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Rock burst mechanism studies at the Lucky Friday Mine

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1 INTRODUCTION

Mining concentrates stress that can cause rock to explode or "burst" into a stope or drift without warning. Rock bursts pose severe safety and productivity problems for deep mines throughout the world, particularly in strong, brittle rock masses where narrow, tabular ore bodies are mined to high extraction ratios (Blake 1987). Such is the case in the Coeur d'Alene Mining District of northern Idaho where rock bursting has been a problem for nearly 50 years. The Bureau of Mines has worked closely with mining companies to study rock burst phenomena, and several burst controls have been developed, such as destressing, preconditioning, stope sequencing, and single level mining (Karwoski et al. 1979; Jenkins and Dorman 1983).

Although the complex mechanisms that produce rock bursts are still not completely understood, researchers have identified four major causes (Hedley 1987):

1. Surface instabilities at or near a stope face. These instabilities are characterized by spalling of the free surface.
2. Propagation of shear fractures in the rock mass ahead of the working face.
3. Sudden collapse of overstressed pillars.
4. Slip along existing geologic features such as faults or bedding surfaces.

Type 1 and 2 rock bursts are generally associated with drift or stope excavations and result in relatively small volumes of rock exploding into an opening. Type 3 and 4 bursts are generally larger-scale events that occur when extensive mining creates instabilities over an area of the mine.

Advances in seismology have stimulated the use of seismic techniques to investigate rock burst mechanisms. Seismic emissions can be detected almost continually in deep mines and their frequency and intensity are directly related to rock mass instability. The Bureau recognized microseismic technology as a potential tool for rock burst prediction as early as 1939 (Obert 1939); however, only a few successful predictions have been achieved to date.

In the mid-1970's in South Africa and Sweden, techniques developed by earthquake seismologists were applied to the study of rock bursts (McGarr and Spottiswoode 1975; Bath 1984). Recently, developments in microcomputers have made the process of capturing, storing, and analyzing seismic records much easier, e.g., high-speed data acquisition hardware capable of converting incoming analog signals to digital records and high-capacity, high-speed storage devices. The research discussed in this paper utilizes these recent developments in seismology and computer hardware to examine individual rock bursts, determine their source mechanisms, and develop improved control techniques to prevent further occurrences. This research is needed not only to reduce bursting at the depths now being mined, but to enable U.S. mines to supply needed mineral resources from even deeper deposits.

2 MACROSEISMIC RESEARCH

The term "macroseismic" is used to distinguish a new type of acoustic monitoring system from older systems. There are two types of these older systems: seismic and microseismic. All systems, including the macroseismic system, consist of the same general components: seismometers, amplifiers, signal filters, and data acquisition and processing equipment. The main difference among these systems is one of scale; that is, the size of the monitored area and the magnitude of the events being detected.

Seismic monitoring of mining-induced events uses conventional technology developed to detect earth tremors (earthquakes). Several mines in the Coeur d'Alene District have a conventional drum-type seismograph that charts earth tremors detected by a seismometer located on the surface. A surface seismic system alone provides little information beyond the time that an event has occurred. Once the location of an event is determined, however, the surface seismic data provide the best on-site indication of the relative magnitude of that event.

Microseismic monitoring systems are designed to monitor acoustic emissions having frequencies of 10 to 5,000 Hz, either for detailed stope monitoring or for mine-wide monitoring. Detailed stope monitoring systems are able to indicate which areas of the mine are unstable so steps can be taken to prevent or avoid failures. Mine-wide monitoring systems serve the same purpose, but are more widely used to locate the epicenter of events. Conventional mine-wide microseismic systems record only the time a signal arrives at a geophone.

Macroseismic systems are designed to record digitally the waveforms of large seismic events that normally cause damage to a mine. Events of Richter magnitude 0.5 to 2.5 are the targets of these systems. Individual waveform records are stored by each seismometer in an array to provide data for rock burst mechanism studies.

