UNDERHAND LONGWALL PROGRAM AT LUCKY FRIDAY MINE, MULLAN, ID

By M. E. Poad,[1] G. Johnson,[2] J. K. Whyatt,[3] and J. R. Hoskins[3]

ABSTRACT

Researchers from the U.S. Bureau of Mines (USBM) have been investigating alternative mining methods to reduce the number and severity of mining-induced seismic events in the deep mines of the Coeur d'Alene Mining District of northern Idaho. In 1984, USBM entered into a three-way memorandum of agreement with Hecla Mining Co., Mullan, ID, and the University of Idaho, Moscow, ID, to design, implement, and evaluate a mining system that could be used safely and productively for vein mining in a rock-burst-prone mine. A mechanized underhand longwall cut-and-fill method using a ramp system for access was chosen for study at the Lucky Friday Mine, Mullan, ID. A 122-m (400-ft) long test stope was developed between the 5100 and 5300 levels. In the underhand method, a block of ground is mined from the top down in a single advancing face, always toward virgin ground; this procedure eliminates the development of a highly stressed sill pillar. Because an engineered fill is placed after each cut, a more competent back is created for the next cycle. Success of the test stope led to adoption of the underhand longwall as the primary mining method throughout the mine.

INTRODUCTION

The U.S. Bureau of Mines (USBM) has been involved in rock-burst research in the Coeur d'Alene Mining District of northern Idaho since the 1970's. As mines go deeper, the number of seismic events, and, correspondingly, the number of damaging rock bursts has increased. (A rock burst is defined here as a mining-induced seismic event that damages mine openings.) The potential for catastrophic injury and loss of life is of ongoing concern.

Control of rock bursts has been pursued in a number of ways. This paper describes a research program directed at improving deep mine safety and productivity through modification of mining methods. In 1979, the USBM conducted a study to examine the potential of the underhand cut-and-fill stoping method as a means of improving ground control in Coeur d'Alene district mines. A subsequent demonstration conducted at Hecla Mining Co.'s Star Mine was limited to pillar recovery but indicated the practicality of the method. The USBM's involvement in the Lucky Friday underhand longwall (LFUL) began in April of 1984 when a three-way memorandum of agreement was entered into with the Hecla Mining Co., Mullan, ID, and the University of Idaho, Moscow, ID.

The LFUL program was not limited to mining methods but included research into backfill, equipment, safety assessment, ground control, seismic response, and productivity. It is not the objective of this paper to report on everything that has been done within the program. A bibliography of related research is included.

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LUCKY FRIDAY MINE[4]

DESCRIPTION

The Lucky Friday Mine is located on the eastern edge of the Coeur d'Alene Mining District of northern Idaho (figure 1). The first claims were filed in 1889; however, it wasn't until 1941 that the first commercial ore was found. In 1958, Hecla Mining Co. purchased a 38 pct interest in the mine, and in 1964, the mine was merged into Hecla. The mine has operated continuously since that time, except when low metal prices and a worsening rock-burst problem forced a partial shutdown between April of 1986 and June of 1987.

Between 1980 and 1983, the Silver shaft was sunk to a depth of 1,890 m (6,200 ft) and is the only circular, concrete-lined shaft in the district (figure 2). The present mining horizon is near the 5500 level. Since the first commercial shipments in 1942, more than 5,715,000 t (6,300,000 st) of ore have been mined, yielding 2,863,300 kg (101,000,000 oz) of silver, 614,200 t (677,000 st) of lead, and 76,200 t (84,000 st) of zinc. Production during 1993 was—

Gold	972 troy oz
Silver	60,180 kg (2,122,738 oz)
Lead	17,960 t (19,795 st)
Zinc	3,980 t (4,385 st)
Copper	310 t (339 st)
Ore milled	162,910 t (179,579 st)

