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THE LANL/LLNL/AFTAC BLACK THUNDER COAL  
MINE REGIONAL MINE MONITORING  
EXPERIMENT

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# THE LANL / LLNL / AFTAC BLACK THUNDER MINE REGIONAL MINING BLAST EXPERIMENT

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## ABSTRACT

Cast blasting operations associated with near surface coal recovery provide relatively large explosive sources that generate regional seismograms of interest in monitoring a CTBT. This paper describes preliminary results of a series of experiments currently being conducted at the Black Thunder Coal Mine in northeast Wyoming as part of the DOE CTBT Research and Development Program. These experiments are intended to provide an integrated set of near-source and regional seismic data for the purposes of quantifying the coupling and source characterization of the explosions. The focus of this paper is on the types of data being recovered with some preliminary implications. A companion paper (Stump, 1995) discusses the mining practices in this mine and the Powder River Basin in general where the mine is located.

The Black Thunder experiments are designed to assess three major questions:

- A. How many mining explosions produce seismograms at regional distances that will have to be detected, located and ultimately identified by the National Data Center and what are the waveform characteristics of these particular mining explosions?**
- B. Can discrimination techniques based on empirical studies be placed on a firm physical basis so that they can be applied to other regions where we have little monitoring experience?**
- C. Can large scale chemical explosions (possibly mining explosions) be used to calibrate source and propagation path effects to regional stations? Can source depth of burial and decoupling effects be studied in such a controlled environment?**

With these key questions in mind and given the cooperation of the Black Thunder Mine, a suite of experiments have been and are currently being conducted. This paper will describe the experiments and their relevance to CTBT issues.

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## EXPERIMENTAL PURPOSE

As discussed by Stump (1995), the Black Thunder Mine conducts large cast blasts with explosive loads on the order of 2,000,000 to 5,000,000 lb. on an interval of between two and four weeks. In addition, explosive shots are conducted on a daily basis in the coal in order to fracture the material at approximately a factor of ten smaller total charge. An experimental plan was developed to: (1) Quantify the amplitude and spectral differences of the cast and fracturing blasts; (2) Document the development of the seismic wavefield from close-in to the explosion at high bandwidth to regional distances at lower bandwidth; (3) Determine possible azimuthal effects that may result from the blasting geometry and affect regional observations which often sparsely sample the wavefield; (4) Investigate the utility of a small, high frequency array within a mine for monitoring blasting activity in the mine and at other mines in the region and (5) Characterize the differences in seismograms from these mining sources and single fired concentrated charges.

An array was deployed in and around the Black Thunder Mine for approximately a three month time period in order to address the above issues. These data are being combined with regional signals for the same events cataloged at the Pinedale Seismic Research Facility (PSRF, 360 km to the SW) and the US National Network Station RSSD (150 km to the northeast). In addition three portable deployments of regional stations were completed by LLNL personnel.

The near-source array consisted of three component velocity instruments with natural frequency of 1 Hz. A 16 station azimuthal array with a radius of approximately 2.5 km was fielded for a large cast blast on 16 June, 1995. These data are being used to quantify the radiation pattern induced by the mine and the blasting practices (3). Two linear arrays of 3 stations each at ranges of 1, 2.5, and 5 km were deployed in the directions of PSRF and RSSD. These stations, in conjunction with three additional portable regional stations, provided the data for quantifying the transition of the wavefield from close-in to distances typical of CTBT monitoring (2). Eleven additional stations were deployed on mine property to form a regional array with interstation spacings ranging from 40 m to 15 km. Each data acquisition system was continuously locked to its GPS clock to provide the necessary timing accuracy for array processing. The purpose of this last component of the experiment was to quantify blasting activity inside the mine as well as provide data for quantifying explosions at other mines in the Powder River Basin (4).

During the three months of the deployment the mine is conducting many explosions so the effects of different blasting practices can be quantified (1). An example of the activity are two casting shots in the south pit conducted on 16 and 23 June 1995. Individual explosive columns in the casting shots range from 3000 to 5000 lb with some holes loaded to as much as 10,000 lb per hole. Borehole diameters are predominately 10.625 inches with some boreholes drilled at 12.25 inches diameter. Typical overburden casting patterns consist of 700 to 1500 individual holes. Timing delays currently used are 100-200 ms between rows with 17 or 35 ms delays between holes in a row. Down hole delays of up to 1400 ms are used to prevent premature disconnection of the firing system at the surface.

