AN ANALYSIS OF LARGE MINING BLASTS IN WYOMING AND CENTRAL ASIA

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ABSTRACT

We have conducted a preliminary analysis of kiloton class, anomalous, mining blasts in Wyoming using IMS seismic data. This research has begun on two fronts. We are examining well documented mine blasts in the Powder River Basin trend in Wyoming using the Pinedale seismic array (PDAR) and the single station ULM. These data are being used with near-regional video, seismic and acoustic data collected by UCSD, LANL, SMU and AFTAC during field experiments in 1996 and 1997. These data are being used to examine differences in the waveforms of mining blasts that are essentially co-located, and detonated with similar planned blasting grids, but for which some have included a significant detonation anomaly (otherwise known as a sympathetic detonation). We are examining coherent and incoherent beams of Pinedale array data in an attempt to detect the large detonations. We are using physical modeling in an attempt to reproduce the waveforms of the anomalous blasts. Our main goal with the modeling is to estimate the explosive yield and timing of the detonation anomalies.

Kiloton class mine blasts are not uncommon in numerous regions worldwide such as Wyoming, Kentucky and, at least historically, the Kuzbass mining region in Russia. Recordings of large blasts in the Kuzbass mining region exhibit time- and frequency-domain characteristics below 10 Hz that are similar to those observed in the Wyoming events. In specific, these features include enhanced surface waves and spectral modulations. We tentatively conclude that the discrimination methods we have found to be useful in Wyoming can also be used in this region. In collaboration with Vitaly Khalturin (LDEO) we are seeking ground truth information on large mining blasts in the Altay-Sayan mining region. This exploratory phase will be followed by physical modeling of the events for which we are able to secure adequate ground truth information.

Key Words: sympathetic detonation, ground truth, spectral modulations

OBJECTIVE

To develop high- and low-frequency seismic techniques to characterize mining explosions and discriminate these events from single explosions and earthquakes. The focus is on mining explosions that detonate as planned and on mining explosions which contain significant detonation anomalies. Our focus has been on spectral modulations and surface waves that will commonly propagate beyond near-regional distances to stations in the IMS monitoring network. We use physical modeling to identify the source processes that give rise to these signals.

This paper summarizes our research on low-frequency signals produced by significant (> 1 kT) anomalous mining explosions in Wyoming. We also report preliminary results from our analysis of Altai-Sayan mine blasts recorded since January 1, 1995 by the IMS seismic station ZAL near Zalesovo, Russia.

RESEARCH ACCOMPLISHED

Wyoming Seismicity

It is not uncommon for mining events to be reported in the PDE catalog. One region where large (> 1 kt of explosive yield) blasts are common is the Powder River Basin coal mining trend in Wyoming. Ther eis little natural seismicity in this area however a plot of event locations taken from the REB shows how mining activity in the Powder River Basin dominates the event catalog (Figure 1). Most of these events were assigned a body were wave magnitude above 3.0 and occurred in the mid day (Figure 2)

All of the large mining events in this catalog used delay-firing and thus a considerable explosive yield is spread out over several seconds and seismic amplitudes are reduced. It is well known that minor deviations from the planned shot pattern are obiquitous. A small subset of these events, however, include a significant detonation anomaly. For reasons as yet not fully understood, a number of shot holes do not detonated at their planned times but detonate simultaneously

