

Can continuously recorded seismic data be improved with signal processing? The application of deconvolution to microseismic data.

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Summary

Passive seismic recording is increasingly being used to record seismic events associated with hydraulic fracture stimulation. The recorded amplitudes of these induced seismic events are relatively small and may be undetectable given the noisy environment in which they are recorded. Here we describe a method using reflection seismic processing techniques applied to continuously recorded passive (microseismic) data. Signal processing has been used for many years in reflection seismic processing to enhance signal quality. Algorithms such as deconvolution, scaling, and various types of filtering have been routinely applied to raw recorded data to enhance the processing and interpretability of the recorded data. In this study we apply a combination of the more commonly used algorithms used in reflection data processing to continuously recorded microseismic data and demonstrate how signal quality can be improved.

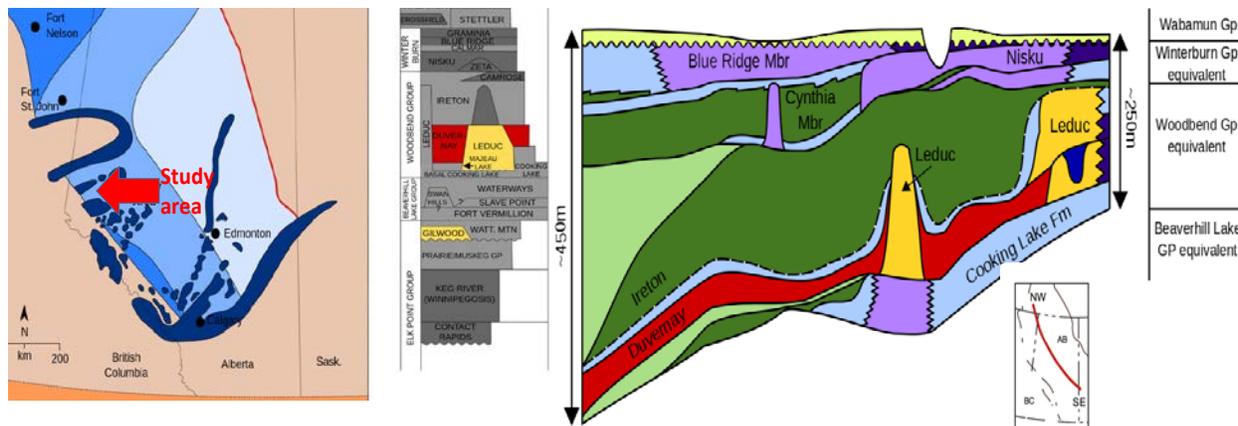


Figure 1.: Map of the study area showing reef outlines, and the Duvernay Formation distribution. The microseismic data used in this study is from the Taylor Creek dual Microseismic Experiment, TOC2ME, near Fox Creek, Alberta. The treatment zone is the Devonian age Duvernay Formation at an approximate depth of 3200 meters.

Introduction

Continuous seismic data (microseismic recording) is obtained by using very long seismic recording times, thereby capturing passive seismic events occurring at times during and after well treatments. Seismic events are identified, and calculations are made to determine the location

(epicenter), depth (hypocenter), and type of event (strike-slip, normal, reverse, explosive), based on moment tensor inversion (Eaton, 2018)

The wave path for an induced seismic event is equivalent to one half of the two-way path for a reflection seismic event, originating from the same formation, as illustrated in Figure 2.

