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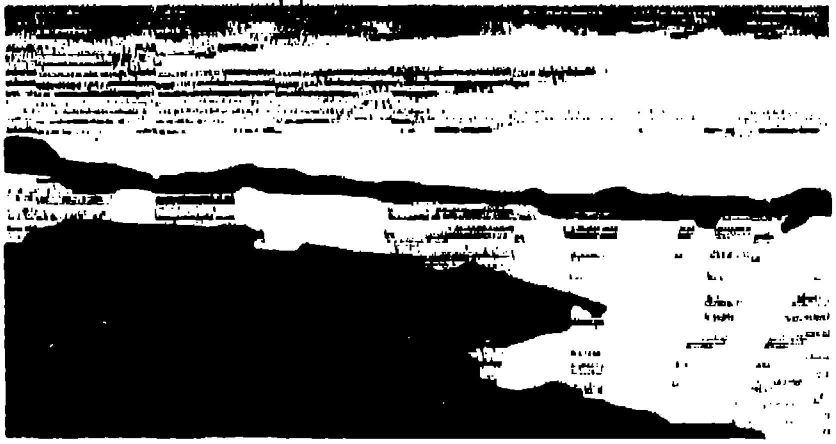

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THE WHITE PINE MINE EXPLOSIVELY INDUCED, CONTROLLED COLLAPSE EXPERIMENT

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ABSTRACT

On September 3, 1995, the White Pine Mine, which is owned by Copper Range Company, conducted the first of a planned series of explosive removal of existing pillars in their underground mining operations. The purpose of this operation is to evaluate the effectiveness of pillar rubbilization and roof collapse for planned in-situ leaching of the copper ore from the rock mass. This type of seismic source is unique in that a large, delay fired, explosive source was expected to be followed by collapse of the rock immediately above the explosion into the void created.

Characterization of this type of mining source is of interest to the CTBT R&D Seismic Program due to its unique properties. These include the controlled nature of the source in time, location, and magnitude, the fact that the source is located in an active region of underground mining, and that natural collapse of large portions of this mine have occurred in the recent past. The Mine operator is concerned with the characterization of the vibration induced by both the explosive and implosive components of the procedure and determination of the depth to which chimneying of the roof proceeded.

This report will document 1) the reasons for conducting both the explosively induced collapse and the Los Alamos National Laboratory CTBT R&D Experimental Field Program experiment, 2) the local and regional seismic, acoustic, and videographic data acquired, 3) analysis of the explosion/collapse seismic signal generated, 4) analysis and location of the aftershocks associated with the collapse, and 5) conclusions made concerning this type of mining explosion in relation to verification of a Comprehensive Test Ban Treaty.

Key words: induced, controlled, mine collapse, local and regional seismology

OBJECTIVES

The purposes of this experiment were to 1) document a type of mining activity which is engineered to produce regional seismic signals similar to unplanned mine collapse events (Taylor, S. R., 1994, Walter, W. R., *etal*, 1996) and 2) determine the locations and temporal occurrence of aftershocks induced by the pillar removal process.

RESEARCH ACCOMPLISHED

THE MINE

The White Pine Mine is located near Lake Superior on the Upper Peninsula of Michigan in the vicinity of the town of White Pine, Michigan. The southern shore of Lake Superior is approximately 9 kilometers to the north of the townsite. The area is sparsely populated. Tourism, harvesting of pulp wood for paper milling, and declining levels of copper mining are the major industries in the area.

The terrain varies from relatively flat lake coastal regions incised with small rivers at elevations ranging from 600 to 110 feet above sea level to semi-mountainous to the west and south with elevations ranging from 1100 to 1800 feet. Vegetation is dense and poses a high degree of hardship for deployment of seismic equipment. Weather conditions are also extreme with high temperatures and humidity in the summer and very low temperatures and large amounts of lake effects snow pack in the winter.

The primary mineral being mined is copper which was hydrothermally emplaced into folded and faulted, low grade metamorphosed, meta-sandstones and meta shales of Cambrian age. Figure 1 shows a map view of a model of the local geological structure at the horizon of the ore body. The well known White Pine Fault is a large normal fault that strikes at 131 degrees (South-east) and dips steeply at 221 degrees (South-west) and is evident in the lower left quadrant of Figure 1. The White Pine fault dissects a large anticlinal structure which plunges at approximately 10 degrees along a strike of approximately 130 degrees (South-east).

