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# Geophysical Time Series Data from a Stressed Environment

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## Summary

As a proxy for stress in mines, passive monitoring from microseismics and active monitoring from controlled source resistivity survey may be utilized to better understand stress state changes. Repeated measurements over a continuous period of time are necessary to study any variations in the subsurface structure due to mining processes and natural events. The controlled source time-lapse surveys must be repeatable for meaningful studies such that any changes in the data are related to the earth's response. This paper presents in-mine geophysical data from passive microseismics and active borehole-to-borehole resistivity surveys which show promising characteristics for stress monitoring.

## Introduction

Geophysical surveys aim to detect anomalous regions in the earth based on physical rock properties. To extend from detection to monitoring, continuous repeated measurements are necessary over a long period of time. If a controlled source is stable, the convolution problem is simplified such that any variation in the geophysical data is an effect of the earth's response. Repeated measurements are important for in-mine use to provide a better insight of stress and strain changes due to microseismic events and mining processes. The development, built-up and redistribution of stress may lead to rock failures and disastrous consequences. In this paper, broadband microseismic data and DC/IP data will be presented to show the potential usage of geophysical data to monitor stress changes. The goal of this research is to capture a wide range of "events" from broadband microseismic data. In addition, we report a high repeatability index for time-lapse measurements, which can be achieved by controlled source borehole-to-borehole resistivity surveys.

## Method

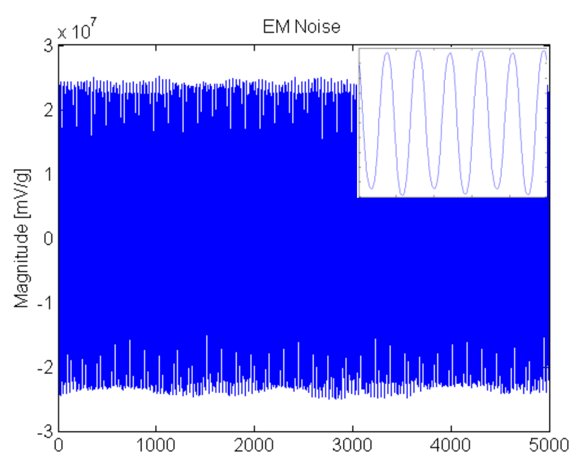
### *Passive Monitoring: Microseismics*

Microseismics has been widely used in geothermal, hydrocarbon and mining applications. For example, stress changes in the formation affect its porosity. It is expected that an increase in stress will lead to changes in P-wave velocity. Moreover, stress-induced fractures will affect seismic wave propagation. The fractures in general reduces the stiffness of the rock matrix, thus a decrease in seismic wave velocities is expected. Seismic data is also sensitive to anisotropy effects due to different orientations of cracks in the rock (Berryman, 2007). In addition, the response of the wave is strongly dependent on the fluids that exist in the gaps of the structure. Microseismic data thus contain the necessary information to study subsurface formations and their variations. This is a standard technique for stress monitoring in deep mines.

In this study, continuous broadband measurements are recorded to "listen" to any events in the mine site (blasts, fractures, noise from mining, etc.) (Lynch, 2010). Microseismics is commonly used in lab, field and mine scale experiments. Conventional microseismic sensors for exploration mainly capture high frequency signals for event detection. The data is compressed by extracting distinct P-wave and S-wave event information. The rest of the data is usually discarded for analysis. For monitoring purposes, however, it is important to have broadband recordings such that any tremor behaviour may be extracted to further understand any activities with long wavelengths.

Broadband triaxial accelerometers are employed in this survey to capture events at a wide range of frequencies (0.1Hz to 8kHz). Three types of recordings are observed: EM noise (Figure 1a), random background noise (Figure 1b) and microseismic data with events captured (Figure 2). The data can be decomposed into its high and low frequency component. Signals in the 10-30Hz range provide information on events that happen at a wavelength of a few hundred meters; likewise, signals in the kHz range correspond to activities at a wavelength of a few meters. The drawback of broadband data is its volume. To store a full day of recordings of ten 3C sensors with a sampling interval of 100µs, a storage space of 100GB will be needed. It is thus crucial to compress the data but at the same time retain the necessary information for analysis.

