GROUND TRUTH WITH MINE COOPERATION Minnesota Taconite Mines

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INTRODUCTION AND GOALS

Detection, location and identification of mining explosions using regional seismic and acoustic observations can minimize the number of false alarms that might arise as a result of monitoring of the Comprehensive Nuclear Test Ban Treaty. The preliminary work described in this document is intended to illustrate one way in which information about blasting provided by a mine operator may be useful in improving monitoring functions.

A cooperative arrangement has been developed with a large taconite mine in the Mesabi Iron Range of Minnesota. Explosives are used to fracture relatively hard rock formations in order to facilitate the recovery of iron. The mine is known as Minntac and is operated by the U. S. Steel Group.

Since June of 1999, the mine has been supplying Southern Methodist University with ground truth information that includes shot time, total amount of explosives and amount of explosives per delay period. The information is typically provided within 24 hours of the blasts and provides an opportunity to investigate the usefulness of such timely data in a monitoring scenario. Additionally, the information can be used to assess the relationships between regional seismic and infrasound observations and the blast parameters.

The primary regional data set used in this study has been obtained through the AUTODRM process. Taking advantage of the large number of stations in the US and Canada that can be accessed in this manner we are building a regional data set to compliment the ground truth information.

This document is intended as a progress report of an ongoing research effort focused on understanding regional signals from hard rock mining practices. Mining operations in the Mesabi Iron Range and at Minntac in particular will be summarized in the first section. This will be followed with examples of the regional data set that is accumulating. Finally some simple interpretations of the data and possible conclusions will be discussed in the final section of the report.

MINNESOTA TACONITE MINES

The Mesabi Iron Range is located in Northern Minnesota. It has been actively mined since ore was first discovered in 1890. The iron ores are composed of high-grade, soft materials which early on were relatively easy to extract even with steam shovels. As these ores have become depleted, mining has turned to the surrounding hard rock materials with magnetic iron particles distributed throughout. These taconite deposits continue to be mined today requiring extensive blasting in the very hard rock. Typical compressive strengths for these rocks are found to be between 30,000 psi to 90,000 psi.

The Minntac Mine is one of the large taconite mining operations in this region. Figure 1a is an overview of the facility at the mine which takes the raw ore and processes it to form small iron balls that are then shipped to steel manufacturing plants. The mine is operated by U. S. Steel. Donald H. Thompson the senior engineer for drill and blast has been our point of contact in this cooperative study.



Figure 1a: Aerial view of the processing facility at the Minntac Mine (www.usx.aa.psiweb.com)



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A unit of USX Corporation

Figure 1b: Minntac is operated by U. S. Steel. The point of contact for this study is Don Thompson, Senior Engineer for Drill and Blast. Minntac drills over one million feet of 16 inch diameter boreholes each year to produce 75 million long tons of taconite. An example 16" borehole is loaded with 36' of ANFO for a total explosive weight of 4236 lbs with an explosive factor of 0.82 lbs/ton. Individual shots will consist of up to several hundred boreholes delay-fired. Since June, the ground truth data base has grown to fourty-three events. As Figure 2 illustrates, these mining blasts are typically detonated around the noon hour.



Figure 2: Shot times for the Minntac blasts from June-November 1999.

The amount of explosives in individual boreholes in the shots can vary from near 1000 lbs to over 4000 lbs. These individual charge sizes result in maximum lbs of explosive detonated in any delay period from 1000 to 15000 lbs. Total charge sizes have ranged from 63000 lbs to 790000 lbs during the study. The total number of boreholes in each shot have ranged from 75 to 287. Figure 3 plots the total explosive weight in an individual shot versus the total number of boreholes. The increase in total explosives with the number of boreholes is a result of the delay-firing process. In this figure the diameter of each symbol is proportional to the maximum amount of explosives detonated in any one delay period. There are shots at all sizes with near the maximum amount of explosives per delay period. There are also shots with smaller amounts of explosive per delay period that fall to the bottom of the distribution of total shot size for a fixed number of boreholes.

It has been well documented that there is little relation between total explosive weight and regional seismic amplitudes. We intend to investigate these relations for this data set with additional comparison to amount of explosives per delay period. The limit on the total amount of explosives per delay period is intended to limit close-in ground motions from blasting and might affect regional amplitudes. As Figure 3 illustrates, there are shots with the maximum amount of explosives per delay period at all values of total amount of explosives. One might expect then that regional signals from this mine might not show a positive correlation of total explosive weight with regional amplitudes but would show a positive correlation with maximum amount of explosives detonated in any delay period. The effect of delay on local and regional amplitudes will naturally be frequency dependent.



