Noise and its Effect on Microseismic Event Locations

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Summary

Noise can be considered anything that interferes with the desired signal. It is generally divided into coherent and incoherent noise. Incoherent noise is random noise that is locally generated and caused by phenomena such as fluid or gas flow through faults, open fractures, and in some cases the wellbore in which the geophones are placed. Due to the random nature of incoherent noise, each geophone experiences a different set of noise signals which can be reduced by stacking geophones and/or increasing the array size and/or length. Coherent noise is typically repeated on several traces of a seismogram and can be caused by multiple reflectors or refractions, processes induced through the electronics, and often surface noise resulting from power lines, pump jacks, generators or vehicles driving or constantly running at surface. Coherent noise, since more organized in its behavior, can be reduced by applying frequency-specific filters. To study the effects of noise on microseismic event locations, a dataset was used in which both coherent and incoherent noise was observed. Frequency-specific filters were applied to a degree which reduced noise but avoided distorting the signal of interest. Excessively aggressive filtering can result in an erroneous interpretation of the waveform. A comparison was made between event locations computed using unfiltered and filtered data. Additionally, a series of random and coherent noise signals were added to the unfiltered seismic signals and the microseismic events were relocated. The effect of noise on event-location accuracy was observed and evaluated. Understanding the effect of noise and the treatment of noise on event-location accuracy is important as noise-related positioning errors can affect the final microseismic interpretation.

Introduction

In our study the microseismic waveforms, created by well-treatment fracturing, are the desired seismic signals. We consider all other signals as noise. Microseisms are desirable signals as they may be mapped in 3-D space, and the distribution and microseismic properties allow us to infer the geometry of induced fractures.

Microseismic noise can be divided into coherent and incoherent noise. Incoherent noise is unpredictable in time and space. Typically incoherent noise is associated with the movement of subsurface fluid or gas, fluid or gas flow travelling within a borehole and random noise from electronics. Coherent noise can be coherent in time (e.g. a pump that emits a regular pulse train, resonances in geophone clamping, AC power-line hum, clock-related noise in electronics). This study shall concern itself with incoherent noise and will demonstrate the effects of noise on microseismic event locations by adding random noise and using frequency filters.

Theory and/or Method

A hydraulic fracture-mapping dataset was used to study the effects of various random noise levels on the microseismic event locations. We also investigate the effects of frequency filtering on the overall accuracy of the event locations. Background noise from a fracture-mapping project was analyzed. We found that the noise was approximately modeled by low-pass filtering a white random signal using a second-order Butterworth filter (-12dB/octave with a corner frequency of 400 Hz).

The original field data was arrival-time picked and analyzed, providing a reference map for all further experiments. The control results are in Figure 1 (right panel). We see a distribution of microseisms indicating a largely-planar fracture with multiple initiation points given the perforation clusters.

