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**Seismic Equipment Used in Rock-Burst
Control in the Coeur d'Alene Mining
District, Idaho**

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UNITED STATES DEPARTMENT OF THE INTERIOR

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Control in the Coeur d'Alene Mining
District, Idaho**

**By William C. McLaughlin, Spokane Mining Research Center,
Spokane, Wash.;**

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SEISMIC EQUIPMENT USED IN ROCK-BURST CONTROL IN THE COEUR D'ALENE MINING DISTRICT, IDAHO

by

William C. McLaughlin,¹ Galen G. Waddell,²
and John G. McCaslin³

ABSTRACT

In the deep vein mines of the Coeur d'Alene mining district, rock bursts are a potential hazard to the mine structure and underground personnel. Damage repair costs are estimated by one company to exceed \$1 per ton of ore mined. The Bureau of Mines, in cooperation with the mining companies, has conducted research intermittently over the past 10 years to help reduce bursts. Onsite inspections of major rock bursts were conducted, and reports were submitted to mine management; these included the geology and geometry of the affected area.

The paper discusses the development and improvement of microseismic and surface monitoring equipment. The underground microseismic network, when operated on a regular basis and the results plotted daily, is capable of detecting stress concentration in certain areas. The surface seismographs record rock bursts, blasts, earthquakes, etc., throughout the district and show approximate location, time, and relative intensity of the event.

INTRODUCTION

A rock burst is defined as "that phenomena which occurs when a volume of rock is strained beyond the elastic limit and the accompanying failure is of such a nature that accumulated energy is released instantaneously."⁴ In coal mines, similar phenomena are called bumps or airblasts.

Rock bursts are experienced in underground mining at various localities in the world, and in at least two districts, the Kolar goldfields of India and the gold mines of the Witswatersrand in South Africa, are a major cause of

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⁴Dictionary of Mining, Mineral, and Related Terms. U.S. Bureau of Mines, 1968, p. 932.

damage. Rock bursts occur in other mining areas such as the mines of Timmins, Ontario, Canada, the Copper Range in Michigan, and the deep silver-lead-zinc mines of the Coeur d'Alene district in northern Idaho. Bursts or "bumps" also are common in many coal mines.

In the Coeur d'Alene district, the country rock includes hard, brittle quartzites and softer argillites of the Precambrian Belt series, which are tightly folded and faulted with resulting high stress fields. When mining operations create stress concentrations, the elastic limit of the rock is often exceeded, causing rock failure and the release of large amounts of stored strain energy. These rock bursts are equivalent to small earthquakes, some recorded at seismograph stations over 200 miles away. One objective of the Bureau of Mines and the mining companies investigation is to reduce the magnitude and number of on-shift bursts.

ACKNOWLEDGMENTS

Special appreciation is extended to Josef Suveg and Ron Kovacs at the Galena mine and Byron Cracraft and Jon Langstaff at the Lucky Friday mine for maintaining the seismograph stations and analyzing the records.

Acknowledgment also is made to Donald Wilson, formerly of the Bureau, for his assistance, particularly in the underground phase of the study, and to the staff at the Newport Geophysical Laboratory, Newport, Wash., for the loan of many of their seismograph records.

Special thanks is extended to Stephen W. Nile, Professor Emeritus of Montana College of Mineral Science and Technology, for correlation of our seismograph records with others in the area.

Acknowledgment is made to Raymond J. Zawadski, formerly of the Spokane Mining Research Center (SMRC), Bureau of Mines, for his improvement of various electronic components and for development of new components.

BACKGROUND

The cooperating mining companies are American Smelting and Refining Co.; the Bunker Hill Co., a subsidiary of Gulf Resources & Chemical Corp.; Callahan Mining Corp.; Day Mines, Inc.; Hecla Mining Co.; and Sunshine Mining Co. Intermittently, as budgeted funds and trained personnel were available since 1965, onsite inspections of major rock bursts have been made. Reports submitted to the companies pointed out the cause (where it could be determined) and possible methods to reduce damage. Progress reports were submitted quarterly also.

The most competent rocks, as a general rule, are the most prone to bursting. These are the hard quartzite host rocks, associated with the commercial veins that contain gangue stringers and inclusions of quartz and siderite, along with the ore minerals of galena, sphalerite, tetrahedrite, stibnite, etc. The geology and geometry of the mine openings are possibly the most important factors in rock burst control.

Geology of the Coeur d'Alene District

Production of silver, lead, and zinc, along with lesser amounts of copper, cadmium, and antimony in the Coeur d'Alene district, has been valued at over \$2.5 billion since 1884. At the present time, about 45 pct of the U.S. production of silver is from mines in this district. Steeply dipping veins are in the Precambrian Belt quartzites and argillites. Tight folds and numerous faults predominate in the structural control of the veins, which lie at acute angles to the bedding planes. A unique feature of the veins is their persistence to great depths and, in some cases, an actual increase in value with depth. At the Star mine in Burke Canyon, lead, zinc, and silver ore is being stoped 7,500 feet below the surface or 1,750 feet below sea level. Planar discontinuities including sills, dikes, faults, and veins affect the stress field when encountered in mining operations, and usually a stress concentration occurs at the intersection; sharp turns in the veins cause stress increase also.

Most of the Belt series consist of competent quartzites, with some argillites, and the Revett formation generally is the most massive, hardest, and most brittle of the series. The folded and faulted Revett is the prevalent host rock for the veins in the lower levels of the Coeur d'Alene mines. Previous studies by the Bureau on the 3300 level of the Crescent mine (17)⁵ determined the properties of Revett quartzite, which are shown in table 1.

TABLE 1. - Physical properties of Revett quartzite

Tensile strength.....psi..	3,800
Compressive strength.....psi..	26,850
Density.....g/cu cm..	2.69
Poisson's ratio.....	0.29
Dynamic elastic modulus.....psi × 10 ⁶ ..	7.93
Shore hardness, scleroscope.....	81.5

Rock tests at the Galena mine on homogenous fine-grained competent Revett quartzite indicate dynamic elastic modulus of 7.30×10^6 psi, Poisson's ratio of 0.29, and compressive strength of 32,500 psi (4). Also at the Galena mine, mineralized quartzite with over 15 pct of vein minerals had a modulus of 6.59×10^6 psi, Poisson's ratio of 0.24, and compressive strength of 11,200 psi (4). The vein material strength at the Crescent mine has not been determined, but it is assumed that it is in the range of that at the Galena.

Two publications describing the Coeur d'Alene district geology in detail are the U.S. Geological Survey Profession Paper 478 (7) and the Idaho Bureau of Mines Guidebook (15).

⁵Underlined numbers in parentheses refer to items in the list of references at the end of this report.

Field Stress Determination

To assist in design of underground openings and structures, the Bureau of Mines has determined the principal stress in the quartzite formations in various mines and at different elevations throughout the district. Measurement techniques include overcore stress relief, initial deformation, and hydraulic stress meter (1, 5, 17-18). For comparison, the magnitude of major stress on the 3300 level of the Crescent mine (5,300 feet below surface) is about 7,000 psi. At the Galena mine (4,000 feet below the surface), the maximum principal stress near a stope was calculated at 13,000 psi. The component in both cases is slightly above the horizontal and is oriented NNW-SSE. The magnitude of the principal stress determined at other locations in the district is between these maximum and minimum values, and the orientation ranges from NNW-SSE to NW-SE. Stress measurement helps determine the best orientation of rectangular openings such as shafts, raises, and winzes.

The in situ rock stress is about proportional to the thickness of pillars when these approach a burst-prone stress condition in horizontal cut-and-fill stopes. For example, at the Galena mine (13,000 psi), bursting may occur after the pillar is reduced to about 70 feet; at the Crescent mine (7,000 psi), bursting does not occur as a rule until the pillar is reduced to about 40 feet in thickness (pillar as used here is the vertical height of the unbroken ore between the stope back and the mined-out level above). Assuming that the strength of the vein material in both mines is about the same, then the theoretical storage of elastic strain energy in confined condition would be about equal, and rock pressure (residual stress in the wall rock) would then be the determining factor in bursting.

The Bureau of Mines (8) has included the Coeur d'Alene district in the study of principal stresses in the mining districts of the United States. Its data shows that the maximum stress component is about horizontal and oriented NNW-SSE.

Two Bureau of Mines publications (5-6) discuss the details of petrographic studies in the Star mine at Burke and are included in the references at the end of this report. These have contributed to a better understanding of the relationship of minute rock fractures to the orientation of the principal stresses in this deep mine. The authors of these papers conclude that during the epochs of tectonic deformation, the maximum and minimum principal stresses were horizontally oriented and acted along northwest and northeast axes, respectively. This condition of regional stress appears to have continued during later folding and associated period of faulting.

DEVELOPMENT AND APPLICATION OF SEISMIC EQUIPMENT

At the time the first seismograph was installed (at the Galena mine in 1966) for rock-burst studies, the Bureau decided to also study subaudible rock noises (microseisms). Hence, the development of microseismic equipment and the surface seismograph network has progressed simultaneously. The development of the microseismic underground geophones and recorders will be described, first, in this part of the report.

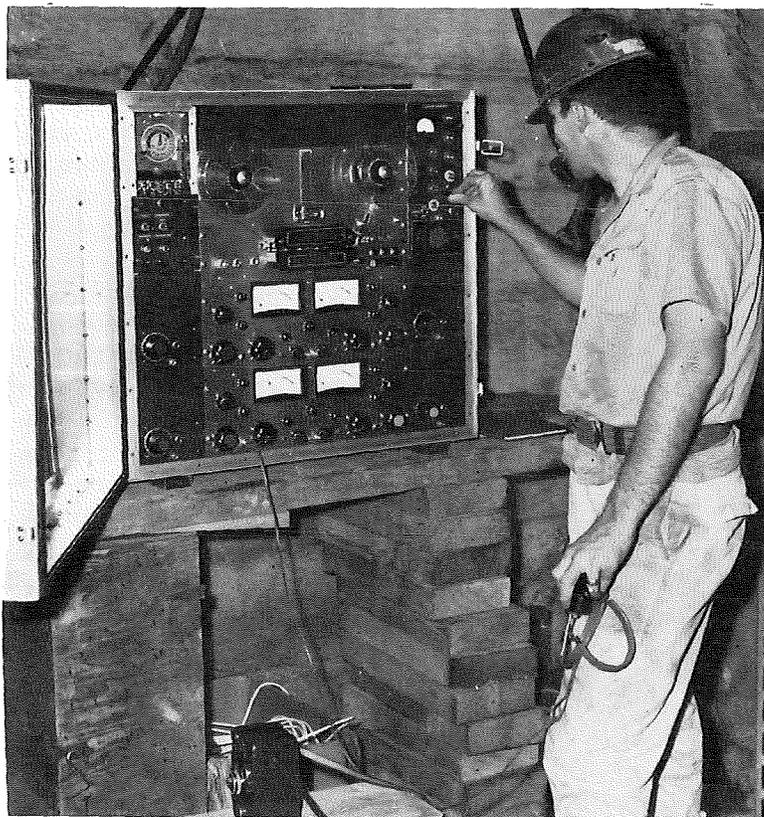


FIGURE 1. - Four-channel magnetic tape recorder—Star mine.

