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A Long-period long duration microseismic event: evidence of Cardium Formation induced microseismicity?

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Summary

Passive seismic data recorded in a deep observation wellbore for the hydraulic fracture monitoring of a multi-stage Cardium Formation treatment are analyzed to search for long-period long-duration (LPLD) events. A previously unrecognized anomaly persists for over 20s and contains numerous low frequency events on all three geophone component orientations, with relatively consistent apparent velocities. The composite event represents the superposition of about 90 individual P- and S-wave arrivals and has characteristics similar to previously published LPLD examples. Such events observed on microseismic data may be analogous to deep low frequency tremor attributed to slow-slip processes along pre-existing fractures or strike-slip regimes at subduction zones. The identification and understanding of LPLD events is expected to contribute to the refinement of hydraulic fracturing processes.

Introduction

In recent years, there has been an increase in the number of horizontal wells drilled and hydraulically fractured to improve hydrocarbon production productivity. This process includes recent horizontal drilling in the last five years in the Pembina Cardium pool in central Alberta. This pool is the largest in Canada based upon well count; there are currently over 7400 wells in oil field. The Pembina Cardium pool contains a tight, low permeability Cretaceous-aged Cardium sandstone/shale reservoir that can be broken down into two facies (Butrenchuk et al, 1995). The lower facies is a well-rounded clast-supported conglomerate that is matrix free or has a coarse sandstone matrix. The upper facies is a well-rounded conglomerate in a mudstone matrix. In the area, porosities range from 9 to 13%, with permeabilities in the 0.1 to 10 mD range (Fic et al., 2011).

In August 2010, an operator drilled and completed a 1500 m long horizontal wellbore in the Cardium Formation and recorded a 5.5 hour microseismic dataset in an adjacent vertical wellbore. Over 1000 conventional (high-frequency) P- and S-wave arrivals were located in a contractor analysis of the data. These arrivals were used to estimate event source positions. The data also contained the recording of a 20 s anomaly recorded on all 36 channels about half-way into the hydraulic fracture treatment. The anomaly is analyzed by examining its characteristics, including frequency spectra, apparent velocity and P- and S- wave signal content. These characteristics are compared to two LPLD events presented in the literature, as well as a recorded earthquake. We also analyze the wellhead treating pressures and microseismic data interpretation. The location of an interpreted fault is considered as a potential source for the LPLD event. The fault orientation is compared to other fault orientations in the area. These orientations agree well with principal stress directions. We summarize by briefly exploring the implications of observing LPLD events.

Observations

Based on examination of the entire 5.5 hours of continuous recording, the low-frequency event shown in Figure 1 is unique in this dataset. The event has little coherent energy above 60 Hz and persists longer than any other recorded signal or noise. Moreover, the anomaly was recorded on all channels. Although the event is evident after 30 s of recording on the spectrogram, the anomaly after this time was difficult to see on the trace data. Finally, this energy was not identified in the contractor report.

Figure 2 shows the rotated but unfiltered trace data for the first 20 s of the anomaly. Although the time scale is too compressed to show detailed events, there is almost vertical time alignment observed for a number of events for each of the three component arrays. Figure 3 shows an expanded and bandpass filtered 3 s portion of Figure 2. There are a number of events that are evident on these data, especially on the vertical channels.