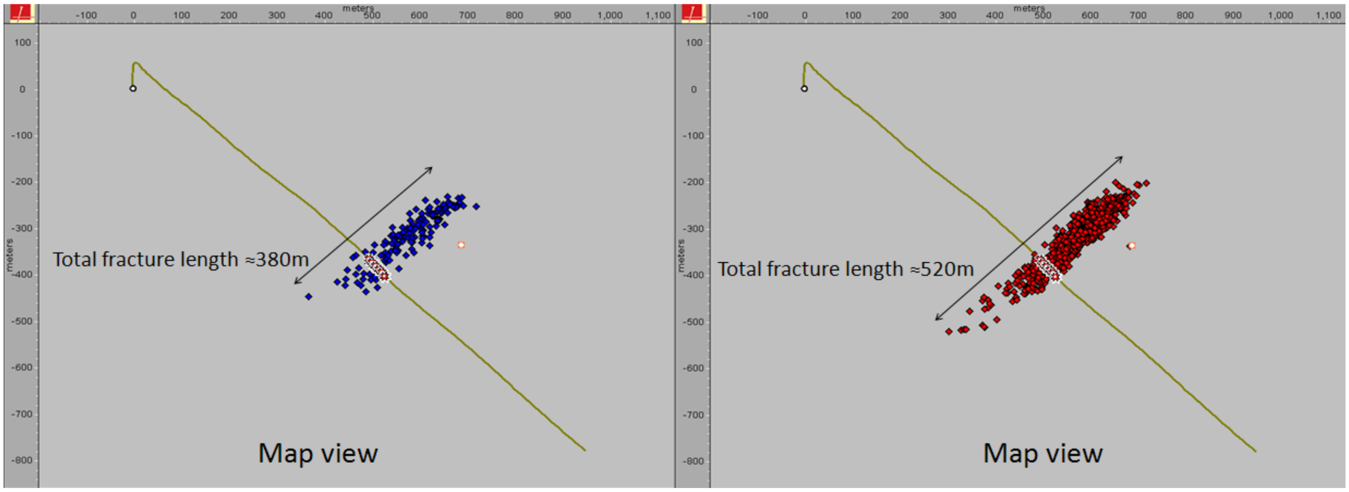
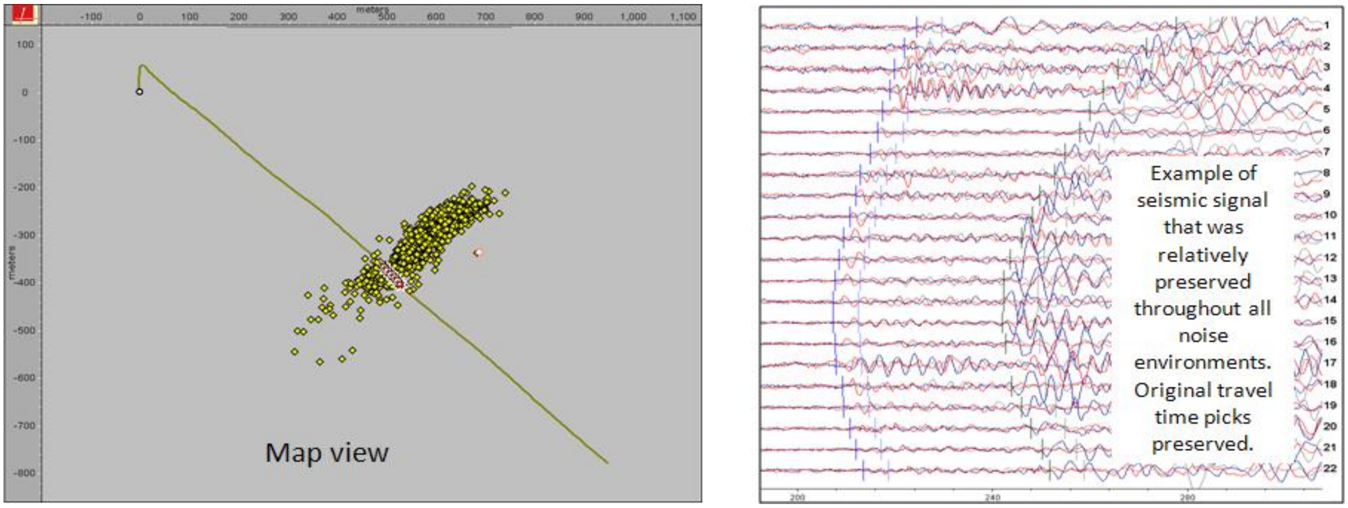


Figure 1: Comparison between microseismic map in a high noise environment (left panel) and low noise environment (right panel) after arrival time picks were quality controlled..

Next we add various amounts of noise to the raw data and re-pick and re-locate the microseisms. Figure 1 shows the result of microseismic events processed in a high noise environment (left panel) compared to the control results (right panel). The original dataset had very low noise levels (≈6nm/s) so we can consider the raw data as almost purely “signal”. When working with noisy data, we typically employ various frequency-selective pre-processing filters prior to picking and locating events. We will also see what (if any) effect pre-pick filtering the data might have on event locations and our final interpretation.