The underground workings at the mine, shown as a map view in Figure 2, are extensive, with rough dimensions of 8 km by 9 km. Historically, portions of the mine have collapsed "naturally" and are denoted by dark black areas in the figure. The naturally collapsed area in the north central portion of the mine has collapsed slowly over a period of many years. The collapsed area south west of the White Pine Fault failed catastrophically, producing a locally felt earthquake and extensive damage to underground mine structures (St. Don, personal communication 1995). The controlled collapse documented here is the first of its type in the White Pine Mine.

Recently discontinued operations at the mine relied on ore removal by the room and pillar mining technique with subsequent movement of the ore to the surface for processing. A number of factors have led to the recent decision to discontinue the room and pillar operation and to begin investigation into the effectiveness of pillar rubblization and in-situ leaching of the ore body remaining in the pillars.

The initial pillar removal operation was conducted on September 3, 1995 at 5:39 PM local time (246:21:39:38 UTM). Prior to the shot, LANL personnel fielded a seismic network designed to characterize the near source wave propagation effects and to determine the locations of aftershocks

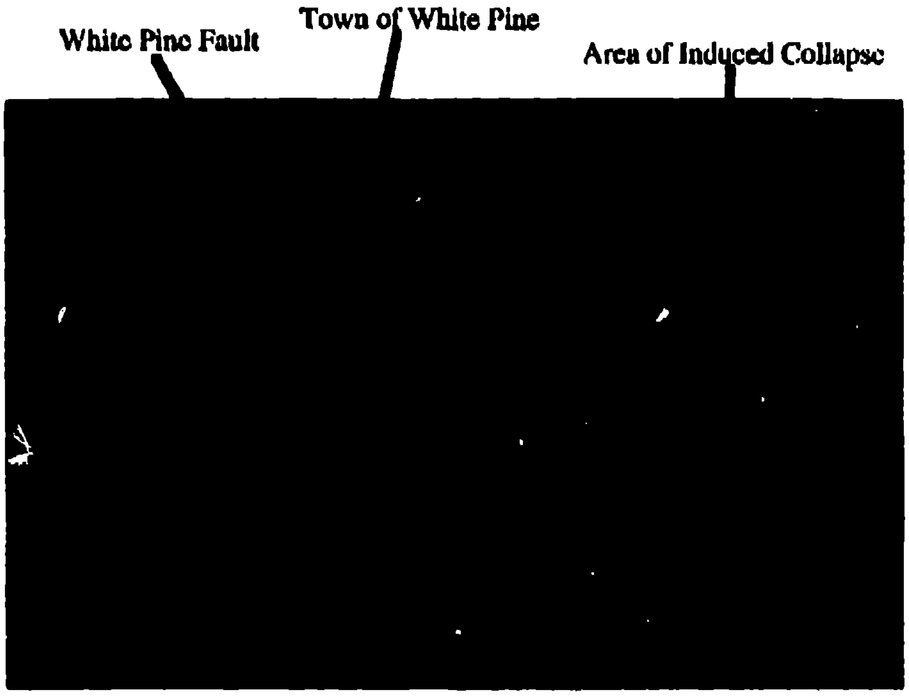


Figure 1. A photograph of a three dimensional model of the White Pine Mine. The White Pine, Michigan townsite, the White Pine Fault, and the area of induced collapse are identified. Structural components readily identifiable are the anticlinal fold which plunges to the south-east and the large displacement White Pine normal fault on the south-west limb. Contour interval 100 feet.

associated with stress redistribution following the explosive pillar removal. Seventy-two (72) pillars with average dimensions of 6.1m by 12.2m were loaded with an average of 1,807 lbs of explosive per pillar for a total explosive source of 130,068 lbs. A millisecond delay firing pattern, 325 milliseconds in length, was used to minimize vibration effects at the surface and propagate the collapse toward the unmined faces. Note that this preliminary test event was designed to be only 1/4 the size of future full scale panel blasts (St. Don, 1995).