Data can be analyzed to determine several parameters, including source location, time, magnitude, strike, dip, amount of slip, moment, and stress drop (Savage 1972; Aki and Richards 1980).

3 LUCKY FRIDAY MINE INVESTIGATION

Based on the recommendations of a University of Idaho study (Sprenke and Hammond 1988), hardware and software were purchased, assembled, and tested in the laboratory. The macroseismic system was then installed at the Lucky Friday Mine. The system consists of five three-component geophones, preamplifiers, signal filters, and the digital recording system.

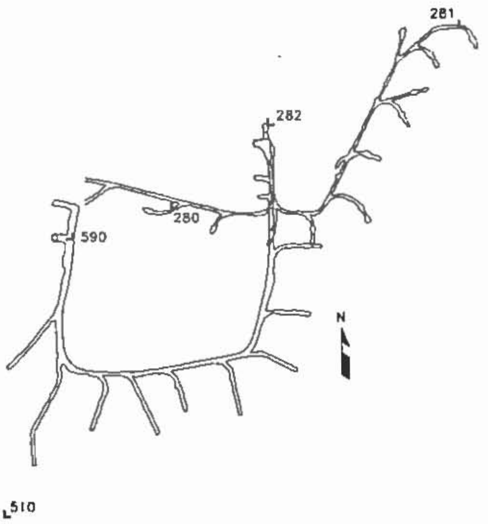

Figure 1. Plan view of the seismometer array.

An optimal array for a macroseismic system would place the geophones at the corners of a cube at distances from 1,000 to 2,000 ft around the active mine area. This configuration would provide complete data for motion studies, ensure that compression and shear waves would be distinct, and ensure that events would not overdrive the seismometers. However, such a configuration was not possible at the Lucky Friday Mine because of the great depths and the limited lateral extent of the mine. Three seismometers, designated 280, 281, and 282, were installed on the 2800-ft level of the mine and two others, designated 510 and 590, were placed on the 5100-ft and 5900-ft levels, respectively. The seismometers were placed far enough from active mining to obtain distinct P- and S-waves while sampling at 300 Hz. All seismometers were installed the same way except for 590, which was installed with an opposite north/south orientation. Figure 1 is a plan view of the seismometer array.

As investigations continue, and as experience dictates, the seismometers will be redeployed and recording parameters changed. The array will be enlarged to provide better coverage of the mine as funds become available.

The software controlling the system was a modified version of XDETECT, which can sample at a rate of 300 Hz. Soon after the macroseismic system began operation, data from several major events were recorded. These data were used to debug the system by operating in several different configurations.

Originally the programmable amplifier was set at 40 dB and the surface gain was set at 4X. These settings created problems, however, because magnification of the signal at the surface also magnified line noise, making P- and S-waves more difficult to distinguish. Currently, the system is run with 60 dB of amplification underground and 2X magnification for the geophones on the 2800 level. There is no magnification for the geophones on the 5100 and 5900 levels. The sampling rate has been increased to 450 Hz to provide better waveforms.

4 JULY 6 ROCK BURST

On July 6, 1989, at 12:07 a.m., a large rock burst was recorded by the macroseismic system at the Lucky Friday Mine. The event had a Richter magnitude of 3.1 to 3.4 and resulted in the most severe damage ever experienced at the mine. Normal operations were disrupted in five