Figure 3a shows microseismic data that provides evidence for a distinct event. A zoom-in at the event in Figure 3b displays clear first-break. Besides the strong signal from the event, low frequency tremors, which contain a dominant frequency of about 28Hz, are observed from the power spectrum (Figure 3c). The magnitude is small, however, over a long period of time the total energy is comparable with a sudden burst of energy from the microseismicity. The ratio of energy in its low frequency component to that in high frequency is about 1.6 for the given window in Figure 3a. It has been proposed that tremors may be associated with changes in stress states from slip events (Kao et al., 2005). In global seismology, non-volcanic tremors show dramatic difference in waveform and source spectra which suggests distinct physical processes for tremors versus local seismic events (Kao et al., 2005). Further studies is required to investigate this tremor behaviour, which may be related to stress propagation in the mine.

a)


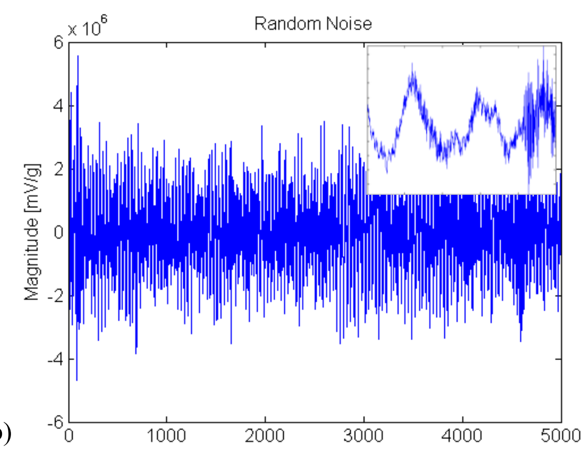

b)



Figure 1: (a) EM noise at 60Hz picked up by a sensor. (b) Random background noise picked up by a sensor. Both insets show a zoom-in window of 0 to100ms.

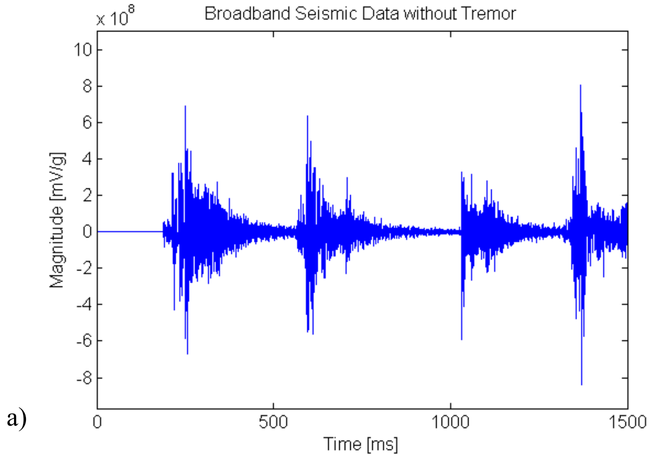
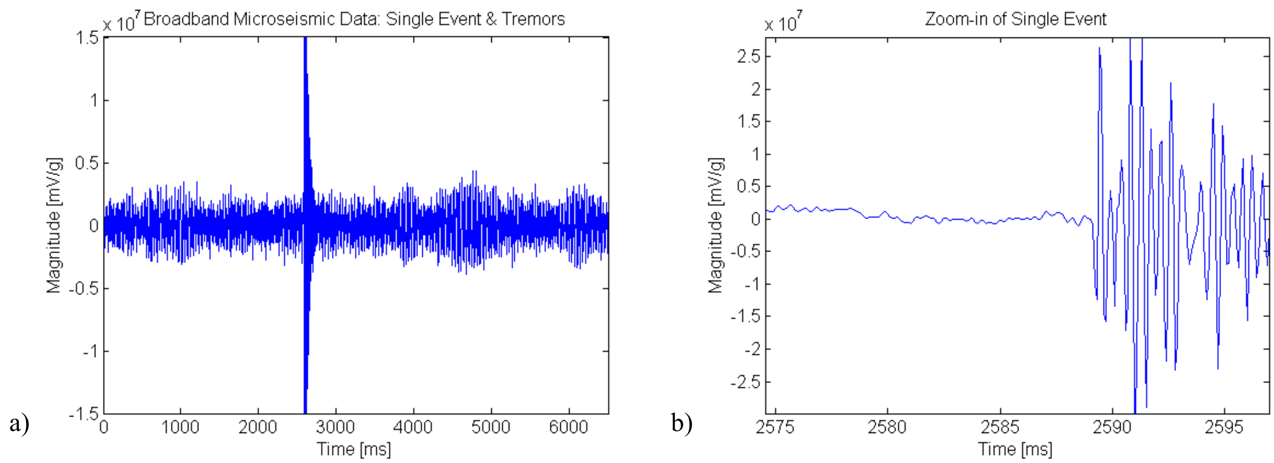