DATA ACQUISITION

The areal extent of the seismic network is shown in Figure 3 while pertinent station location information relative the ground zero station are listed in Table 1. The network was designed primarily to aid in the determination of the extent to which chimneying of the overlying rock propagates following the pillar removal. The level at which the explosion occured is approximately 330 m below the surface.

Twelve stations of the seismic network were distributed in azimuth and range out to approximately 1000 m (3 Depth of Burial). The thirteenth seismic station was located at a range of approximately 5 km to primarily record the electrical shot break signal and secondarily to characterize the wave-field as it propagates away from the source region. Each station was instrumented with a six channel, Refraction Technology Model 72A-08 data logger which was continuously locked to GPS broadcast timing signals for adequate timing accuracy. Three

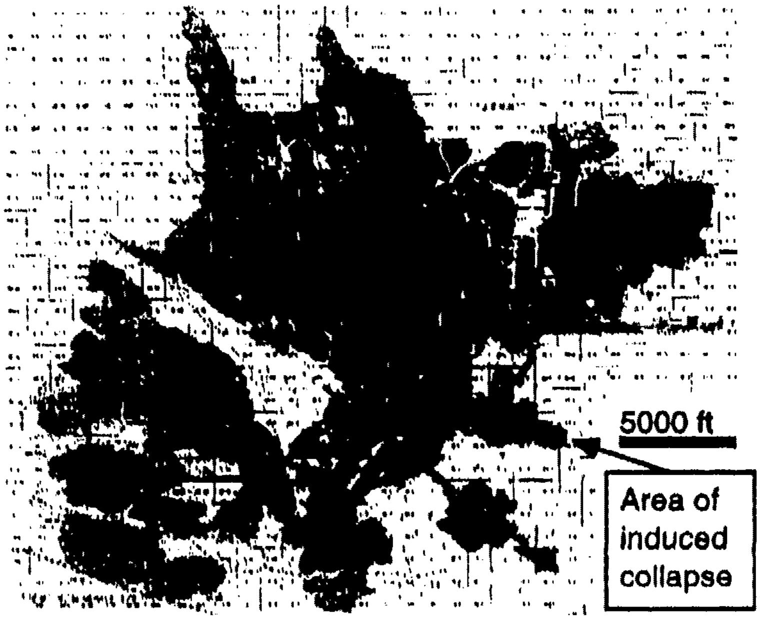
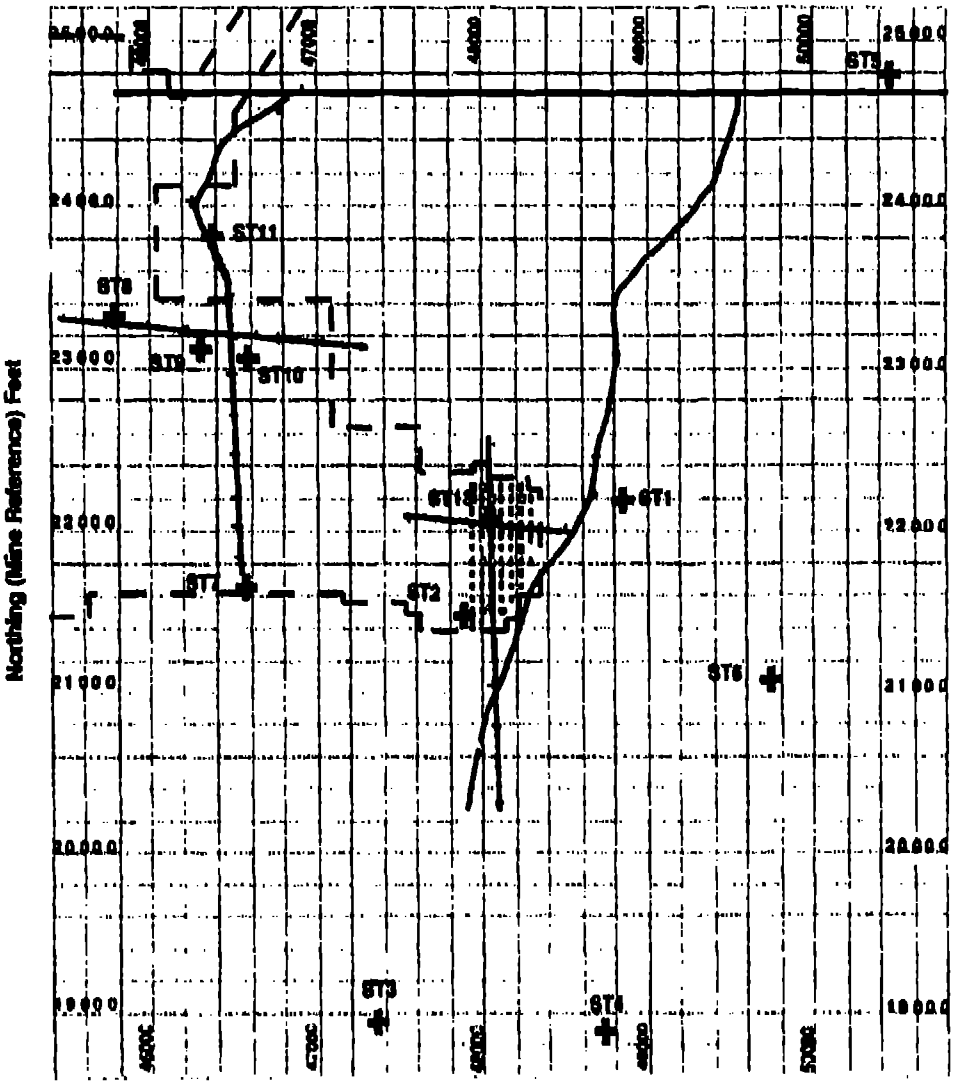