Figure 3: The total amount of explosives detonated in a blast is plotted against the number of boreholes in the blast pattern. The diameter of the symbol is proportional to the maximum amount of explosives detonated in any delay period.

One way of characterizing the blasts and their efficiencies is to compare the total lbs of explosives to the tons of material blasted. Typical this ratio is called the powder factor and can vary from small values (0.1 to 0.3) for weak materials that are easily broken to large values (0.7 to above 1) for hard materials or where cast blasting is employed. As noted earlier, the relatively large blasting factors reflect the large compressive strengths of the rocks in this region.

The total amount of explosives in lbs is plotted against the total amount of fractured rock in tons in Figure 4. An apparent linear relation is found for the blasts studied at Minntac. This relation illustrates that as the total amount of explosives is increased at the mine the amount of rock affected by the explosives increases linearly.

MINNTAC TOTAL EXPLOSIVES VS ROCK MASS



Figure 4: The total amount of explosives in lbs is plotted against the total amount of rack fractured by the explosion in tons.

REGIONAL OBSERVATIONS

The key to this the study is the determination to what extent simple blasting records can be utilized in regional studies of mining explosions. The blast records that have been summarized in the previous section provide the trigger to request seismic data in specified time windows. The seismic stations surrounding the mine are listed in the table below. The closest station is EYMN at 112 km and the farthest listed in the table

Sta	Туре	Latitude	Longitude	Elev	From	For	Km	Degrees	Azimuth	BackAzimut
Epic		47.4354	-92.52767				0	0	0	0
EYMN	3C	47.94619	-91.495	0.475	USGS	MN	112	1	59	240
ТВО	2C	48.6473	-89.4083	0.468	Canada	MN	268	2.41	59	241
SOLO	1C	50.0213	-92.0812	0.373	Canada	MN	289	2.6	6	187
ULM	6C	50.2499	-95.875	0.281	Canada	MN	398	3.58	323	141
ISM1	1C	50.187	-96.018	0.281	Canada	MN	399	3.59	321	139
ISM2	1C	50.201	-96.027	0.281	Canada	MN	399	3.59	321	139
ISM3	1C	50.207	-96.013	0.281	Canada	MN	399	3.59	321	139
ISM4	1C	50.207	-96.039	0.281	Canada	MN	399	3.59	321	139
JFWS	3C	42.91489	-90.2488	0.318	USGS	MN	533	4.8	160	341
KAPO	6C	49.4504	-82.5079	0.21	Canada	MN	773	6.95	69	257
AAM	3C	42.29972	-83.65611	0.249	USGS	MN	902	8.11	126	312
BLO	3C	39.17194	-86.52222	0.246	USGS	MN	1039	9.34	150	334
CCM	3C	38.05567	-91.24458	0.223	USGS	MN	1048	9.42	174	355
CBKS	3C	38.814	-99.73739	0.677	USGS	MN	1122	10.09	214	29
FCC	6C	58.7616	-94.0866	0.039	Canada	MN	1264	11.37	356	175
MIAR	3C	34.5457	-93.573	0.207	USGS	MN	1435	12.91	184	3

is MIAR at 1435 km. Many of these stations operate an AUTODRM so that automated requests for data can be sent.

Broadband vertical records at EYMN for 10 of the Minntac blasts are plotted in Figure 5. This simple display of the data illustrates three important characteristics of the data. First, the waveforms from one shot to another are very similar. This might be further investigated through a correlation analysis. Second, at this close range (112 km), the fundamental Rayleigh wave known as Rg has large amplitude. This secondary phase dominates the longer periods. Third, the P wave coda is very well excited.



USSteel MINTAC Shots

Figure 5: Ten, vertical broadband seismic records of Minntac blasts recorded at EYMN (112 km).

Data from a second station, ULM, is reproduced in Figure 6. This station at 398 km illustrates the effect of increasing propagation path distance on both the character and the signal to noise ratio on the signal. At this greater range the Rg phase is no longer

observable. The waveform consists of a P package and a Lg package. Some of the smaller events such as the 14 July are just barely observable above the background noise. This result suggests that the mining shots from Minntac despite ranging in total explosive weight to nearly 800,000 lbs may only be observed at near-regional distances.