The event locating capability of the broad-band microseismic equipment bracketing the mining area is 15 to 50 feet depending on location and number of geophones. The like capability of the seismograph is limited--for example, minor bursting at blasting time is recorded, but the exact time of the blast must be known to locate the bursting to a particular working place.

Microseismic Magnetic-Tape Recorder

Geophones were installed in bored holes in the wall rock, and signals from the geophones were recorded on an updated (solid-state), four-channel magnetic tape recorder (fig. 1). This equipment was installed on the 7100 level of the Star mine in 1965, and the study

continued for 2 years. Because of high temperature and humidity, it was determined that if these studies were to succeed, special equipment would have to be designed. Although the electrical equipment was housed in an air-conditioned, dehumidified shed on 7100, it needed constant attention and even then was inoperative for a considerable part of the time. The most satisfactory solution was, in spite of the cost of cable and installation, to install the recording equipment at the surface.

The microseismic studies at the Star mine also brought out certain deficiencies in the geophones. They were the mineral-crystal type with a battery-powered preamplifier and were rather fragile and had high resonance rate. Because of the high signal-to-noise ratio, it was difficult to locate the source of rock noise. Most of the operational troubles were solved during the development of the present broad-band microseismic system (2, 4-10) in the period 1968-71.

Initial traveltime measurements at the deep level of the Star mine showed that the velocities ranged from 3,000 to 23,000 fps within short distances. For example, traveltime in the mill tailings used for stope fill were about 3,000 fps, and traveltime in the hard quartzite was about 23,000 fps. The ore body itself and wall rock alteration had intermediate values.



FIGURE 2: - Portable microseismic equipment—Galena mine.

Portable Microseismic Unit

Supplementing the tape recorder for microseismic studies, a portable unit was tried out at several mines in 1966-67. The unit consisted of a borehole-type geophone, a battery-powered amplifier, and earphones for monitoring subaudible rock noise. Figure 2 shows the unit in operation underground at the Galena mine.

Results with the portable microseismic equipment were encouraging. It was possible to locate approximately the source of rock noise, determine the noise rate, estimate the magnitude, and thus detect stress buildup on a semiquantitative basis. It appeared that an early-warning system for rock bursts was entirely possible. However, to be a usable tool, the exact location of stress buildup was needed, and this wasn't

obtainable with the portable system. Loud noise far away could not be separated from softer noise at close range. In 1968, the Bureau of Mines Denver Mining Research Center (DMRC) began developing a broad-band solid-state microseismic system that was far superior to the earlier vacuum tube models. Spokane Mining Research Center devoted its efforts to developing a surface seismograph network, making onsite inspections and reports, and conducting destressing studies using vein-wall closure measurements.

Broad-Band Microseismic Equipment

The broad-band microseismic monitoring systems will have from 15 to 27 geophones with preamplifiers, high-gain amplifiers, and a slow- and a high-speed recorder, automatic monitor, listening circuit, and oscilloscope. The Galena rock-burst monitor (RBM) system with only 5 geophones operating is shown to be inadequate to cover the mining area. Therefore, this network is being increased to 12 geophones. The second-generation equipment at the Lucky Friday mine includes, as part of the system, a general purpose, sensor-based minicomputer and programable calculator. For details of the RBM, refer to reference 3 in the list at the end of this report. Because storage capacity of the memory portion of the minicomputer is limited, some events are not

recorded. Supplementing the RBM, the direct-readout seismograph records most, if not all, of the seismic events at the mine, including the individual shots in a blast round and minor bursting after the blasts. Figure 3 shows the general purpose, sensor-based minicomputer in the mine office at the Lucky Friday mine. The seismograph recorder is in the same room.

Up to 23 geophones are used at the Lucky Friday mine. They are strategically located throughout the mine with the signal from each being fed into the minicomputer of the equipment. The computer continually monitors each of the geophones in sequence. Should a seismic event or subaudible microseisms occur, the signals from the geophones are checked by the computer. If the signal from five or more are of sufficient magnitude, the computer prints out the coordinate location of the event. If multiple events occur, these are handled using an interrupt technique that stores 8 to 10 events per minute. If a large event such as a major burst or quake occurs at blasting time, then the regular seismograph records this. A blast of 3 sticks of 1-1/8- by 16-inch dynamite is picked up by an entire network of geophones.

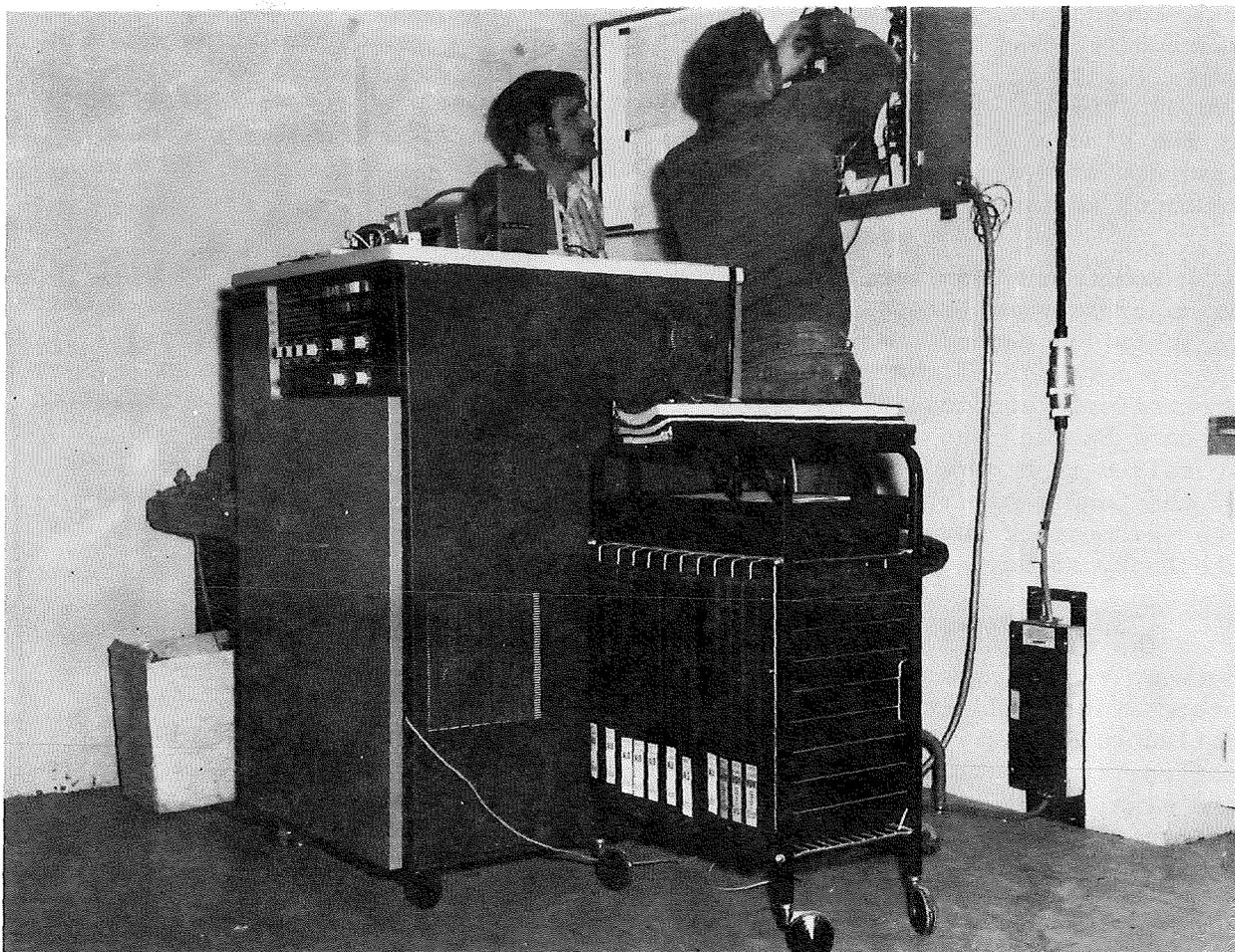


FIGURE 3: - Rock-Burst Monitor (RBM)-Lucky Friday mine;

An estimate of the energy released by a burst is made by noting the vertical displacement on the seismogram.

The computer solves simultaneous equations based on geophone arrival time differences and prints out the coordinates. These location coordinates are plotted, and potential rock failure zones are delineated. The data must be recorded and analyzed on a routine basis to determine changes in rock stress. Mapping of analyzed data must be kept up to date so that a potential burst-prone area can be detected and steps taken to reduce the stress.

Short-period, Photographic-Type Seismograph

In 1966, the first seismograph was installed in a near-surface adit at the Galena mine to monitor activity in the mine and major bursts throughout the district. This was a complete seismograph station, similar to those used for earthquake studies, on loan from the U.S. Coast and Geodetic Survey. This equipment, including a single-drum photographic paper recorder, a 0.5-sec seismometer, a master clock accurate to less than 1-sec variation per month, and accessories, was installed in a dark room near the Callahan hoist, a few hundred feet from the portal and about 200 feet below the surface. The overall gain of the seismic signal could be amplified from 50,000 to 100,000 times. A shortwave radio for standard time signals was installed in the mine office, and the tender used a stopwatch to "hand-carry" time accurate to 0.1 sec into the station. The station was tended by the mine research engineer on a daily basis including weekends.

Continuous monitoring of rock bursts and blasts at the mine as well as major seismic events throughout the district was sufficiently successful to install a second station in 1968 at the Lucky Friday mine to give better coverage of the district and to supplement and correlate with microseismic studies (3) by DMRC. This was the beginning of the correlation of data between the two seismograph stations. The second recorder was installed in a dark room off the mine office to eliminate the tedious task of the tender making a trip back in the adit each day to change the records. The seismometer was placed about 600 feet back in the adit. Figure 4 shows the Lucky Friday seismograph and galvanometer.