Figure 2. A plan view of the extent of underground workings at the White Pine Mine. Hachured areas indicate room and pillar mined areas while black indicates failed pillar areas in the mine. The failed area outlined in the lower left quadrant on the hanging wall of the White Pine Fault was a catastrophic event which generated regional signals in January of 1989. All other failed areas have experienced slow failure which does not generate large seismic events.

Table 1. Azimuths and distances from ST13 (surface ground zero) to other stations. Magellan Map Datum WGS84.

STATION NAME	BACK AZIMUTH	RANGE (km)	Latitude (deg min)	Longitude (deg min)
ST1	78	0.244	46 43.80	89 29.91
ST2	152	0.201	46 43.68	89 30.03
ST3	191	0.976	46 43.27	89 30.26
ST4	166	0.986	46 43.26	89 29.93
ST5	39	1.104	46 44.23	89 29.53
ST6	119	0.585	46 43.62	89 29.70
ST7	253	0.459	46 43.71	89 30.45
ST8	298	0.782	46 43.98	89 30.64
ST9	299	0.620	46 43.95	89 30.52
ST10	303	0.542	46 43.94	89 30.45
ST11	314	0.727	46 44.06	89 30.50
ST12	300	3.067	46 44.63	89 32.17
ST13	0	0	46 43.78	89 30.10



Easting (Mine Reference) Feet

Figure 3: Experimental design for the White Pine Mine Explosively Induced Collapse Experiment. Only that portion of the underground mine that underlies the near source seismic network is outlined with a dashed line. The pillars that were blasted are also shown in the center of the figure. Seismic stations were located along existing roads and survey lines due to the density of vegetation in the area.

component, 1 Hz, Mark Products Model L4-3C geophones were fielded at each station and a 3 component, Terra Tech SSA-302 accelerometer was fielded at ST2. All stations were programmed to record event triggered data using a STA/LTA algorithm with the exception of ST13 (near surface ground zero) which recorded continuously. All channels were initially programmed to record with unity gain to avoid clipping. In addition to the seismic stations, a Hi 8 video camera was deployed at ST13 to document surface motion and acoustic signals.

All seismic stations triggered on the induced collapse event and continued to trigger during the aftershock sequence. The seismic traces recorded at ST12 were contaminated with strong 60 Hz noise induced by ground loop with the electrical firing system. Due to the fact that there was no noticeable expression of the collapse at the detonation point, the video camera deployed at ST13 was recovered within 1 hour of the event to verify that the explosives had detonated and the collapse had occurred. During recovery of the camera, Stump noted that aftershocks could be felt and heard at ST13.