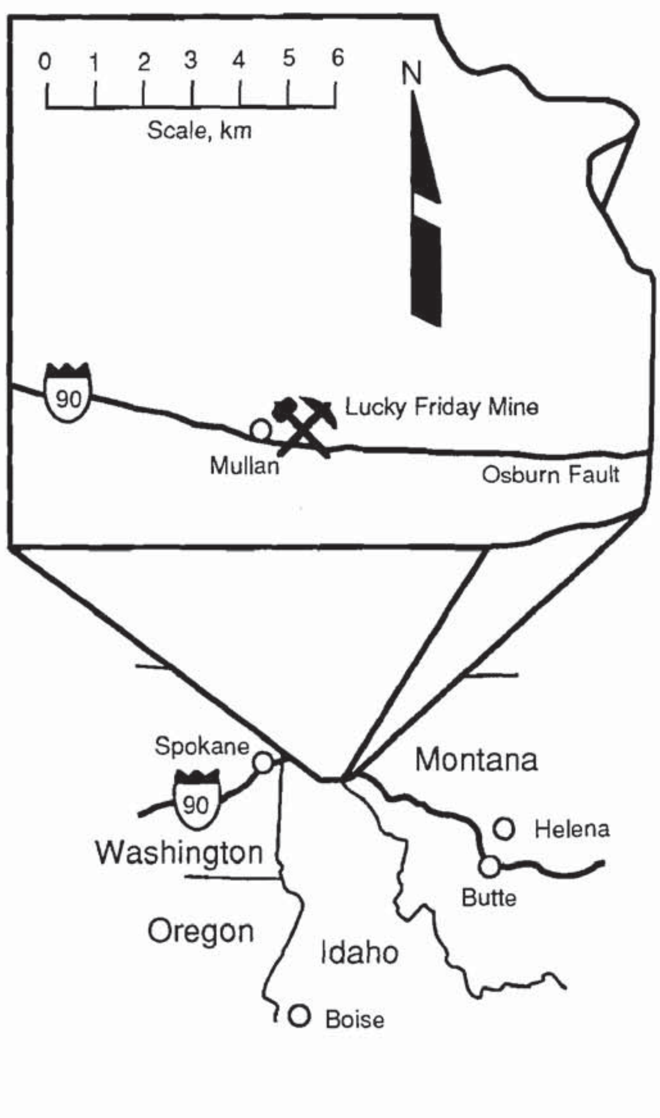
GEOLOGY

The Lucky Friday vein at 1,600 m (1 mile) below the surface forms an S-shape in plan view extending horizontally about 490 m (1,600 ft). Splits off the main vein extend the potential stope length to over 610 m (2,000 ft) along strike. Mineralogically, the vein is composed of galena, sphalerite, and tetrahedrite in a quartz and siderite gangue. The vein is 0.6 to 9 m (2 to 30 ft) wide and averages about 1.5 m (5 ft) wide. The vein is in the Precambrian Revett Formation, which hosts most of the silver- and lead-producing mines in the Coeur d'Alene district.

Because the vein itself dips steeply (70° to 90°) to the south and east, it comes into contact with progressively older rocks with depth (figure 3). Presently, mining is encountering Precambrian Superbelt rocks of the upper submember of the lower member of the Revett Formation.

Numerous faults and secondary folds are apparent, and some of these intersect the vein structure. The most pronounced faults are the North and South Control Faults that delineate the ends of the 460-m (1,500-ft) long Lucky Friday vein. The rock mass surrounding the vein is made up of vitreous quartzite and sericitic quartzite beds from 30 to 91 cm (12 to 36 in) thick with soft interbeds of argillite generally less than 2.5 cm (1 in) thick. These beds have been grouped into 15- to 46-m (50- to 150-ft) thick subunits of predominantly hard, brittle, vitreous quartzite and relatively soft, plastic argillite and sericitic quartzite (figure 4).

Figure 1
Location of Lucky Friday Mine, Mullan, ID.



[4]Mine information was provided by D. G. Wollant, unit manager, Lucky Friday Unit, in a report on the history of the Lucky Friday Mine, January 1993.

Figure 2
Map of Lucky Friday Mine.