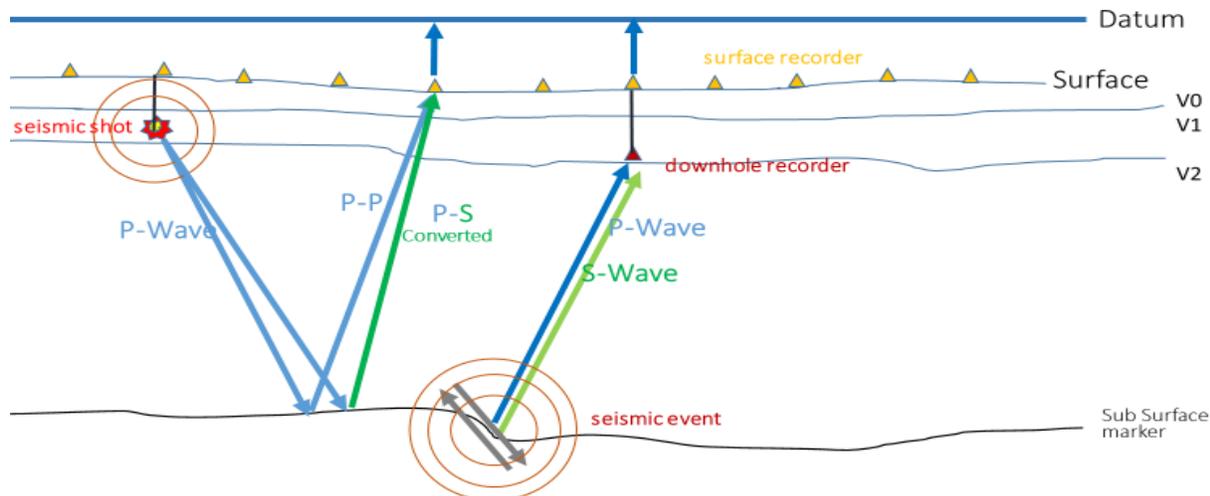


Figure 2. An illustration of the passive and active seismic sources. The passive seismic event can be thought of as the one-way equivalent of a reflected seismic event coming from the same depth. Attenuation effects will be similar in that the seismic signal travels through the same media on its way to the geophone recording array.

Noise considerations for both reflection seismic data and passive data recording are similar, as are dispersion effects. There is 60 cycle interference from overhead power lines, noise from producing wells, pipelines, vehicle traffic, and drilling activities. In both cases the objective is to improve the signal to noise ratio within the usable bandwidth of the seismic data.

Discussion

A passive seismic event, whether an earthquake (magnitude 4 or greater) or an event resulting from hydraulic fracturing (magnitude <4) share certain characteristics, a P wave followed by an S wave. A multi component reflection survey seismic records both PP and PS arrivals as well. The recorded reflection data contains seismic events, multiples, and coherent and random noise. The amplitude spectra of the raw seismic record are typically skewed to the lower frequencies due to attenuation. The dispersive nature of the earth may cause the higher frequencies to attenuate more quickly in the subsurface.

Higher frequencies within the usable bandwidth of the data can be recovered using deconvolution to enhance the high frequency content. (Margrave, 2005, Robinson et al. 1980). The deconvolved data is subsequently filtered to limit the high frequency noise. For this data used here, the maximum usable frequency was determined to be 65 Hz. A subsequent zero phase deconvolution operator was applied as illustrated in figure 3. to shift the frequencies to zero phase

For direct (microseismic) arrivals, the following equations apply:

$$T_p(t) = W_p(t) * G(t) * I(t) + N(t) \text{ for P arrivals} \quad (1)$$

$$T_s(t) = W_s(t) * G(t) * I(t) + N(t) \text{ for S arrivals} \quad (2)$$

Where $T_p(t)$ is the p wave time direct arrival, $T_s(t)$ is the direct shear wave arrival, and $N(t)$ is noise, all as a function of time. $G(t)$ is a Green's function describing the subsurface impedance, and $I(t)$ is the instrument response

In a seismic reflection survey, the following equations apply:

$$T_{pp}(t) = W_p(t) * R_p(t) * I(t) + N(t) \text{ for P-P reflections} \quad (3)$$

$$T_{ps}(t) = W_{ps}(t) * R_{ps}(t) * I(t) + N(t) \text{ for P-S (converted) reflections} \quad (4)$$

Where $R(t)$ is the reflectivity series, $W(t)$ is the source wavelet, $I(t)$ is the instrument response, and $N(t)$ is noise, all as a function of time, and $*$ is the convolution operator.

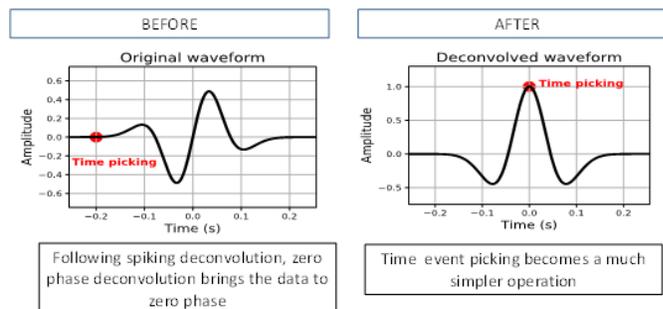


Figure 3. A schematic diagram of the effect of zero phase deconvolution, and how seismic events are commonly identified. The onset of a seismic event on raw data is correlated as the seismic event; the deconvolution processes used here shifts the phase spectrum to zero phase, such that the event is picked on the maximum amplitude. Note the location of the seismic picks, denoted by the red circles, before and after processing.

For both reflection and induced seismic data, the source wavelets, $W_p(t)$ and $W_s(t)$, are assumed to be mixed phase, and subject to dispersion through the medium the wave passes through. Deconvolution recovers the high frequency lost due to dispersion (Leinbach, 1995), and subsequently converts the data to zero phase, as shown in figure 3.

Perforation shots can be difficult to detect on unprocessed data (Einspigel 2013). Figure 4. shows the result of deconvolution on a recorded perforation shot. The perforations shot is visible on the processed record on the vertical H, and horizontal channels H1 and H2. and filtering. Figure 5 shows the spectral display of a same data

Conclusions

Given the examples shown here, reflection seismic data processing has useful applications in the conditioning of continuously recorded seismic data for microseismic monitoring. Processes such as deconvolution, filtering and scaling can enhance the signal to noise ratio and improve the identification of induced seismic events.

