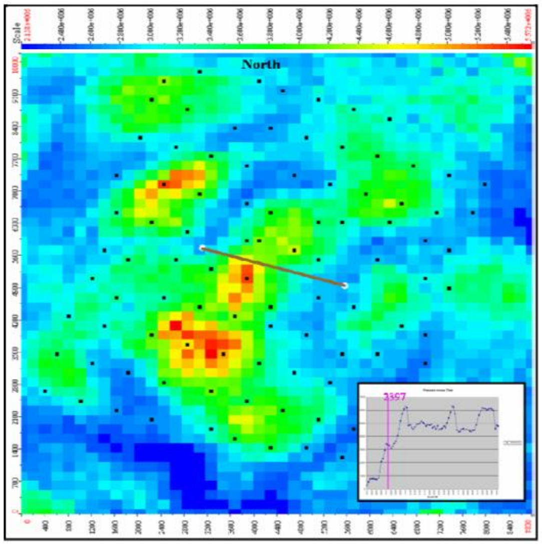

Figure 1. PSET® depth slice at 7800' from surface. Energy summation calculated over a minute period using the vertical component. Distribution of energy values plotted as colored pixels with higher energy values corresponding to warmer colors. Black dots are surface station locations. Brown line traces well deviation. Inset of pressure history curve shows location of minute relative to surface pressure. During this time, the surface pressure dropped rapidly once 3000 psi was obtained. This one-minute period contained the highest seismic energy seen in the early stages of pumping activity. The energy pattern traces out two NE-SW trends with an orientation similar to the inferred S_H. The NE-SW trend offset from the well is suspected to result from the reactivation of a pre-existing hydraulic fracture from another completed horizontal well to the north. The NE-SW energy near the center of the C. W. "B" 19-H appears to be reoriented into an orthogonal direction near the SW tip of the hydraulic fracture. This reorientation is suspected to result from the hydraulic fracture encountering a natural fracture system in the Barnett. The time at the loss of pressure corresponds to the intersection of the hydraulic fracture with the natural fracture system and is accompanied by a large seismic energy release.

A direct comparison of surface based microseismic mapping results to the preliminary downhole microearthquake locations was made for a subset of data during the early stage of the hydraulic fracture treatment. This time period showed the strongest, most dynamic behavior. Picks of high energy events from 5 discrete minute energy volumes were overlaid with the downhole microseismic locations to verify that the high energy locations correspond to seismic energy originating at depth.

Results

Analysis of the surface microseismic data showed the onset of seismic activity within 10 minutes of start of pumping. An initial NE-SW oriented pattern of seismic activity centered on the wellbore propagated bi-directionally, rapidly and orthogonally from the borehole during the first 20 minutes of pumping.

The energy pattern achieved a fracture half-length of ½ mil at which point it was reoriented in a WNW-ESE fashion accompanied by significant microseismic activity (Figure 1). These observations are consistent with the anticipated hydraulic fracture growth direction and interaction with the natural fracture system.

A couple of events were detected and located at the heel of the well. The events appear to link up with another strong lineation directly to the north of the well. The strong energy emission seen in this area is near the location of a previously completed horizontal well. It is suspected that pressure communication from the heel of the well to the hydraulic fracture in the earlier well is reflected by this microseismic activity.

The comparison between the surface based microseismic mapping and the preliminary results provided by the borehole mapping show certain similarities and differences over the short time period analyzed. There is strong spatial and temporal correlation of events from the two data sets in the NE quadrant of the horizontal well (Figure 2).

Discussion

Some of the discrepancy between the exact number of events seen between the two arrays is likely related to the fact that the downhole results provided here were only preliminary results obtained from the field processing and represent only a portion of the total number of events that were recorded and able to be located. That the surface array detected more events to the SW of the borehole is not surprising considering the location of the observation well relative to this seismic activity. The observation well was offset 1500' from the toe of the C.W. "B" 19-H well and events on the southern side of the horizontal are approaching the detection limits of the downhole monitoring technique (Warpinski, et al., 2005).

The locations of the similar events do not correspond exactly and the discrepancy in the location is likely related to the combined errors in the two methods. The surface

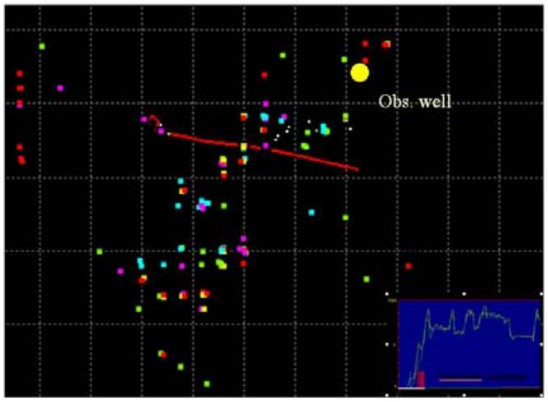

Figure 2. Comparison of preliminary downhole and surface derived locations. Squares are high energy cells from 5 one minute energy volumes. Circles are the downhole locations over the equivalent time period. Large yellow circle is the location of the observation well. There is a strong correspondance of locations to the NE of the well, but many more events to the SW of the well are not seen by the downhole array. The inset shows the time period for which the downhole and surface events were compared.

based locations were mapped on a subsurface grid of 200' on a side, so that lateral resolution less than 200' is not possible. The 200' resolution is controlled by the effective bandwidth used in the processing.

While the surface array is showing more events detected over this time period, there is unlikely to be any exact one-to-one correlation. The process of energy summation over a period of time much longer than the duration of the discrete events, suggests that the hypocenters determined from the energy stacks may be the result of the contribution of multiple sources occupying a single cell during the time period.

The downhole array and the surface array also have different detection thresholds. The downhole array is better suited to discriminating and locating smaller events, especially near the observation well. The detection threshold of the surface array is ultimately controlled by the attenuation of cultural noise at the surface through the data processing and stacking operations. The average ground motion for the Barnett play in this area is on order of 0.5 um/s and varies widely across the array with the buried stations substantially more quiet. For the data presented here, the processing provided a factor 8-10 amplitude increase or nearly a 20 dB boost in signal.. This level of increase in S/N is consistent with the square root of number of stations. The cultural noise and S/N increase show that the detection threshold for locating microearthquake events from the surface is slightly below a local magnitude, $M_L = -2$.

Conclusions

Surface based microseismic monitoring provides an important and complementary technique to downhole micoearthquake monitoring techniques. Given the S/N at the surface and the array design, events at magnitude levels similar to those seen downhole can be mapped. The frequency content of these events at the surface results in reduced resolution compared to the downhole results. While the detection threshold and location accuracy are not as impressive near the observation well, the fact that the larger surface array is able to detect and locate microseismic activity over a larger area allows greater access to the complexities of hydraulic fracture growth and interaction with the natural fracture system at distances that have not been investigated in the past.

References

Warpinski, N.R., Kramm, R. C., Heinze, J.R., Waltman, C.K., 2005, Comparison of Single- and Dual-Array Microseismic Mapping Techniques in the Barnett Shale, SPE 95568.

Acknowledgements

The authors wish to thank Burlington Resources for permission to show the data presented here.

EDITED REFERENCES

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REFERENCES

Warpinski, N. R., R. C. Kramm, J. R. Heinze, and C. K. Waltman, 2005, Comparison of single- and dual-array microseismic mapping techniques in the barnett shale: 75th Annual International Meeting, SEG, Expanded Abstracts, 1261–1264.