A set of explosive product test holes will be detonated in the near future in close proximity to the two production cast shots described above. These test holes will be fired simultaneously to provide an impulsive source for the CTBT mining blast wave propagation experiments (5) while providing the mine personnel with valuable information concerning explosive performance. The total amount of explosive emplaced in the test hole shot is expected to be in on the order of 100,000 lb.

## **LOCATION OF THE EXPERIMENT**

The Black Thunder Mine is located in the Powder River Basin approximately 50 miles south-southeast of Gillette, Wyoming (see Stump, 1995 for a discussion of the Powder River Basin). The mine is operated by the Thunder Basin Coal Company, a subsidiary of ARCO. Experimental design and implementation has been facilitated by the excellent support of Mr. Bob Martin, Drilling and Blasting Manager and other personnel at the mine. Martin and King (1995) report that the mining operation is recovering coal from a 68 foot thick seam located under up to 120 feet of overburden. Cast blast explosions are used to remove the overburden which consists of weathered sandstone and mudstone.

An aerial photograph acquired on 11/23/94 is overlain on the land map provided by the Black Thunder Mine in Figure 1. Station locations, primary and secondary roads, and the locations of overburden cast shots and future single detonated test shots are also depicted in Figure 1.

## **QUANTIFICATION OF MAGNITUDE-YIELD RELATION AND BLASTING PRACTICES (1&2)**

The Black Thunder Mine shoots cast shots about every two to four weeks. They operate out of four pits with different geographical orientations (Figure 2). Some of the recent cast blasts demonstrate the size and frequency of the blasting operation: 2 Dec 94 (3,000,000 lb.); 15 Dec 94 (3,500,000 lb.); and 25 Jan 95 (2,000,000 lb.). In addition to these types of explosions, they typically shoot in the coal to break the material. The 14 Dec 94 Coal Shot was 68,890 lb. These coal shots can be quite large as exemplified by the 20 January 95 coal shot which was 700,000 lb. The frequency and variety of these explosions coupled with the fact that even the smallest of the above explosions was observed at the PSRF makes this blasting program ideal for identifying magnitude-yield relations in a controlled environment.

The near source and regional stations will be used to quantify the generation and evolution of the regional signals with range. The data gathered from this integrated experiment will provide a basis for assessing not only the size and nature of the regional signals at different ranges but possible variations in magnitudes from such events. We anticipate recovering data from approximately six overburden cast shots and as many as 50 coal fragmentation shots during this long term deployment phase of the study. The analysis of the regional signals from these events will be coordinated with AFTAC.

## **AZIMUTHAL RADIATION EFFECTS AND GENERATION OF REGIONAL SIGNALS (3)**

This portion of the Regional Mining Blast Wave Propagation experiment is designed to quantify the azimuthal variation in the seismic radiation in the near-source region and then link these observations with those at regional distances. Utilizing the motion field estimated from the 15 Dec 94 Cast Shot, the near-source azimuthal array described earlier was deployed (Figure 1). Sixteen near-source velocity gauges, all located within the mine property, were fielded with interstation spacing of 22.5 degrees at a range of approximately 2.5 km from the center of a large cast shot in the south pit. Figures 3, 4, and 5 depict the vertical, radial and transverse velocity seismograms recorded for the 16 June 1995 south pit cast blast. Time increases from the outer portion of the plot toward the middle with constant time demarcations every 5 seconds. The center of the figures shows a representation of the spatial extent of the cast shot and indicates the direction of propagation of the delay firing system. It is interesting to note that the largest amplitudes propagate at directions sub perpendicular to the free face of the pit which faces north. Instruments located in the northern half of the mine on previously mined and reclaimed surfaces show significantly smaller peak amplitudes and poorly developed surface wave components.

