OPTIMIZING MICROSEISMIC SOURCE EVENT LOCATION BY APPLYING A VARIABLE VELOCITY MODEL TO A COMPLEX GEOLOGICAL AND MINING SETTING AT THE NEW GOLD, NEW AFTON BLOCK CAVE

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ABSTRACT

Microseismic (MS) methods offer one of the few ways to monitor a 3D volume of rock and essentially see into the rockmass and the regions of real time rock fracture. This is a critical component when considering workplace safety as well as the economic viability of a mining operation. New Gold Inc. New Afton Mine, an intermediate copper-gold mining company located 350km northeast of Vancouver in the south-central interior of British Columbia, Canada, has recently installed a MS system to help understand the block caving process in space and time. For a block cave mining operation is it important to utilize the MS events to map out the seismogenic zone related to the regions of stress concentration and fracturing mechanisms which lead to caving. The geological setting within the local array is complex, consisting of several distinct lithologies with unique material properties that each affect the microseismic signal differently. The block cave consists of a muck filled void, also affecting the seismic waveform path. This paper compares the use of a single velocity model to a variable velocity model which accounts for the differing lithologies and cave. The variable velocity method determined 3D raypaths for all source to receiver possibilities through five irregular shaped geological domains and the estimated cave. For calibration blast data, the variable velocity model is found to successfully decrease the error for event location from an average of 38m to 20m (47% improvement), and its importance to location accuracy is expected to increase as the cave develops in size.

KEYWORDS

Microseismic, Block caving, Variable velocity, Hard rock mining, Source location accuracy.

INTRODUCTION

New Gold's New Afton Mine is a new block caving operation located 8 km west of Kamloops in British Columbia, Canada (Figure 1). Primary development providing access to the orebody started in the beginning of 2009 and progressed rapidly to allow the first cave blast on June 27, 2011. The cave production footprint now encompasses a total of 54 drawbells as of December 2012. Approximately 11,000 tons per day are drawn from the orebody to induce the required steady state cave propagation. Over the projected mine life of 14 years, the New Afton Mine is expected to produce on average, 85,000 oz./yr. of gold and 75 million lb./yr. of copper.

The economic portion of the deposit is gold-copper alkali porphyry, measuring approximately 900m in length, 100m wide and spanning a true height of 275m to 400m measured from the base of the plunge along its full strike length. Of great significance and influence are the large bounding steeply dipping fault structures to the north and south of the deposit. Geological mapping of the underground workings, in conjunction with extensive geotechnical core logging provide clear evidence of a highly jointed rockmass containing an abundance of clay material throughout. Furthermore, the quality of the orebody rockmass, using the Bieniawski (1976) classification system, places it in a rock mass rating (RMR) range of 35-55, classifying it as a poor to fair rockmass. This geological and geotechnical data reinforced the findings during the initial feasibility reports, which indicated that New Afton Mine has suitable rock mass characteristics to employ a block caving mining methodology.

In order to monitor and manage cave mining induced seismicity, a seismic system is required to assist in understanding cave growth and possible boundaries in the cave geometry. Numerous studies (e.g. Trifu et al., 2002; Hudyma et al., 2010) have shown how a seismic system can be used to track the progression of a geometrical profile of an advancing front in time and space. At the New Afton Mine, a 57 channel ESG monitoring system has been installed. This paper presents some of the calibration and initial results from the first stages of this caving operation.