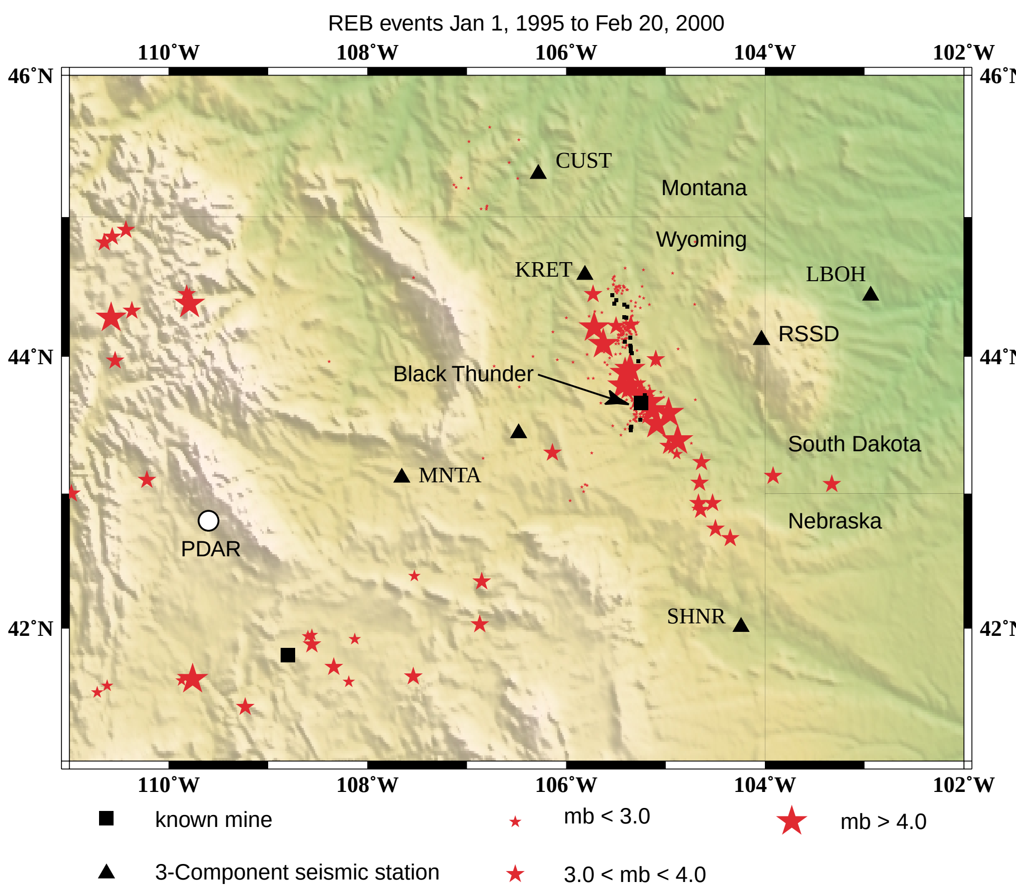

Figure 1. Two regional experiments were conducted in Wyoming by LANL, SMU, AFTAC and UCSD in 1996 and '97. Four broadband seismic stations (3-component STS2's) were deployed in a ring surrounding the Powder River Basin (PRB) at a range of 200 km from the Black Thunder coal mine. A fifth station (KRET) was deployed to the northwest at a range of 100 km. Permanent seismic stations are located at PDAR and RSSD. Mining explosions reported in the PDE catalog between Jan 1, 1995 and Feb 20, 2000 are plotted and correlate well with known mines.

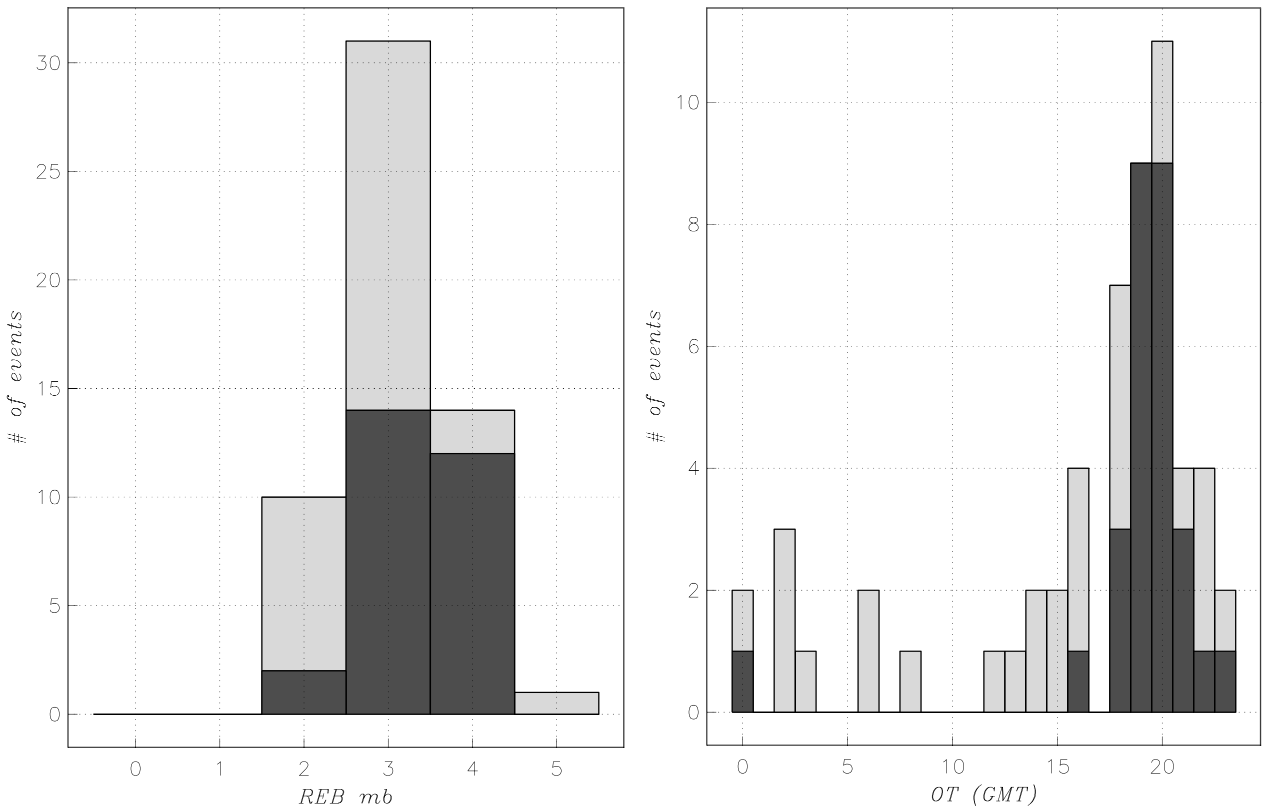

Figure 2. Body wave magnitudes (left) and event origin times (right) as reported in the PDE catalog. Events in these histograms are plotted in Figure 1.

