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Low-frequency tremor signals from a hydraulic fracture treatment in northeast British Columbia, Canada

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Summary

The Rolla Microseismic Experiment was undertaken August 7-28, 2011 to record a multistage hydraulic fracture stimulation of a Montney gas reservoir in northeastern British Columbia. The field deployment included a 6-level array of 4.5 Hz geophones with downhole digitization, a set of 22 portable broadband seismograph systems, and a 12-channel surface array of 10-Hz geophones. The scientific objectives of this project are to compare surface and downhole microseismic recordings in order to assess the general suitability of surface microseismic acquisition for the Montney play in northeastern BC, and to investigate low-frequency characteristics of microseismic events induced by hydraulic fracture stimulation, with particular focus on a recently discovered class of long-period long-duration (LPLD) events. By analogy with tectonic tremor, LPLD events have been interpreted as slow-slip processes along pre-existing fractures. Although we find that they are less common in the Montney than in the Barnett, results confirm the presence of some LPLD events, which are dominated by signals from 5-50 Hz. Other signals recorded during the experiment include local and regional earthquakes, persistent tremor-like signals and numerous high-frequency (> 100 Hz) microseismic events with moment magnitudes ranging from −2.3 to −1.4 to distances up to 1.2 km. In addition, perf shots were well recorded to distances of about 2 km, and were used to estimate *Q.* Noise characteristics of the surface sites were also extensively studied.

Introduction

A project to acquire microseismic data (Rolla Microseismic Experiment) was undertaken August 7-29, 2011 in northeast B.C., Canada. Multistage frac treatments at a depth of ~1950m in two horizontal wells were recorded using both surface and borehole sensors (Figure 1). The borehole toolstring was deployed in a depth range of 1670-1830 m and consisted of a 6-level array of 4.5 Hz geophones with downhole digitization, with sensitivity of 4500 V/m/s. Surface sensors included 22 broadband seismometers (Trillium Compact seismometers and Taurus digitizers) deployed in 7 mini-arrays over an area of ~ 0.5 km^2, and a 12-channel array with a mix of vertical and 3-C geophones. Acquisition parameters are summarized in Table 1. The approximate minimum recording frequencies of the equipment are: broadband seismometers, 0.0083 Hz (= 120 s); borehole sensors, 0.1 Hz; short-period surface array, 5 Hz. Taking advantage of this unusually broad range of recording frequencies, a primary objective of the experiment was detection of long-period, long-duration (LPLD) microseismicity (Das and Zoback, 2011), together with any associated ultralow frequency phenomena. By analogy with tectonic tremor, LPLD events have been interpreted as slow-slip rupture along pre-existing fracture surfaces.

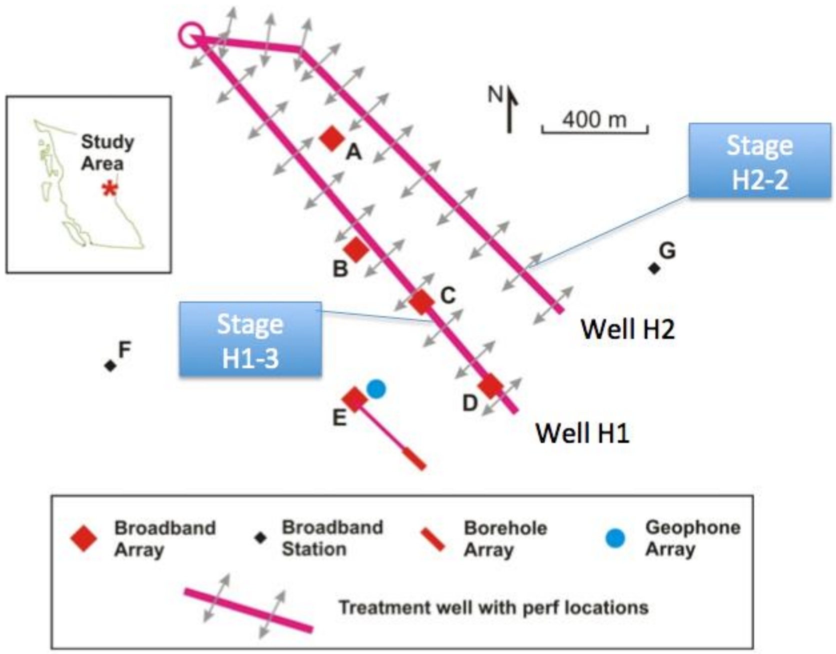

Figure 1: Location and layout for the Rolla Microseismic Experiment.

