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Organizing 4D Seismic Data from an Active Mine Site

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Summary

The physical parameters of most rocks depend on stress conditions. For an active deep mine, the changing of the stress field is dominantly controlled by: tectonic forces, production blasting, excavation and backfill. Monitoring the variability of P- and S- wave velocities is a suitable way to monitor these stress changes. Sensors and events are distributed in the three-dimensional volume of the mine. We propose a new method to better organize the seismic data in both space and time. Specifically, we extract common-source gathers (CSG), common-receiver gathers (CRG), common mid-point gathers (CMG), common offset gathers (COG) and common azimuth gathers (CAG) from several years of production blast recordings. Instead of common event/source gathers (CSG), we evaluate CRG and CMG because the number of events is much larger than the number of receivers.

The 3D sorting algorithm for the seismic database is tested using a synthetic production blast sequence and receiver geometry. For data processing, we use a homogeneous background velocity model, a layered velocity model and a tilted layered velocity model in conjunction with the 3D special receiver distribution. The seismic data recorded from all production blasts at the same receiver show excellent coherency. The CSG, CRG, COG, CMG and CAG are extracted for further computation or processing, such as seismic inversion and tomography.

Introduction

We are currently working on a deep mine monitoring project, which collects 3D seismic data. Seismic monitoring of microseismic events and production blasts is used to observe stress and strain in the mine. Figure 1 shows the mine model with dipping ore bodies and a 3D distribution of seismic sensors. However, microseismic and production blasts are often difficult to analyze in a noisy environment (Figure 2). The number of blast events is much larger than the number of receivers in our data. If the blasts are located near each other, common receivers will record similar traces and these traces could show apparent consistency (A. Reshetnikov, S.A. Shapiro 2014). Instead of using low signal/noise ratio single event/source gathers, we investigate alternative binning and sorting strategies, including CRG, COG, CMG and CAG (Figure 3).

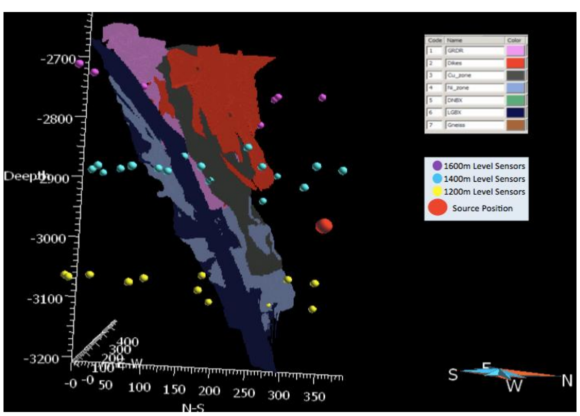


Figure1. 3D distribution of sensors and ore body

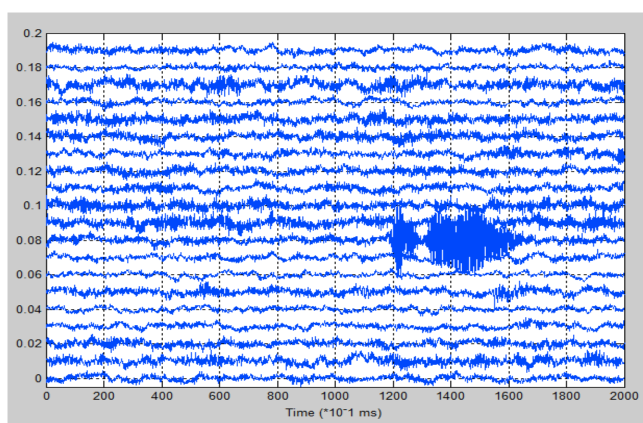
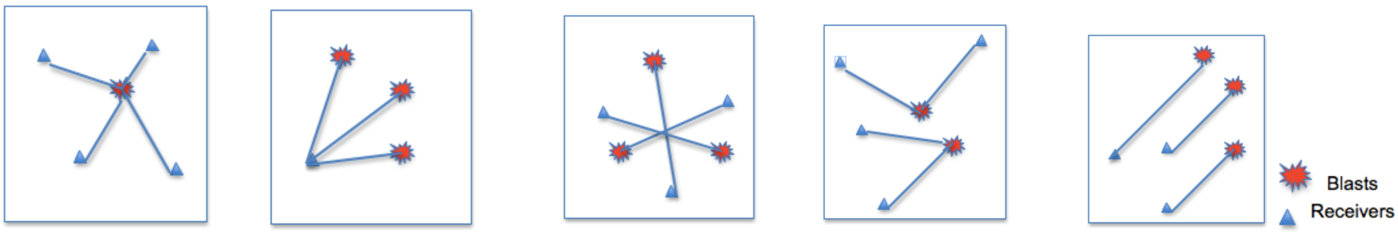