Background Noise

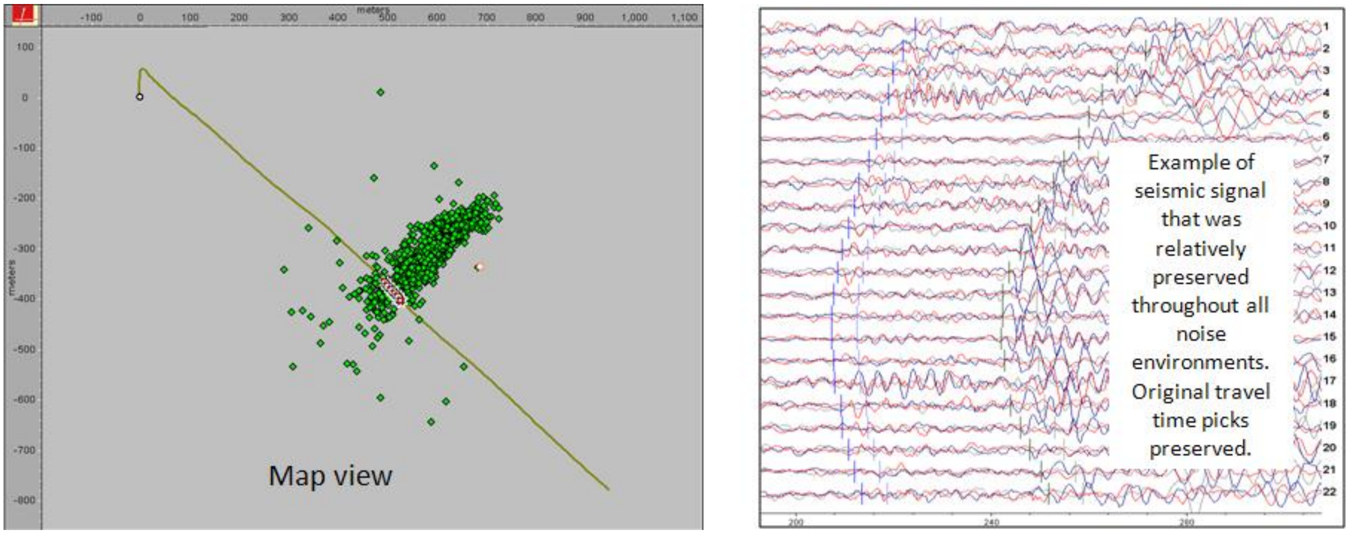
Figure 2 shows the microseismic mapped results (left panel) after introducing a noise level of 10nV and a waveform example (right panel) of a microseismic event. The average signal-to-noise (SNR) is 2; this is slightly lower than the original event which had an SNR of about 3. The overall fracture interpretation would not change from the original results in Figure 1 (right panel).



Example of seismic signal that was relatively preserved throughout all noise environments. Original travel time picks preserved.

Figure 2: Microseismic mapping results based on a low noise environment (left panel) and waveform example (right panel) with original travel time picks preserved.

Figure 3 shows the microseismic mapped results based on an average noise environment (~25nm/s). Far-field events could suggest a more complex fracture network with multiple fracture planes. The original P- and S-wave arrival time picks are preserved, but the identification of the P-wave arrival is hindered by the increase in background noise. The average SNR was reduced to 1.5.



Example of seismic signal that was relatively preserved throughout all noise environments. Original travel time picks preserved.

Figure 3: Microseismic mapping results based on an average noise environment (left panel) and waveform example (right panel) with original travel time picks preserved.

The results, based on a high noise environment (≈50nm/s), were also examined. The P-wave arrival became almost indiscernible, but some P-wave energy was still detectable. The SNR dropped to about 1.2. Since data quality is extremely compromised in a high noise environment, filters can often be applied in order to discriminate against certain frequencies relative to others according to Telford et.al.

Filtering

The amplitude spectrum of this particular data set is largely between 50 Hz and 500 Hz (Figure 4). A band-pass and low-pass filter was applied in order to preserve the frequencies of interest and make the P- and S- phases more recognizable. The arrival time of the P- and S-waves are also displayed in Figure 4 to show the signal of interest.