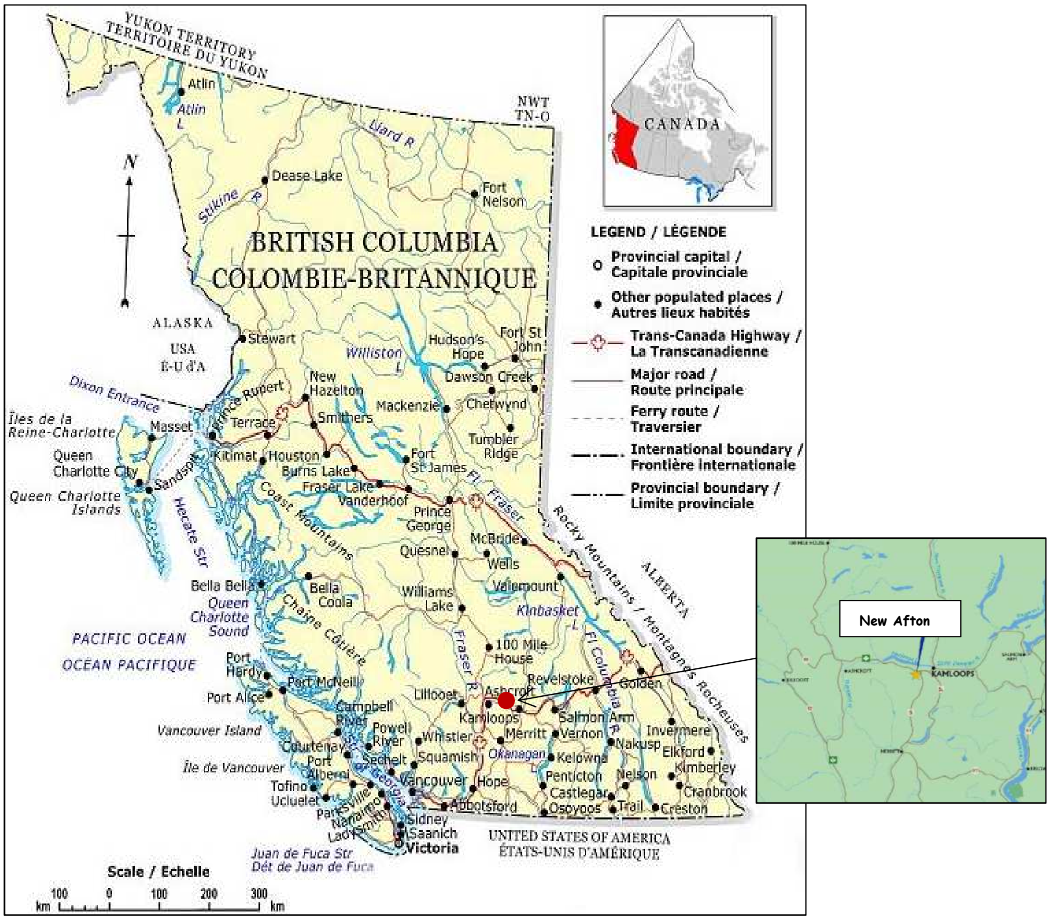

Figure 1 – The site location.

METHODS

Seismic Array Design and Performance

A microseismic array design was created in March 2011. The design recommended a mixture of 21 (twenty-one) 1V/g uniaxial accelerometers and 11 (eleven) 15Hz triaxial geophones. The 32 sensor positions were chosen based on a number of criteria, including:

- Spacing the sensors throughout the volume of interest
- Using a combination of subvertical long boreholes from surface and short boreholes from underground tunnels for sensor installation to optimize drilling time and costs
- Restricting boreholes to not pass through the two main subvertical fault zones to reduce the chance of sensor cables being damaged by shearing
- Preservation of sensors for as long as possible to obtain maximum seismic data during cave growth
- Reducing the amount of drilling through the geological unit Picrite, which casuses problems for diamond drilling.

One third of the array used triaxial sensors which have benefits of high accuracy for source parameters and source mechanism analysis (assuming enough sensors and a good array coverage) since the ground motion is being recorded in three directions at each location. Triaxial sensors also allow the seismic S-wave phase to be very accurately determined which will improve location accuracy. Triaxial geophone sensors were chosen to focus on the middle magnitude range (-1.5Mw to +1.0Mw) of the expected seismicity.

The remaining two thirds of the array utilized uniaxial sensors which have the cost benefit of only requiring one seismic channel compared to a triaxial sensor which requires three seismic channels. Uniaxial sensors can also be used in source parameter and source mechanism analysis by use of a calibrated correction factor to the seismic amplitude (Trifu and Shumila 2002). The use of uniaxial sensors allows a higher density of sensors to be installed (3 to 1), for the same number of seismic channels, which leads to a higher source location accuracy as well as a higher sensitivity or lower magnitude detectability. Uniaxial accelerometer sensors with high gain were chosen to increase the detectability in the 1000-2500Hz range to allow the possibility of recording events with magnitude <-2.0Mw.