Figure 2: (a) Broadband seismic data without tremor. Multiple events are captured in this recording. The SNR is high, indicated by the quiet period at the beginning of the time series. The frequency content ranges from DC to around 2kHz. (b) Zoom-in view of (a). This is an example of classical P- and S-wave arrival with clear first-break.



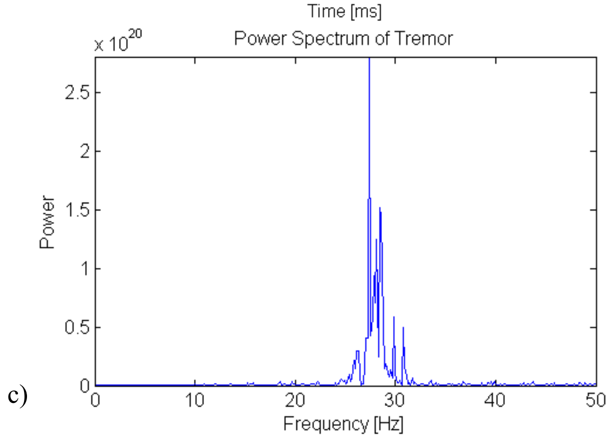
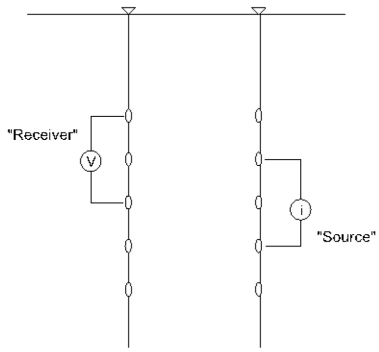




Figure 3: (a) An example of a single event with tremors recorded. Red asterisk marks the event time extracted from the archive of the database. (b) Zoom-in view of (a). Clear first-break is observed. (c) Power spectrum of (a). Tremor exhibits strong signal at about 28Hz.

### *Active Monitoring: Controlled Source Cross-hole DC/IP*

Since it is difficult to deploy repeatable broadband seismic source (DC to kHz) for continuous monitoring, controlled source DC/IP surveys are employed for active monitoring. Fluid that exists in rock fractures increases the conductivity of the resistive matrix. Any changes in stress and strain will have a direct impact on the pore size of the formation, thus disturbing the fluid that is contained in the pore space. Thus resistivity measurements may be indicative of stress state variations over time.




When current is injected into the formation, voltage is induced. Once the source is switched off, the potential will decay as a function of time. Resistivity can be calculated depending on the obtained measurements of voltage, current, and acquisition geometry. The decay of potential depends on the composition and physical properties of the material present in the formation. Cross-hole DC/IP surveys provide resistivity information of the subsurface structure. This provides information between the two boreholes (Qian et al., 2007). In this DC/IP survey, both current and voltage electrodes are placed in two boreholes. The positions of the electrodes are free to change so as to study different parts of the formation (see Figure. 4).