Data acquisition parameters were changed approximately 12 to 14 hours following the main collapse by increasing the pre-amplifier gain. Stations at 2 to 3 depth of burial surface ranges were increased to a gain of x32 and stations at less than 2 depths of burial were increased to a gain of x8. Data acquisition continued for approximately 36 to 40 hours following the main collapse.

Local and Regional Seismograms

High quality three component velocity seismograms were acquired at each of the local stations. Figure 4 shows the Vertical, North/South, and East/West velocities at station 13 (surface ground zero) which have been corrected for instrument response and their associated spectra. At surface ground zero, the vertical component of motion is a factor of 5 larger than the horizontal components. At this scale, the individual explosive sources in the pillars are not resolved but failure of the pillars is indicated by the high frequency arrivals on the vertical component. These failure signals are followed by a long period signal which indicates an initial upward motion associated with release of the material above the working level. Detailed analysis of the data following the collapse event shows that distinct aftershocks are occurring immediately afterward (as with the explosive signals, these aftershock events are not resolved at the graphic level shown). The spectra shown below the time series in Figure 4 indicate the peaked nature of the vertical component at surface ground zero. Horizontal spectra at surface ground zero are essentially flat to 5 Hz and exhibit spectral modulation similar to the vertical component.

Figure 5 shows the Vertical, North/South, and East/West velocities at ST10 which have been corrected for instrument response and their associated spectra. Station 10 was at a surface range of 0.5 km from surface ground zero and exhibits the effect of slant range on the relative amplitudes of the vertical and horizontal traces. In the 0.7 to 3 Hz band, the horizontal components exhibit larger amplitudes than that of the vertical component. Longer period first motions of all components are consistent with a collapse event located to the south-south-east of ST10.

Regional seismograms of the White Pine Induced Collapse were recovered from stations at ranges from 200 to 1000 km. Figure 6 shows the Vertical, North/South, and East/West velocities at station EYMN (range 202 km, 313 degrees azimuth) and their associated spectra. High signal to noise ratio body and surface waves are evident in the data which have been high pass filtered at 0.75 Hz. Spectra of the regional components indicate that in the 1 to 2 Hz band, the vertical component has the largest amplitude. Detailed analysis of the first motion shows that the compressional P arrival is very impulsive with a dominate frequency of 1 to 2 Hz.

Aftershock Locations

All data recorded by the 12 station network were used to associate aftershock events which triggered at least 3 stations. This *computational* association process and subsequent *analyst* event