Additionally, a 4.5Hz geophone, strong ground motion sensor (SGM), was installed. About 85% of the array was installed by December 2011 and since January 2012 approximately 8000 events have been recorded, with about 1000 events related to cave advance.

Currently, the seismic network at New Afton is 90% installed, with 10% pending development. Figure 2 shows the installed sensors in relation to the open pit, extraction level, and the two main subvertical fault zones.

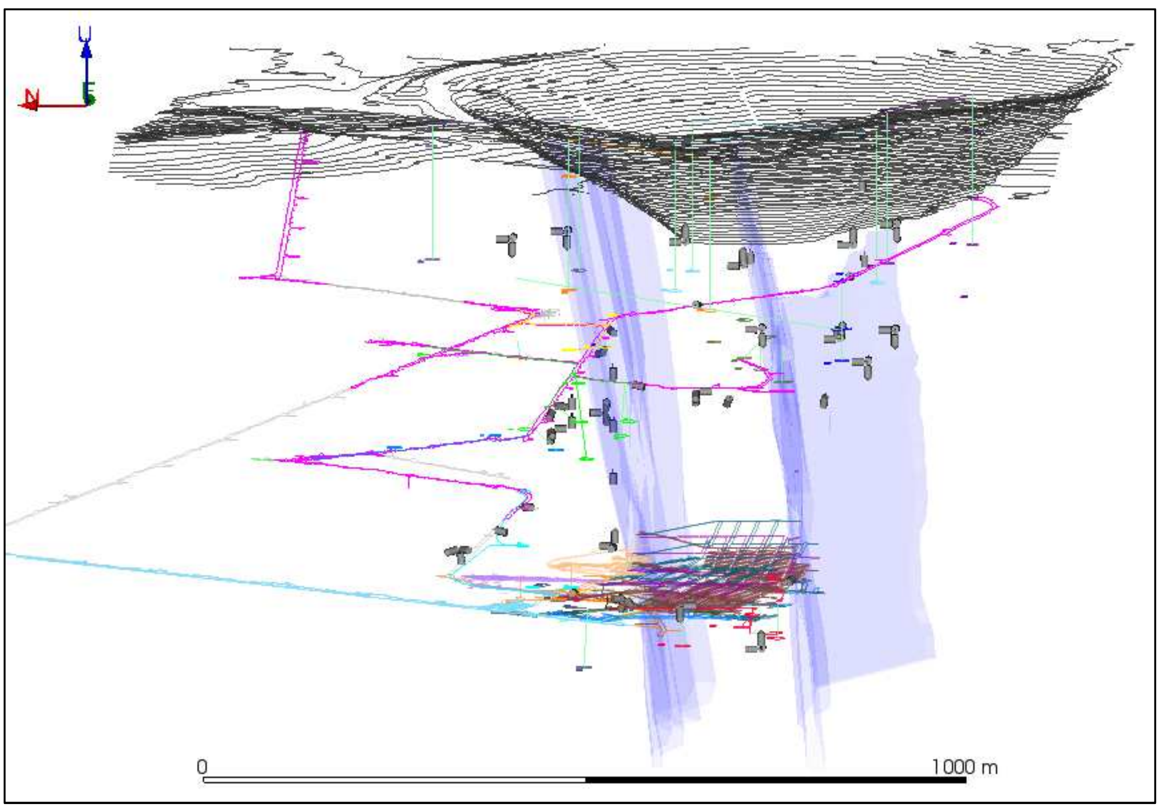

Figure 2 – The microseismic array as of January 2013, consisting of 21 uniaxial accelerometers and 11 triaxial geophones (grey symbols) to monitor cave induced microseismicity. The surface and open pit is

shown as well as the extent of the two subvertical fault zones that approximately bound the extraction level and expected cave.

To date, the amount and frequency of recorded seismicity from undercutting and cave advancement has been less than originally anticipated. This may be due to higher than expected seismic signal attenuation occurring in the rock mass, which affects the amplitude and frequency content of the seismic source with distance. The seismic acquisition system, which records continuously at 10 kHz sampling, has been optimally set up with a very sensitive trigger level relative to the background noise. Each seismic channel is processed with an individual custom filter before event triggering to strip away background noise and maximize the signal detection.

To assess the progress of the cave, it is very important to accurately locate the recorded seismic events. To provide additional confidence in the caving induced event locations, the existing single velocity model was investigated and the ability to implement a variable velocity model was explored.