(Martin et al., 1997). From a monitoring perspective, these events are the most important as the singular release of energy might be regarded by some as the signature of a masked test.

We have investigated these events with the intent of developing the means by which seismic data can be used to identify them as non-nuclear. An important first step in this process is identifying events which are anomalous is to develop the means by which the explosive yield of the sympathetic detonatinon can be constrained.

Analysis of detonation anomalies

Physical modeling of normal, and anomalous, mining blasts can be accomplished given the early work of Barker et al. (1990, 93) and McLaughlin et al. (1994) and recent work by X. Yang who has modified the linear elastic algorithm of Anandakrishnan et al. (1997) and packaged it into an interactive MATLAB package (MineSeis; Yang, 1998). The algorithm assumes the linear superposition of signals from identical single-shot sources composed of isotropic and spall components. Both shooting delays and location differences among individual shots are taken into account in calculating delays of the superposition, although the Green s functions are assumed to change slowly so that a common Green s function is used for all the single shots. We used a reflectivity method to calculate the Green s functions. A 1-dimensional velocity model was used (Prodehl, 1979; Anandakrishnan et al., 1997).

We have used the MineSeis code to model one event which detonated anomalously. The event occurred on Aug 1, 1996 in the Black Thunder coal mine and involved 2.5 million pounds of ANFO (Hedlin et al., 2000; Figures 3 and 4 in this paper). The event included a significant detonation ~ 1.75 into the shot sequence. The simultaneous detonation boosted the body wave magnitude to 4.0 (PDE catalog). Photos taken from a nearby vantage point (Figure 3) give clear, visual, evidence of a singular detonation within this shot sequence.

Incoherent beams from the Pinedale seismic array (PDAR; Figure 1) reveal a strong resemblance between a 40,000 pound single shot (top trace in Figure 5; Stump et al., 1999) and the August 1 event. The calibration shot compares less well with a routine 4.5 million pound cast blast and one that used 8.3 million pounds but also is known to have included a simultateous detonation (B. Stump personal communication).

FIGURE 3. Three photos of the August 1, 1996 Black Thunder cast blast. The start at 19:33:05 (top), 1.7 seconds later (middle) and the finale at 19:33:09. The significant release of energy into the air resulted from a sympathetic detonation which occurred part way through the shot sequence.

