



Tony Creek Dual Microseismic Experiment (ToC2ME)

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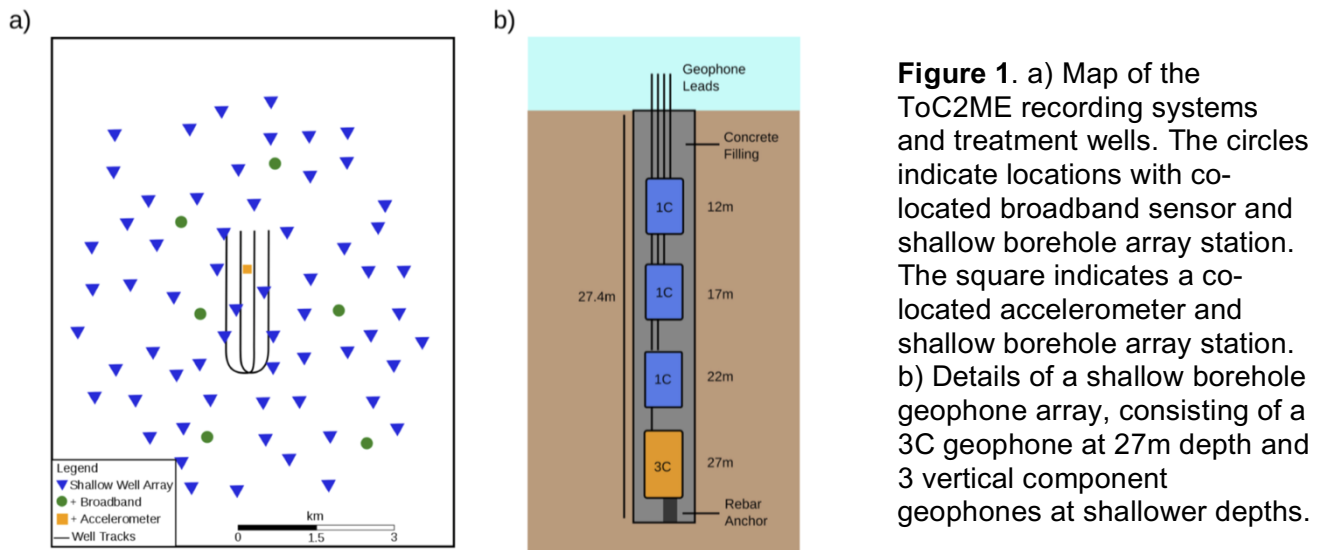
Summary

The Tony Creek Dual Microseismic Experiment (ToC2ME) is a field program that employed a diverse set of sensors to record a hydraulic-fracturing completion program at a 4-well pad west of Fox Creek, Alberta. The acquisition systems consisted of a 68-station shallow borehole array, six broadband seismometers and one strong-motion accelerometer. This paper summarizes progress in processing and analyzing this dataset, which yielded a substantial record of induced seismicity up to M_w 3.2, including over 4,000 events with well determined hypocentres. The largest events have strike-slip mechanisms and clustered above the treatment zone, along a well defined N-S lineament. Several other event clusters are more diffuse and have distinct magnitude characteristics and mechanisms. Horizons extracted from 3-D seismic data reveal several structural fabrics that are subparallel to event clusters, although the microseismic lineaments do not appear to correlate exactly with seismically imaged features. The ToC2ME dataset forms the core for an integrated suite of co-ordinated academic research projects that include construction of a regional geomodel using publicly available data, reprocessing and interpretation of co-located multicomponent 3-D seismic data, development of innovative microseismic processing methods, and geomechanical studies including laboratory analysis.