Single Velocity Model

Based on initial calibration blasting from February 2012, the velocity model for the New Afton site was given a Vp = 4980 m/s and Vs = 2840 m/s. Substantial additional calibration using different blasting techniques was completed in January 2013. The revised calibration indicated a changing velocity model of Vp = 4700 m/s and Vs = 2530 m/s, suggesting a significant decrease in P wave velocity and S wave velocity. This reduction in velocity is believed to be mainly due to the development of the cave above the extraction level on the west (Figure 3).

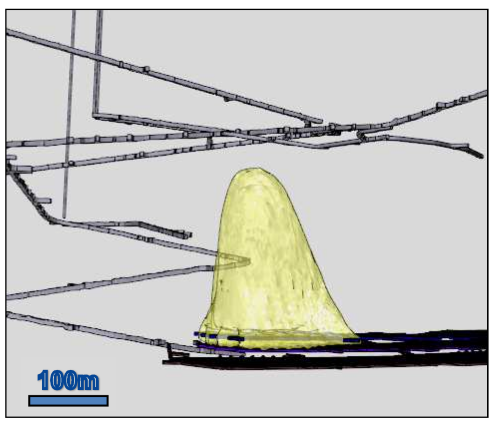

Figure 3 – New Afton development tunnels and January 2013 cave in a North-East view.

Variable Velocity Model Based on Geology and Cave

In order to develop a variable velocity model that was computationally efficient, the lithological boundaries had to be simplified to represent the main trends and significant changes in velocity. Initial velocity values were given to the lithologies based on a database of laboratory velocity testing on drill cores. Velocity testing of drill core is known to not be an exact representation of rock mass velocity, since the value can be dependent on factors such as sample size, seismic signal frequency, and rock quality (Coon and Merritt 1970). However, the laboratory velocity values identified that the different geological domains had different velocity ranges, with mean values that varied by about 20% which is significant for seismic location. These values were used as a starting point for the development of an optimal variable velocity model. The simplified boundaries of the 5 geological domains, and available laboratory velocity values are presented in Figure 4.

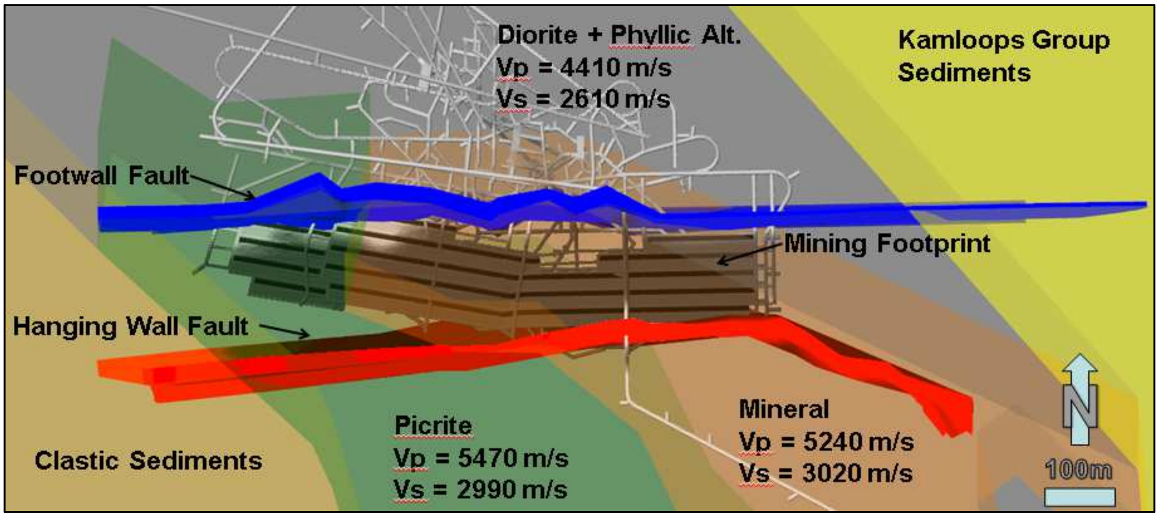

Figure 4 – New Afton footprint and simplified geology model displaying lab drill core velocity results.