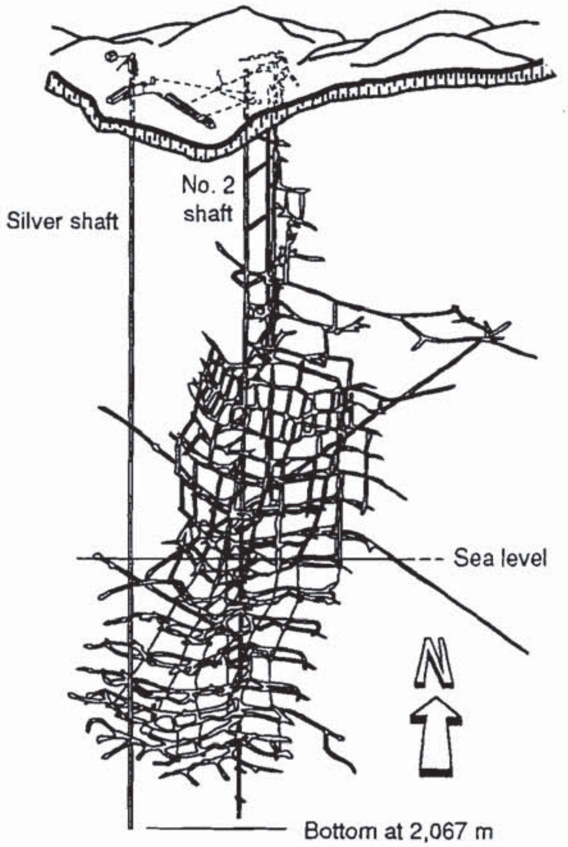


Figure 3
Major Geologic Structures of Lucky Friday Mine, Plan View.

