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In-Mine Seismic Imaging Revisited

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SUMMARY

Currently, only microseismicity is used as a proxy for stress near deep mines. However, most of the physical properties of crystalline rocks are highly stress dependent. As such, the nonlinear and anisotropic variability of the in situ P- and S-wave velocities can potentially be linked directly to changes in the stress field. At an in-mine seismic laboratory, multi-component sensor arrays are deployed in multiple locations (3D) allowing for both controlled source and passive recordings. Previous in-mine seismic observatories have experienced a number of challenges with regards to sensitivity and longevity. Hence, the geothermally cool but highly stressed Sudbury mining camp offers a favourable setting for fundamental research in to time-lapse monitoring of seismicity, stress, and stress dependent physical properties at a deep mine.

Introduction

Currently, only microseismicity is used as a proxy for stress near deep mines. However, most of the physical properties of crystalline rocks are highly stress dependent. As such, the nonlinear and anisotropic variability of the in situ P- and S-wave velocities can potentially be linked directly to changes in the stress field. At an in-mine seismic laboratory, multi-component sensor arrays are deployed in multiple locations (3D) allowing for both controlled source and passive recordings. Previous in-mine seismic observatories have experienced a number of challenges with regards to sensitivity and longevity. Hence, the geothermally cool but highly stressed Sudbury mining camp offers a favourable setting for fundamental research in to time-lapse monitoring of seismicity, stress, and stress dependent physical properties at a deep mine.
Mine development imposes stress changes in the surrounding rock that typically induce or trigger seismicity with a wide range of magnitudes. These microseismic events typically have high frequency content up to a few kHz that leads to small wavelengths on the order of a few meters in hard rock environments (Figure 1). It should be noted that in-mine controlled-source seismic exploration methods such as cross-well seismic for ore-body delamination operate in the hundreds of hertz to kHz range (McDowell et. al., 2007).

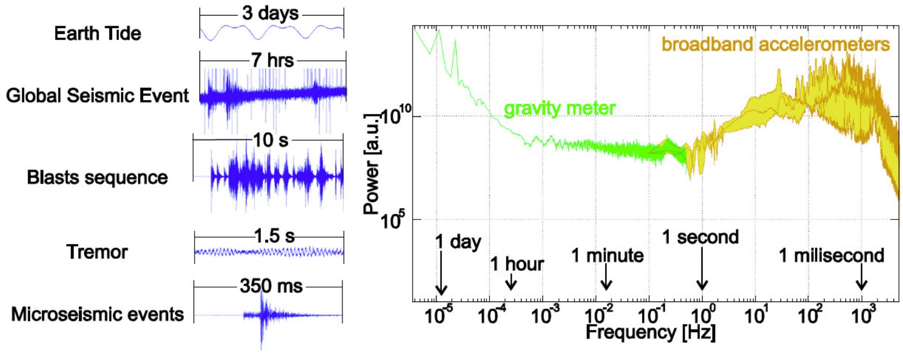

Figure 1 The spectrum of different acquired seismic data at a mine site shows frequency range of more than 8 orders of magnitude (B. Valley et. al., 2012).

In a mine, the presence of very strong elastic contrasts, such as massive ore-bodies, tunnels, stopes and infrastructure have a significant impact on the propagation of seismic waves (Figure 2). The travel time and amplitude of seismic waves derived from the conventional constant velocity models are inadequate for such heterogeneous medium. Since the complexity of seismic wave propagation can affect the distribution of energy significantly, the use of a more accurate model is required to predict the ground motion. For example, the conventional empirical method used to calculate peak particle velocities and accelerations (PPVs/PPAs) tends to underestimate the intensity of seismic waves in stopes or areas close to blast sites, which could be corrected if a more realistic model was implemented.

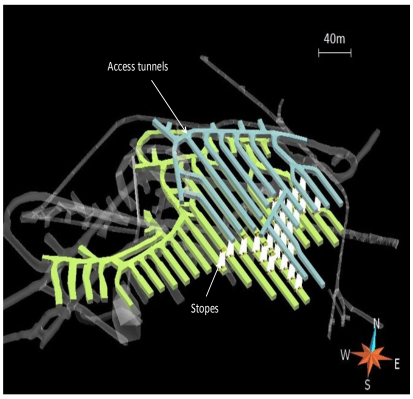

Figure 2 The overall geometry of an underground mine includes access tunnels, ore-bodies, and stopes.