The cave is likely made up of a muck pile of unloaded and loaded (varying swell factor) broken rock. In the variable velocity model this zone was given a low Vp (P wave velocity) value of 300 m/s (value for air) since it is expected that the relevant fast travelling seismic energy will pass around the cave to any particular sensor.

Variable Velocity Model Algorithm

The algorithm used is built on the work of Trifu and Shumila (2010) who present a method for source location using 3D raytracing around an open pit mine with heterogeneous geological units. In this study, as with the New Afton Mine, the boundaries of the geological units are more complex than a standard layered model. Trifu and Shumila (2010) show how a variable velocity model can be calculated using the Fast Marching Method (FMM) which is an approach to wave front reconstruction proposed by Sethian and Popovici (1999). The algorithm has been further developed by incorporating methods of Rawlinson and Sambridge (2004) which provide special treatment for grid cells intersecting a velocity interface and control of the wave front curvature. In this study, the algorithm has been adapted to work with closed low velocity 3D volumes such as a cave. Figure 5 shows a 2D horizontal section through the 3D gridded volume for New Afton, from which the 3D raytracing algorithm is run to produce the variable velocity model.

Recent advances in computer power are allowing this type of algorithm to be run in a few hours for a reasonably fine grid. Once the variable velocity model is produced, the final source location is determined within a few seconds using an iterative Simplex location method.

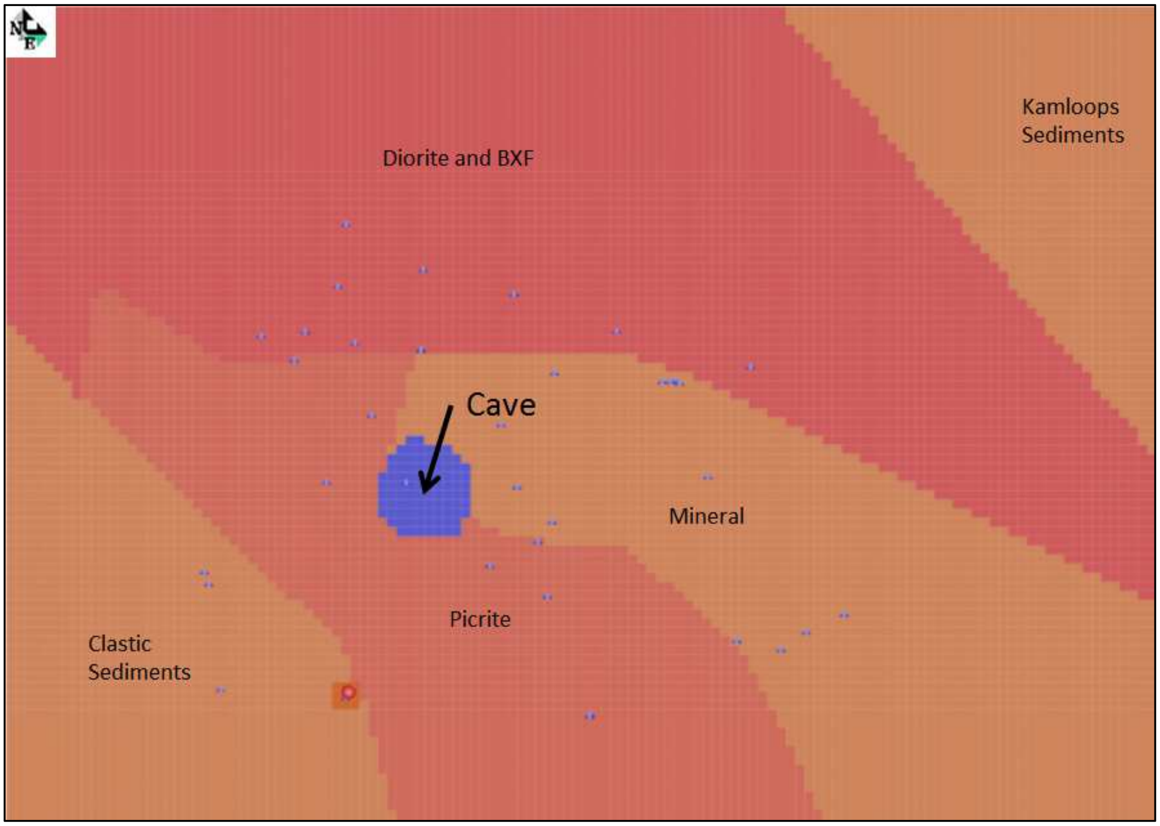

Figure 5 – A cross section through the 3D gridded volume of New Afton mine, incorporating the different geological domains as well as the cave.