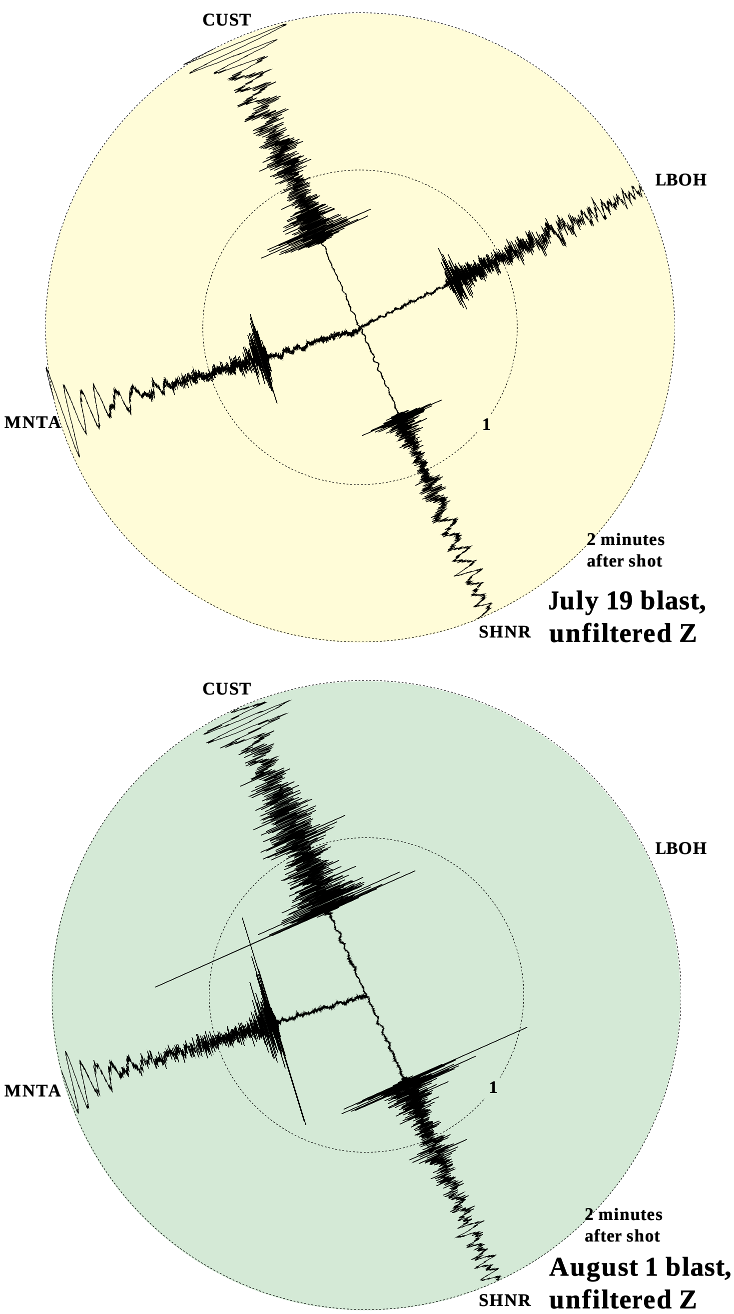

Figure 4. Vertical component recordings of a 4.5 million pound Black Thunder blast (top) and a 2.5 million pound blast at the same mine (bottom). The latter event included a significant detonation anomaly that boosted the body wave magnitude, as reported in the PDE, to 4.0.

Physical modeling of the August 1 event indicates that as few as 5 of the subshots (37,000 pounds total yield) are required to detonate simultaneously in order to explain the boosted body wave am plitudes (Figure 6). This estimate is almost certainly low as the modeling code assumes that all shots are perfectly coupled. The degree of decoupling that results from rock fracturing is, as yet, not well constrained.

Altai-Sayan events

The mines in the Altai-Sayan region in western Siberia produce 100 to 200 blasts each year with a magnitude of 3.5 or above (Khalturin et al., 1997; Figure 7). Of these, ~ 2 each year have a magnitude above 4.0 (Khalturin et al., 1997). This region includes the Kuzbass mine (~ 200 km SE of Novosibirsk) and the Abakan mine. This region is believed to generatethe most energetic seismic signals of all regions in Russia (Khalturin et al., 1997). The mines are believed to be extracting coal. The high magnitudes likely result from shooting entire rows of shots with no delay in each row (Paul Richards pers. comm.).

Stations in the network operated by the Siberian Branch of Russian Academy of Science give a more complete picture of seismicity in this region. Using the empirical relationship between event magnitude and energy class (k) mb = .44K-0.80 (Vitaly Khalturin, personal comm.) we find that a significant number of events in this region are expected to have a body wave magnitude of above 3.0 and that most events occur during local working hours (Figure 9).

Despite having essentially no ground truth information, we have examined events in this region to determine if the methods that appear to be effective in Wyoming also work here. What follows is a preliminary study of 18 events that were recorded at the IMS station ZAL from Jan 1, 1995 to July, 1999. Event and mine locations are shown in Figure 8.

Recordings by the long-period sensor at ZAL reveal that a significant surface wave packet is produced routinely by large mining blasts in this region. The surface wave appears at all ranges to at least 225 km (Figure 10).

The mine blasts also commonly produce significant spectral modulations below 20 Hz (Figure 11). The modulations are typically spaced at

