

## Hoadley Microseismic Experiment: Reprocessing and characterization of long-duration tremor signals

*Enrico Caffagni and David W. Eaton*

*Department of Geoscience, University of Calgary*

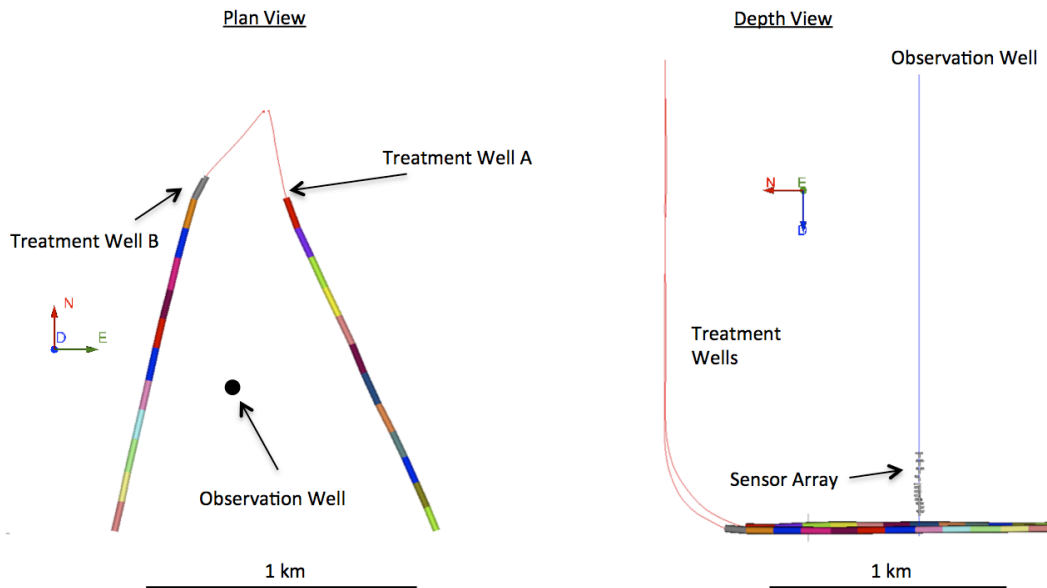
### Summary

Downhole seismic monitoring of an unconventional tight-sand unit in central Alberta was undertaken during a multi-stage hydraulic fracture treatment in September 2012. Acquisition of continuous passive seismic data continued during the subsequent flowback and production periods spanning over 10 months, with the objective of developing a geomechanical model for microseismic activity associated with treatment, flowback and production of the unconventional gas reservoir. More than 1650 microseismic events were located during the two-day hydraulic fracture treatment program. Reprocessing of the raw microseismic data is currently being undertaken using in-house software, with the objective of better characterizing the relationship between microseismic source type (shear versus tensile) and the treatment program. Long-duration tremor-like events occurred episodically during all stages of the acquisition and, by analogy with long-period long-duration (LPLD) events, these are interpreted as activation of slow slip on pre-existing fractures. Two of these tremor-like events occurred during the post-pumping period after the first day of treatment. They both exhibit frequency characteristics that are consistent with a slowly cascading rupture process.

### Introduction

The Hoadley flowback microseismic experiment (HFME) was undertaken commencing August 2012 for long-term passive seismic monitoring of a multi-stage hydraulic fracture treatment together with a variety of ancillary studies. A 12-level geophone array was deployed in a vertical monitor well situated between two horizontal treatment wells (Figure 1). A “tuning fork” configuration for the treatment wells provided decreasing separation of the treatment zones from toe to heel. In addition to real-time microseismic monitoring of an open-hole multistage hydraulic fracture treatment in the Glauconitic member (Hoadley gas field, central Alberta) the scientific goals of this project are to document and develop a geomechanical model for microseismic activity associated with flowback and production stages of development of a tight-gas reservoir, and to integrate microseismic analysis with rate-transient analysis, frac-fluid tracer studies and reservoir modeling. About 1650 events were located during the two-day hydraulic fracture treatment program (Eaton et al., 2013). The distribution of microseismicity reveals a relatively complex fracture pattern.