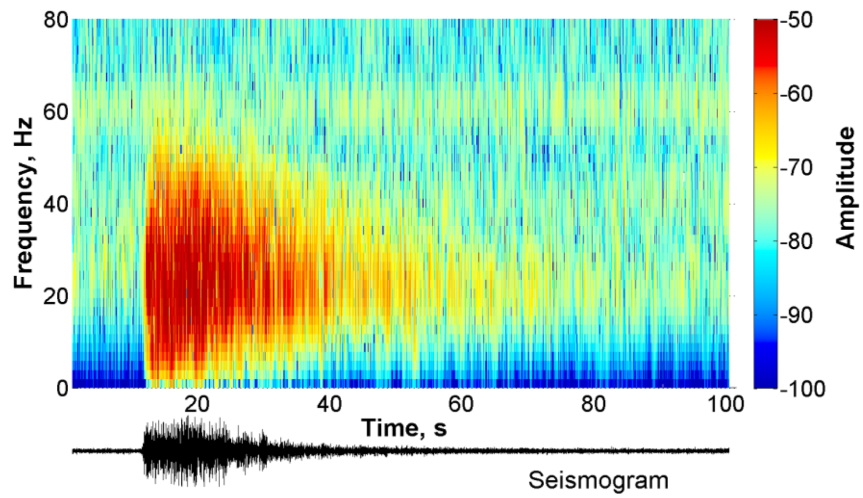

Figure 1 – A spectrogram for the 10th vertical component trace (1152 m depth) from the dataset along with the 10th vertical trace. The 60 Hz maximum signal at the onset of the event gradually decreases to about 30 Hz near the end of the event.

Discussion

The apparent velocity was calculated for 28 events on the Z-channel traces shown in Figure 2. These calculations and a velocity model were used to estimate a source position for the LPLD event coincident with the fault line shown on the bottom part of Figure 4. This figure highlights where the contractor located microseismic events for hydraulic fracture stages 4, 5 and 6. The two plan views show interpreted source locations of the detected events with respect to the horizontal well. The upper figure shows the event locations for fracture stage 4 in a green circled "cloud" centered at the stage 4 lateral location ("stage locations" on the figure), as well as a number of events ~ 200 m west.

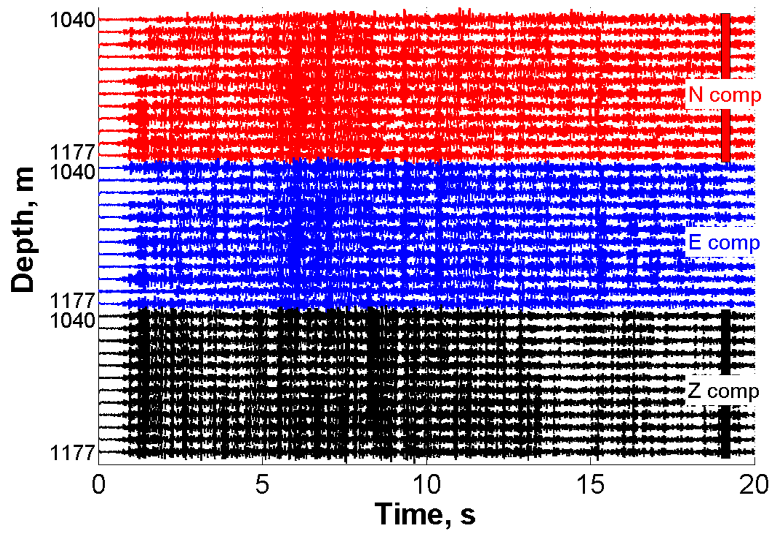

Figure 2 – A 20 s record (starting at 10 s with respect to Figure 5.5) showing an LPLD event recorded on all channels. About 90 individual events can be discerned.

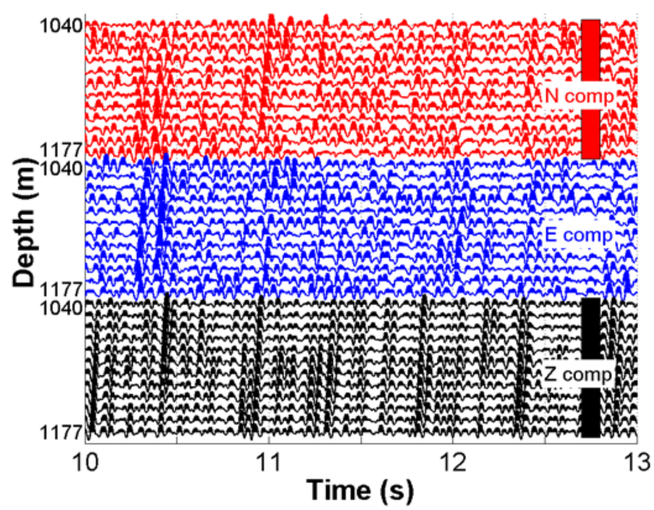

Figure 3 – A trace-normalized three second recording from Figure 5.1. The data were rotated to north and east orientations and have been bandpass filtered with a 5-100 Hz filter. The coherent energy is strongest on the Z component, except for the arrival at ~ 10.3 s.