Method

The complexity of scattered seismic waves due to effects of strong elastic contrasts are illustrated using a 2D/3D finite difference modelling method [Bohlen, 2002]. With the recent availability of detailed 3D rock property models of mines, in addition to the development of efficient numerical techniques and parallel computation facilities, a solution for the propagation of seismic waves at the mine size scale is achievable. Modelling results in Figure 3 clearly show the complexity of the propagating waves in mine models. For those models with a central source at frequencies above 500 Hz, energy is more scattered and amplitude variation is more significant. Also at some locations the presence of shadow zone is observed. Moreover, the cemented backfill region, a low velocity region, has trapped the energy and this effect is more dominant for S-waves.

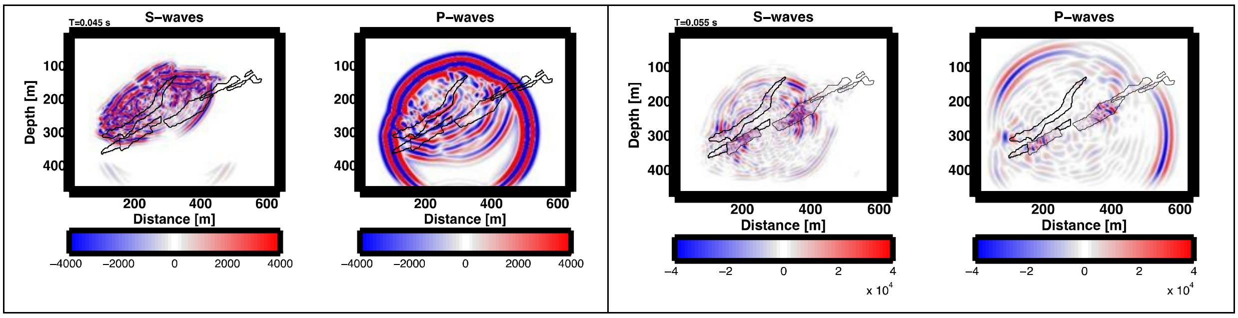

Figure 3 *Snapshots of scattered seismic wave for P and S wave. On the left, model represents orebodies hosted in gneiss and norite background. On the right, parts of orebodies are mined out and remaining voids are backfill cemented.*

In addition to full wave forward modelling, newly developed passive seismic imaging algorithm is introduced (Haung et. al., 2013). The technique is based on earthquake seismology to jointly locate induced microseismic events and update the velocity of the rock model illuminated by the seismicity. Derived travel-time based on the fast sweeping method account for complex 3D distribution of velocity and use the adjoint method to transform the inverse problem to a forward problem, which can also be solved, by the fast sweeping method.

Conclusions

A homogeneous velocity background model is inaccurate in deep operating mines due to the presence of very strong elastic contrasts. This very heterogeneous medium results in a complexity of wave propagation with variations in amplitude, travel time, and phase. The significance of these effects strongly depends on the size, shape, petrophysical properties and the frequency content of seismic source. The modelling results verify the amplification effects at regions with high Vp/Vs ratio (such as voids or cemented backfill) for both P and S wave amplitudes. Sources of higher frequency content displayed changes in polarity and/or creation of shadow zones. The observe complexity of the wave propagation suggests the necessity for further consideration of such effects in the determination of focal mechanisms and full moment tensor inversions.

Acknowledgements

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References

Bohlen, T. [2002] Parallel 3-D viscoelastic finite difference seismic modelling. *Computers and Geosciences*, **28** (8), 887-889.
Huang, J.W., Reyes-Montes, J.M. and Young, R.P. [2013] Passive three-dimensional microseismic imaging for mining-induced rock-mass degradation. *Rock Mechanics for Resources, Energy and Environment*, 135.
McDowell, G.M., Stewart, R and Monteirp, R.N. [2007] In-Mine Exploration and Delineation Using an Integrated Approach, *iProceedings of Exploration 07*, edited by B. Milkereit, p. 571-589.
Valley B., Milkereit, B, Pun, W., Pilz, M., Dusseault, M., Thibodeau, D. and Forsythe, A. [2012] Rock mass change monitoring in a sill pillars at Vale's Coleman mine (Sudbury, Canada). *Proceedings of CIM*, 8p.