Hoadley is a giant gas-condensate field that was discovered in 1977 (Newbert et al. 1987). The field is hosted by the Glauconitic member of the Lower Cretaceous Mannville Group (Figure 1), a lithologically diverse unit derived from the adjacent Cordillera. Mannville strata form a foreland-basin clastic wedge that extends across the Western Canada Sedimentary Basin (Hayes et al., 1994). The Hoadley barrier represents a southwest-to-northeast trending marine barrier bar system that marks the northern limit of continental to marginal-marine depositional environmental (Hayes et al., 1994). Modern analogs include Galveston Island, Texas, and the north shore of Prince Edward Island (Reynolds et al., 2012). The lithology of the Hoadley shoreface complex varies from porous sand facies to interbar lagoon and tidal-



**Figure 1.** Layout of the treatment wells, observation well and sensor array.

channel facies (Newbert et al., 1987). The barrier system contains progradational marine sandstone bodies up to 32 km in length, each of which hosts several distinct reservoirs (Newbert et al., 1987).

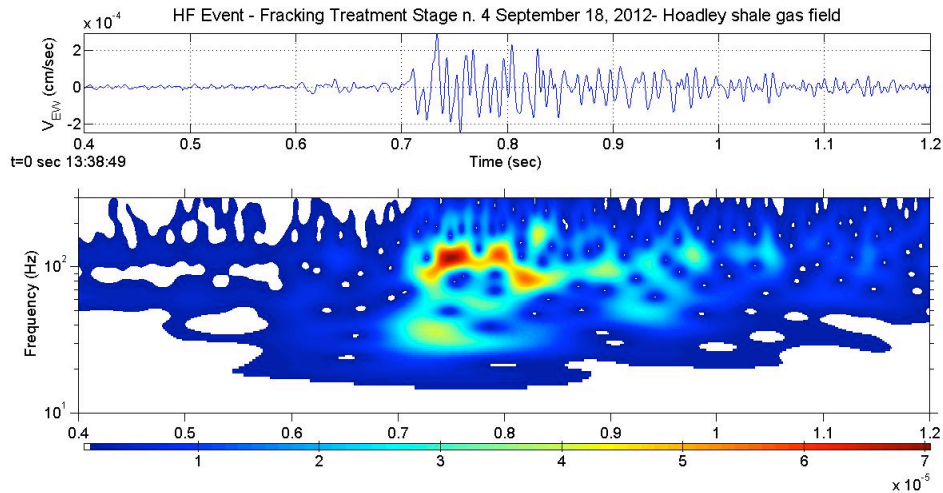
Initial production from the Hoadley field made use of vertical wellbores and was confined to the most permeable sand bodies. The recent introduction of multiple fractured horizontal well (MFHW) technology has opened up a large unconventional resource play (Reynolds et al., 2012).

The objectives of this study are twofold. First, complete reprocessing of the raw microseismic data is being undertaken using in-house software, with the goal of improving our understanding of the relationship between source type (shear versus tensile) and the treatment parameters. Secondly, we have performed a systematic search for long-period long-duration events during and after the treatment program. These events have recently been described from the Barnett play in Texas (Das and Zoback, 2013a; 2013b) and have been interpreted as slow-slip along pre-existing faults (Zoback et al., 2012).

## Microseismic reprocessing

To date, reprocessing of the raw microseismic data has consisted of automatic event detection, arrival-time picking, estimation of hypocentral distance based on S-P time difference, source parameter estimation (magnitude, S/P amplitude ratio and spectral content) and comparison with the hydraulic-fracture treatment curves. Eaton et al. (2014) discuss how the S/P amplitude ratio can be used to discriminate between shear-dominated and tensile-dominated microseismic sources using a limited-aperture monitoring array. In general, an S/P amplitude ratio that is less than 5 is indicative of a component of tensile failure in the focal mechanism.

Figure 2 shows an example of a high quality microseismic waveform. In addition, time-frequency frequency analysis of the signal has been performed using the S-Transform (Stockwell et al., 1996). This example shows a S/P amplitude ratio that is large, indicative of a dominant component of shear failure. The dominant frequency of the S wave is slightly greater than 100 Hz.



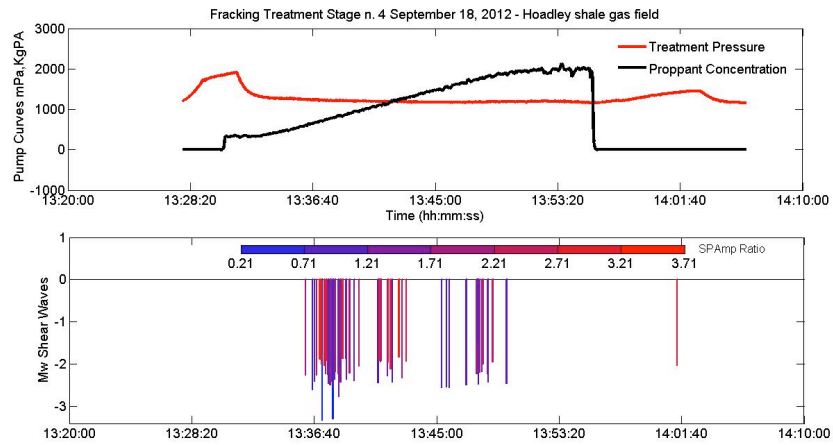
**Figure 2.** Example of a high-quality microseismic waveform and its S-Transform.