The events for fracture stage 5 are shown in pink. Most of these events were located to the west of the stage 5 port lateral location. Moreover, most of these events overlay the westerly stage 4 events. The contractor report remarked that the observation well witnessed 'growth' (as defined by event locations propagating outward from the wellbore) in the stage 6 port location during both stage 4 and 5. Specifically, the entire stage 5 appears to have been pumped into the stage 6 area as shown on the bottom half of Figure 4, at the location of the contractor interpreted fault. Finally, the stage 6 locations shown in blue are in this same position.

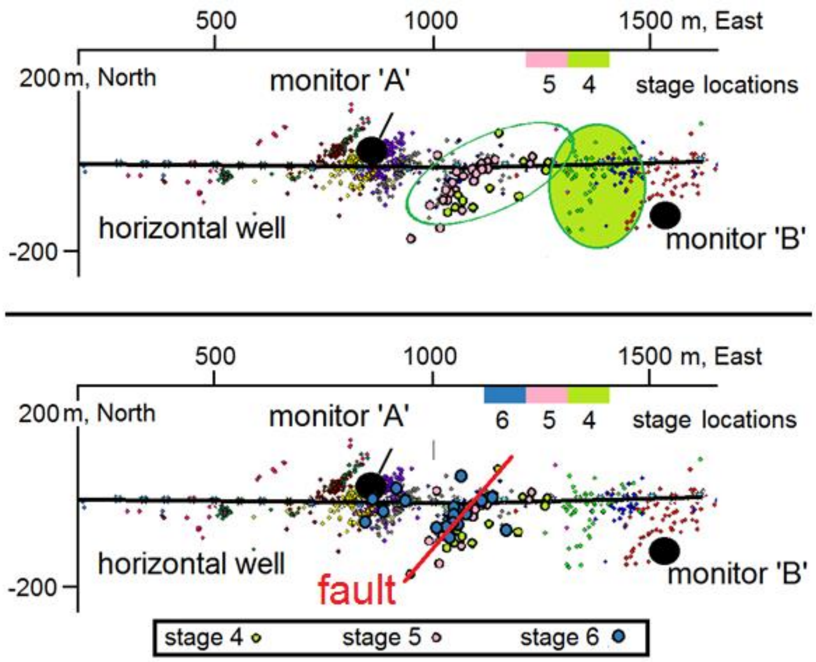

Figure 4 – A plan view of the contractor's located events detected using monitor well 'A'. Stage 4 had located events in the green shaded and open green circles (highlighted for effect only, not event magnitude). Stage 5 events were located close to most fracture stage 6 events, as shown on the bottom view. The N 45° E fault is interpreted by the contractor.

The anomaly presented here is consistent with events identified as LPLD events recorded on microseismic data as reported by Das and Zoback (2012). The anomalies have an upper frequency limit that is much lower than P-wave microseismic arrivals that gradually declines as a function of time. There are consistent apparent velocities within both datasets; each LPLD event is composed of multiple adjacent sources within a narrow range of angles. This suggests a localized source area, perhaps representative of movement on a pre-existing fracture or fault. We postulate that a single LPLD event was generated close to the hydraulic fracture stages and initiated with the "out of area" events for stages 4 and 5. The N 45° E fault strike is consistent with the principal stress in the area.

Conclusions

A long-period long duration seismic event was identified during the hydraulic stimulation of tight sandstone. The event had numerous closely spaced P- and S-wave arrivals. The interpretation of the microseismic events is consistent with a contractor mapped North 45° East striking fault at the LPLD event location. This event may have been generated by slow shear slip on a pre-existing natural fracture that had fluid injected by the hydraulic fracture. This process might be contributing significantly to the stimulation. Microseismic data should be examined for other LPLD events to aid in our understanding of the hydraulic fracturing process.

Acknowledgements

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