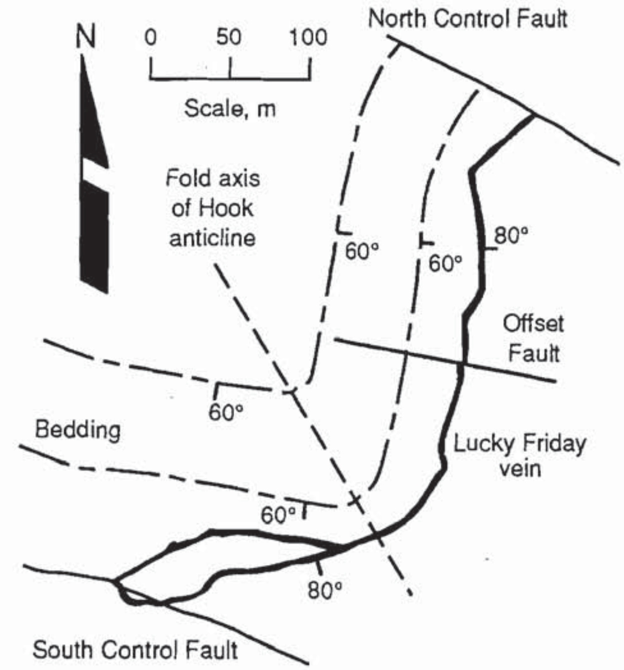
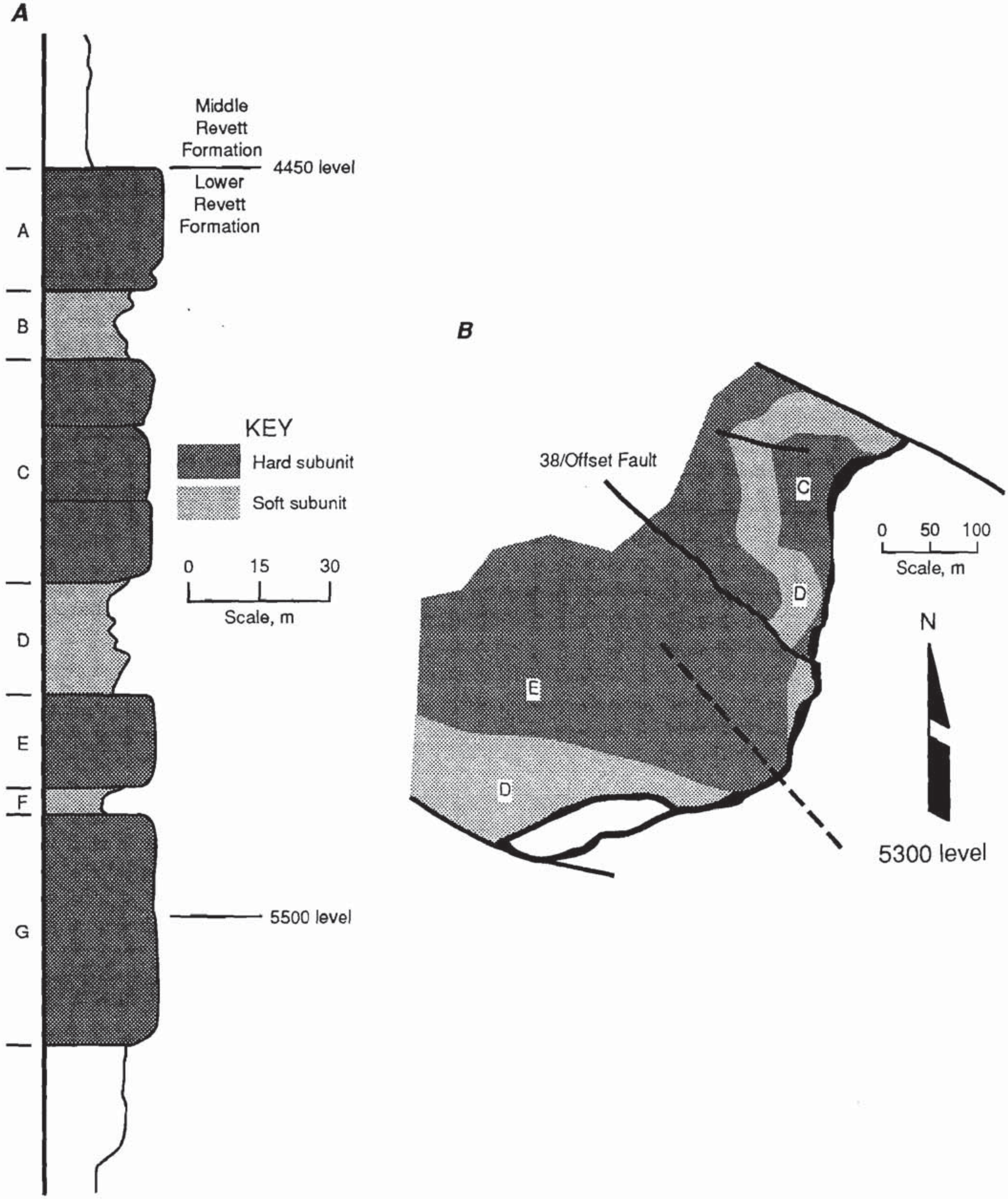


Figure 4
Geology Around Lucky Friday Mine.



A, Simplified geologic column; *B*, geology and faults near Hook anticline (dotted line), 5300 level.

MINING METHODS

TRADITIONAL MINING METHOD—OVERHAND CUT-AND-FILL

The Lucky Friday vein was mined by a traditional overhand cut-and-fill method until 1986. The vein was developed vertically on 61-m (200-ft) intervals with track haulage levels driven parallel to the vein and extending between the Silver and No. 2 shafts. Crosscuts from the main haulage levels were driven horizontally at approximately 76-m (250-ft) intervals.

Large, heavily timbered raises were constructed at vein-crosscut intersections, with eight stopes generally developed per level. At 6 m (20 ft) above the track elevation, a sublevel was mined for approximately 76 m (250 ft) along strike. Overhand stoping and breasting down on an unconsolidated mill tailings backfill using jackleg drills and electric slushers advanced the stope upward in a series of 2.4-m (8-ft) high lifts toward the next working level. Timbers were placed in at least 15 m (50 ft) of the stope length, and at times along the entire length of the stope. Productivity in these overhand stopes ranged from 11 to 18 t (12 to 20 st) per crew member per shift over a cut-and-fill cycle. Approximately 24 developed stopes were needed to ensure a production rate of 900 t/d (1,000 st/d), which required a minimum of three developed levels to be operating at once. Because of rock-burst damage, the need to replace timbers, and sandfilling, only 50 pct of the stopes were generally producing ore on any given day. Broken ore was slushed from the stope into ore chutes, loaded into 2.7-t (3-st) cars, and transported to the skip loading systems at either shaft. Figure 5 illustrates a typical overhand stope with its raise, ore chute, backfill operation, and active stoping area.