## **NEAR-REGIONAL SEISMIC ARRAY (4)**

There are twenty-two active coal mines in the Powder River Basin, several of which utilize cast blasting. This is the type of region that has been suggested for special instrumentation under a CTBT monitoring regime. As an example of the frequency of blasting in the region on 27 January 95 two explosions (one from the Black Thunder Mine) occurred within 5 minutes of one another in different mines (Vindell Hsu, personal communication).

Hsu reports that the first of these events had a  $m_b$  of 2.3 and the second 3.1. An unmanned deployment of a near-regional, high-frequency array in the Powder River Basin has been implemented. As noted earlier, the 17 element array provides a range of scale lengths from 40 m to 15 km. A recent maintenance trip to the array indicates that an average of 3-4 mining blast events per day are being detected. Work is in progress to locate the events and characterize them. This array of stations will remain deployed until after completion of a contained shot of approximately 100,000 lb. scheduled for late August 1995.

## **FULLY CONTAINED EXPLOSION (5)**

Comparison of the near-source waveforms from the Black Thunder Cast Shot and the NPE (Stump, 1995) suggests that at low frequencies the well coupled NPE is approximately an order of magnitude larger with the Cast Shot having more energy at high frequencies. This result is consistent with the magnitude estimates for the two sources. Unfortunately the NPE is in a different media, detonated in well saturated materials, and so the comparison cannot be relied upon for anything more than inference. The fact that the 14 Dec 94 Coal Shot (68,890 lb.) was recorded at PSRF suggests that a moderate size, contained, singly detonated, chemical explosion could be used to quantify similarities and differences between the delay fired cast shot and a

fully contained explosion. The success in modeling the NPE and the NPE CAL (Stump, Pearson and Reinke, 1995) further supports the use of the moderate size contained explosion.

Detonation of a moderate size (>50,000 lb.), singly detonated contained explosion has been explored with the mine. A target of opportunity has been identified since the mine is planning to conduct a series of explosive performance tests. They have agreed to fire all the explosive columns in each of two tests simultaneously, providing the CTBT Field Experiment with two large, contained shots. The depth of such an explosion would most likely be conducted at normal burial depths for an overburden cast shot (70 ft explosive column with 30 ft of stemming).