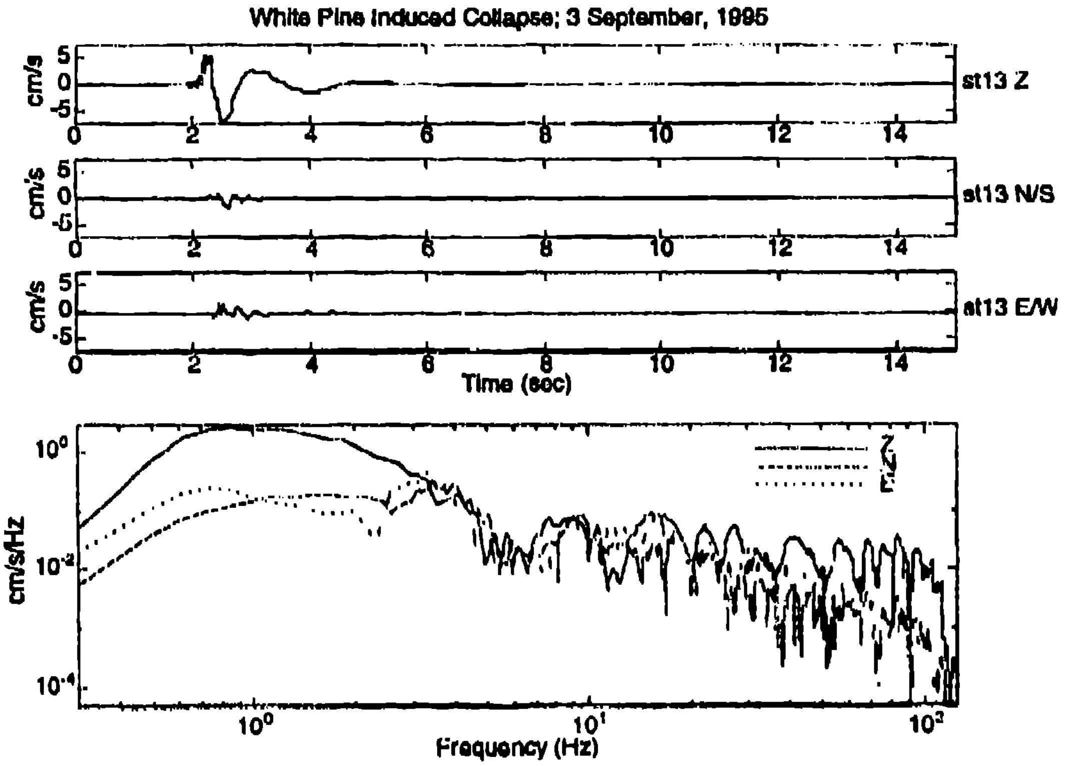


Figure 4. Three component seismogram and spectra of the collapse event at ST13 (surface ground zero) with instrument response removed. Note the high frequency failure events leading to the longer period collapse signal on the vertical component and the peaked nature of the vertical spectrum.

creation and quality control provided a set of 85 aftershocks which were located. Both P and S phases were picked and classified according to quality and polarity for each station and each event.

A velocity model was created based on reflection surveys provided to LANL by the White Pine Mine. This model was used in conjunction with the shot break information recorded at ST12 and first motions at each station to provide station corrections due to static effects of elevation and weathered layer thickness. A relative location algorithm was employed with the known location of the collapse event used as the master event.

Results of the aftershock location exercise are shown in Figure 7. Both a plan view and a cross sectional view are shown. Station locations are indicated by stars (note that stations ST3 and ST4 are not shown on the map view), aftershock locations are indicated by circles with black filled circles for events greater than 250 feet above the working level, gray filled circles for events at the working level to 250 above the working level, and open circles for events located below the working level. Further analysis of those events located below the working level indicates that these events are most likely multiple events that made it difficult to pick associated phases.