Figure 4: Schematic of the acquisition geometry of cross-hole DC/IP survey. Combinations of electrode positions are varied to collect data for full 2D tomographic resistivity inversion.

A controlled, bipolar square wave of current is injected to the borehole and the voltage response is measured (see Figure 5). Since the current source is stable, the convolution problem is simplified such that any variation in the potential readings is an effect of the earth's response, which may be correlated with stress, strain and rock mass changes over time. Repeated measurements at the same location are collected every 2 hours. The stability of "source" and the temporal variation of the response are investigated.

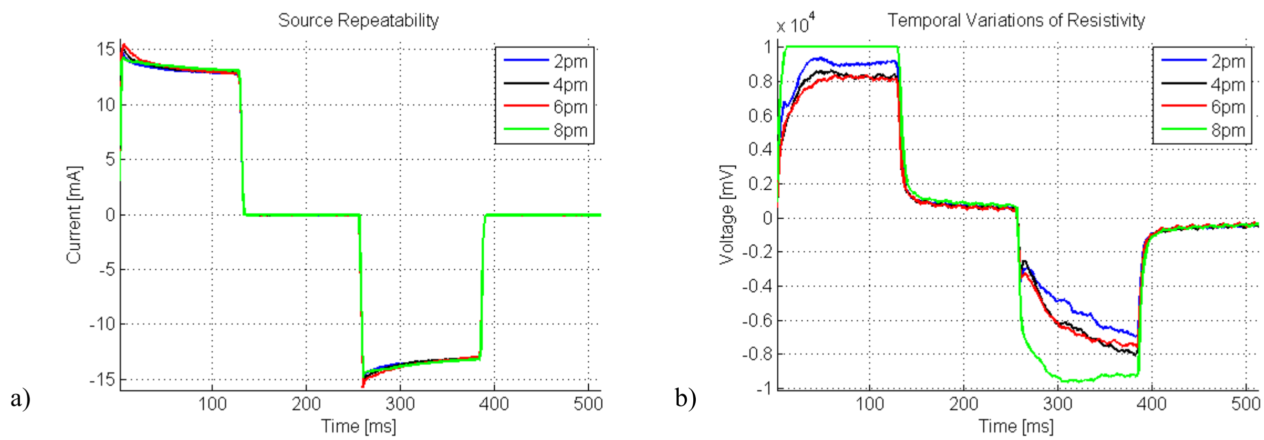



Figure 5: (a) Current injection. A bipolar square wave is used as the controlled source. The waveform is stable and is ideal for repeated measurements. Readings are taken every 2 hours. (b) Voltage response. Transients are observed when the source is changed abruptly. Recorded signals are different, indicating changes in the formation over time.

## Conclusions

The analysis of time-lapse geophysical data has the potential for mining induced stress changes studies. Broadband microseismic data reveals low frequency tremor behaviour which may reflect stress field variations over time. Controlled source cross-hole DC/IP exhibits stable performance of the input current so that any changes observed in the induced voltage will be an effect of the earth's response. Further studies is required to understand any correlations that may exist.


## Acknowledgements

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**References**


Berryman, J. G., 2007, Seismic waves in rocks with fluids and fractures: Geophysical Journal International, 171, 954-974

Kao, H., Shan, S. J., Dragert, H., Rogers, G., Cassidy, J. F., and Ramachandran, K., 2005, A wide depth distribution of seismic tremors along the northern Cascadia margin: Nature, 436, 841-844

Lynch, R. A., 2010, Passive and active seismic monitoring in mines: 5th Deep and High Stress Mining Seminar, 16p

Qian, W., Milkereit, B., McDowell, G., Stevens, K. and Halladay, S., 2007, Bore resistivity logging and tomography for mineral exploration: Exploration 07 International Conference on Mineral Exploration, 1115-1118