Introduction

The Tony Creek dual Microseismic Experiment (ToC2ME) is a research-focused field program acquired by the University of Calgary, in collaboration with industrial partners, between October 25, 2016 and November 29, 2016. Sensors consisted of six broadband seismometers, one accelerometer, 68 shallow borehole arrays and two surface 3-component (3C) geophones, surrounding a four-well hydraulic fracturing operation west of Fox Creek, Alberta. During the acquisition of this dataset, several sequences of induced earthquakes were recorded up to M_w 3.2. The ToC2ME microseismic and induced-seismicity dataset is complemented by available 3-D multi-component seismic data from the same area (Weir et al., 2018), as well as deep crustal seismic data, well logs and cores, providing exceptional opportunities for integrated interpretation. The objectives of the ToC2ME program are to characterize the microseismic and induced-seismicity response to hydraulic fracturing within the Kaybob-Duvernay region and to elucidate links between seismicity and structural features discernible in 3-D seismic data. The ultimate aim of this research is to develop a robust geomechanical framework and improved mitigation strategies for seismicity triggered by hydraulic fracturing.

The geometry and borehole array configuration are shown in Figure 1. The geophones had a natural frequency of 10 Hz, and continuous data were recorded using OYO GSX-3 systems with a sampling rate of 0.002 s. The broadband seismometers were Trillum Compact units provided by Nanometrics. These sensors have a flat frequency response from 20s to 100Hz, enabling the determination of the low-frequency response for larger events. A Nanometrics Titan strong-motion accelerometer was also deployed, which enabled accurate recording of ground acceleration. The acceleration records provide unclipped waveforms for larger events, which clipped on most of the other sensors. During the deployment, three hammer shots were



recorded at each station in order to determine the orientation of the geophones. The three-component traces were plotted and, through hodogram analysis, the true orientation could be determined. The microseismic data were formatted into 60-s SEG-2 files, totalling 3.5TB.

Data Processing

The first step in the data processing workflow was event detection. Several methods were used to detect events based on the borehole 3C continuous data, including methods based on energy threshold, amplitude envelope, and cross-correlation. All of the detected events were then manually reviewed to select those with a high signal-to-noise ratio (SNR). In order to verify event detections, each potential event was visually inspected and assigned to a category (i.e. event vs. noise) depending upon the interpreted likelihood to be an event, SNR and the accuracy of automatic time picks. Figure 2 shows the number of events detected per day throughout the program. Although there was a large number of events on November 3 and 5, no event exceeded magnitude 2.0 until November 10. Prior to this, the magnitude distribution contained abundant of events below magnitude 1.0, with periods of repetition of similar magnitudes. After November 10, distinct events sequences occurred. There was a period of quiescence starting November 16th due to a pause in hydraulic fracturing operations. Seismic activity resumed when operations restarted.

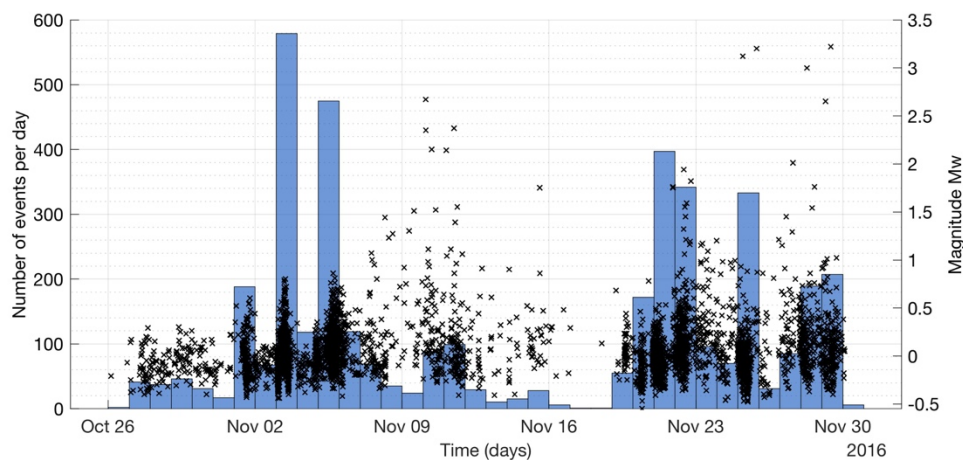


Figure 2. Time sequence showing the number of detected events per day (blue bars). Locations and magnitudes were obtained for a subset of these events, as indicated by the x symbols.