## REFERENCES

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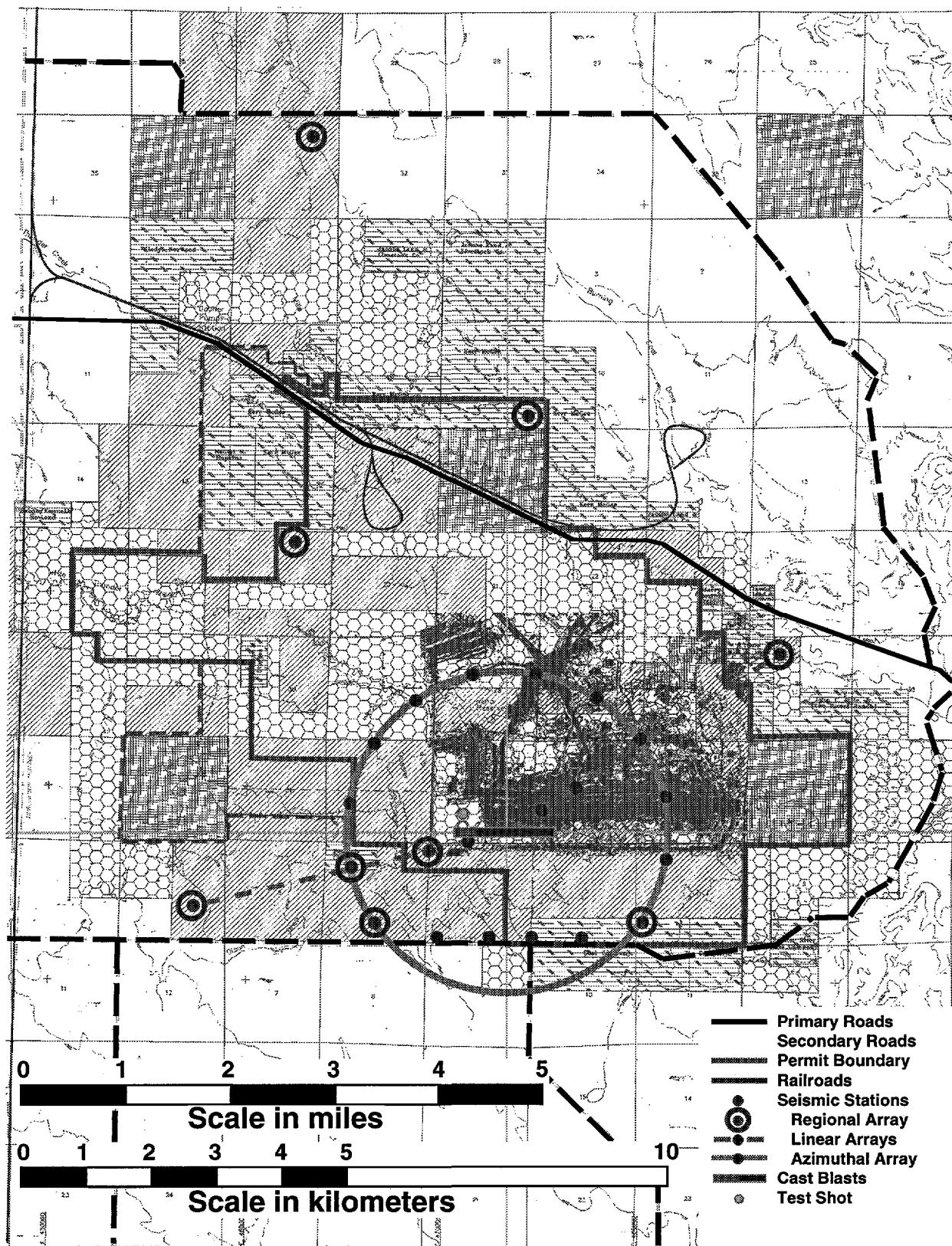


Figure 1. Experimental design for the azimuthal study. Seismic instruments were deployed in an azimuthal array on a 2.5 km radius circle centered on the first of the two overburden cast shots. Two linear arrays were deployed in the directions of Pinedale, Wyoming and RSSD in northwest South Dakota. A nine station regional array is shown, however, a total of 17 stations comprise the regional array which is being operated throughout the summer of 1995.