Figure 3 correlates the time history of detected microseismic events during one stage of the treatment with several pumping curves (treatment pressure and proppant concentration). The microseismicity occurs primarily in bursts of activity during the injection. This data show a tendency for greater amount of shear-dominated microseismic activity early during the treatment stage, as indicated by bars that have a red colour. As the stage progress, we can see an increase in the abundance of tensile-dominated activity, as shown by the bars coloured in blue.

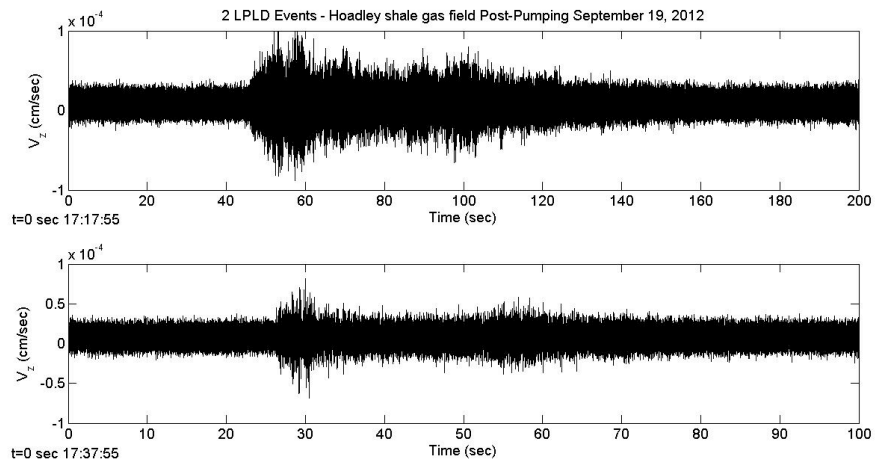
### Long duration tremor signals

Several long-duration tremor signals were detected during the post-pumping period after treatment of well A (Figure 4). The S-transform of one of these signals is shown in Figure 5. Like the LPLD events described by Das and Zoback (2013a) and St-Onge and Eaton (2014), these events have a significantly longer duration (in this case about one minute) compared to typical microseismic events, which typically have a duration of less than 1 s. Unlike previously documented LPLD events, however, the dominant frequency of these tremor signals of about 100 Hz is similar to the S-wave dominant frequencies of for microseismic events (Figure 2).

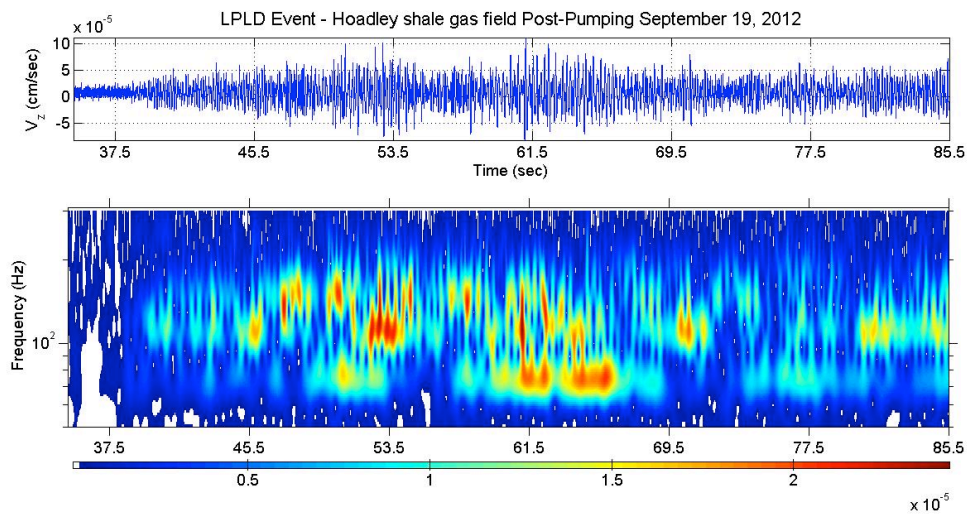
Zoback et al. (2012) and Das and Zoback (2013b) have interpreted LPLD events to represent slow slip along fractures that are misaligned with respect to the principal stress directions. For surfaces that are misaligned with the stress field, conventional seismic slip is not energetically favoured. Instead, slip has been postulated to progress at a rate that is determined by the rate of fluid diffusion along the fracture. The similarity in frequency of the tremor signals with other microseismic events suggests that they may represent a cascading rupture process along a fracture. Such a process may also be controlled by the rate of fluid diffusion along a fracture.