Of the detected events, 15 were used as template (parent) events for processing using a matched-filtering algorithm (Caffagni et al., 2016). These templates were used to detect child events based on waveform similarity. The detected event families were then used to obtain the relative location of the child events with respect to the parent using an energy stacking approach with iterative refinement. This method is akin to the double-difference method, in that the relative locations are precise, but the absolute locations depend on the event used to anchor the locations.

Interpretation

Figure 3 shows located events in map view. In part (a), symbols are colour-coded according to event time, with colder shades (blue) indicating events that occurred earlier in the treatment program, progressing to hotter shades for later events. There are several clusters that can be identified. The first cluster forms an approximately 1.5 km long N-S lineament to the west of the wells. This cluster was activated in two time intervals, first during the completion of the initial well (the second from the west) well and again during the completion of the westernmost well. This cluster experienced persistent induced seismicity, hosting four of the largest events. A representative focal mechanism along this lineament shows a strike-slip mechanism with a N-S nodal plane. A second cluster is located near the centre of the program, and is characterized by lineaments at an orientation of N30E. This orientation differs from the expected N45E orientation along SHmax for typical operationally induced microseismicity. There was no event over magnitude 1.0 in cluster 2, and they were re-activated twice, much like cluster 1. A third cluster is located about 400 m the east of well A, and experienced four $M_W > 2.0$ events within the same day. Additionally, a representative focal mechanism has a different character than the pure strike-slip mechanism along cluster 1, with a component of oblique slip on a non-vertical fault. Another cluster is located north of the toe of well B, and was the first to be activated. 3-D seismic data (Figure 3b) reveals structural fabrics that are somewhat aligned with the observed microseismicity.

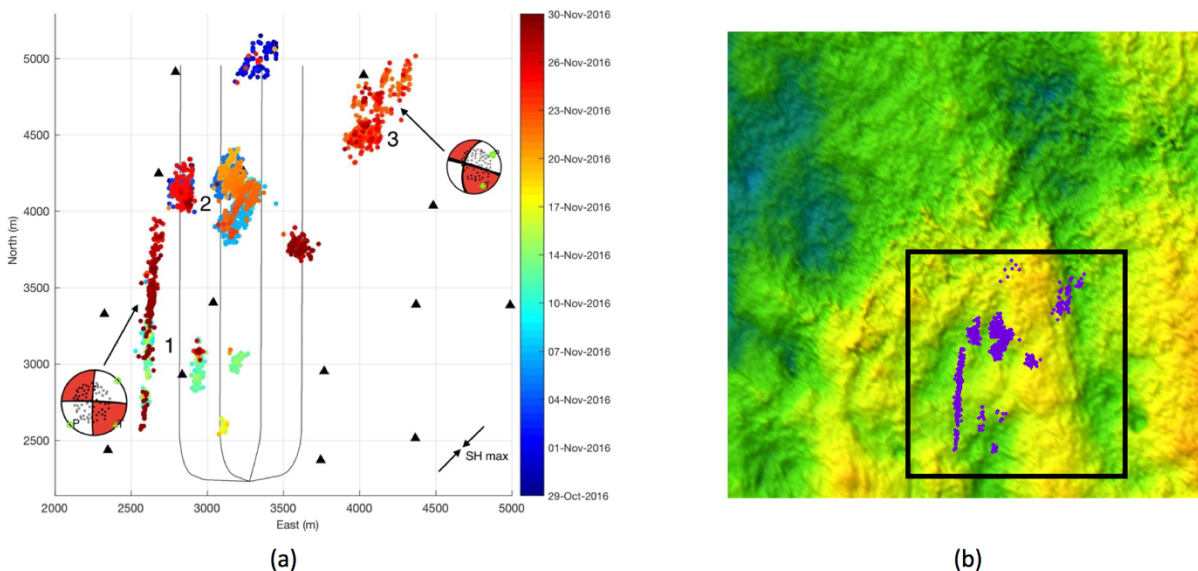


Figure 3. (a) Map view of > 4,000 well located events, colour-coded in time, showing relative location of the hydraulic fracturing wells. Significant event clusters are labelled, and the direction of SHmax is shown with the black arrows. The two representative focal mechanisms shown were obtained based on the P-wave first motion. (b) Microseismic events overlaid on a time-structure display of the Swan Hills horizon, which underlies the Duvernay shale, extracted from 3-D seismic data. Box shows the extent of part (a). Low areas are plotted in blue-green, while high areas are plotted in yellow-orange. N-S and NE-SW structural fabrics are evident that appear to be parallel with the microseismic lineaments.