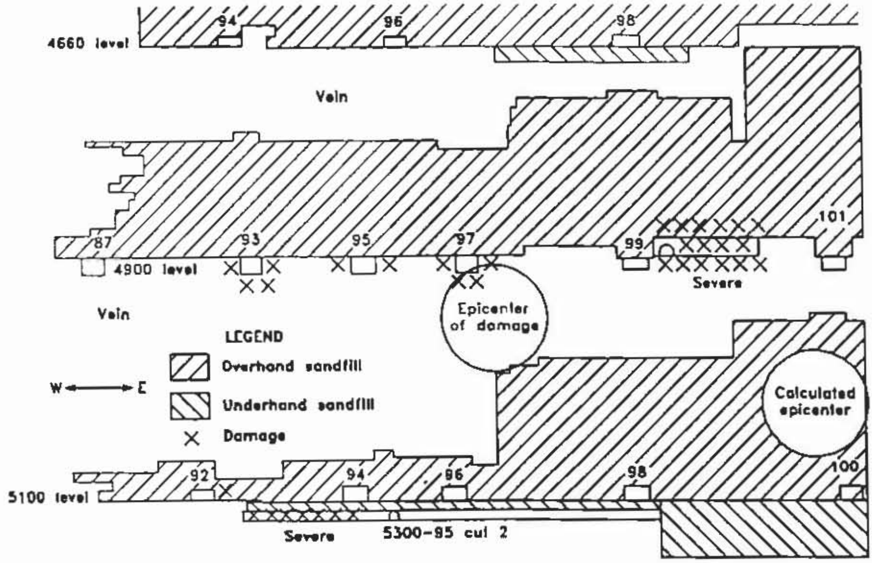

Figure 2. Cross-section along the vein showing the relative position of the July 6 damage.

stopes. Areas around the 93, 95, 97, and 99 stopes on the 4900-ft level and on the 5300-95 underhand stope 20 ft below the 5100-ft level were damaged.

Figure 2 is a cross section along the vein showing the relative position of the damaged areas, the center as determined by the damage, and the center as determined by microseismic records. The large magnitude made calculation of an epicenter suspect because the waves arriving at a geophone may have come from different parts of the rupture area.

Of particular interest was the contrast between the extreme damage in the 4900-99 stope and the west side of the 5300-95 stope and the moderate damage in the areas between these stopes. The areas damaged by the burst provided physical evidence of what occurred; however, as is the case with many of the bursts at the Lucky Friday Mine, the burst mechanism was difficult to distinguish on the basis of the physical evidence alone. The wide extent of the burst damage provided an excellent opportunity to use the macroseismic data in an attempt to determine the actual source mechanism. Figure 3 is a map of the 4900-ft level in the damaged area.

The raise structure (raise prep) and the manway up to the overhand stope in 4900-93 footwall were damaged, but the stope remained intact. It was impossible to identify the direction of movement, but damage in the raise appeared to have been caused by closure across the backfilled stope. Damage to the 4900-95 crosscut was limited. There was some floor heave and raise prep damage at its intersection with the footwall vein and damage to the floor and lower east wall between the footwall and main veins. The 95 stope was not damaged. Damage in the 95 crosscut indicated the epicenter was to the east and below the crosscut.

There was 2 to 3 ft of floor heave in the 4900-97 crosscut from the intersection of the footwall vein to the end of the crosscut, but the walls were barely damaged. Timbers in the footwall vein raise prep

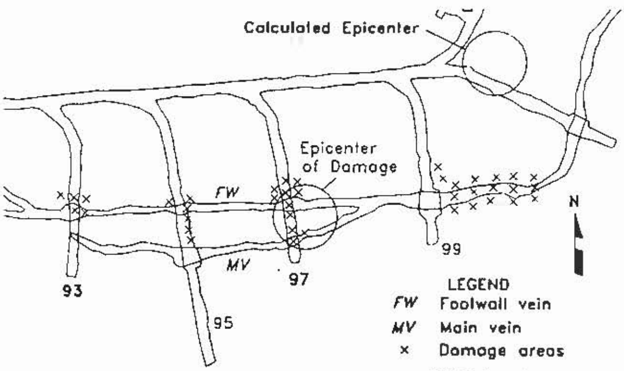

Figure 3. Map of the 4900 level in the area damaged by the July 6 rock burst.

were punched up into the caps, and one was offset to the north. The main vein raise prep timbers were not as severely damaged. The floor in the east end of the main vein area heaved and damage occurred to the north wall. The displacement direction of failed rock indicated that the epicenter was directly below the crosscut along the footwall vein or in the pillar between the footwall and main veins.