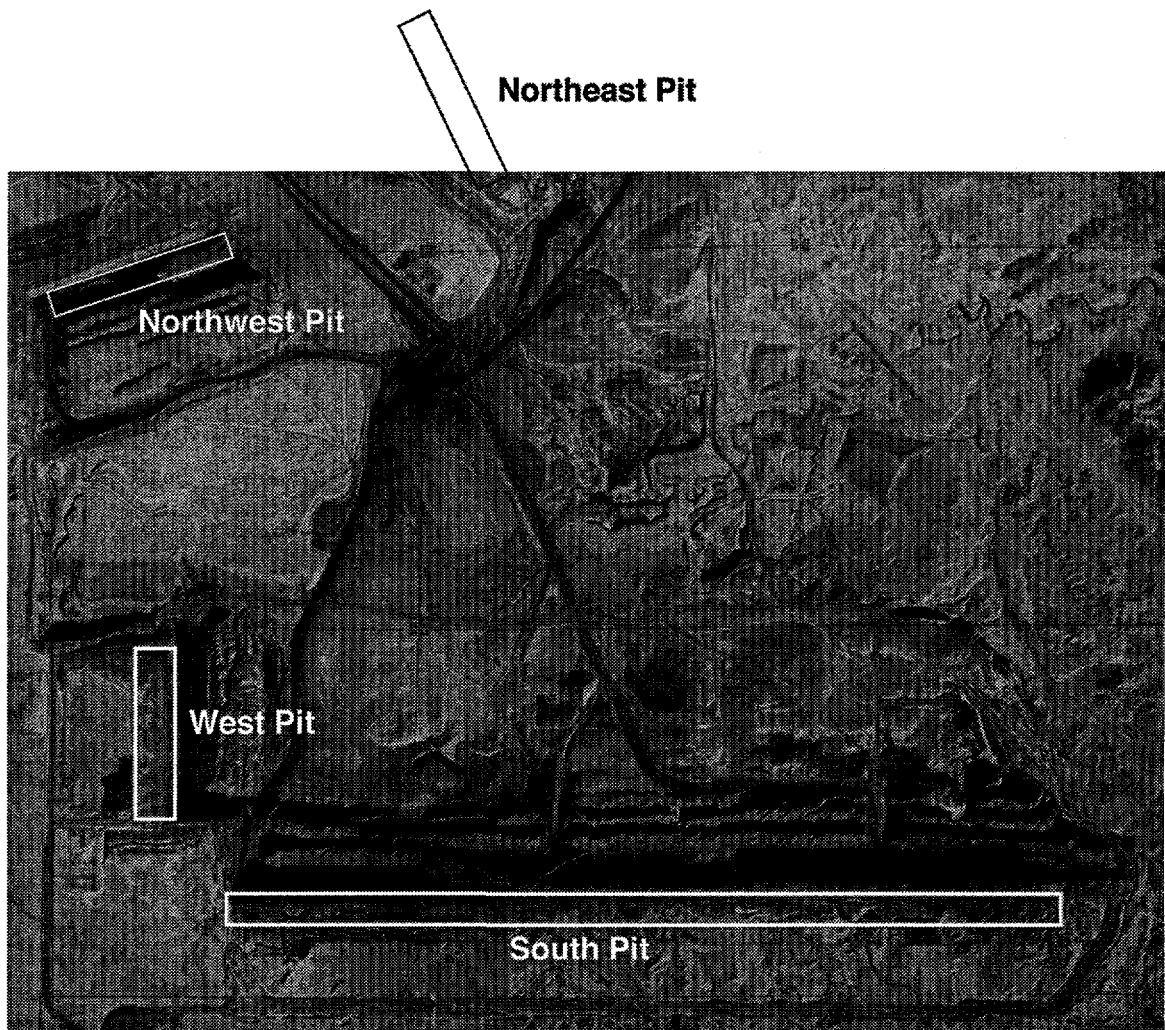


Figure 2. An overhead aerial photograph of a portion of the Black Thunder Mine in November, 1994. Outlines of the active pits in the mine show the variability of the strikes of the pits and indicate that azimuthal variation of the blasts radiation pattern could complicate regional locations and magnitude estimates.