Manufacturer	Type of Sensor	Number of Sensors	Sample Rate (ms)	Start/end dates	Sensor spacing	Archival Format
Spectraseis	4.5 Hz 3C geophones	6	0.5	Aug. 15-18 and Aug. 21-25	32 m (borehole)	PSEGY
Nanometrics	Broadband seismometer (Trillium Compact)	21	2.0	~ Aug. 8 to Aug. 27	50 m (4-element surface array)	mini-SEED
ESG	10 Hz geophones (mix of Z and 3C)	8	0.5	Aug. 15-18	20 m (8-element surface array)	SEGY

Table 1: Summary of instrumentation and data acquisition parameters.

Geological Setting

Significant gas reserves are hosted by the Triassic Montney Formation in northeastern British Columbia and northwestern Alberta. Although estimates of natural gas in place are highly variable, ranging from 80 to 700 Tcf, in recent years production has increased dramatically to over 400MMcf/d (Walsh et al., 2006). The Triassic Montney Formation is an extensive siliciclastic-dominant unit that occurs from west-central Alberta to northeast British Columbia (Dixon, 2000). In the area of this study, it is overlain by the Triassic Doig Formation and underlain by the Permian Belloy Formation. The Montney contains significant reserves of gas in Alberta and British Columbia. The depositional environment ranges from shallow-water shoreface sands to offshore marine muds (NEB, 2009). The Montney consists of interbedded shale, siltstone and sandstone layers; the dominant lithology is shale and silty shale (Dixon, 2000). Thickness can range up to 300m, while porosity is very low, ranging from 1.0-6.0% (NEB, 2009).

Examples

As described by Das and Zoback (2011), LPLD events from the Barnett shale are prominent in the 20-80 Hz frequency band. These LPDL events are ~ 60s in duration and are strikingly similar in character to tectonic tremor. In the present microseismic survey from northern Canada, data from the treatment stage closest to the monitor well (~ 400m) contain numerous microseismic event detections, including low-frequency events. Time-frequency analysis using a short-time Fourier transform (STFT), however, reveals relatively few LPLD-like signals. We observed a diverse variety of other low-frequency phenomena, however, that may provide important clues about deformation processes linked to fluid injection.