The disadvantage of the photographic-type seismograph is the time lag between recording and having the record available for reading. Since processing facilities were not available at either mine, the records were mailed to SMRC for development. As the records from both stations were mailed, it was possible to correlate events before returning the records to the mine; however, this required another day, so there was a week's lapse before the record was available for inspection by mine personnel.

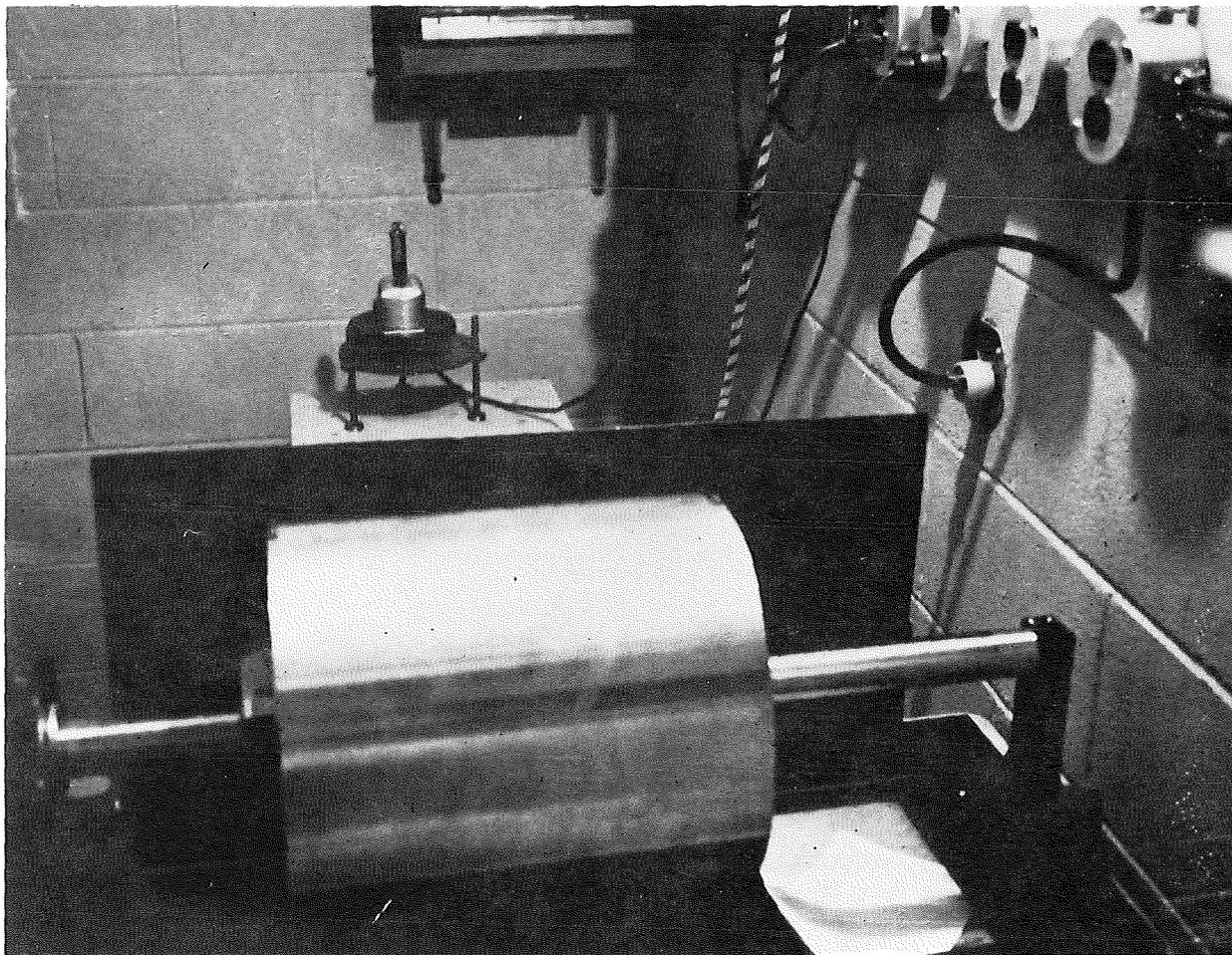


FIGURE 4; - Photographic paper seismograph drum recorder and galvanometer—Luck Friday mine.

Strip Chart Recorder

An interim development in the rock-burst program was the installation of seismometers in the stoping area of the mine and the recording of the signal on various types of strip chart recorders (fig. 5) stationed a distance away. One temporary installation was made at the Lucky Friday mine where the seismometer was near the surface and the recorder was placed in the mine office to give instant readout of major bursts. The major disadvantage was lack of sensitivity; many of the weaker bursts were not recorded.

Direct-Readout, Short-Period Seismographs

After several years experience with seismic instrumentation in the district, operators and the Bureau were overwhelmingly in favor of direct-readout recording equipment. With the direct readout, the mine superintendent or engineer has an instantaneous record of bursts that occur in the district.

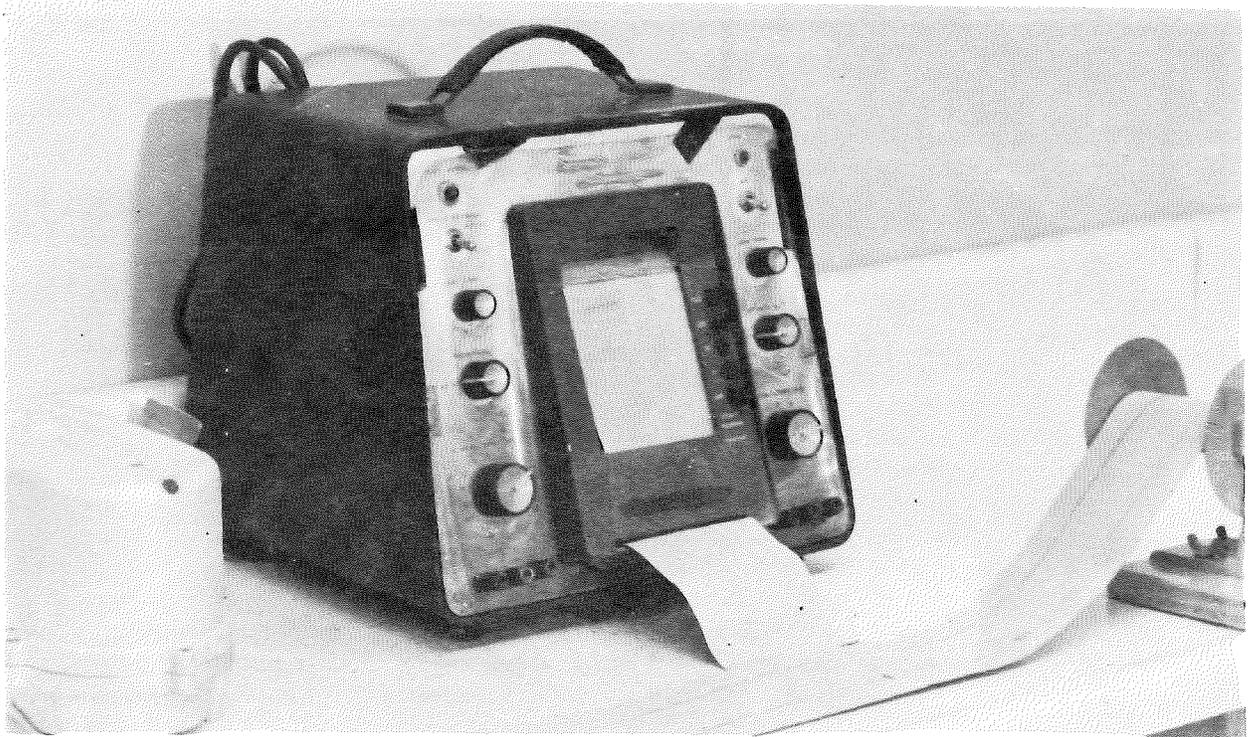


FIGURE 5: - Strip chart recorder and seismometer.

Of particular interest are those triggered by regular blasting or by distressing blasts. It also encourages better reporting of suspicious bumps or ground movement that may be felt by underground personnel. Since the recorder is in the mine office, the miner can stop to look at the record if he believes he felt or heard a burst. When the broad-band microseismic networks and RBM equipment became partly operational at the Galena and Lucky Friday mines, it became imperative to install direct-reading seismographs to enable immediate correlation between microseismic and seismograph data (2, 9-10).

Three new seismographs of the latest design were installed in early 1973. They were at the Galena, the Lucky Friday, and the Crescent mines. Because of production curtailment at the Crescent mine, this seismograph has been removed and will be reinstalled at the Star mine. The direct reading equipment consists of pen-and-ink stylus, a three-drum recorder, plus standard equipment of a regular seismograph station. The cost for each seismograph was about \$10,000. Figure 6 shows the seismograph station (except for the seismometer) at the Lucky Friday mine. The recorder has a radio and digital clock. The voltage regulator is on top of the console. Storage-battery auxiliary power is in the lower cabinet. The records on occasion are correlated with the records of other stations in northeast Washington, northern Idaho, and western Montana. The area stations are shown in figure 7 and listed in table 2.

TABLE 2. - Area seismograph stations

Agency	Installation	Location
U.S. Geological Survey.....	Newport Observatory.....	Newport, Wash.
Do.....do.....	Spruce Canyon, Wash.
Do.....do.....	Nordman, Idaho.
Do.....	University of Idaho.....	Moscow, Idaho.
Do.....	University of Montana....	Missoula, Mont.
Do.....	Montana Tech.....	Butte, Mont.
U.S. Bureau of Reclamation...	Hungry Horse Dam.....	Hungry Horse, Mont.
U.S. Corps of Engineers.....	Libby Dam.....	Libby, Mont.
U.S. Bureau of Mines.....	Galena mine.....	Wallace, Idaho.
Do.....	Lucky Friday mine.....	Mullan, Idaho.
Do.....	Star mine.....	Burke, Idaho. ¹

¹Has been located at the Crescent mine; presently being moved to the Star mine.