**Figure 3.** Upper panel: pumping curves for stage 4, well A showing treatment pressure (red) and proppant concentration (black). Lower panel: time history of microseismic events, coloured based on S/P amplitude ratio.



**Figure 4.** Long duration tremor events detected during the post-pumping period.



**Figure 5.** S-Transform of the initial part of the first example Long duration tremor event.

## Conclusions and future work

This paper describes ongoing work to reprocess microseismic data acquired during a multistage hydraulic fracture treatment from the Hoadley field in 2012. The focus of our investigation is to improve our understanding of the relationship between source mechanism and pumping parameters. Our initial approach to characterize the source mechanism makes use of S/P amplitude ratio, which can be used to discriminate between shear-dominated and tensile-dominated rupture (Eaton et al, 2014). We are observing patterns of activity that are suggestive of variations during the treatment program.

This paper also reports several long-duration tremor events that occurred during the post-pumping periods. Although similar in duration, these tremor signals differ from previously described LPLD events by virtue of frequencies that are similar to other observed microseismicity. We interpret the long-duration tremor as a cascading rupture process along a pre-existing fracture surface.s

Future developments in our processing workflow are focusing on the use of cross-correlation of the raw data using reference events, in order to extract additional signals that are too weak for automatic detection.

## Acknowledgments

This work was supported by the Microseismic Industry Consortium Sponsors. A special thanks to ConocoPhillips for their support of this project.

## References

- Das, I. and Zoback M.D. (2013a): Long-period, long-duration seismic events during hydraulic stimulation of shale and tight-gas reservoirs — Part 1: Waveform characteristics. *Geophysics*, 78, KS97–KS108.
- Das, I., and M. D. Zoback, 2013b, Long-period long-duration seismic events during hydraulic stimulation of shale and tight gas reservoirs — Part 2: Location and mechanisms: *Geophysics*, 78, KS109-KS120.
- Eaton, D. W., Davis, C., Matthews, M., van der Baan, M., Mostafa, M. Costa Sousa, M., Brazil, E., Williams-Kovacs, J. and Clarkson, C. (2013). Hoadley flowback microseismic experiment, Progress Report. In van der Baan M. and Eaton, D. (Eds), Microseismic Industry Consortium, Annual Research Report, 3, 95-114.
- Eaton, D.W., Van der Baan M., Birkelo, B. and Tary, J.B. (2014): Scaling relations and spectral characteristics of tensile microseisms: Evidence for opening/closing cracks during hydraulic fracturing. *Geophysical Journal International*, in press.
- Hayes, B.J.R., Christopher, J.E., Rosenthal, L., Los, G., McKercher, B., Minken, D., Tremblay, Y.M., and Fennell, J., 1994. Cretaceous Mannville Group of the Western Canada Sedimentary Basin, in *Geological Atlas of the Western Canada Sedimentary Basin*, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, <[http://www.ags.gov.ab.ca/publications/wcsb\\_atlas/atlas.html](http://www.ags.gov.ab.ca/publications/wcsb_atlas/atlas.html)>, Accessed Feb. 12, 2013.
- Newbert, J.D., Westmin Resources Ltd.; Trick, M.D. (1987). A Systematic Deliverability Analysis for the Hoadley Gas Condensate Field. Society of Petroleum Engineers 16938-MS.
- Reynolds, M., Thompson, S., Peyman, F., Hung, A., Quirk, D., and Chen, S., (2012), A Direct Comparison of Hydraulic Fracture Geometry and Well Performance Between Cemented Liner and Open Hole Packer Completed Horizontal Wells in a Tight Gas Reservoir, SPE 152185.
- Stockwell, R.G., Mansinha, L. and Lowe, R.P. (1996): Localization of the Complex Spectrum: The S Transform. *IEEE Trans. Sign. Proc.*, 44, 998-1001.
- St-Onge, A., and Eaton, D.W. (2014): A Long-period long duration microseismic event: evidence of Cardium Formation induced microseismicity? *Geoconvention 2014*.
- Zoback, M.D., Kohli, A., Das, I and McClure M. (2012): The importance of slow slip on faults during hydraulic fracturing stimulation of shale gas reservoirs. SPE 155476, 1-9