The ramp to the underhand stope in the 4900-99 crosscut was badly damaged for the last 30 ft to the vein, and the stope was totally closed immediately east of the ramp. Analysis of the damage in the stope indicated that some closure came from all directions, with the greatest amount coming from below and from the north. Damage in this area indicated a pillar failure-type burst.

Other than rocks being shaken down, there was no damage on the 4900-ft level or in the 5100-100 crosscut, which is 200 ft directly below the most severely damaged area on the 4900-ft level. There was minor rock fall on the 5100-ft level, and the raise prep in the 92 crosscut was slightly damaged.

The west side of the 5300-95 main vein underhand stope 20 ft below the 5100-ft level was severely damaged. The last 90 ft of the north wall was blown into the stope along the bedding. The last 20 ft of the stope was damaged along the South Control fault; however, there was no apparent movement along the fault. The entire 250-ft-long east end and the first 40 ft of the west end of the 5300-95 main vein stope were undamaged, but measurements at the intersection of the ramp and the vein showed some closure. The lack of damage in this part of the stope is particularly puzzling because of the severe damage above and to the west. A fault slip-type mechanism would help to explain the damage pattern.

Based on an analysis of the damage, there are two possible explanations as to the source mechanism for this burst: 1) slip along the vein below the 4900-ft level or 2) failure of the pillar caused by compression between the 5100 and the 4900 stopes. However, it is impossible to identify which was the actual mechanism.

5 FIRST-MOTION ANALYSIS

Seismic records from the July 6 burst were available from both the Bureau's macroseismic array and the Lucky Friday's mine-wide micro-

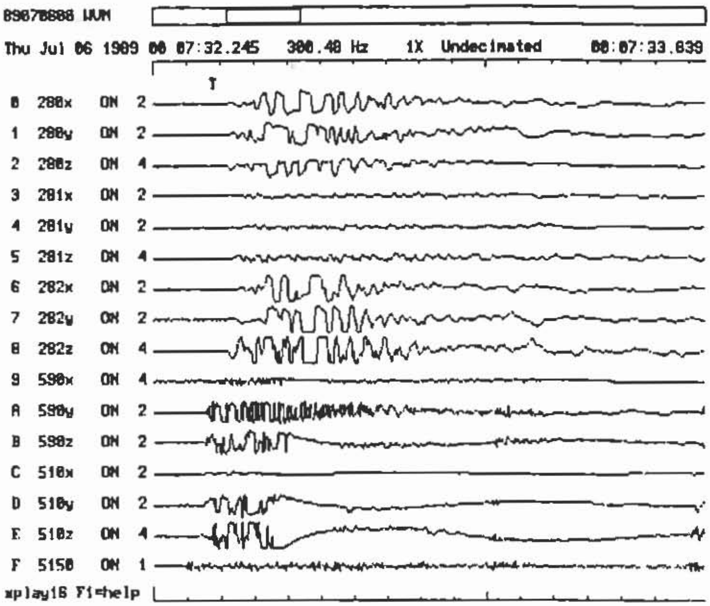

Figure 4. XPLAY data for July 6 event.

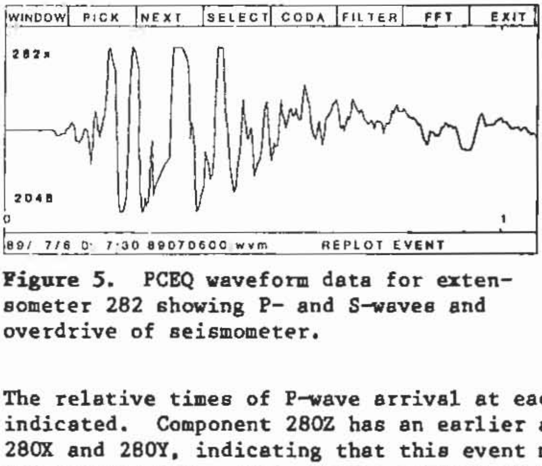

Figure 5. PCEQ waveform data for extensometer 282 showing P- and S-waves and overdrive of seismometer.

seismic system and were analyzed using standard first-motion methods. The source location and event time were obtained from the microseismic system and hence were independent of data from the macroseismic system.