Figure 2. Noisy environment recorded by 20 traces



CSG (Source) CRG (Receiver) CMG (Mid-point) COG (Offset) CAG (Azimuth)

Figure 3. Cartoons of various source-receiver acquisition geometries suitable of analyzing seismic data in 3D earth models

Methodology

To better understand seismic travel times in a deep mine environment, we investigate 3 types of background velocity earth models: 1) homogeneous 2) layered 3) tilted layered.

Travel time computation for constant velocity and layered velocity models are based on Equation (1) and (2), respectively.

<u>Homogeneous earth model</u>:

$$T_i - T_0 = [(X_i - X_0)^2 + (Y_i - Y_0)^2 + (Z_i - Z_0)^2]^{1/2} / V_p \qquad (1)$$

(X_i, Y_i, Z_i) is sensor location, (X_0, Y_0, Z_0) is source location.

V_p is the velocity, T_i is the sensor start time and T_0 is the source time (Holland and Welsch, 1977)

<u>Layered earth model</u>:

$$X_N = \sum_{n=1}^{N} x_n = \sum_{n=1}^{N} \frac{p_n v_n}{\sqrt{1-(p_n v_n)^2}} \cdot z_n, \qquad (2)$$

$$T_N = \sum_{n=1}^{N} t_n = \sum_{n=1}^{N} \frac{1}{v_n \sqrt{1-(p_n v_n)^2}} \cdot z_n, \text{ and } \quad p_n = \frac{\sin(i_n)}{v_n}$$

where z_n is the thickness, v_n is the wave velocity and i_n is the incident angle all for the n^{th} layer, X_N is horizontal offset and T_N is travel time between source and receiver (Lay and Wallace, 1995). An offset and travel time table is stored in the model database.

For a constant velocity background, it is easy to calculate the offset between the source and receivers. Based on the average velocity in the mine (Vp =6160m/s), we can create the time table between source and receivers (Equation 1). In the layered earth model, time can be calculated at any offset with Equation 2. The tilted earth model is a rotated version of the layered model, allowing analytical offset-traveltime solution for any arbitrary source-receiver configuration.

Seismic data acquisition for arbitrary sensor distribution

To simplify the case, we utilize three synthetic models (3D) which contain 10 receivers distributed around the ore body and 50 blasts concentrated in the center area of the ore body model (Figure 4a. 4b. 4c). The tilted layered background velocity model (Figure 4c) is a good approximation of the real geologial setting (see Figure 1).