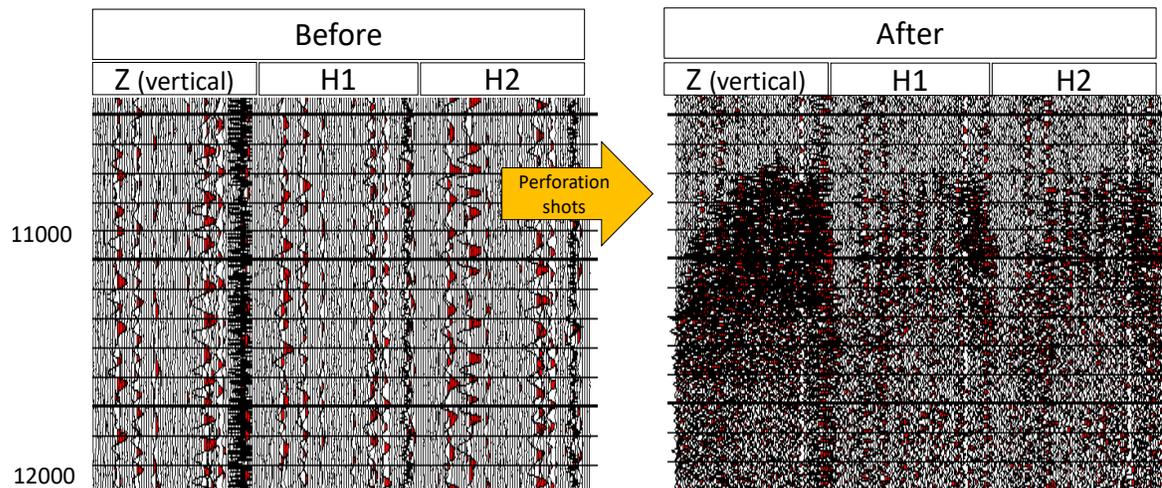


Figure 4. A recorded perforation shot, before and after deconvolution. Perforation shots are visible on the processed record.

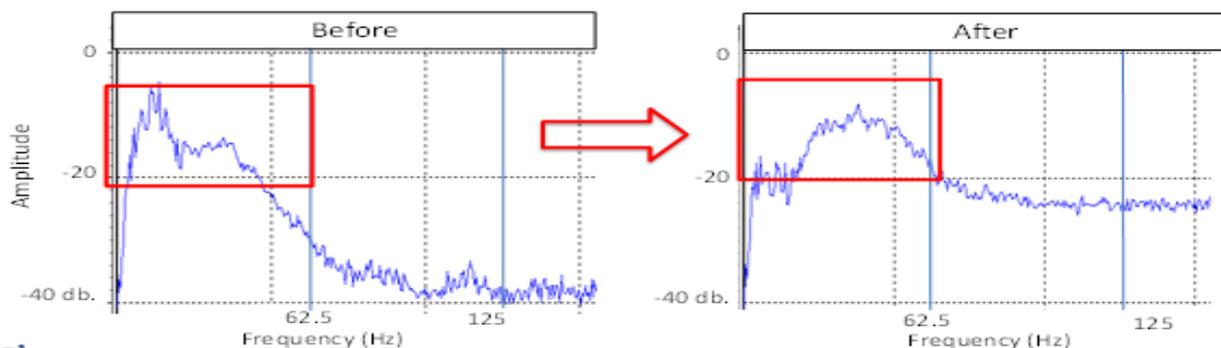


Figure 5. A spectral analysis of the 60 second record from FIG. 4, before (a) and (b) after deconvolution. The effect of the spiking (Weiner) deconvolution is to balance the frequency spectra (Margrave, 2005).

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References

Eaton, D. (2018) *Passive seismic monitoring of induced seismicity, Fundamental Principles and Application to Energy Technologies*. Cambridge University Press.

Einspigel, David and Leo Eisner (2013). The differences in the detectability of perforation shoats and microseismic events in the surface monitoring. The attenuation effect. *Acta Geodyn. Geomater.*, Vol. 11, No. 2 (174), 159–164, 2014

Robinson, Enders A., Sven Treitel. (1980) *Geophysical signal analysis*, Prentice-Hall Inc, Englewood Cliffs, N.J.

Leinbach, Jim (1995). Wiener spiking deconvolution and minimum-phase wavelets: A tutorial. *The Leading Edge*, 14(3), 189-192. fore and after.

Margrave, G. F., (2005). *Methods of seismic Data Processing Geophysics 557/657 Course Lecture Notes*. The CREWES project, Department of Geology and Geophysics, The University of Calgary.