Black Thunder Cast Shot 16 June 1995; Azimuthal Array Z Component

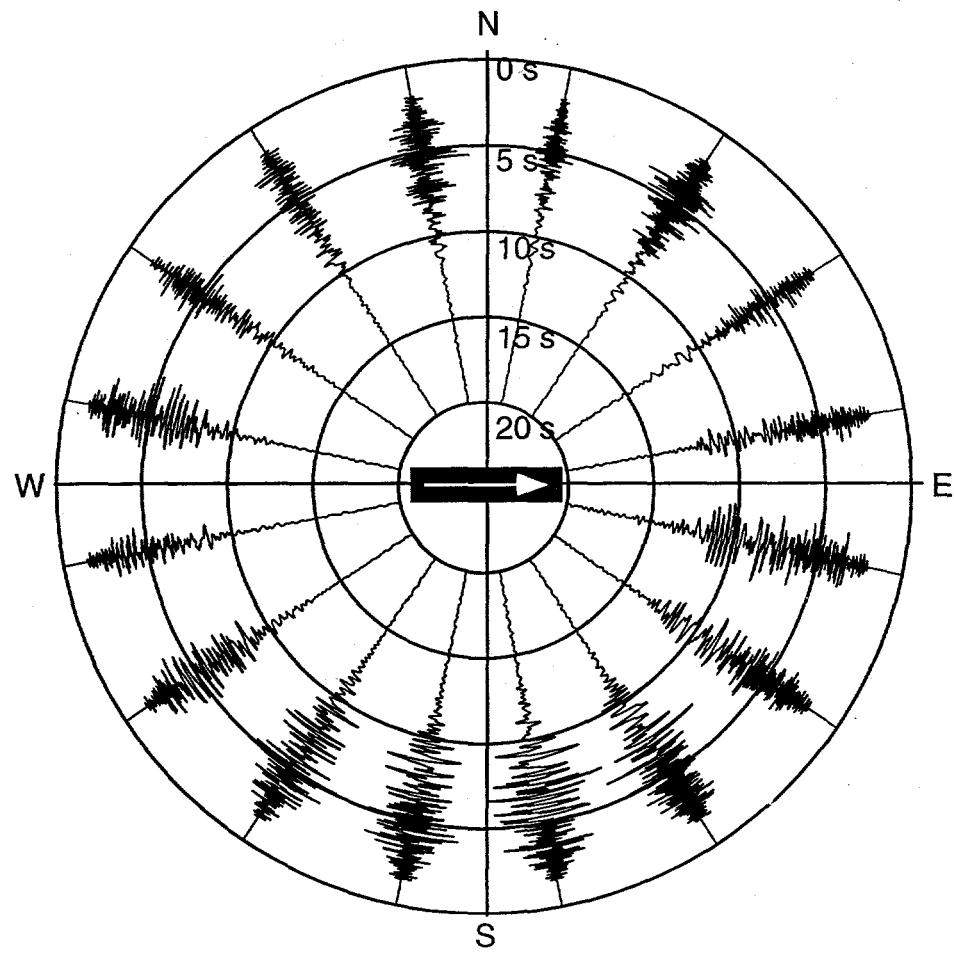


Figure 3. Vertical velocity seismograms centered on a 4.7 Mlb cast shot at the Black Thunder Mine on 16 June 1995. The orientation and shooting direction of the cast shot are indicated in the center of the figure.

