THE CHARACTERIZATION OF SEISMIC AND INFRASOUND SIGNALS FROM MINING EXPLOSIONS

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GOALS

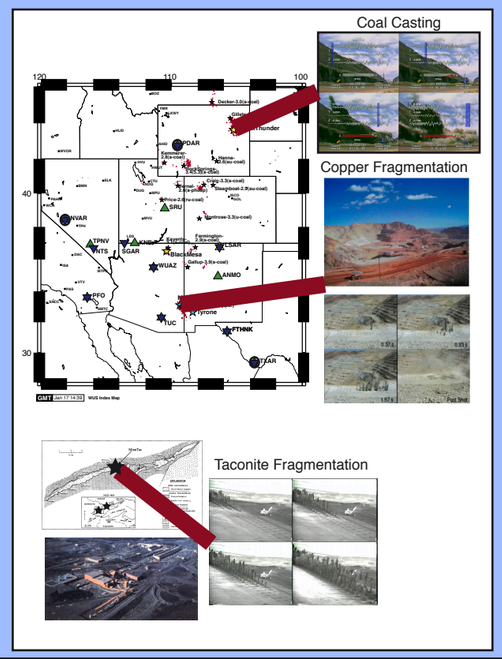
Seismic	Infrasound
Quantify mining explosion coupling.	Number of seismic signals associated with infrasound.
Develop source models for mining explosions.	Blasting characterisitics that contribute to infrasound signals.
Determine the effect of different blasting practices on generation of seismic waves.	Combined seismic and infrasound event identification.
Physical basis for seismic event identification.	Catalog of seismo-acoustic events.

CONCLUSIONS

Seismic	Infrasound
Peak seismic amplitudes from delay-fired mining explosions show little relation to explosive yield.	A small percentage of mining explosions are observed to have infrasound signals.
Source models for mining explosions can replicate coupling observations including the generation of intermediate period surface waves.	Observation of infrasound are related to event size and propagation path effects.
Great deal of variability of blasting practices between mines and within mines.	Shallow explosions may produce no regional seismic but infrasound.
	Infrasound signals may document source duration.

TYPES OF MINING EVENTS

This study focuses on seismic and infrasound signals from three types of mining operations which are illustrated below. Type 1 - Coal overburden casting (Black Thunder) where explosions are designed to expose coal. Type 2 - Rock fragmentation for copper recovery (Morenci) where explosions are designed to break the rock for further processing. Type 3 - Rock fragmentation in hard rock for iron recovery (Minntac). Each mine has a set of distinctive blasting practices that are reflected in regional seismic and infrasound signals illustrated in this poster.



COUPLING

Peak amplitude of regional signals is independent of total amount of explosives in coal cast blasts (Fig 1), taconite(iron) fragmentation (Fig 3 and 4), and copper fragmentation blasts (Fig 5). In-mine peak amplitudes are also independent of total amount of explosives (Fig 6). A series of contained, single-fired explosion experiments (in the coal mine) produce a linear relation between peak amplitude and total amount of explosives. Delay-firing, casting and fragmentation are responsible for the independence of peak regional and close-in amplitudes and total amount of explosives.

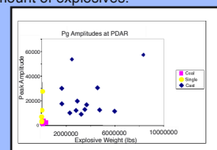


Figure 1: Coal Casting

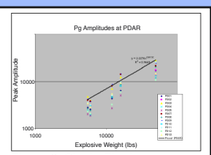


Figure 2: Single-Fired

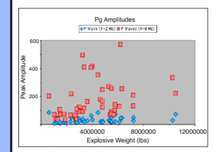


Figure 3: Iron Fragmentation

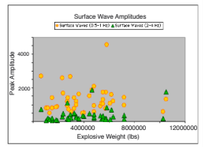


Figure 4: Iron Fragmentation

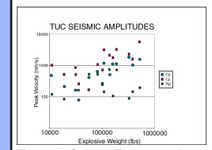


Figure 5: Copper Fragmentation

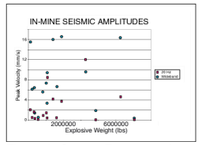
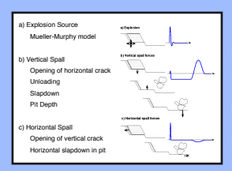
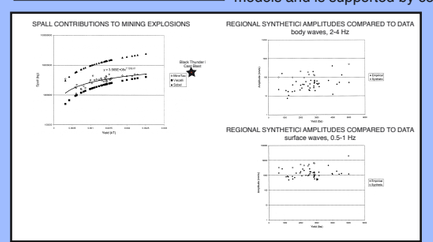


Figure 6: Copper Fragmentation

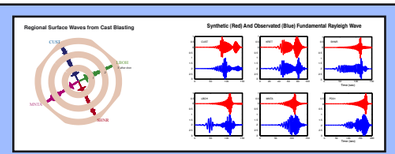
MODELING



An equivalent elastic source model for the mining explosion is used to develop regional synthetics. The source model components shown to the left include: (a) explosion; (b) vertical spall; and (c) horizontal spall. The timing of the explosive pattern is also included. In the box below is the empirical scaling relation for mining explosion spall developed from observations at Minntac. The data fall between the Sobel and Viecelli scaling models and is supported by coal cast data (red star).