RESULTS

3D Raytracing

Theoretically, a single velocity model represents a homogeneous isotropic material, which results in all seismic energy propagating in straight lines outwards from the source with a 3D spherical wave front. This model has been shown to work well in many hard and soft rock mines for locating induced seismic events to a reasonable accuracy of 10m or better (Alexander and Trifu 2005). For certain mines (coal, salt) as well as petroleum/gas reservoirs, the induced seismic events are generally located using a layered velocity model to account for the different geological bedding layers, to get the expected location accuracy (e.g. Baig et al 2012).

In comparison, Figure 6 presents a plan view cross section of the New Afton Mine, with isolines of equal travel time from a seismic source (red circle) through a variable velocity model. The isolines are observed to be significantly affected by the cave (white ellipse) as well as the different geological domains with irregular boundaries.

A black line drawn between the red circle and red star symbol tracks the approximate path that the fastest seismic energy would take between these two locations. This distance (614m) is relevant because the red circle and red star symbols represent a calibration blast location and sensor location (Bay_16_G) at the New Afton Mine. The straight ray assumption (for a single velocity model) is shown as a red line which covers a considerably shorter distance of 553m.

Figure 7 shows the recorded waveform at sensor Bay_16_G for the calibration blast with known location. The theoretical P and S wave arrival times are identified by red circles for both a single velocity model and variable velocity model. Figure 7 also marks the arrival times of the actual P and S waves. It is clear that the theoretical arrival times using the variable velocity model are a much better match to the actual arrival times than for the single velocity model. Since a source location method is based on minimizing the difference between the actual (measured/picked) P and S arrival times and the theoretical P and S arrival times, this example shows the importance of using a velocity model that is optimised for the monitoring volume.