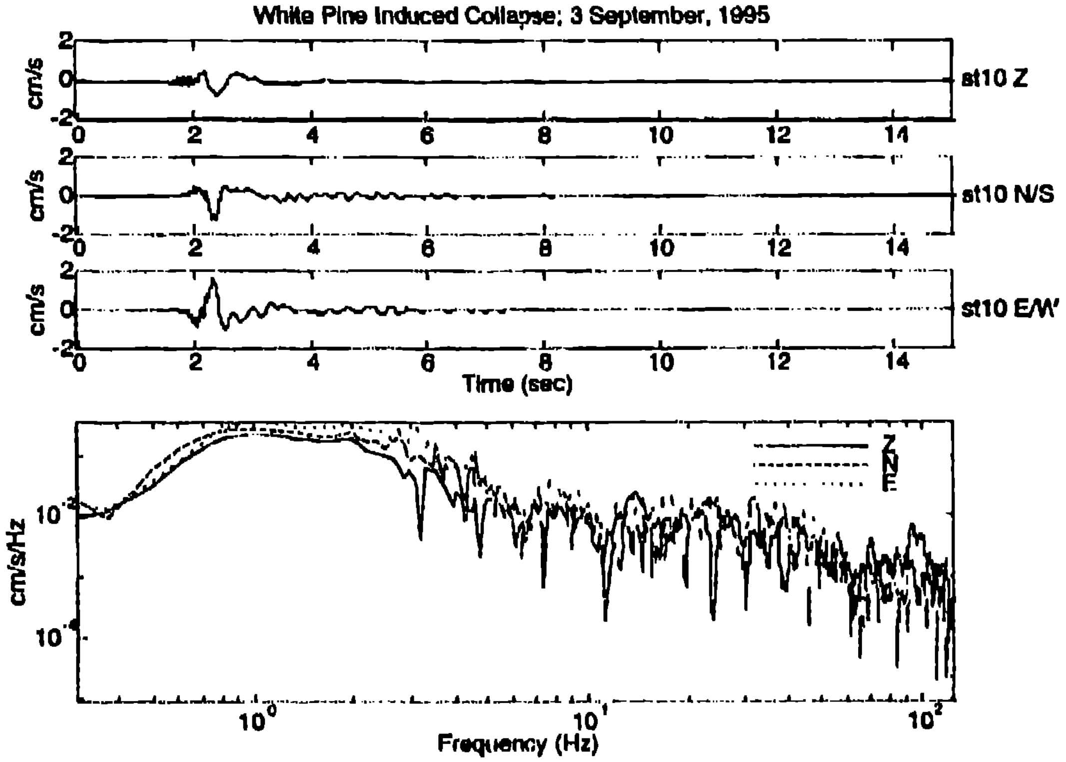


Figure 5. Three component seismogram and full record spectra of the collapse event at ST10 with instrument response removed. Note the high frequency failure events leading to the longer period collapse signal on all components and the similar nature of all spectra.

The frequency of aftershock occurrence decayed rapidly following the collapse event with more than 90% of the high quality aftershocks located occurring within 4 hours of the collapse. The remaining 10% of the high quality aftershocks located occurred during isolated swarms of activity through the remaining 36 hours of network operation. It should be noted that the largest of the aftershocks recorded were more than 2 orders of magnitude smaller in amplitude than the collapse event.

CONCLUSIONS AND RECOMMENDATIONS

The explosively induced collapse of a panel in an underground room and pillar mine indicates that this type of controllable event will generate seismic signals which will propagate to at least near regional distances (as great as 1000 km). Findings by the mining personnel indicate that the event behaved as planned and further work in the pillar rubbilization pilot project will proceed.

Near source monitoring of the mining collapse show that the observed ground motion agrees well with previous work on mining collapses. The individual explosive charges emplaced in the pillars do not produce strong seismic signals, however, the failure of the

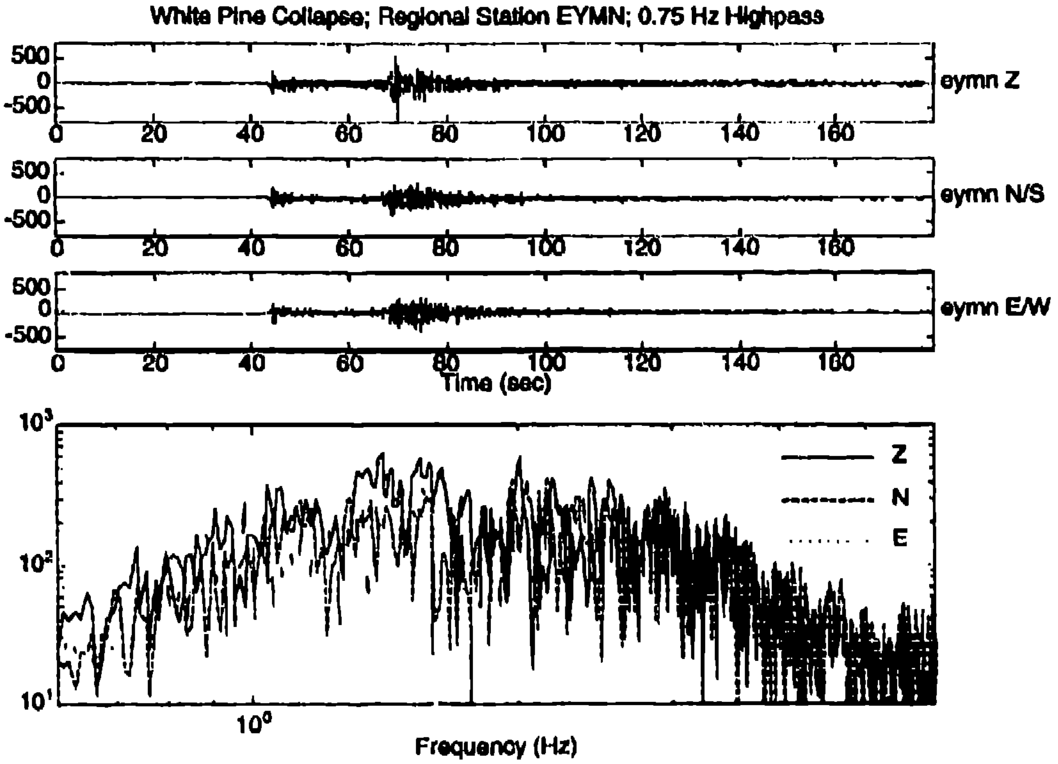


Figure 6. Three component regional seismogram and spectra of the collapse event at station EYMN (range 202 km, 313 degrees azimuth), high pass filtered at 0.75 Hz. Full waveform spectra indicate that the vertical component is peaked between 1 and 2 Hz as was the case in the on-site measurements.