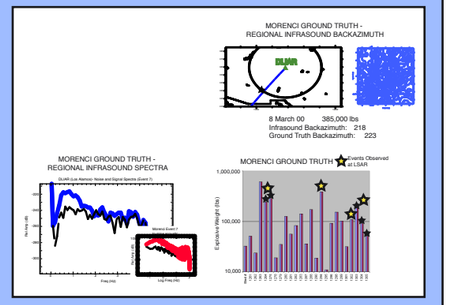
The source model above in conjunction with a regional propagation model was used to produce synthetics for the Minntac taconite fragmentation blasts. The models are able to replicate the insensitivity of peak amplitudes to total amount of explosives in the blast.

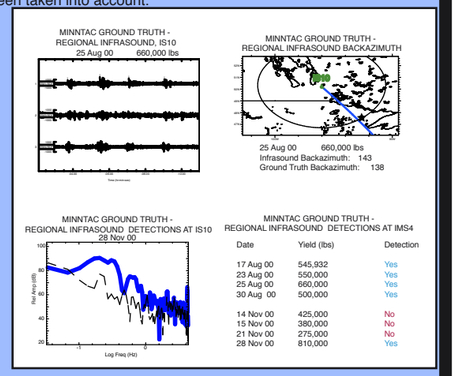


Large scale coal cast blasting produces regional surface waves in the 5-12 s period range. A regional velocity model is developed from the dispersion. This propagation model in combination with the above source model replicates the regional surface waves.

SEISMO-ACOUSTIC

Infrasound signals have been reported to accompany mining explosions and may provide a source diagnostic. Critical to the interpretation of the infrasound data is the association with regional seismic observations as well as linkage to source information for interpretation. Coupling issues must be assessed as well as models related to atmospheric propagation and source physics. Ground truth from within two mines (Morenci and Minntac) provide the neccesary source constraints. Preliminary results from Morenci (bottom left) and Minntac (bottom right) are illustrated below. Both mining operations regularly generated seismic and infrasound signals. Regional infrasound signals from 7 of 25 ground truth events at Morenci in February 00 were observed. Only explosions above 100,000 lbs were observed but not all large explosions. The frequency content of the infrasound signal was 1-3 Hz. Backazimuth estimates, as demonstrated in the example, were within 5 degrees of the actual. Two time-periods (August and November 00) produced infrasound signals for 5 or 8 Minntac explosions. Backazimuth estimates were within 5 degrees of the actual. The frequency content of infrasound signals from the Minntac explosions extended from 10s to several Hertz. All explosions over 500,000 lbs generated infrasound. In both cases the well known effects of seasonal winds in the infrasound propagation have not been taken into account.

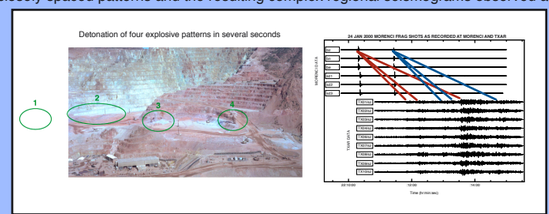




Date	Yield (lbs)	Detection
17 Aug 00	545,932	Yes
23 Aug 00	550,000	Yes
25 Aug 00	660,000	Yes
30 Aug 00	500,000	Yes
14 Nov 00	425,000	No
15 Nov 00	380,000	No
21 Nov 00	275,000	No
28 Nov 00	810,000	Yes

UNUSUAL EVENTS

Close-in observations provide source constraints that can be used to interpret regional seismic and infrasound signals. Morenci often detonates multiple shot patterns over very short time spans (seconds). The photo below left documents four patterns that were detonated at close time spacing. Below, right, are in-mine seismic and acoustic records (top six waveforms) from two closely spaced patterns and the resulting complex regional seismograms observed at TXAR.



Infrasound signals (below, left) from the explosion and subsequent burning of a gas pipeline explosion. Data from all three acoustic and one seismic sensors in the array are displayed in ten minute segments. The pipeline burned for over 40 minutes. Details of the infrasound signal are compared to near-source seismograms (bottom, right) illustrating that the complex nature of the explosion is reflected in the infrasound and seismic data. The gas pipeline explosion produced no regional seismic signals at TXAR.