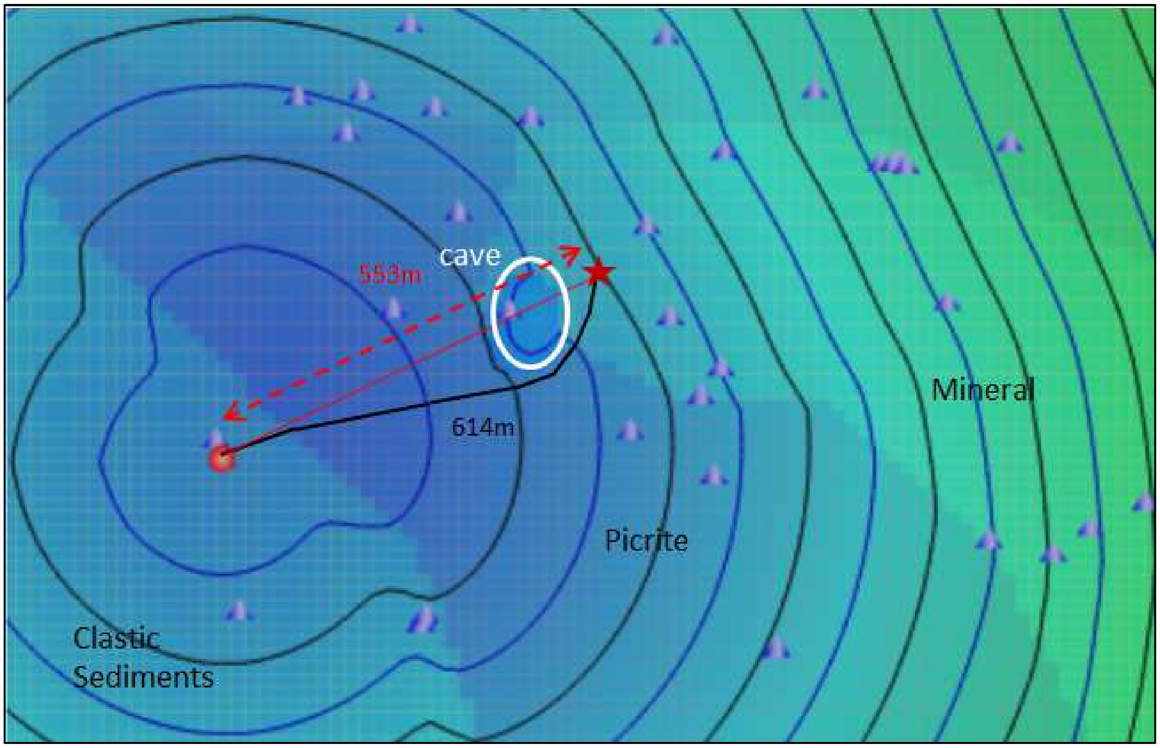

Figure 6 – Isolines of equal P wave propagation time are shown, emanating from the red circle location. The isolines are significantly affected by the boundaries and properties of the different geological units, as well as the cave.

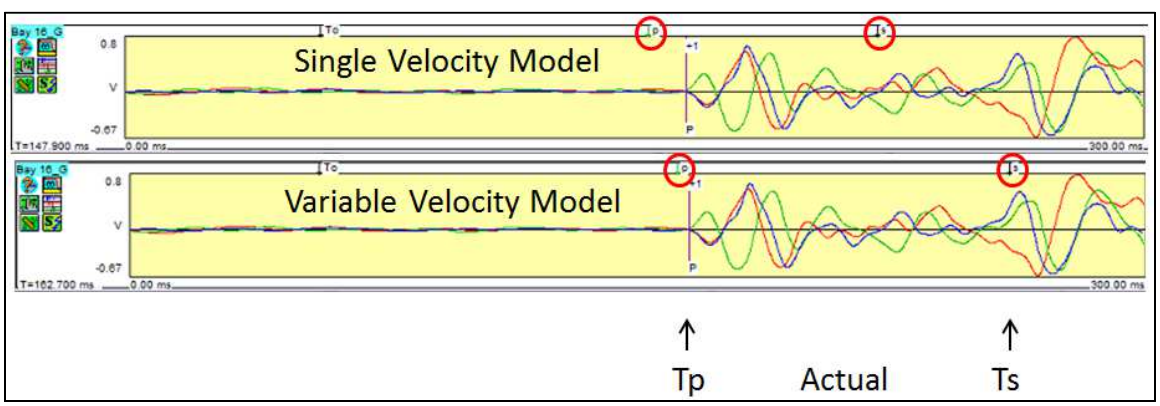

Figure 7 – The seismic response on sensor Bay_16_G from the calibration blast of January 16 2013. The theoretical arrival times are identified by red circles for both the single and variable velocity models. The variable velocity model which accounts for the path around the cave and through different geological units is found to have an excellent match to the actual P and S wave arrival times.

Location Accuracy Using the Variable Velocity Model

Table 1 provides a comparison of the absolute location accuracy for the 10 calibration blasts with known locations for both optimized velocity models. The variable velocity model is shown to reduce the location error by 47% from an average of 38m to 20m.

Table 1 – Comparison of the source location error (in meters) for the 10 calibration blasts using a single and variable velocity model.

Blast#	Date	Time	Single Velocity Model – Absolute Error (m)	Variable Velocity Model – Absolute Error (m)
1	01 Jan 2013	5:34:48.909	66	27
2	01 Jan 2013	5:42:22.404	103	20
3	01 Jan 2013	17:40:39.602	13	11
4	03 Jan 2013	17:42:50.282	9	10
5	04 Jan 2013	17:46:02.005	82	20
6	05 Jan 2013	17:41:18.037	33	25
7	07 Jan 2013	17:43:57.370	21	30
8	08 Jan 2013	17:56:34.870	20	13
9	13 Jan 2013	17:58:33.784	25	20
10	20 Jan 2013	17:36:22.262	27	21
Average			**38**	**20**

CONCLUSIONS

The assumption of a single velocity model may limit the possible location accuracy. Mines are generally a complex distribution of voids in a complex distribution of lithology. With the ongoing development of seismic algorithms and computational power, developing variable velocity models that account for the complex voids and lithology is efficiently possible as developed and shown in this paper. Calibration blast data recorded at the New Afton Mine with a mixture of uniaxial and triaxial sensors are shown to have a 47% improvement in location accuracy when using a variable velocity model compared to a single velocity model.

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