One characteristic of the overhand stoping method is that it produces a pillar of vein rock as mining proceeds upward toward previously mined areas. This pillar is steadily reduced in size until it is completely removed. As the pillar becomes smaller, stress concentrates in the remaining portion until it eventually fails. Failure may be violent or nonviolent, depending upon the relative stiffness of the pillar and the wall rock. A nonviolent failure is characterized by gradual fracturing and yielding, while violent failure is characterized by the release of seismic energy. When sufficient seismic energy is produced to damage mine openings, the failure is called a rock burst.

Ground control, including the necessity of preventing or reducing the magnitude of rock bursts, is the single largest factor influencing mining method, safety, and costs at the Lucky Friday Mine. Argillaceous beds nearly parallel to the vein dry out and lose cohesion after exposure to air, requiring vigilance to spot loose ground in the stope after every blast. The heavy lead ore itself is very brittle and prone to spalling. Once an opening is made, the rock will not support itself long without timber or rock bolts. Wall rocks experience significant squeeze and over 0.6 m (2 ft) of closure is common in raise areas. These factors make the mine prone to large-scale, unpredictable rock bursts.

DEVELOPMENT OF THE LUCKY FRIDAY UNDERHAND LONGWALL MINING SYSTEM

Increasingly difficult economic conditions prompted Hecla Mining Co. to form a Mining Research Department in 1983 to identify and test alternative technologies and techniques that would improve the safety and profitability of its overhand cut-and-fill operations.[5] The research department quickly determined that its primary objective would be to find a solution to the rock-burst problem. The department also forged a close working relationship with the USBM and students and staff of the Department of Mining and Metallurgy at the University of Idaho. University of Idaho participation was funded largely by the USBM's Generic Minerals Institute program.

Promising results from a USBM study at Hecla's Star Mine encouraged Hecla's research group to begin investigating variations of the underhand cut-and-fill method. Underhand cut-and-fill operations at Magma Copper's Superior Mine, Superior, AZ, and Homestake Mining Co.'s Bulldog Mine, Creed, CO, were reviewed (Cummings and Given, 1973; Murray, 1982). Canadian research and practice, primarily in Inco, Ltd.'s, large nickel mines in northern Canada (Hustrilid, 1982), were also studied.

Underhand cut-and-fill stoping is a method in which a block of ore is mined by cutting and filling in sequence from the top of the block to the bottom (rather than from the bottom to the top as in the overhand cut-and-fill method), so the intact vein forms the stope floor instead of the stope back. As in the overhand cut-and-fill method, the vein is accessed through crosscuts from laterals, and mining is conducted with a conventional drill, blast, and muck cycle. Figure 6 shows a typical underhand cut-and-fill stope with ore chutes and a filled area above the stope.

Design and Evaluation

As a result of this review, Hecla determined that a successful mining method must include the following design factors:

1. It must reduce rock-burst activity by removing remnant pillars.

[5]Company information supplied by S. Lautenschlaeger, unit manager, Lucky Friday Unit, in a report on the Lucky Friday Mine, Jan. 1990.

Figure 5
Overhand Cut-and-Fill Stope.