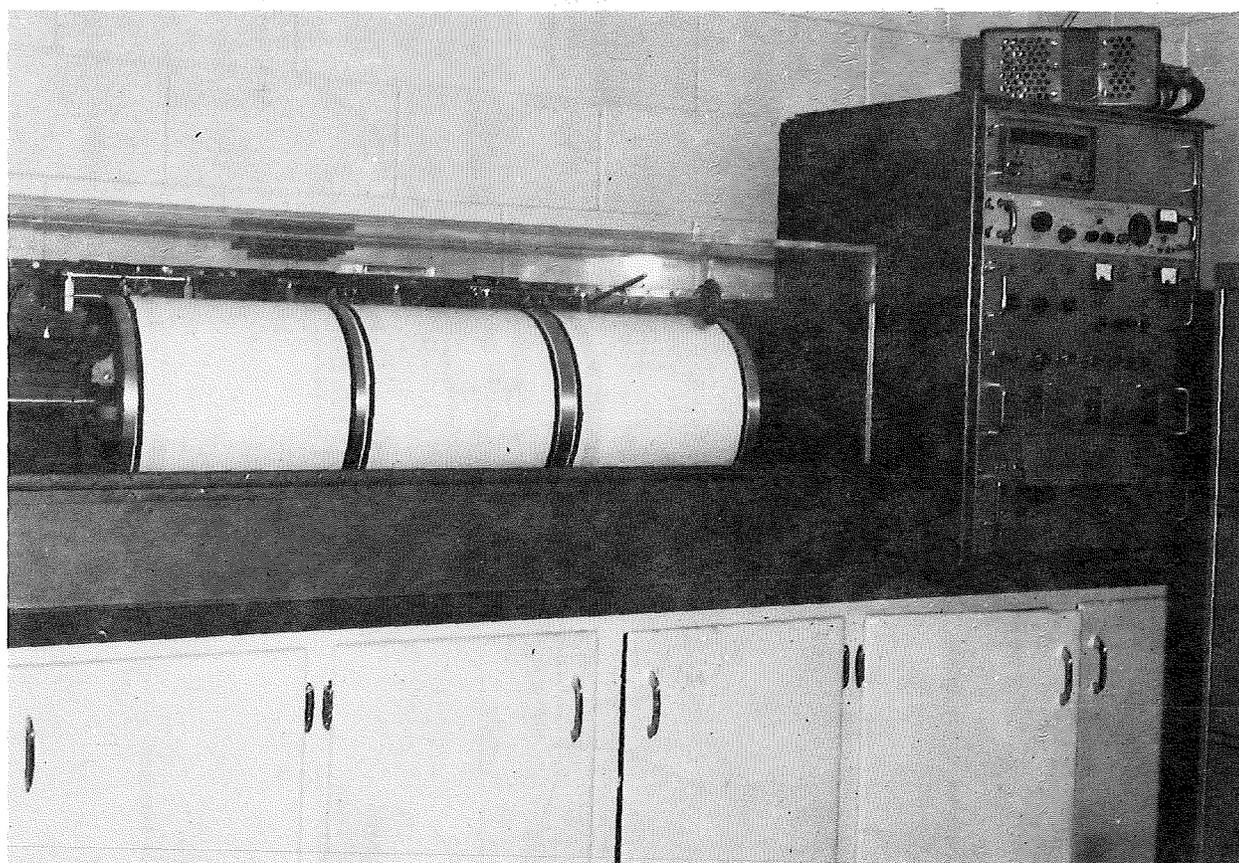


FIGURE 6. - Direct-readout seismograph recorder—Lucky Friday mine.

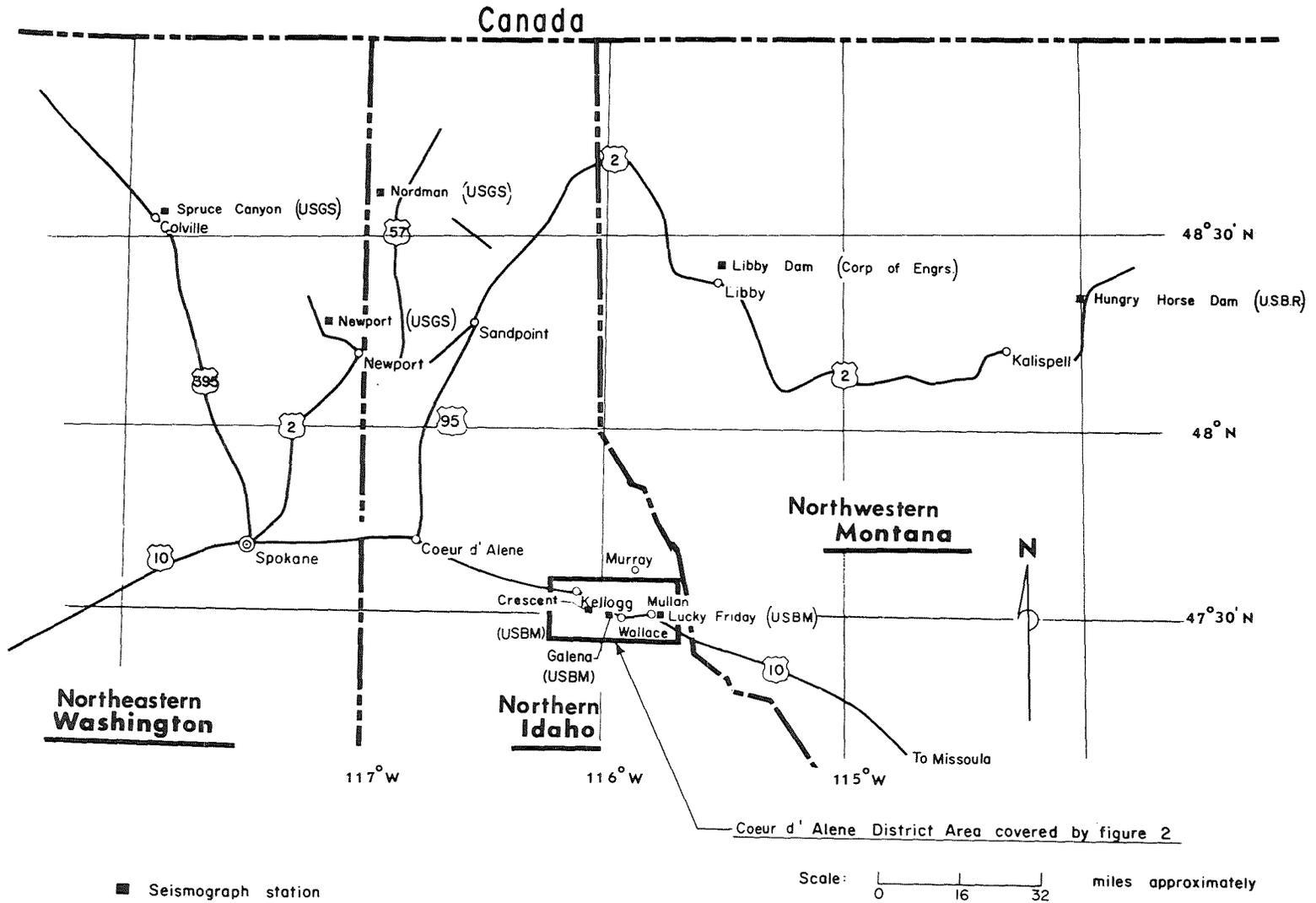
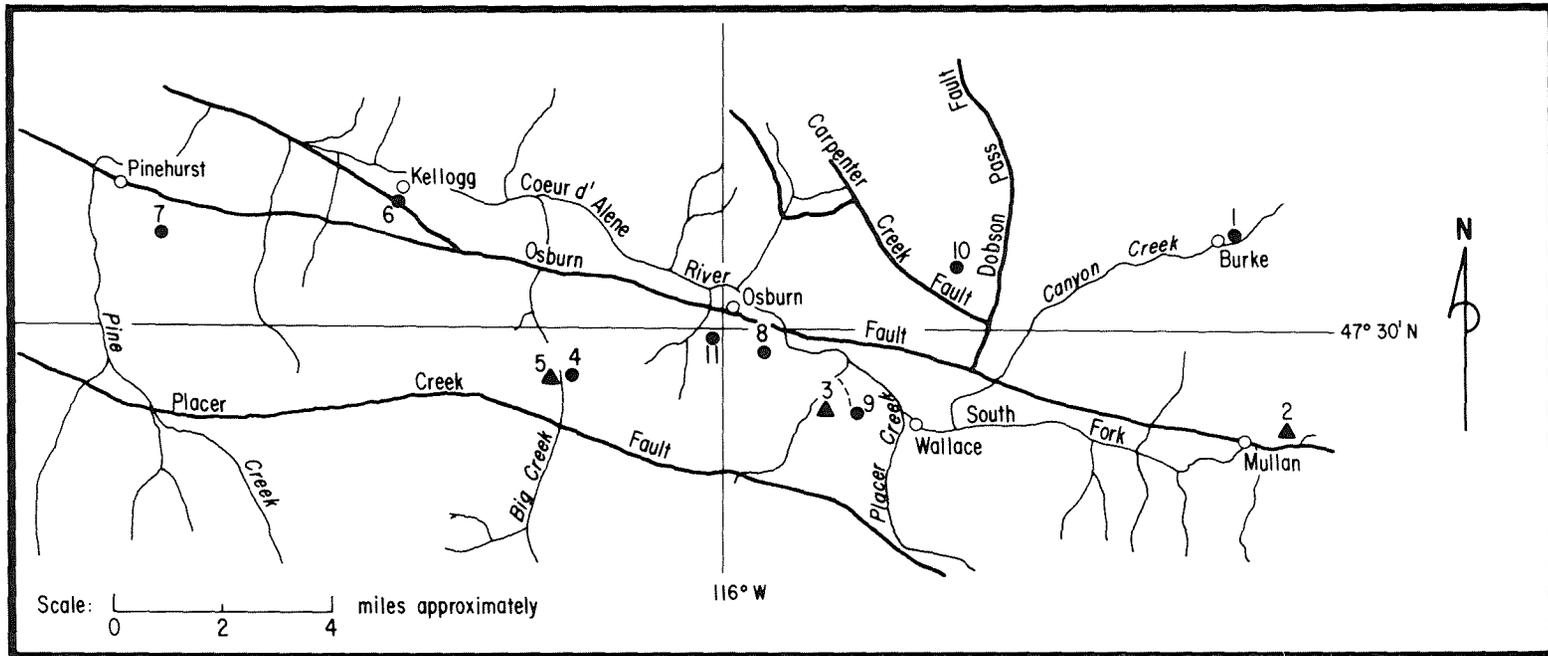


FIGURE 7: - Map of regional seismograph stations;



- | | | | |
|----|---|----|--|
| 1 | Hecla Mining Co., Star tunnel | 7 | American Smelting and Refining Co., Page mine (inactive) |
| ▲2 | Hecla Mining Co., Lucky Friday mine | 8 | American Smelting and Refining Co., Coeur shaft |
| ▲3 | Callahan Mining Corp., Galena mine (operated by ASARCO) | 9 | Caladay project, Callahan Mining Corp. and Day Mines, Inc. |
| 4 | Sunshine Mining Co., Sunshine mine | 10 | Day Mines, Inc., Dayrock mine |
| ▲5 | Bunker Hill Co., Crescent mine | 11 | Hecla Mining Co., Silver Summit mine |
| 6 | Bunker Hill Co., Bunker Hill tunnel | ▲ | Seismograph station, Bureau of Mines |

FIGURE 8. - Map of seismograph locations and major operating mines in Coeur d'Alene mining district of Idaho.