Figure 4 displays data from the program IASPEI XPLAY for the July 6 event (No. 89070600). Certain features should be noted. The relative times of P-wave arrival at each seismometer are clearly indicated. Component 280Z has an earlier arrival time than components 280X and 280Y, indicating that this event must have been directly below seismometer 280. Also, P-wave arrival time at seismometer 510 was much earlier than arrival time at 281 because seismometer 510 was closest to the epicenter. The 282 seismometer was overdriven (fig. 5), but the other seismometers responded very well to the event, which was greater than the system was designed to record.

The source solution shown in figure 6 was obtained by assuming a constant velocity model. Distances between the event and the various geophones and arrival angles were calculated. The figure is still being analyzed because the data repre-sent arrivals in the near field from a relatively large event. Note that near the location of the event, the strike of the Lucky Friday vein is approximately N75E, while the strike of the rupture plane is approximately N56E. The reason(s) for this

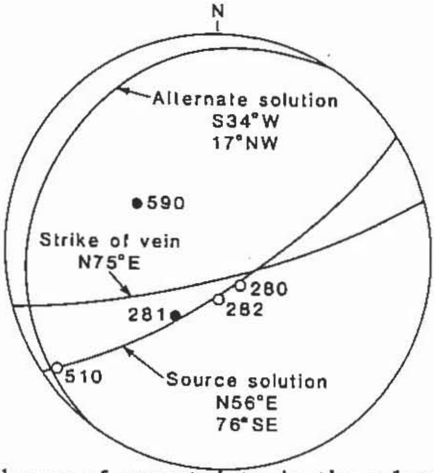

Figure 6. Source solution for the 89070600 event using a lower hemisphere stereonet projection. Numbers indicate seismometers; solid circles indicate compression wave arrivals; and open circles indicate dilation wave arrivals. Also shown is a projection of the strike of the Lucky Friday vein.

discrepancy is presently unknown, but could be the result of several factors. 1) The rupture plane may not correlate with the strike of the vein. 2) The data are a minimum set and so there is a large degree of uncertainty in the solution. 3) There may have been as-yet unrecognized instrument problems that affected the results. 4) The data represent near-field observations and may represent arrival times from different portions of the rupture plane.

6 CONCLUSIONS AND SUMMARY

The physical evidence supports two possible hypotheses:

1. Slip--A slip mechanism could be inferred from the different amounts of damage observed in the hanging wall and the footwall. This could be explained if the severely damaged hanging wall moved upward in relation to the stationary, undamaged footwall. Floor damage on the 4900-ft level and wall damage in the 5300-95 stope indicates the rupture plane was between the two levels. The bedding in this area of the mine is nearly parallel both to the vein and to the principal fault direction. Mining could therefore reduce the normal forces and allow slip to occur.

2. Compressive failure--Damage in the 4900-99 stope appeared to be related to compressive failure of the pillar between the two veins. The damage in the 5300-95 stope could also be explained by shock waves traveling down favorably oriented bedding. The closure observed in the 4900-93 manway and the 5300-95 stope can be explained more readily as a pillar failure than a slip failure. The major problem in accepting this hypothesis is that the orientation of the beds in the 4900 crosscuts should have resulted in severe damage to the footwall instead of the hanging wall.

The first-motion analysis supports the slip mechanism hypothesis. Slip along the vein would account for the relative block motions suggested by the stereonet projection for event No. 89070600.

The macroseismic research at the Lucky Friday Mine has thus far been encouraging. Waveform data from the macroseismic system are providing additional information on block motions that are difficult to measure directly. When analyzed in the context of mining, geological variables, and the visible damage, the macroseismic data can provide a better understanding of burst mechanisms.

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