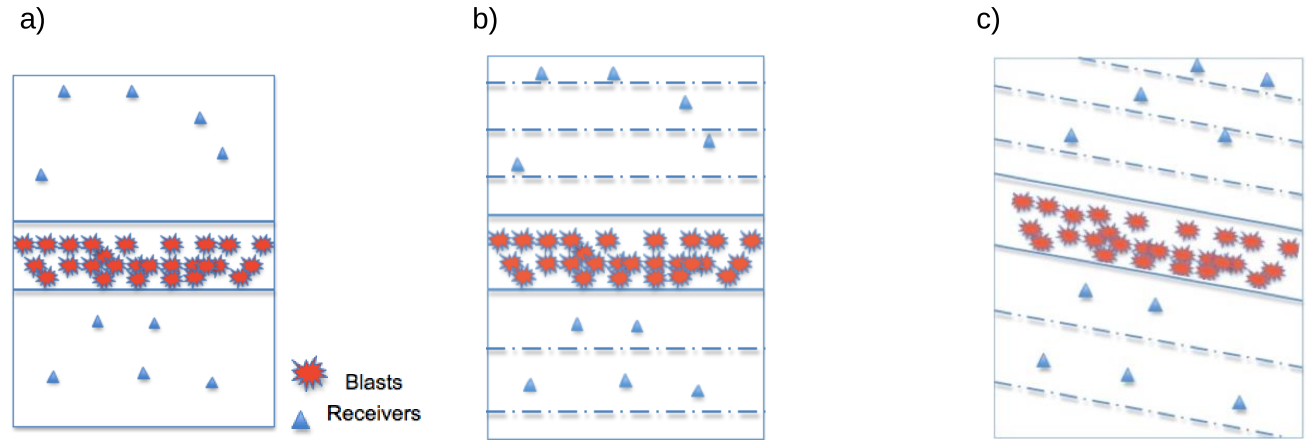


Figure 4 a) Synthetic homogeneous model of the underground mine with production blasts within the ore zone. b) Synthetic layered earth model based on borehole seismic data. c) Synthetic tilted layered earth model

Homogeneous model (constant velocity= 6160 m/s Figure 4a)

A constant velocity earth model has a straight ray path geometry. For a given distribution of receivers in 3D, we sort blasts and microseismic data into CSG and CRG (Figure 5). Among these recordings, conventional CSG is difficult to process due to the limited number of receivers and the noisy environment (see Figure 2). Only after velocity correction according to Equation 1 (linear moveout - 'LMO'), we can extract some useful information, which is also good for quality control tool. If the velocity model is correct, all the events will be flat. In contrast, events are easier to identify and analyze in CRG. Similarly to CSG, after LMO application, events will be flat.

Common event/source gather (CSG) Common receiver gathers (CRG)

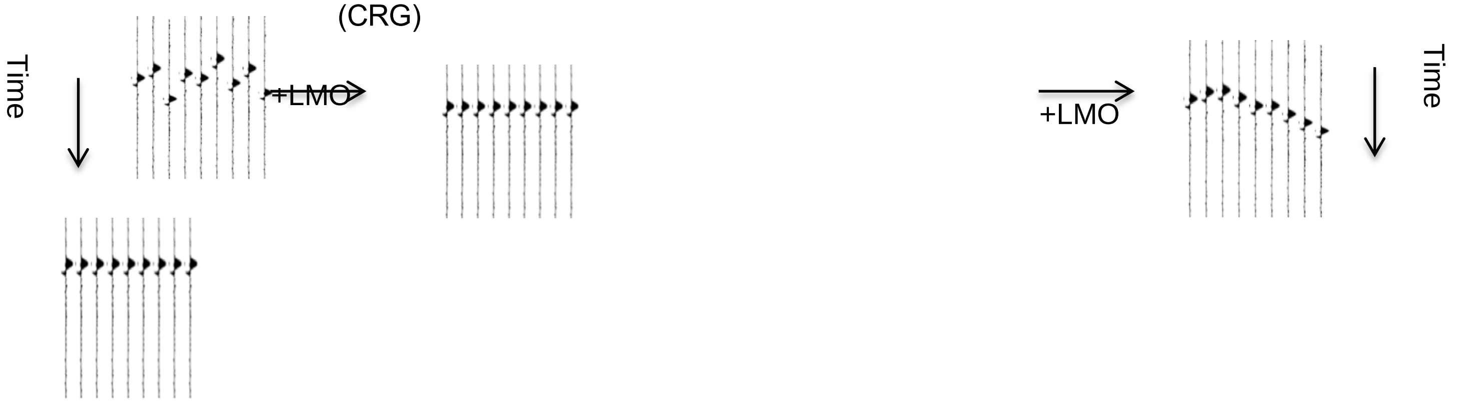


Figure 5a. Synthetic seismogram of CSG in homogeneous model with linear moveout correction application

Figure 5b. Synthetic seismogram of CRG in homogeneous model with linear moveout correction application

Layered earth model (Figure 4b)

We use a simple layered background velocity model. The velocity is increasing gradually from upper layer (6000 m/s) to lower layer (6800 m/s). The ray path will bend in the layered earth model while it is straight in homogeneous earth model. We can easily create the time offset or time depth table based on Equation (2).