The stations at Newport and Spruce Canyon, Wash., and Nordman, Idaho, have long- and short-period seismographs and are a part of the Pacific early-warning system for seismic sea waves (tsunamis) as well as for monitoring earth slides at Lake Roosevelt (Grand Coulee Dam) whenever the lake level is lowered.

The stations at Butte and Missoula, Mont., and Moscow, Idaho, are regular seismograph stations primarily installed for monitoring earthquakes. The stations at Libby and Hungry Horse, Mont., record the effects of changes in the stress fields from filling the reservoirs. The stations at Mullan, Wallace, and Burke, Idaho, were installed and are maintained by the Bureau of Mines--here the short-period seismographs were set up primarily for monitoring rock bursts, but on occasion, the records are used for correlation with other stations on earthquakes, slides, explosions, other seismic events, and stress field changes.

Figure 8 is an enlargement of the insert of the Coeur d'Alene mining district and shows the location of the seismograph stations as well as the major faults that control ore deposition. It also shows the principal drainage of the area. Since the canyons are deep and the walls precipitous, the roads necessarily follow the streams. When RBM networks are added, another seismograph station will be established.

DETERMINATION OF EPICENTERS

When an earthquake, rock burst, or explosion occurs, the original waves are a complex mixture of amplitudes and wavelengths. A Fourier analysis shows a large number of sine waves of different wavelengths and amplitudes. The high frequencies or short wavelengths are damped out over a very short distance, so after a few miles the only components that are recorded have a period of the order of magnitude of tenths of a second.

To determine the epicenter of an earthquake, the traveltimes of different components are measured. For local quakes, only the P (longitudinal) and S (transverse) waves can be measured, but since the P wave travels at a much higher velocity, the difference between the arrival times, S - P, is commonly used to compute the distance to the epicenter. Since the arrival times are dependent upon wave velocities in an area, empirical formulas can be determined for a particular geologic area. Richter (16) established the following empirical relationships for California earthquakes:

$$\text{Distance from the epicenter} = 8.5 (S - P) \text{ kilometers,}$$

or

$$\text{distance from the epicenter} = 5.25 (S - P) \text{ miles.}$$

$$\text{Traveltime of P wave} = 1.37 (S - P) \text{ seconds}$$

for distances up to 100 km. These formulas have been used by Stephen Nile, Professor Emeritus of Montana College of Mineral Science and Technology, for Montana earthquakes and have given excellent results for major rock bursts in the Coeur d'Alene area recorded at the Newport Seismological Observatory

(81 miles). Studies in the district have indicated that velocities may range from 3,000 to 23,000 fps within a mine, and with this variation, present published curves and empirical formulas are not applicable. Some work has been done to determine local traveltime curves, and it is hoped that more will be determined in the future.

It is beyond the scope of this report to discuss the details of earthquake mechanism and the interpretation of seismograms other than to explain the distinguishing elements of various events. The authors recommend Richter's "Elementary Seismology" (16) or Neumann's "Principles Underlying the Interpretation of Seismograms" (13) as excellent references.

It is normally easy to distinguish between rock bursts and other seismic events on the seismograph records. Since the distance from the Galena to the Lucky Friday mine is about 9 miles, the arrival of the P wave and the S wave (S - P) is less than 2 sec apart, which is about 2 mm distance on the record. Thus the larger bursts that record at both stations are easily identified. If the burst is, for example, at the Galena mine, the P wave and S wave arrive about the same time at the Galena seismograph and cannot be separated, while at the Lucky Friday seismograph the P and S arrivals are about 2 sec apart. Rock bursts in other mines can be monitored if they are of sufficient magnitude to record at both stations. For example, a rock burst at the Sunshine mine would show a S - P of about 1 sec at the Galena and 3 sec at the Lucky Friday station. There is, of course, no way to distinguish from the records of other seismic events, such as quakes, that may occur in the immediate area. Fortunately, the closest earthquake belt is in western Montana, and these quakes are easily separated on the records from rock bursts in the Coeur d'Alene district.

REPRESENTATIVE SEISMOGRAMS

After some experience in reading the seismograms, the ground control engineer can quickly separate the various events. These include underground blasting, bursts of varying intensity, earthquakes, surface blasts, and others. Following are examples and discussion.

The seismograph drum speed can be varied to record at 30 mm per minute laterally, or a faster 60 mm per minute. The slower speed is used for the weekend (when the mines are idle), so that a continuous 48-hour record is obtained without a paper change. During the mine operating period, the 60 mm per minute lateral speed is used to lengthen the wave trace and permit more accuracy in reading the seismogram. The record is changed every 24 hours. In the following examples (figs. 9-12), figures 9 and 11 were recorded at the faster speed, and figures 10 and 12 were recorded at the slower speed.

Figure 9 is part of a seismogram showing a major rock burst triggered by a destressing blast in the pillar of a stope. There was damage to the stope, but the miners were safely away. Note the three short spikes in the minute before the burst--these indicate explosive detonations. The P and S waves arrive almost simultaneously, showing the burst occurred at the mine of the seismograph location.

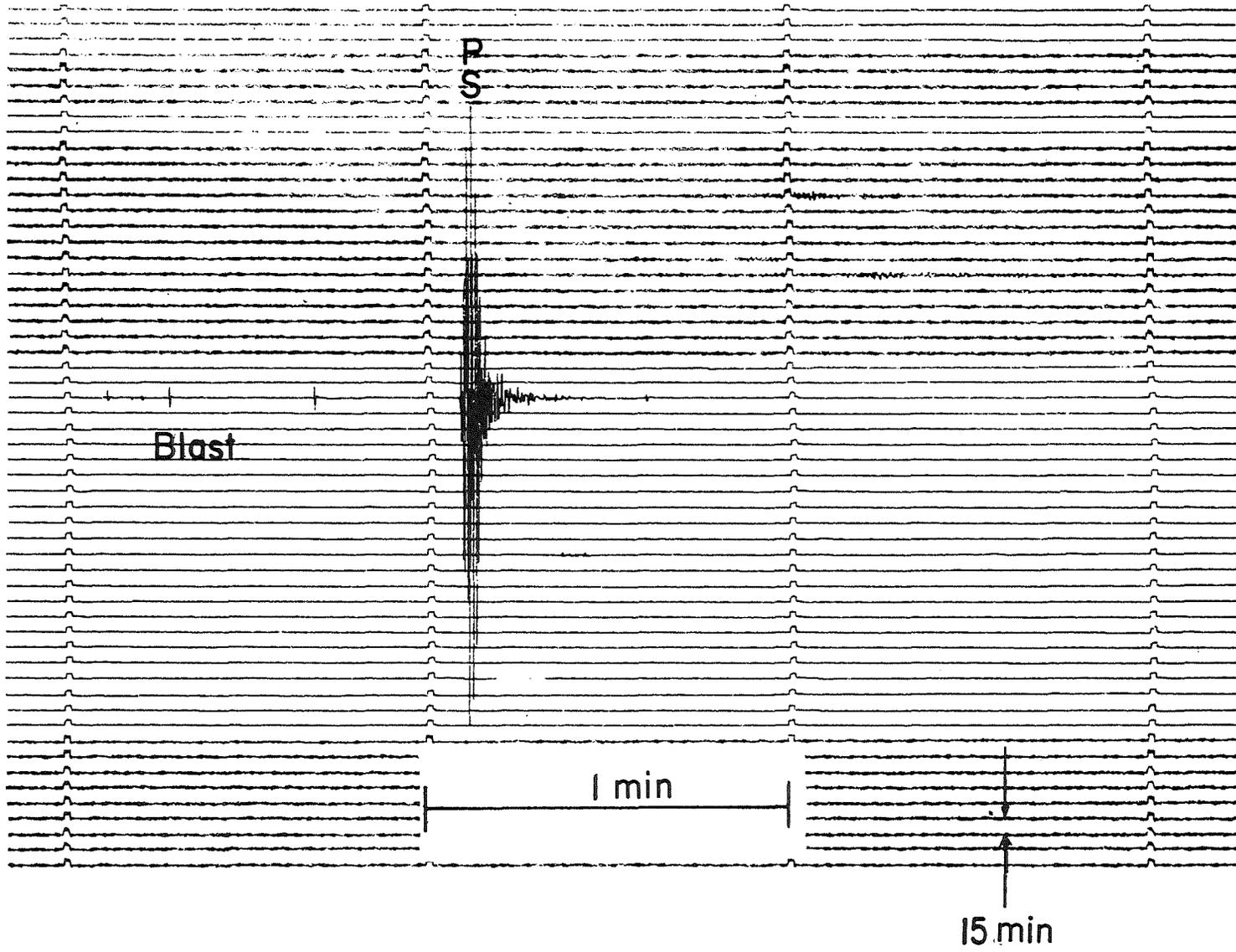


FIGURE 9: - Seismogram of a destressing blast triggering a major burst.