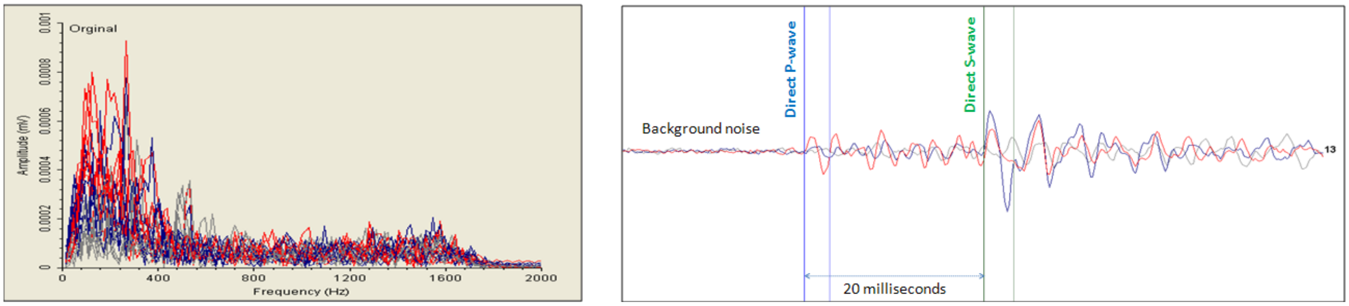


Figure 4: Amplitude spectrum of a sample event (left panel) and waveform of sample event from one sensor (right panel)

Figure 5 shows microseismic maps for the same stage, but with varying strengths of low-pass filtering applied. With each consecutive increase in filter strength, the microseismic map becomes spread-out appearing more complex in nature (Figure 5). Although frequency filters help enhance the microseismic signal, applying too aggressive of a filter can cause a misidentification of the P- and S-arrivals and phase, thus causing the microseismic events to display a more complex appearance. A band pass filter was also applied and found to have a similar effect.

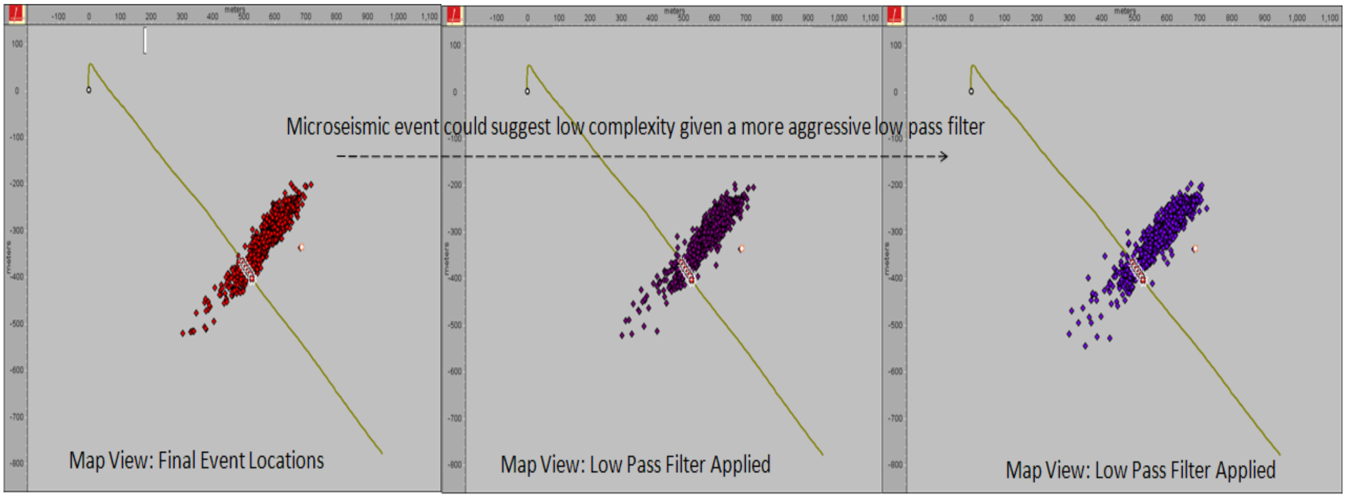


Figure 5: Original event locations (left), applying a conservative low pass filter (centre), and application of an "aggressive" low pass filter (right).

Conclusions

1) High noise levels conceal low energy events causing a bias in the number of events that actually get mapped, thus underestimating the fracture dimensions.
2) High noise levels can cause incorrect identification of arrival times, causing an inaccurate interpretation of the fracture results. Planar fracture might be incorrectly interpreted as being more complex than they are.
3) Frequency-specific filters can alter the seismic waveform enough to cause slight changes in the overall microseismic event locations and can cause an incorrect engineering interpretation.

Acknowledgements

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References

Telfor, W.M., Geldart, L.P. and Sheriff, R.E.,1990, Applied Geophysics – 2nd ed. Cambridge University Press.