pillars and the material above the working level do produce strong seismic signals. Work continues on determination of local and regional magnitude associated with the White Pine collapse event and the relationship of this magnitude to the area collapsed. It can be concluded that the explosive component of the induced collapse source does not produce regional seismic signals but that the resulting collapse can be expected to be seen regionally.

Aftershocks that occur following the collapse are at least 2 orders of magnitude smaller in amplitude than the ground motion generated by the collapse. The frequency of occurrence of the aftershocks decays rapidly following the collapse. These two observations could be used to argue that it would be extremely difficult to use aftershocks to improve the location determined by regional observations.

Aftershock locations performed surprisingly well in great measure due to information provided by White Pine Mine personnel including reflection profiles and access to recording the shot break signal. The cooperation of mining personnel was critical to the success of this experiment.

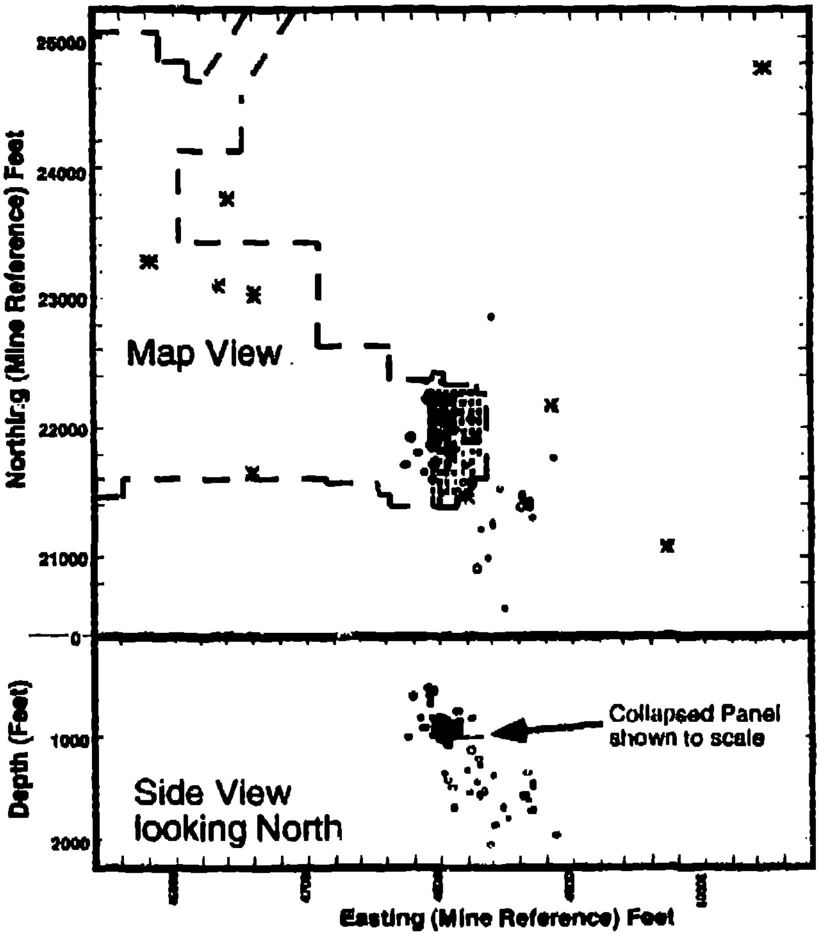


Figure 7. A plan and north looking side view of preliminary aftershock locations for the White Pine Collapse Experiment. Event locations are given by circles where black filled circles locate over 250 feet above the working level, gray filled circles locate from the working level up to 250 feet above the working level, and open circles locate below the working level. Station locations are indicated by the stars.

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