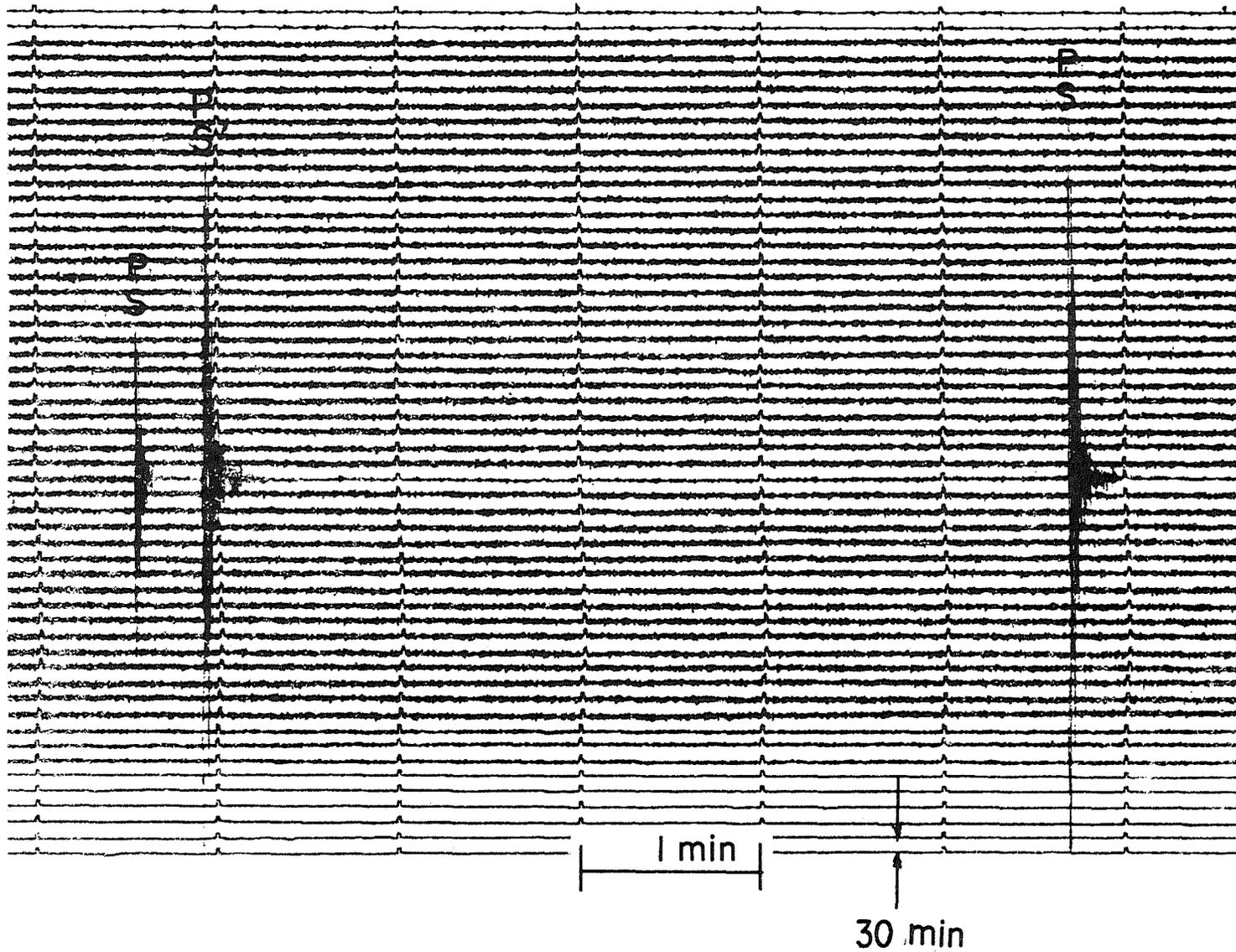


FIGURE 10: - Seismogram of a back-stopping round triggering major bursts.

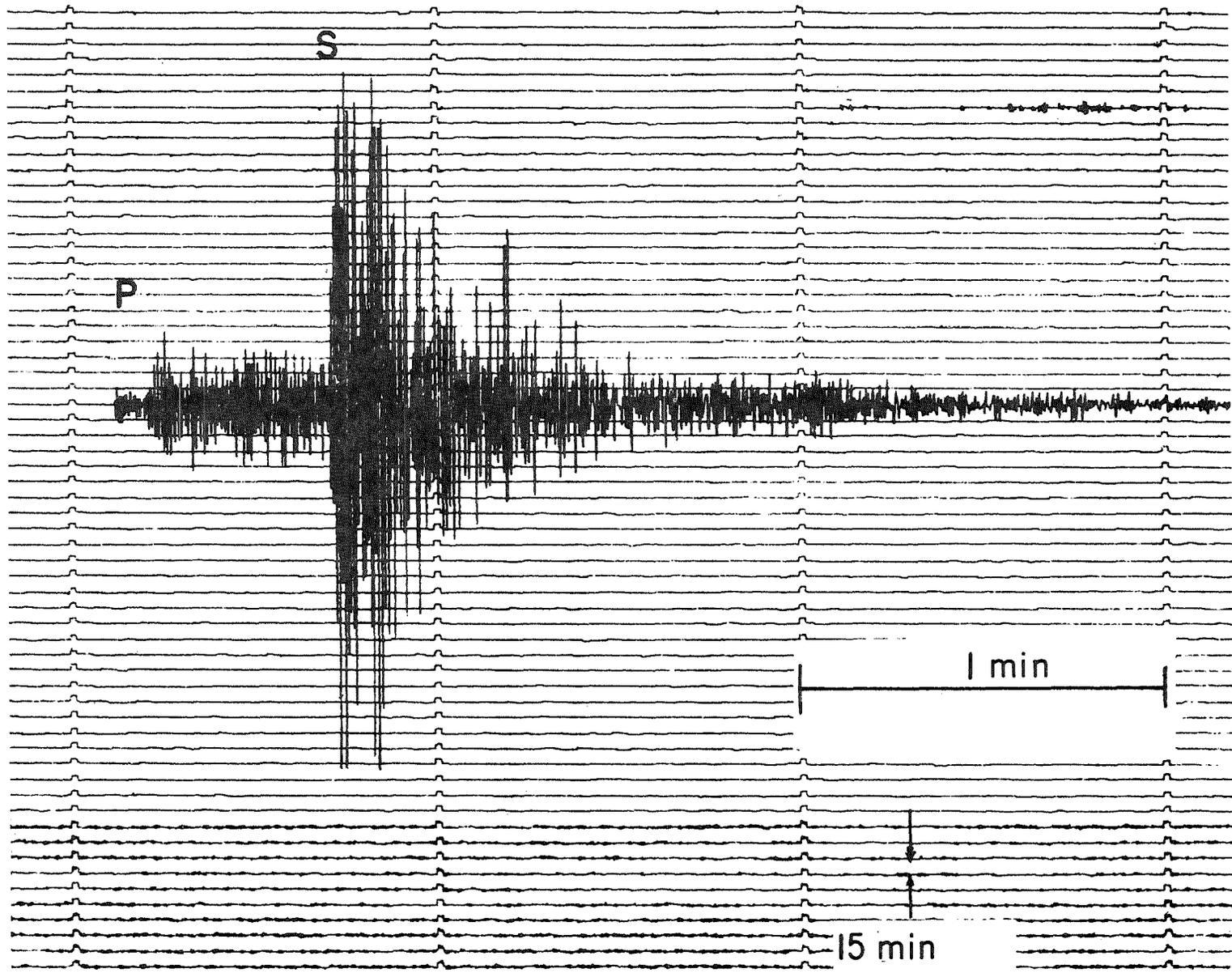


FIGURE 11: - Seismogram of a local earthquake.

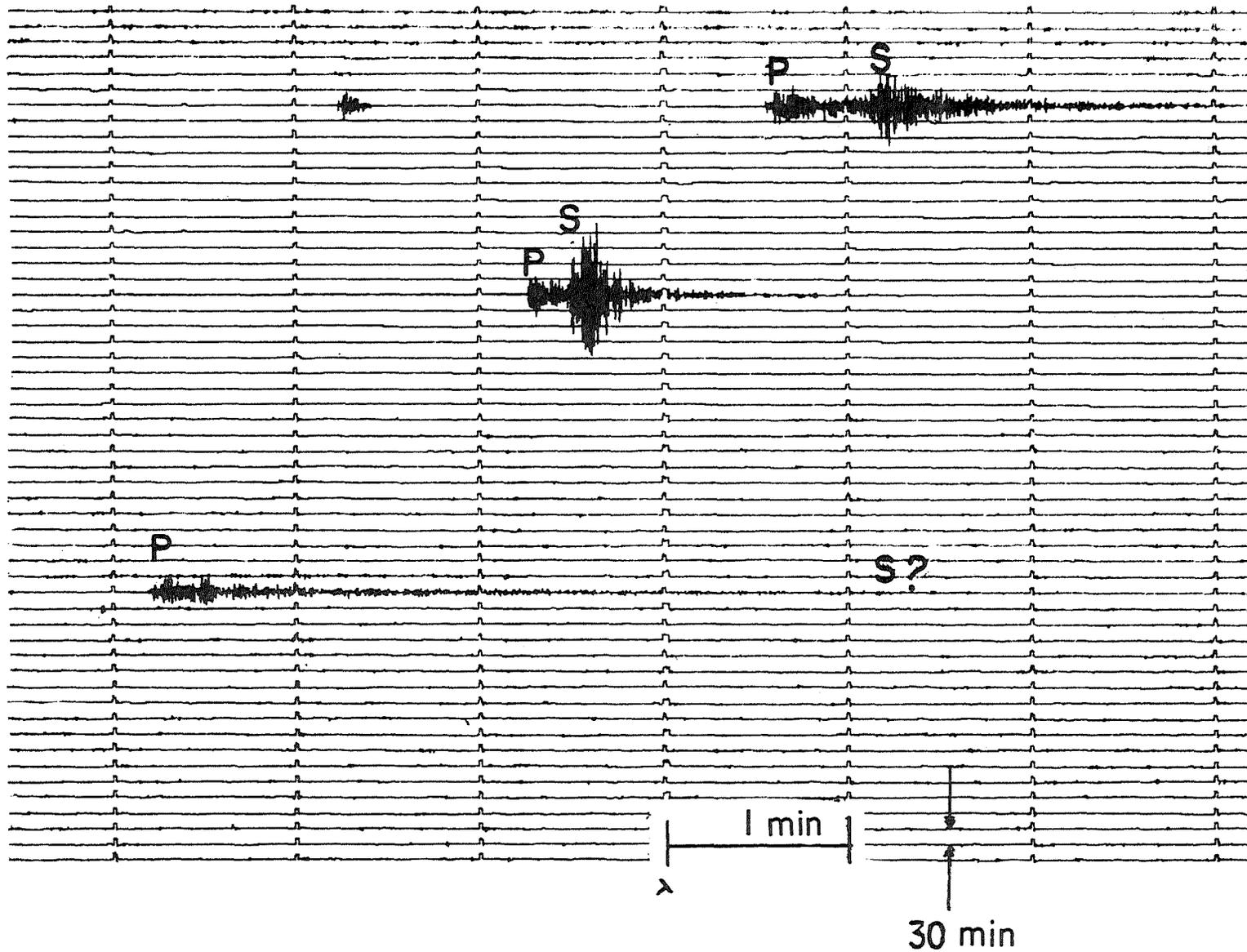


FIGURE 12. - Seismogram of various events except bursts.