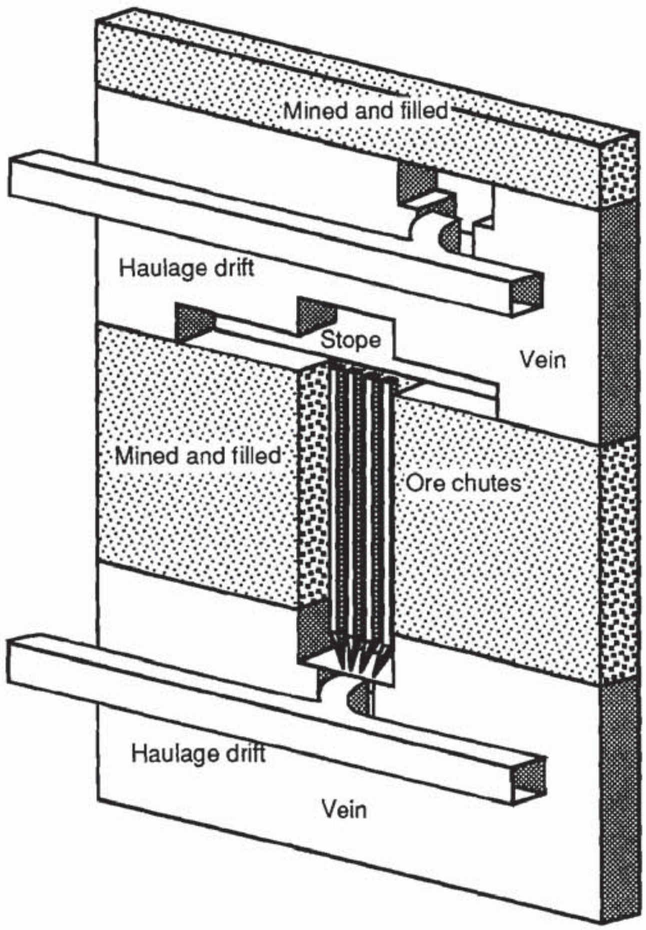
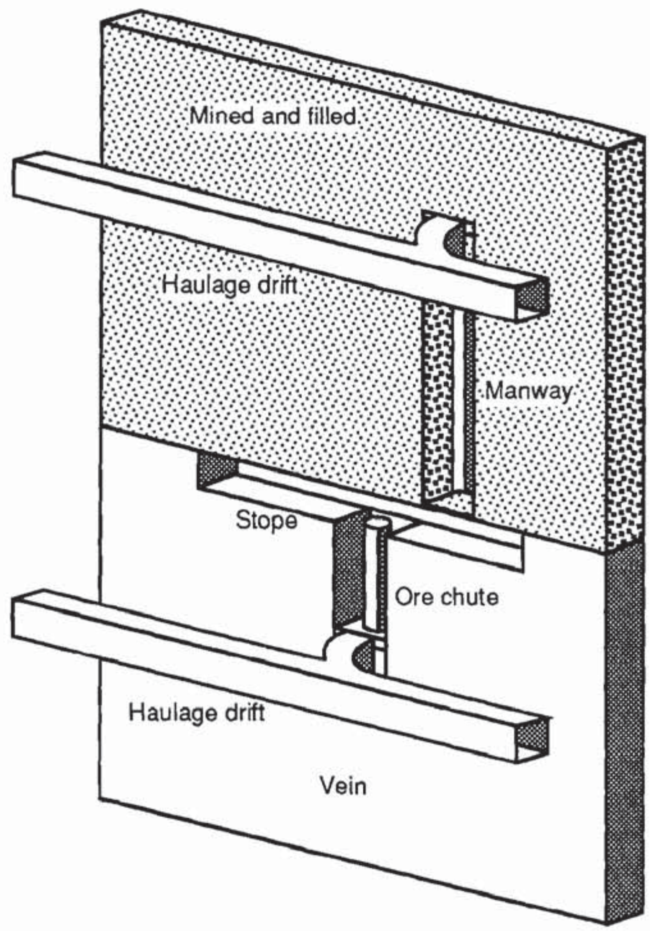


Figure 6
Underhand Cut-and-Fill Stope.



2. It must be mechanized to reduce the direct cost of mining.
3. It must include a competent, reinforced fill back resistant to shock loading and able to support high regional in situ stresses.