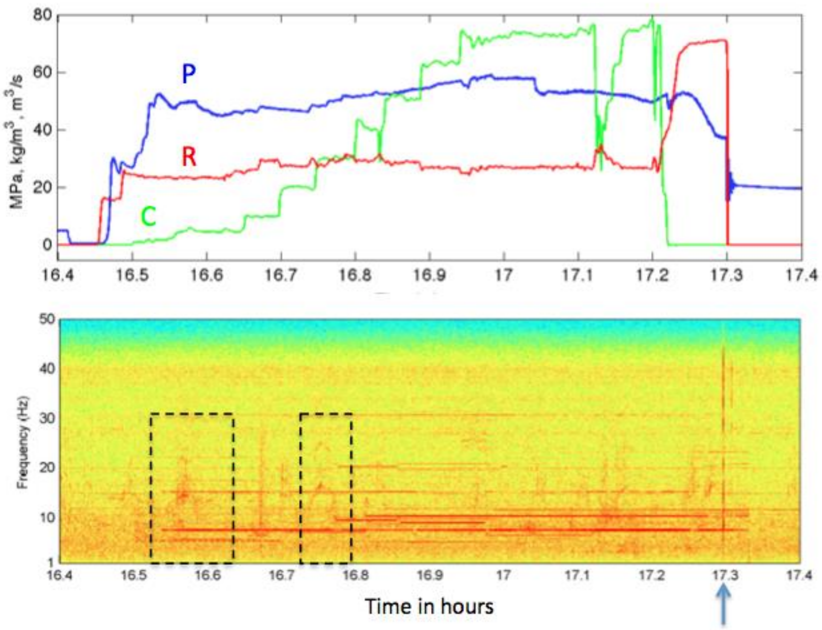

Figure 2: Treatment curves and time-frequency plot for stage H1-3. Top panel shows treatment curves; P is treatment pressure (MPa), R is slurry rate ×10 (m^3/s), C is proppant concentration ÷ 20 (kg/m^3). Lower panel shows frequency-time analysis for vertical-component recording for one receiver level, using the short-time Fourier transform. Dashed boxes show examples presented below.

Our data exhibit high-amplitude signals in the 8-10 Hz band. Although it is not clear what role pump-generated noise at the treatment location might play in modulating these signals, peak amplitudes in this band vary slightly in frequency and build gradually in amplitude over the duration of fluid injection (Figure 2). We also observe instances of narrow-band signals with a characteristic frequency of ~ 15 Hz (e.g., Figures 3-5). These signals are monotonic and have been interpreted as resonance of fluid-filled cracks or successions of small repetitive events (Tary and van der Baan, 2012). In many cases, the 15-Hz tremors appear to be precursors to high-frequency microseismic events, suggesting a possible causal link. We have also detected several instances of discrete microseismic events with unusually low frequency (Figure 6). We are currently investigating if the frequency content of these events could reflect low-velocity rupture processes associated with tensile failure (Walter and Brune, 1993).

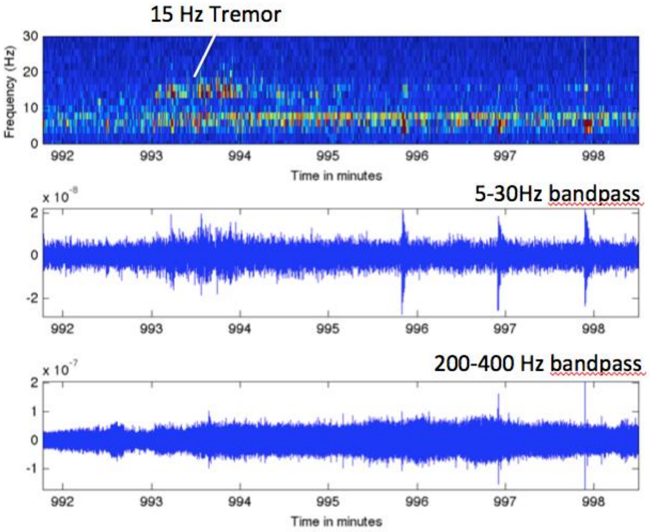

Figure 3: Example of low-frequency tremor and high-frequency microseismic events, from stage H1-3. Note increasing high-frequency content of the 3 events.

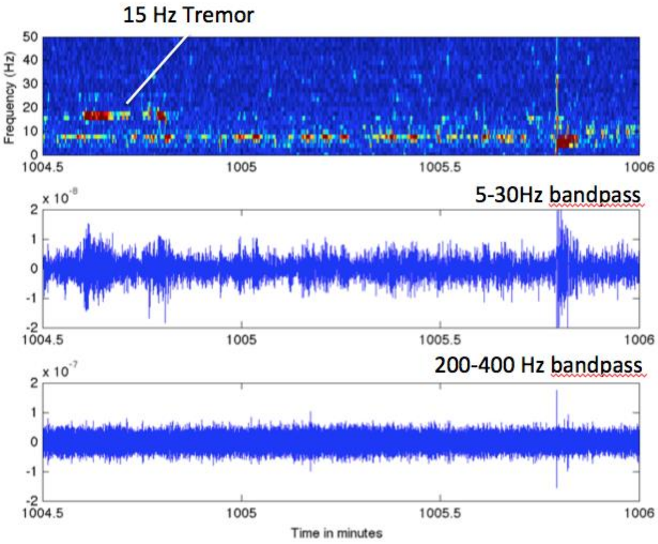

Figure 4: Example of low-frequency tremor and high-frequency microseismic events, from stage H1-3.