Figure 10 shows one medium and two major bursts triggered by a back-stopping round in a stope pillar. The mine structure was damaged, but the miners were safely away from the area. Simultaneous P and S wave arrivals indicate the bursts occurred at the same mine as the seismograph location. Wavy horizontal lines are due to distant microseisms or mining interference.

These rock-burst records are contrasted with the seismogram of a shallow-depth, local earthquake in figure 11. The S - P is 35 sec, and the epicenter is about 300 km (190 miles) from the recorder. The epicenter was near Othello, Wash., and the magnitude was 4.0 on the Richter scale. Note the length of the wave laterally (almost 3 min), as contrasted with the burst wavelengths of a few seconds in figures 9 and 10.

Examples of various seismic events (other than rock bursts) are shown in the seismogram of figure 12. Top is a blast as a strip mine in British Columbia (S - P of 35 sec), preceded by a small local quake; center is a western Montana quake near Libby Dam (S - P is 15 sec); bottom is a distant quake (the S wave is damped out and not recorded).

A major burst is defined here as causing extensive damage to the mine workings. Production loss is considerable while repairs are being made. These bursts are recorded on all of the seismographs; the rock displaced is from 100 to 1,500 tons per event.

A medium burst is defined here as causing some damage to the mine structure and is felt and reported by the underground crew. Production loss is not as serious as in a major burst. These are usually recorded on two seismographs, and the rock displaced is from 25 to 100 tons per event. Back-stopping at times triggers bursts in this category.

Minor bursts are defined here as small enough not to cause a loss in production with only a few tons of rock displaced. This type is usually triggered by blasting and is normally only recorded on the seismograph at the mine where it occurred. Many of these bursts are purposely triggered to prevent the continued buildup of stress.

Although considerable progress has been made in rock-burst control, more research needs to be done. Figures 13-15 show the damage caused by a major burst in a stope. The rock displaced was about 250 tons, causing a month's production loss in the stope. There were no injuries because the burst occurred with the regular blast round.



FIGURE 13: - Rock-burst damage in a stope pillar.



FIGURE 14. - Damage in drift from burst in pillar below.

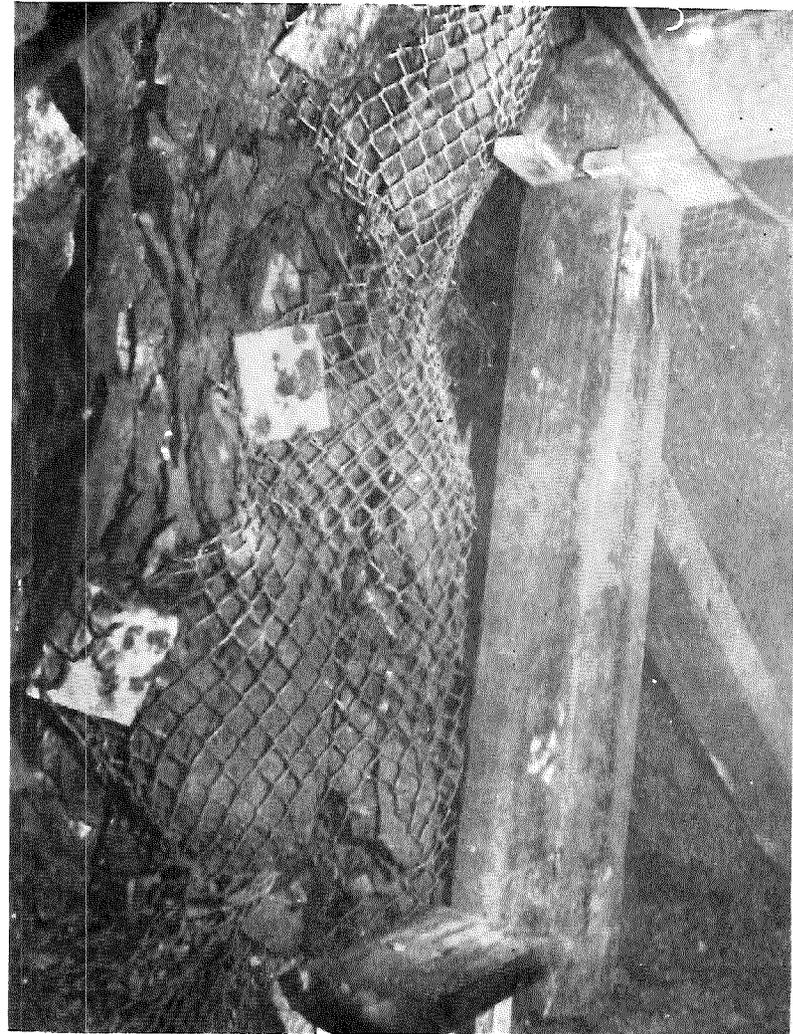


FIGURE 15. - Damage in rib of drift from burst in pillar below.

ROCK BURST CONTROL--STATE-OF-THE-ART

The sudden, violent release of energy that takes place when the elastic limit of rock is exceeded can be compared with an explosion or earthquake. The magnitude of rock bursts can range from small cracks in a few cubic feet of rock, which is neither felt nor heard (except as subaudible rock noise), to the violent explosive movement of thousands of tons of rock felt and heard not only in the mine but also over a considerable distance on the surface. The larger bursts are regularly recorded as earthquakes at the Butte seismograph station (200 miles), and smaller ones not felt at the surface are recorded at the Newport seismograph station (87 miles).

The exact time of a rock burst, like an earthquake, cannot be predicted. Current research is rapidly approaching a point where the time frame of a burst may be predicted from telltale signs; that is, increased stress concentrations, level of seismic activity, etc.

The rock mechanics group from SMRC has documented the progress in burst control, which is included in the list of references at the end of this report (1, 5-6, 12, 17-19). Early-warning systems that locate areas of high stress, using microseismic methods, were first studied by Obert and Duvall (14) in the 1940's. Research has continued, and there are broad-band microseismic systems (rock-burst monitors or RBM) initially operating at the Galena and Lucky Friday mines (2-3, 9-10). The system at the Lucky Friday mine property was not built by the Bureau but was developed by Hecla Mining Co. using standard manufactured components. The IBM System/7 computer⁶ is a standard minicomputer but the application of it to the rock-burst monitor system depends entirely on the Hecla-perfected software (10).

In the Coeur d'Alene area, the loss of production and damage repair have been estimated by one company to add a dollar per ton to the cost of mining the ore. Research to reduce or prevent rock bursts is, by its nature, costly in time and money. Unlike most research where there is a one-time setup, rock-burst instrumentation must be installed, calibrated, and kept in operation 24 hours a day, 7 days a week. Significant progress has been made to control rock bursts and reduce the damage. Some of the methods are as follows:

1. Destressing holes blasted ahead of the working face control bursting. This practice is widely used in development headings as drifts, raises, and shafts (19). Generally, two holes are drilled about twice the depth of the holes in the round and detonated with the round.

2. Blasting of a number of holes at the same time has triggered bursts. This is done between shifts or on a weekend when the miners are on the surface. Locally this is called back-stoping and is used in stopes above the same level and at about the same elevation. The seismograph records the approximate intensity and number of bursts so triggered and indicates on a semiquantitative basis if stress has been relieved.

⁶Reference to specific equipment does not imply endorsement by the Bureau of mines.

3. It has been established that stress concentrations and rock bursts have a cause-and-effect relationship. If the stress can be reduced, then there is a tendency to reduce bursting. These methods include underground opening design, a possible optimum mining rate permitting redistribution of stress concentration without bursts, and destressing blasts. The primary purpose of destress blasting is to soften the pillar; that is, to reduce its modulus of elasticity and thereby reduce the amount of strain energy that can be stored. The stress probably is not reduced appreciably but is channeled into crushing rock that has been microfractured rather than storing energy for rock bursts. In destressing of stope pillars, hole spacing of 5 to 7 feet and loading the holes to within 5 feet of the collar with explosive (9) has been satisfactory. The seismograph records bursts so triggered.

4. The Bureau of Mines DMRC and the mining companies have developed broad-band microseismic systems to locate areas of stress concentration. Three microseismic networks will be in operation in the Coeur d'Alene district (9-10), with plans for a fourth installation (at the Sunshine mine).

5. A monitoring method, based on the rate of vein-wall closure to determine if a pillar is successfully destressed, has been developed for smaller mines that cannot afford the investment required for microseismic equipment.⁷ Figure 16 graphically shows an increase in the closure rate, indicating that the destressing was a success.

Studies at one mine have shown that 80 pct of the rock bursts occurred with or immediately after blasting of regular rounds. Since the miners are away from the stoping area at blasting time, these were not hazardous, but the remaining 20 pct occurred on shift, or between shifts, and presented a hazard.

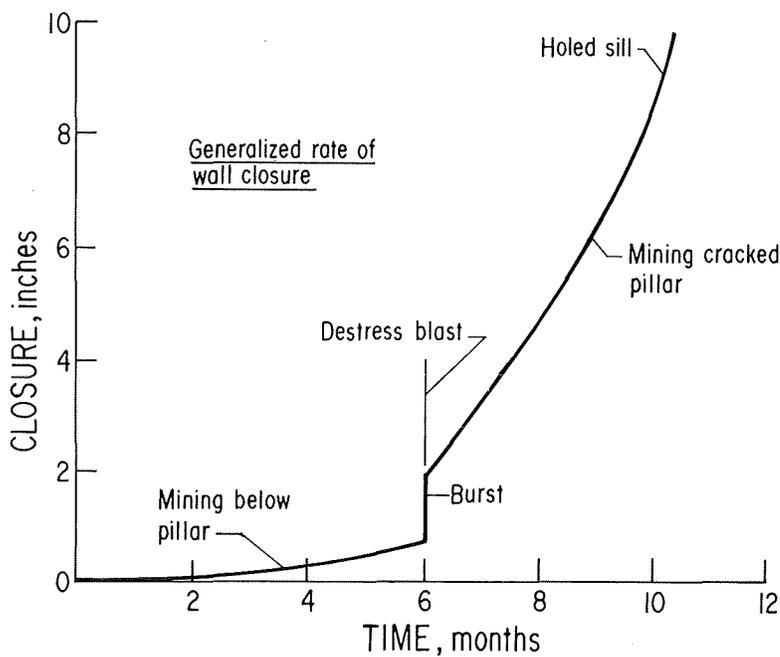


FIGURE 16; - Graph of wall closure rate.