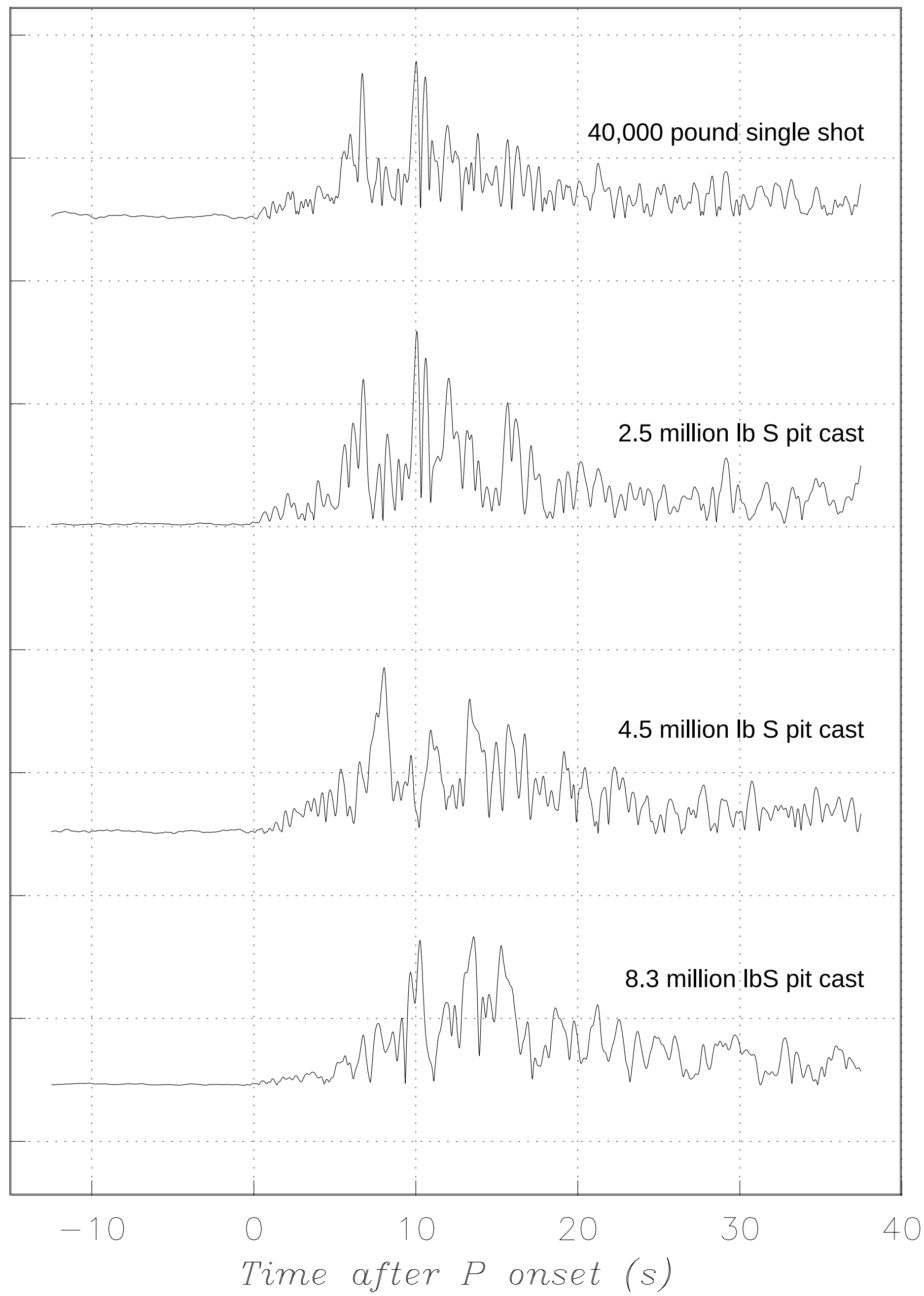

Figure 5. Incoherent beams from events Black Thunder coal mine events recorded by the Pinedale seismic array (PDAR). The top trace is taken from PDAR recordings of a 40,000 calibration sho that occurred in 1995 (Pearson et al., 1995; Stump, 1995). The next three traces are incoherent beams from large cast blasts. The upper and lower cast blasts are known to have included significant simultaneous detonations. The 2.5 million pound cast blast occurred on Aug 1, 1996 and is discussed in more detail in Hedlin et al. (2000). The incoherent beam from this event is matched, almost exactly, by the beam from the calibration shot indicating the significance of the anomaly. The 4.5 million pound shot (July 19, 1996) is believed to have detonated normally. The 8.3 million pound cast blast has been documented by Stump et al. and is known to have included a detonation anomaly ~ 4 s into the shot sequence - a delay that is seen clearly in the incoherent beams presented here. The weaker correlation of this beam with that taken from the calibration shot suggests a smaller explosive yield in the simultaneous detonation relative to the yield of the overall shot.