Events Recorded at Station ULM, Filtered Highpass 1 Hz

Figure 6: Eight, vertical broadband seismic records of Minntac blasts recorded at ULM (398 km).

PRELIMINARY ANALYSIS AND CONCLUSIONS

Timely cooperation with an active mine has proven that shot records can be used to develop a data base of regional seismic signals from blasting. The key to this study has been the availability of blast records within 24 hours of the explosions. This information has then been used to assemble a the set of all available seismic records using autodrm. The procedure avoids the need to wait for data archives to be made available and provides quick study of events of interest.

A number of simple measurements on the waveforms developed during this study are presented to further illustrate the importance of the explosive source on the waveforms. Figure 7 contains bandpass filtered time series from one of the blasts observed at EYMN. This representation illustrates further the importance of Rayleigh waves at the longer periods. Even though the observations are only at 112 km one can also see the development of Lg in the 1-2 and 2-4 Hz band. Finally the relative importance of the P waves increases at the highest frequency band.



US Steel MINTAC Shot 30 June 1999

Figure 7: Bandpass filtered time series of one Minntac blast observed at EYMN.

A similar filtered representation is made for station ULM in Figure 8. There is little or no long period signal (0.1 to 1 Hz) at this more distant range. The Rg phase has probably been destroyed by heterogeneity in the shallow crustal wave guide. The Lg phase is now well developed at intermediate frequencies. P energy has its largest relative contribution at the highest frequencies.



Figure 7: Bandpass filtered time series of one Minntac blast observed at ULM.

Peak amplitude of P and Lg waves were measured in different frequency bands in order to determine the effect of charge weight an regional seismic amplitudes. Figure 8 plots peak P wave amplitude in three frequency bands (2-4, 4-8, 8-16 Hz) against the maximum pounds of explosive per delay period. Typically the delay period over which the charge size is determined is 8 ms. All frequency pass bands show increase in peak amplitude with increasing pounds per delay. The signal strength of the P wave is greatest at the higher frequencies. The 8-16 Hz pass band shows the strongest increase in peak amplitude, consistent with the delay period being very short.

Similar comparisons are made for the Lg waves in Figure 9. The pattern is much more complex in this case with the largest amplitudes at the lower frequencies. Measurements were made out to the 8-16 Hz band although the phase measured may not be strictly Lg. The fact that Lg is dominated by lower frequencies may mean that peak amplitudes of this phase may not directly reflect the lbs per delay period but may reflect the amount of explosives detonated over a time period more comparable to the inverse of the frequency dominating the phase. We intend to investigate this possibility through additional data analysis and modeling.

Average P Peak Amplitudes



Figure 8: Peak P wave amplitude for three frequency bands (2-4, 4-8, 8-16 Hz) plotted against the maximum charge weight per delay period.



Figure 9: Peak Lg wave amplitude for three frequency bands (2-4, 4-8, 8-16 Hz) plotted against the maximum charge weight per delay period.

FUTURE WORK

Through cooperation with personnel at Minntac, we have begun a study of regional seismograms from a hard rock mine in Minnesota. Data provided by the mine and regional broadband seismograms provide the basis for beginning the assessment of issues related to explosive coupling and event characterization.

It appears that this study can be extended to infrasound recordings as well. Discussions with David McCormack at the Canadian Geological Survey have indicated that mining blasts in the Mesabi Iron Range are generating infrasound signals at IS10 in Canada, near ULM. Signals from three blasts at one element of the infrasound array are reproduced in Figure 10. These data in conjunction with the ground truth from the mine will allow this study to be extended to include both seismic and infrasound signals.



Figure 10: Infrasound signals on one element of IS10 near ULM. They represent three mining explosions in the Mesabi Iron Range.

Much work remains in this initial empirical study. We continue to expand the data base with input from Minntac. Additional sources of seismic data are being investigated. Cooperation with the Canadian Geological Survey is anticipated in order to extend the study to infrasound signals.

After completion of the data gathering and interpretation phase, we intend to begin a modeling exercise of the seismic data. Our intention is to first investigate coupling issues associated with these delay-fired explosions. Particular emphasis will be placed upon replicating the relative characteristics of the peak amplitude data in the different frequency bands. The data set also offers the opportunity to investigate possible mining explosion discriminants for stable continental propagation paths.

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