BURSTS IN THE DISTRICT--
JANUARY 1, 1973, TO
JUNE 1, 1975

A burst summary covering the period from January 1, 1973, to June 1, 1975, indicates progress in rock burst control has been made. This is evidenced by the decrease with time in the ratio of the number of damaging bursts to the total number of bursts shown in figure 17. Damaging bursts

⁷This method is the subject of an upcoming Report of Investigations by W. C. McLaughlin and J. Songstad.

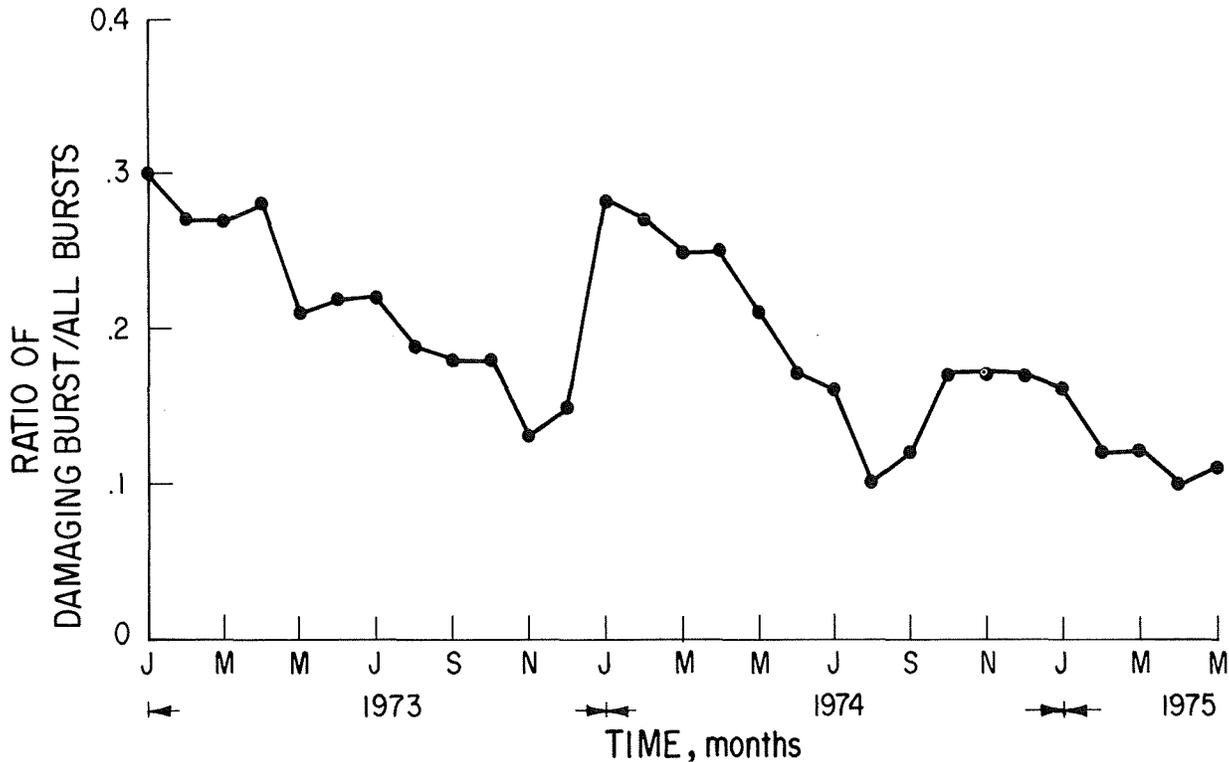


FIGURE 17. - Ratio of damaging bursts/all bursts.

range from that that break timbers to major bursts that displace hundreds of tons and cause extensive damage to the workings.

The absolute number of all bursts with time is shown in figure 18. The total number of bursts is increasing with time, but this includes controlled rock bursts that occur with or shortly after destressing blasts. The total number of bursts is increasing because more destressing is practiced. These controlled rock bursts are shown as the shaded area in figure 18. Controlled rock bursts are desirable because they relieve the stress and make the stopes safer for the miners.

The number of damaging rock bursts shown in figure 18 is rather constant, but certain factors must be considered in interpreting this data:

1. The mines are deeper than before, and stope development is in geologic conditions very conducive to rock bursts.
2. The individual mines have improved the reporting and recording of rock bursts. In fact, the rock-burst problem has in some mines been assigned to a specialist in ground control. This tends to increase the number of reported and confirmed rock bursts. Equipment to record bursts is more widespread.

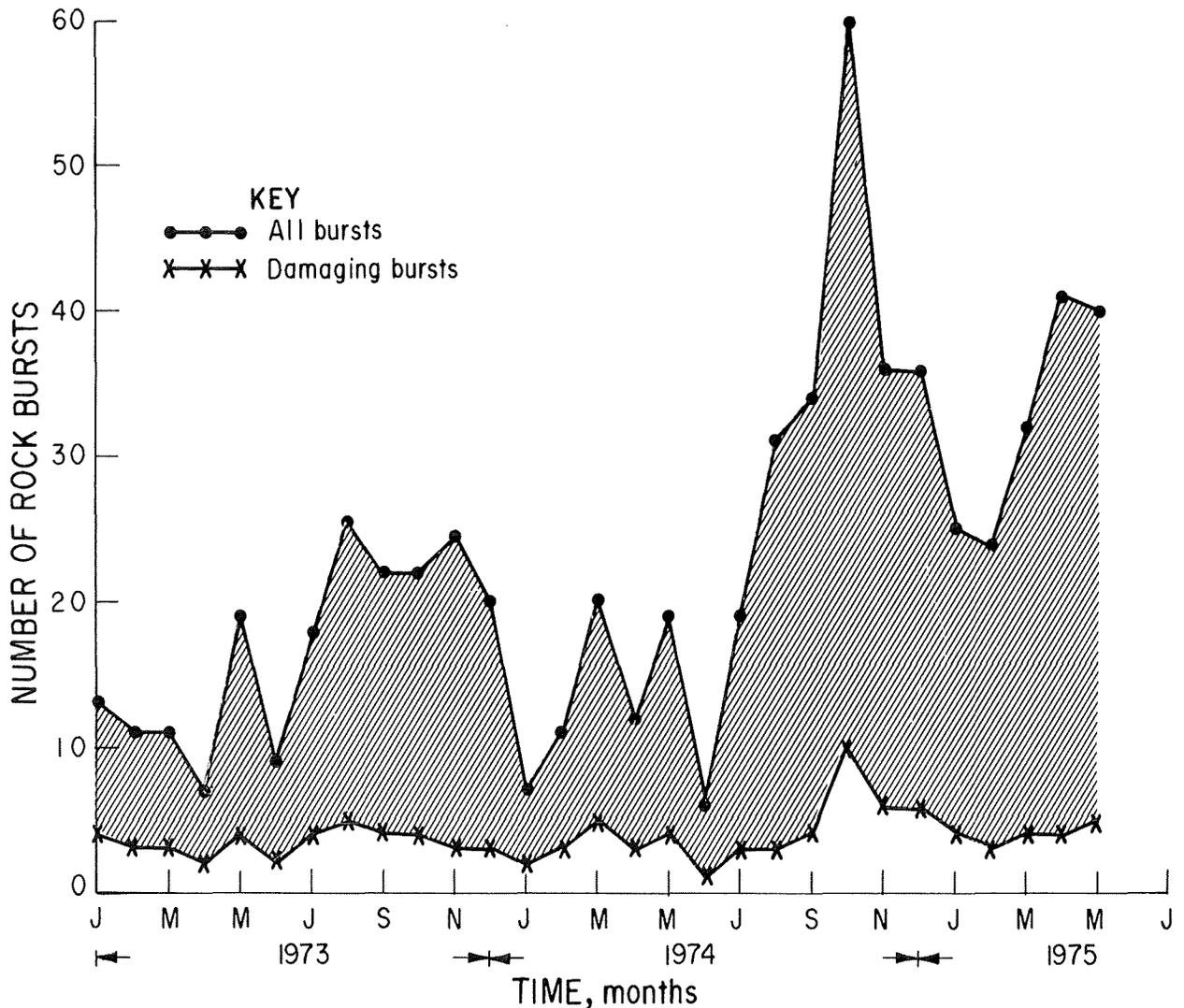


FIGURE 18: - Total rock bursts recorded.

3. Rock-burst monitoring is improved along with interpretation of data for destressing studies. This tends to increase the number of bursts detected and recorded. If destressing practices had not been improved, factor 1 would have caused an increase in the number of damaging bursts.

CONCLUSIONS

Cooperative research has helped the mining companies to maintain a fairly good measure of rock-burst control even though the in situ conditions increase the chance of rock bursts with greater mining depths. Developing and applying the RBM early-warning system to detect and locate areas of stress concentration has contributed to rock-burst control. Also, the surface seismographs are a necessary part of the system to supplement data from the RBM, particularly at blasting time. Due to the proximity of the microseismic pickup units (geophones) to the blast, most bursting thus triggered is masked on the

RBM but records on the seismogram the number and relative intensity of the bursts in a semiquantitative measure of stress relief. Also, the geophones can be placed more strategically by correlation with the seismogram. Generally, there is an increase in the level of seismic activity prior to a major burst. This is noted on the seismograph record.

Geologic factors, including planar discontinuities as dikes and sills, and folding and faulting of the quartzites--all affect the stress field and contribute to burst-prone conditions. These are considered by the operators in deciding where and when to destress. Pillars and remnants result in stress concentrations, and past experience is a guide to destressing. The geology and geometry of the openings, along with the microseismic and seismograph records, are used as tools to help reduce burst intensity and incidence.

The long-range solution to rock bursts, in the opinion of some researchers and mine operators, lies in the development of a mining method that does not leave pillars and remnants where stress buildup can occur. Stopping configurations other than the present horizontal cut-and-fill might be tested where the major stress is lateral. These include undercutting, angle cutting, and vertical slotting.

For the short term, it is suggested that other methods of stope-pillar destressing be tested and applied. One method is to drill large-diameter destressing holes from the drift above the stope using a drill jumbo and a large-bore drifter and destress pillars both below and above the drift (where pillars are left above). Present practice generally is to drill destressing holes up into the pillar from the stope and from the drift, using jackleg drills; the depth and diameter of hole drilled with the jackleg is limited and drilling may be from beneath a highly stressed pillar. Further study of destressing hole depths, diameters, loading patterns, and spacing should be conducted to determine the best configuration in various types of ground.

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