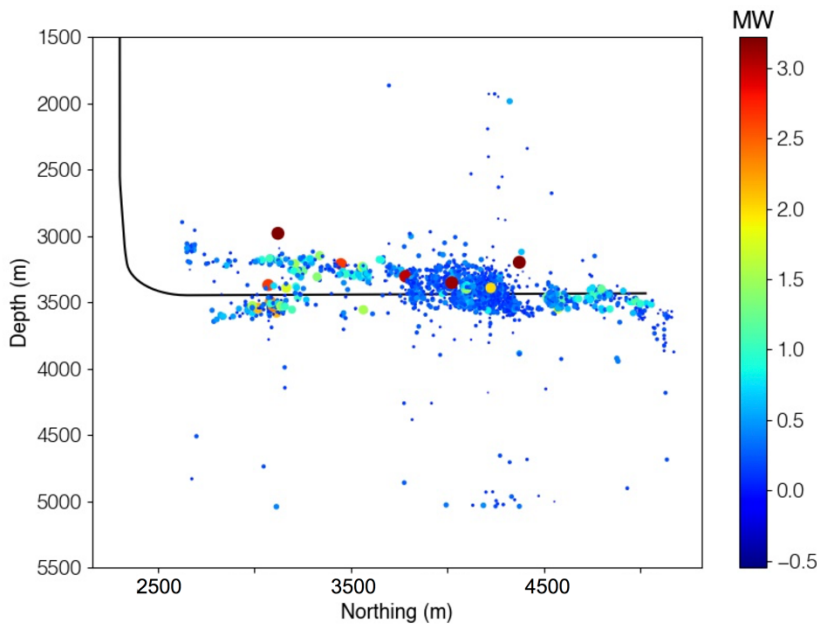


Figure 4. North-south cross section showing event hypocentres in depth in relation to the injection wells. Symbols are coloured and scaled by magnitude. Events from cluster 1 are primarily located above the Duvernay, marked by the depth of the lateral segments of the treatment wells. Total lateral length of the treatment wells was ~2.5km.

The inferred depth distribution of events is shown in Figure 4. The majority of events occurred above the treatment well. Cluster 2 is represented by a dense cluster of blue dots at a northing of 2700-4400 m in Figure 4. Cluster 1, appears as a gently dipping linear feature within the Ireton shale, above the Duvernay. Finally, cluster 4, at the toe of the well, appears to outline a vertical structure that is illuminated by very small events.

Conclusions

This report describes processing and initial interpretation of continuous data from the Tony Creek Dual Microseismic Experiment (ToC2ME) during Fall 2016. The ToC2ME dataset, along with a co-located multicomponent 3-C seismic survey, represents the core for a suite of co-ordinated academic research programs. Induced seismicity event clusters discussed in this paper include: 1) a set of events with higher magnitude, defining north-south trending lineaments in the southwest part of the program; 2) a dense cluster of microseismicity in the central part of the program; 3) a cluster located east of the program, at an offset > 500 m from the nearest well (well A); 4) a cluster at the toe of well B, at the north end of the program. Clusters 2-4 exhibit a general trend of about N30E, which is about 15 degrees from the expected orientation of SHmin in this area. Event focal depths for all of these clusters is dominantly at or above the Duvernay zone.

Acknowledgements

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References

Caffagni, E., Eaton, D.W., Jones, J.P., and Van der Baan, M. 2016. Detection and analysis of microseismic events using a Matched Filtering Algorithm (MFA). *Geophysical Journal International*, **206**(1), 644–658.

Weir, R., Eaton, D.W., Lines, L., Lawton, D., and Ekpo, E., 2018. Inversion and interpretation of seismic-derived rock properties in the Duvernay play. *Interpretation*. In press.