The company proposed an underhand longwall method that uses the principle of a single advancing face in conjunction with the underhand cut-and-fill method to reduce rock-burst hazards. This method had been recommended by the South African High-Level Committee on Rock Bursts and Rock Falls (1977) as a means of reducing rock-burst hazards associated with mining remnants (or sill pillars) as early as 1924 and is now standard practice in South Africa.

Two ground control conditions were identified as crucial to successful implementation of the underhand longwall mining method. These were that—

1. The ramp system must remain stable and operational throughout the life of the stope, and
2. The rock mass response to changing the mining method should not make conditions worse, and should reduce, rock-burst hazards, especially for rock bursts originating at the mining face.

The Hecla research department developed a proposal for evaluating the LFUL test stope. Hecla committed funding for the study and entered into a joint research agreement with the University of Idaho and the USBM for a cooperative project involving stope instrumentation and analysis. The research program concentrated on ground control, mechanization, and fill technology. The University of Idaho worked primarily in mechanization and fill technology while the USBM examined the state of in situ stress, numerical modeling of deep mines, mechanized mining equipment, and backfill technology.

An instrumentation plan was developed for the LFUL stope with the goal of monitoring conditions during mining the first half of the stope block [about 30 vertical m (100 vertical ft)].

Test Stope

The first rock was broken in development for the LFUL test stope in January of 1985. The stope is located on the east end of the Lucky Friday vein between the 5100 and the 5300 levels in the 5300-107 block, approximately 1,555 m (5,100 ft) below the surface and 520 m (1,700 ft) below sea level. Scott (1990) provides an in-depth description of stope geology. This block of ore lies in the upper submember of the lower member of the Revett Formation.

The LFUL test stope uses conventional underhand cut-and-fill methods and a ramp system to provide access for mechanized mining equipment.[6] Slushers were replaced with load-haul-dump equipment (LHD's), which increased mucking efficiency sufficiently to allow stope lengths to be increased from 61 to 275 m (200 to 500 ft), thereby reducing the number of development ramps required.

Each cut is about 3 m (10 ft) high and extends approximately 76 m (250 ft) along the vein to each side of the ramp. The declination of the ramp provides one "turn" adjacent to the ore body every 9 vertical meters (30 vertical feet). Crosscuts are driven from the turning point of the ramp to provide access for services and LHD's. Once a cut is completed, the stope and crosscut are filled with cemented fill. After the fill sets up, a new crosscut is driven from the ramp to the next stope level. Noyes, Johnson, and Lautenschlaeger[7] described the method in detail as it emerged during the development of the experimental LFUL stope. Figure 7 shows the resulting mining plan as implemented in the experimental LFUL stope.

Ground control and backfill data gathered from instruments in the LFUL stope and ramp system provided sufficient basis for confirming the geomechanical soundness of the underhand longwall stope design (Williams and Cuvelier, 1988). Approximately midway through the test stope demonstration in June of 1987, Hecla's executive staff felt that sufficient safety and economic benefits were being shown to justify full implementation of an underhand longwall mining system throughout the mine.

Current LFUL Mining System[8]

The vein is excavated in 24-m (88-ft) intervals vertically by sublevels accessed from a main ramp in the footwall of the vein. Crosscuts from each sublevel are driven to divide the vein into four stopes between 122 and 198 m (400 and 650 ft) long. Development openings 3.4 m (11 ft) wide and 3 m (10 ft) high are advanced by crews utilizing a hydraulic drill jumbo and a 1.5-m^3 (2-yd^3) LHD.

An 3.4-m (11-ft) high cut is drilled and blasted horizontally along strike. Broken muck is removed by either 0.8- or 1.5-m^3 (1- or 2-yd^3) LHD's and hauled to the shaft in a 14.5-t (16-st) truck. After the entire cut is mined, a high-quality cemented backfill is hydraulically placed in the stope to provide safe cover overhead during the next cut. Mining crews then reaccess the vein for a new cut by blasting the floor at a grade of -20 pct to reach the vein at proper elevation. A sublevel plan for the 5400 through 5930 levels is shown in figure 8.

[6] See footnote 5.