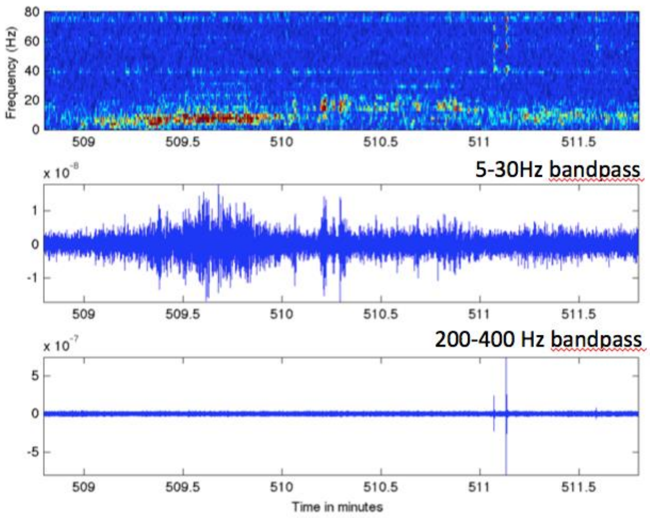

Figure 5: Example of low-frequency tremor and high-frequency microseismic events, from stage H2-2.

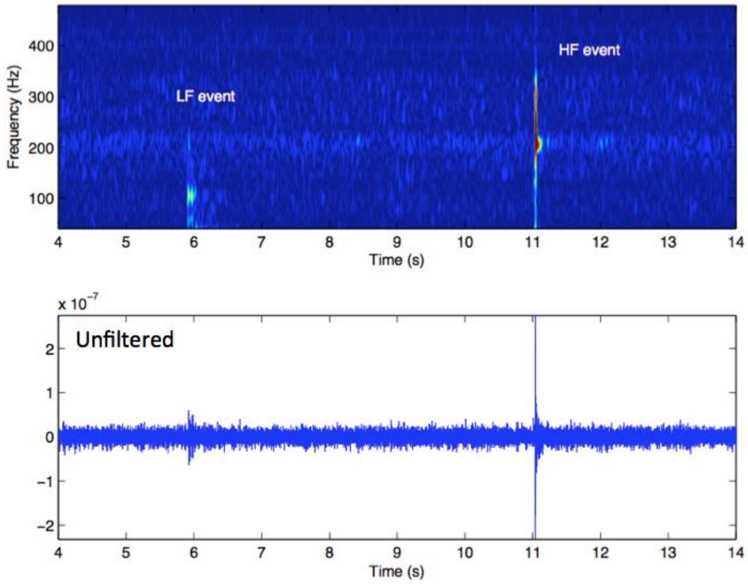

Figure 6: Example of low-frequency (LF) and high-frequency (HF) microseismic events, from stage H1-3.

Noise characteristics of the surface sites were also extensively studied. Non-coherent noise from the surface sites was used to assess installation issues such as tilt and sensor performance. Other quality-control measures included computation of time-domain alignment matrices for mini-arrays, and calculation of power spectral density (PSD) plots to compare noise signatures before, during and after treatment. For a given station, the noise characteristics were relatively time-invariant, but the noise environment varied considerably from array-to-array and station-to-station. Signals from the majority of high-frequency microseismic events, however, were found to be below the background noise levels of the surface arrays.

Conclusions

Continuous passive recordings were successfully acquired over a three-week period using three types of systems: surface geophones, borehole low-frequency geophones and broadband seismometers. The relative paucity of LPLD signals in our data differs from published examples from the Barnett Shale (Das and Zoback, 2011) where this phenomenon appears to be more common. Unlike our present study region, the Barnett shale is noted for complex fracture systems that are generated by hydraulic fracturing (McKeon, 2011). The presence of low-frequency (~ 15 Hz) tremor may be an indicator of resonance in fluid-filled cracks. An apparent tendency for these events to precede high-frequency microseismicity in our data provides a tantalizing suggestion that these processes may be genetically linked.

Acknowledgements

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