Black Thunder Cast Shot 16 June 1995; Azimuthal Array R Component

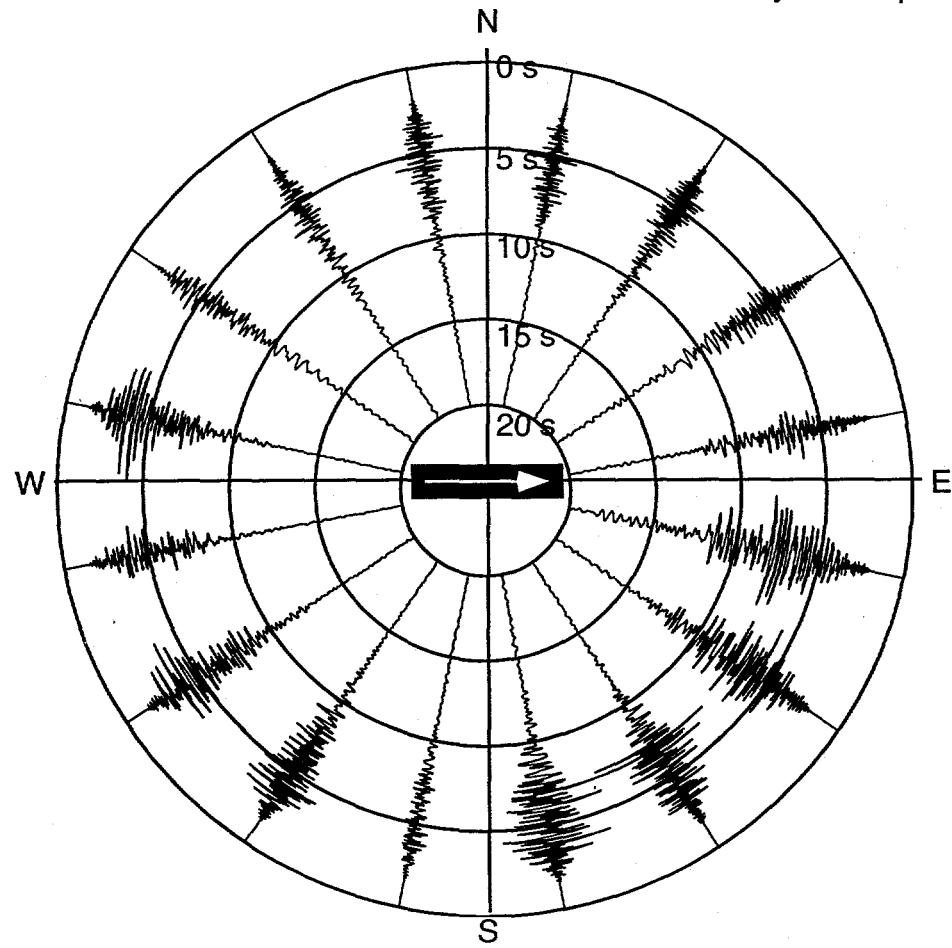


Figure 4. Radial velocity seismograms centered on a 4.7 Mb cast shot at the Black Thunder Mine on 16 June 1995. The orientation and shooting direction of the cast shot are indicated in the center of the figure.

Black Thunder Cast Shot 16 June 1995; Azimuthal Array T Component

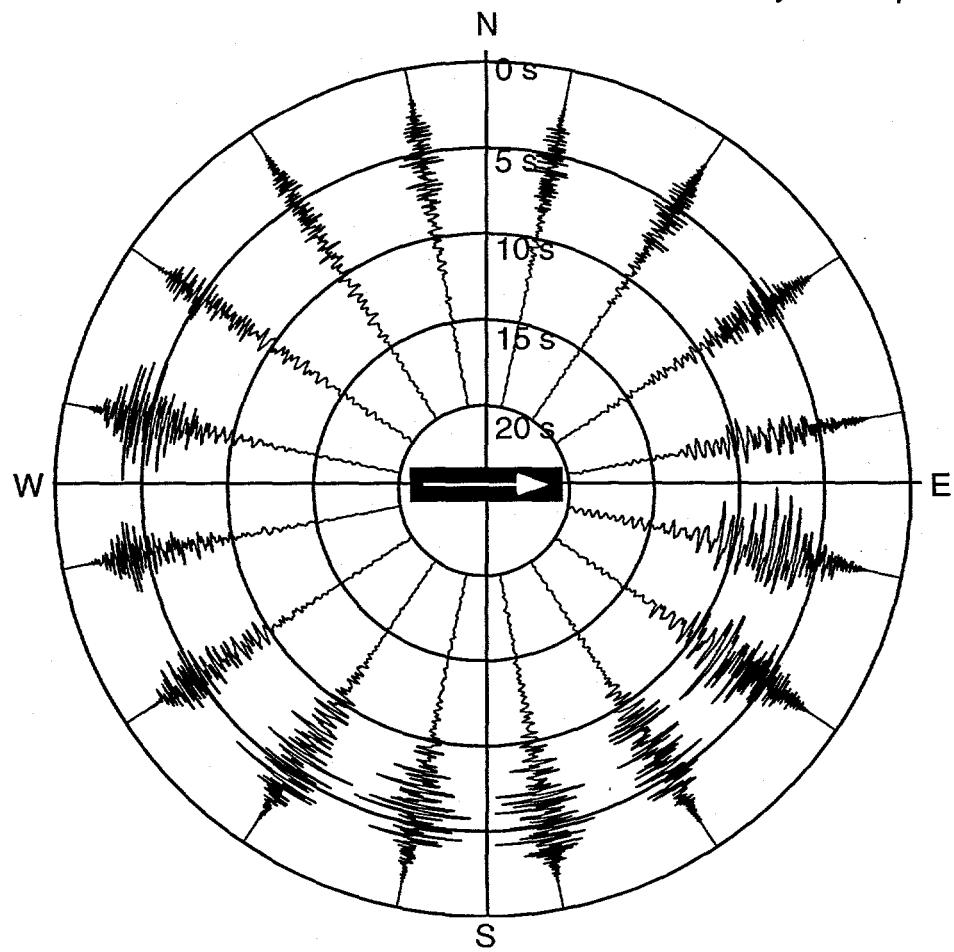


Figure 5. Transverse velocity seismograms centered on a 4.7 Mlb cast shot at the Black Thunder Mine on 16 June 1995. The orientation and shooting direction of the cast shot are indicated in the center of the figure.