Tilted earth model (Figure 4c)

A common receiver gather is shown in Figure 6. For this given common receiver, a dipping production blast sequence is generated along the extended ore body (Figure 7). Similarly, Figure 8 illustrates the CRG using

LMO correction. For the tilted layered background velocity earth model is a good approximation for the dipping ore body showing in Figure 1.

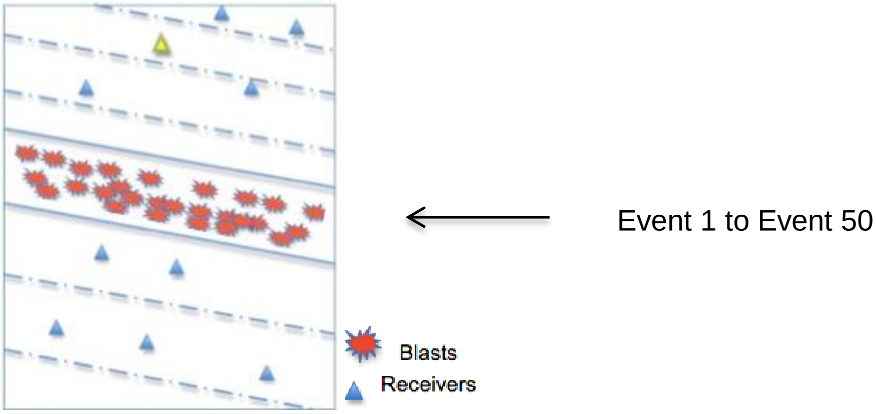


Figure 6. Acquisition geometry for selected receiver (yellow) and production blast sequence (events 1-50)

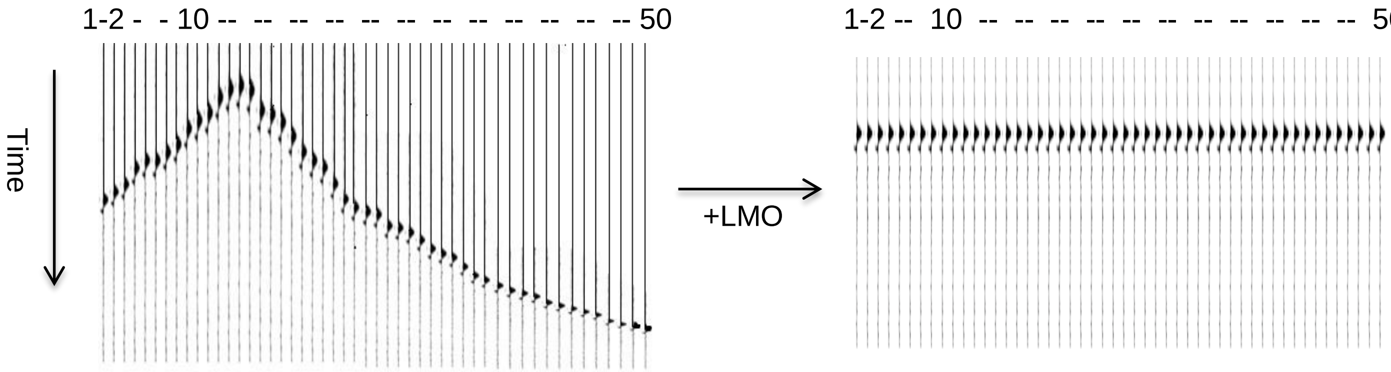


Figure 7. Synthetic CRG for dipping layered earth model and productive blast sequence with events 1-50

Figure 8. Synthetic CRG for dipping layered earth model with tilted, layered travel time correction applied

Conclusions

We use a new sorting algorithm to extract blasts for a 3D seismic distribution in order to better organize the large seismic database. Based on the location relationship between sources/events and receivers, we can create CSG, CRG, CMG, COG and CAG sections. We have then verified that the CRG from a number of blasts is aligned after application of the linear move out. The CRG of microseismic events and blasts sequences are suitable for processing and interpretation of large data volume and for monitoring seismic data at an active mine site. For monitoring purposes, common source/event gathers are often noisy. Therefore, CRG, CMG, COG and CAG offer a new approach to harvest a large microseismic/blast database. These gathers will be useful for time lapse 4D seismic monitoring and wave field processing such as reverse time migration and monitoring variation of P- and S- waves velocities and attenuation.

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