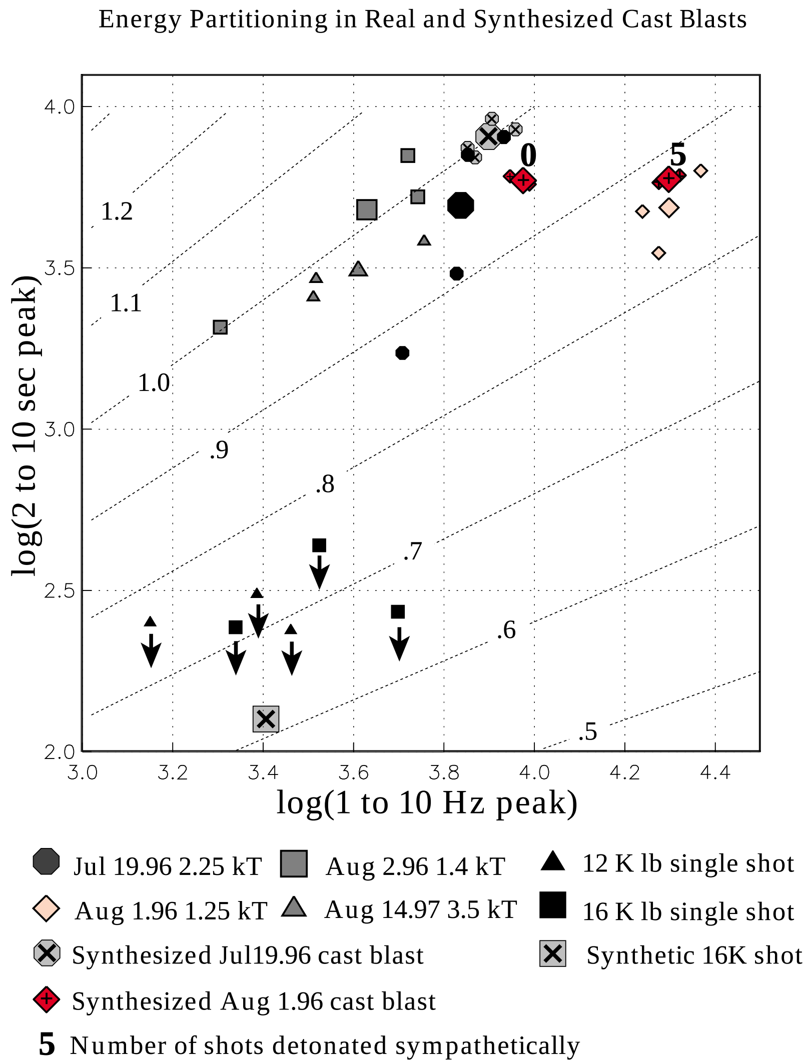

Figure 6. A comparison of 2 to 10 second surface wave and 1 to 10 Hz P wave peak amplitudes using recordings made at a range of 200 km by MNTA, CUST, LBOH & SHNR (Figure 1 in this paper; Hedlin et al., 2000). All events occurred in the Black Thunder coal mine. Each trace is filtered, converted to an envelope and adjusted downward by an amount determined by pre-onset noise. Above are displayed the logarithms of the individual station peak amplitudes. The large symbols represent the network average for each event. Each labeled curve indicates a constant ratio of surface wave to *P* wave amplitude [*i.e.* log(2to10s peak)/log(1to10Hz peak)]. As expected the calibration shots yield essentially no surface wave energy above noise. The downward arrows indicate that the maximum *P* wave amplitude is well constrained but the surface wave amplitude lies below noise. For this reason, no network averages are displayed for these events. The Aug 1.96 cast shot appears as being somewhat explosion-like due to the sympathetic detonation. The sympathetic detonation greatly boosted P wave amplitudes but left the surface waves untouched. Unadjusted amplitudes are plotted as all stations are at the same range from the mine. We also display peak amplitudes from a synthetic version of the July 19 cast blast, from a synthetic 16,000 pound calibration shot and an event that matches the August 1 planned grid but includes 5 shots that detonate simultaneously. The energy partitioning from the synthetic events is in agreement with observations.

~ 5 Hz and suggest an interrow time spacing of ~ 200 msec.

CONCLUSIONS AND RECOMMENDATIONS

We have focused on large mining events in Wyoming as ground truth data in that region is relatively easy to obtain. Several analyses of data from this region indicate that large mining events in this region produce distinctive surface waves and spectral modulations. We have used physical modeling to further the link between these observations and processes at the mine (Hedlin et al., 2000).

From our preliminary analysis of Altai-Sayan mining events we believe that there is strong evidence that the methods that have proven to be effective for characterizinglarge mining events in Wyoming will also be useful in the Kuzbass mining region of Russia. Most Russian mine blasts produce spectral modulations and surface waves that are recorded by the IMS station ZAL. These observations remain tentative as we do not have ground truth information to constrain these events. We have begun a collaboration with Vitaly Khalturin (Lamont) under which we will strive to strengthen communication links between our groups and mining experts in the Kuzbass region.

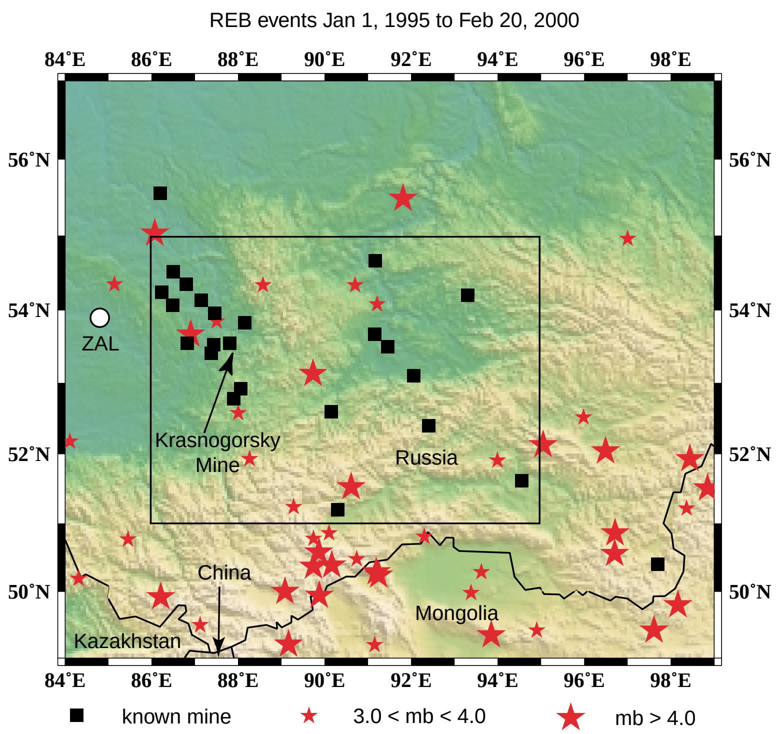

Figure 7. Events reported in the REB catalog between Jan 1, 1995 and Feb 20, 2000 are plotted with known mine locations in the Kuzbass region of Russia. The event locations do not correlate with known mining activity.

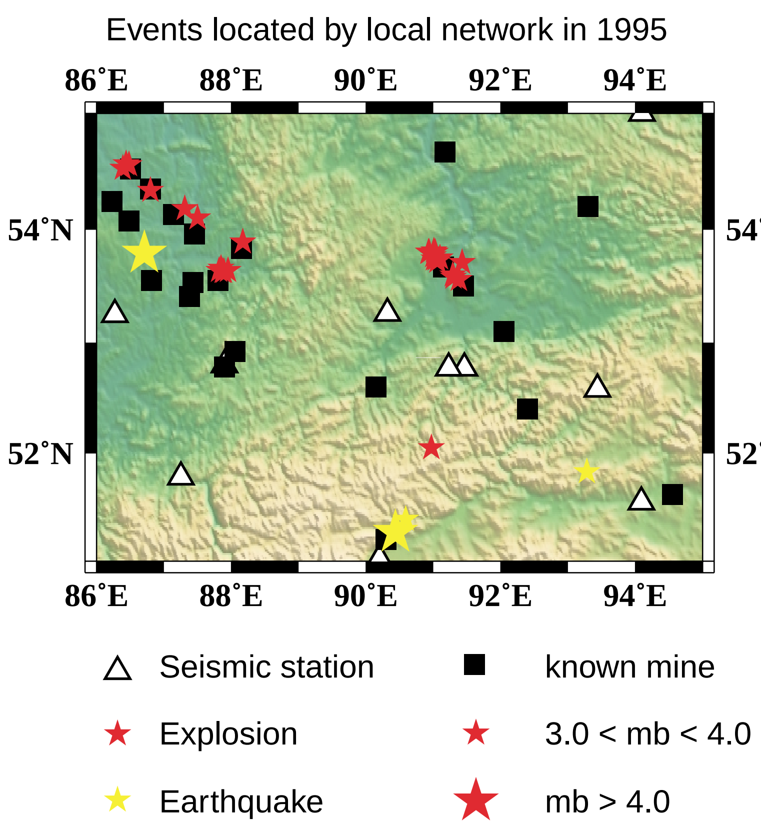

Figure 8. Events detected by the 16 station network in the Kuzbass region. Of the 16 stations, one (ZAL) is part of the IMS. The others are part of the Altay-Sayans Seissmological Expedition of the Siberian Branch of Russian Academy of Science. Body wave magnitudes were estimated from the energy class ratings using .mb = .44K-0.80 (Vitaly Khalturin, personal comm.) Significant events located using the dense network correlate well with known mines. All mine and event locations/magnitudes were generously provided by V. Khalturin.

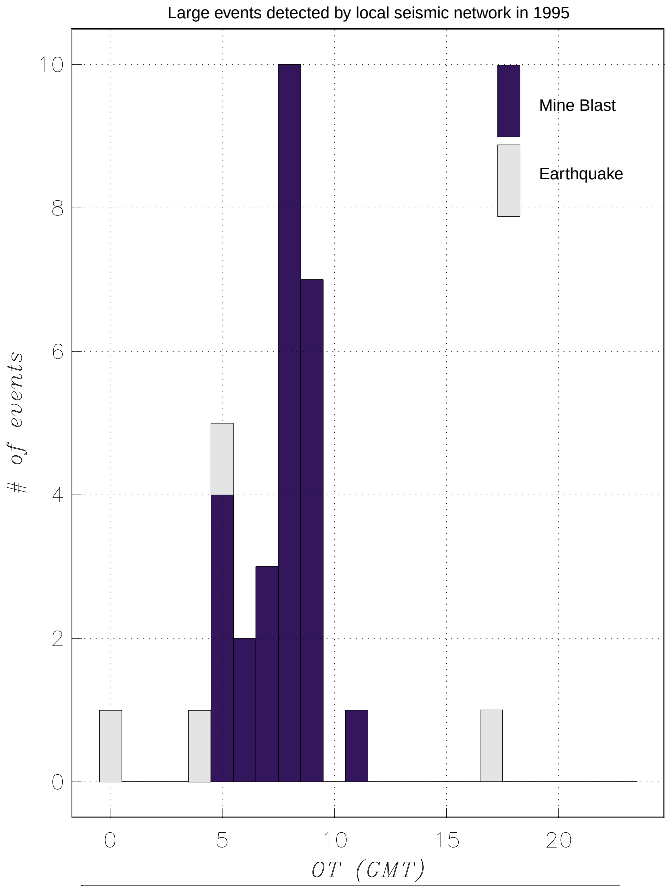

Figure 9. Histogram of origin times of events presented in Figure 8.

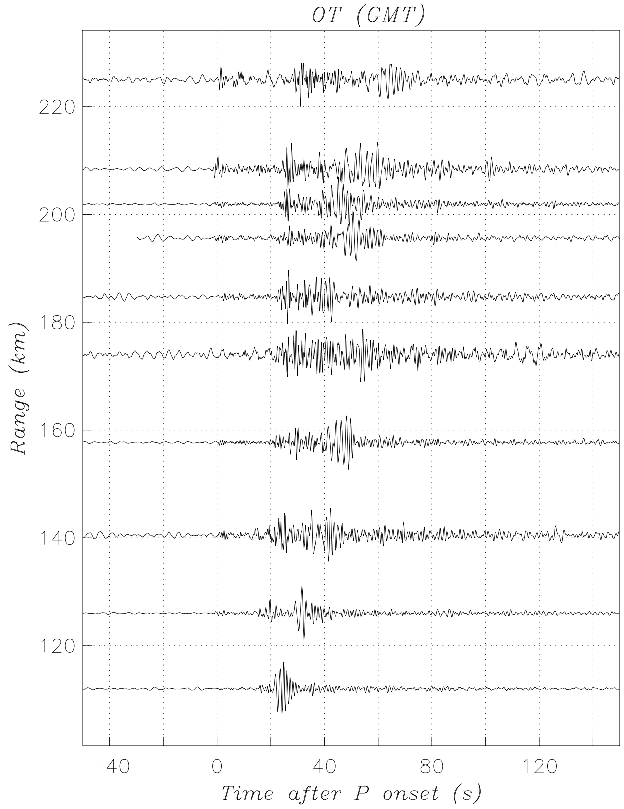

Figure 10. Recordings of Kuzbass mining events made by the MHZ long-period channel at the IMS station ZAL. Large surface waves are seen in most recordings.

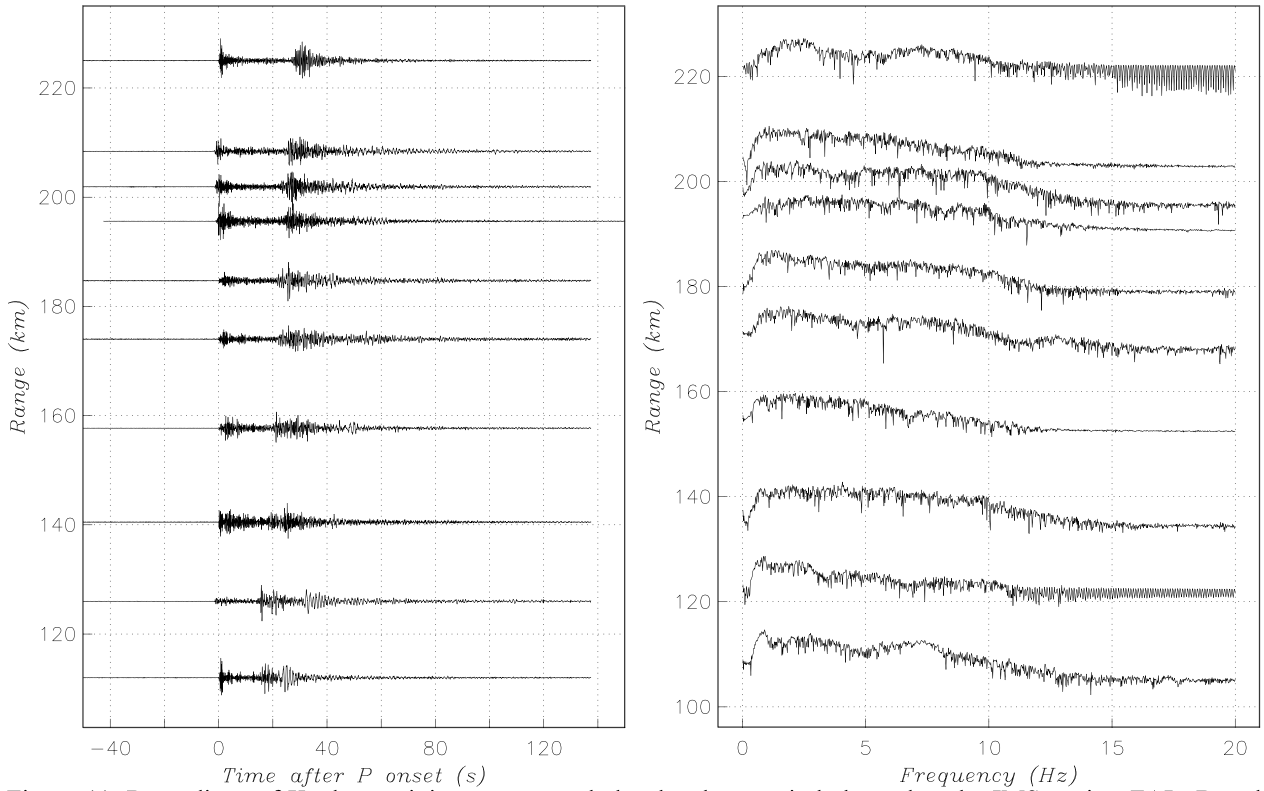

Figure 11. Recordings of Kuzbass mining events made by the short period channel at the IMS station ZAL. Broad spectral modulations are seen most of the events.

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