[7] Presentation at the 94th annual meeting of the Northwest Mining Association, Spokane, WA, Dec. 2, 1988.

[8] See footnote 4.

Figure 7
Lucky Friday Underhand Longwall (LFUL) Test Stope.

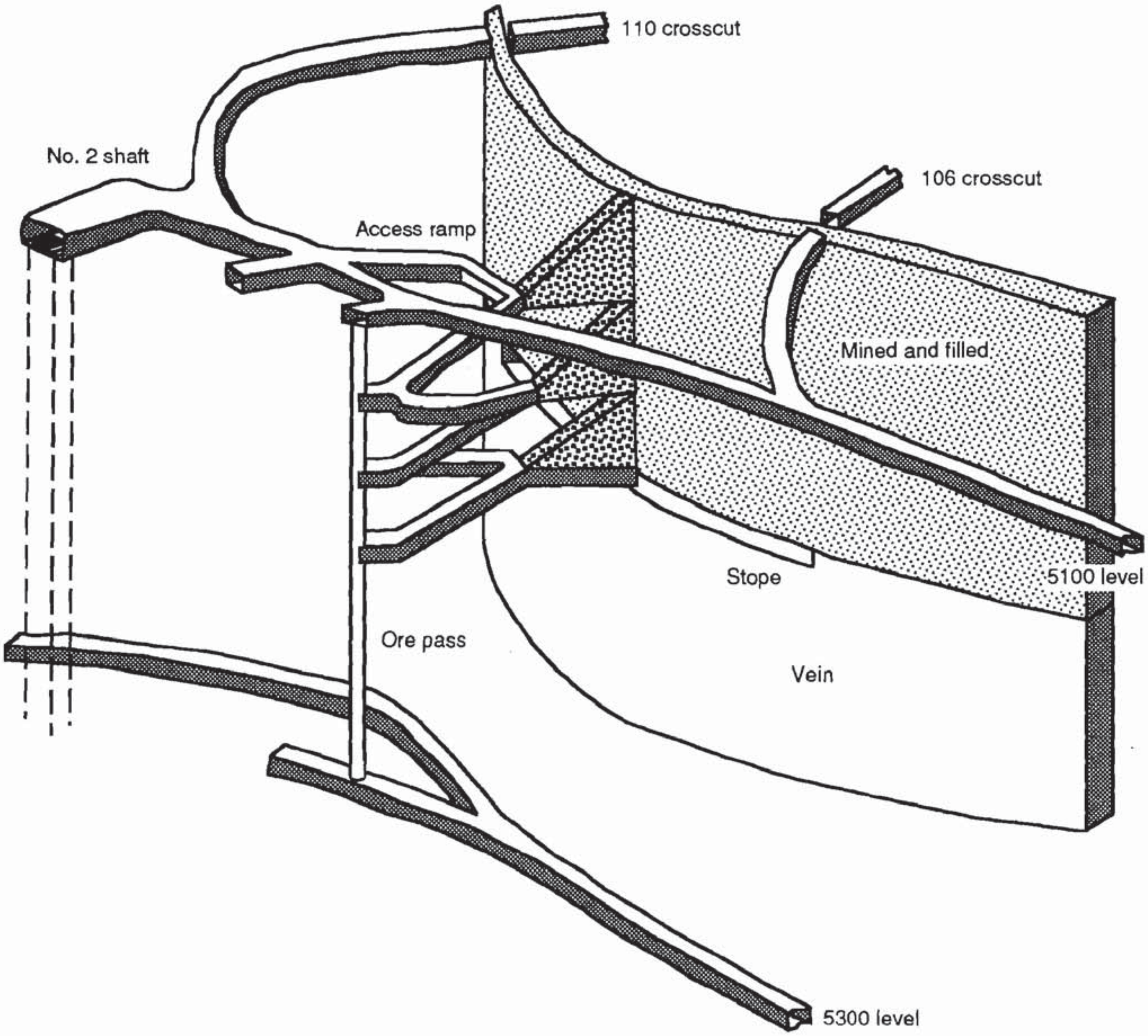
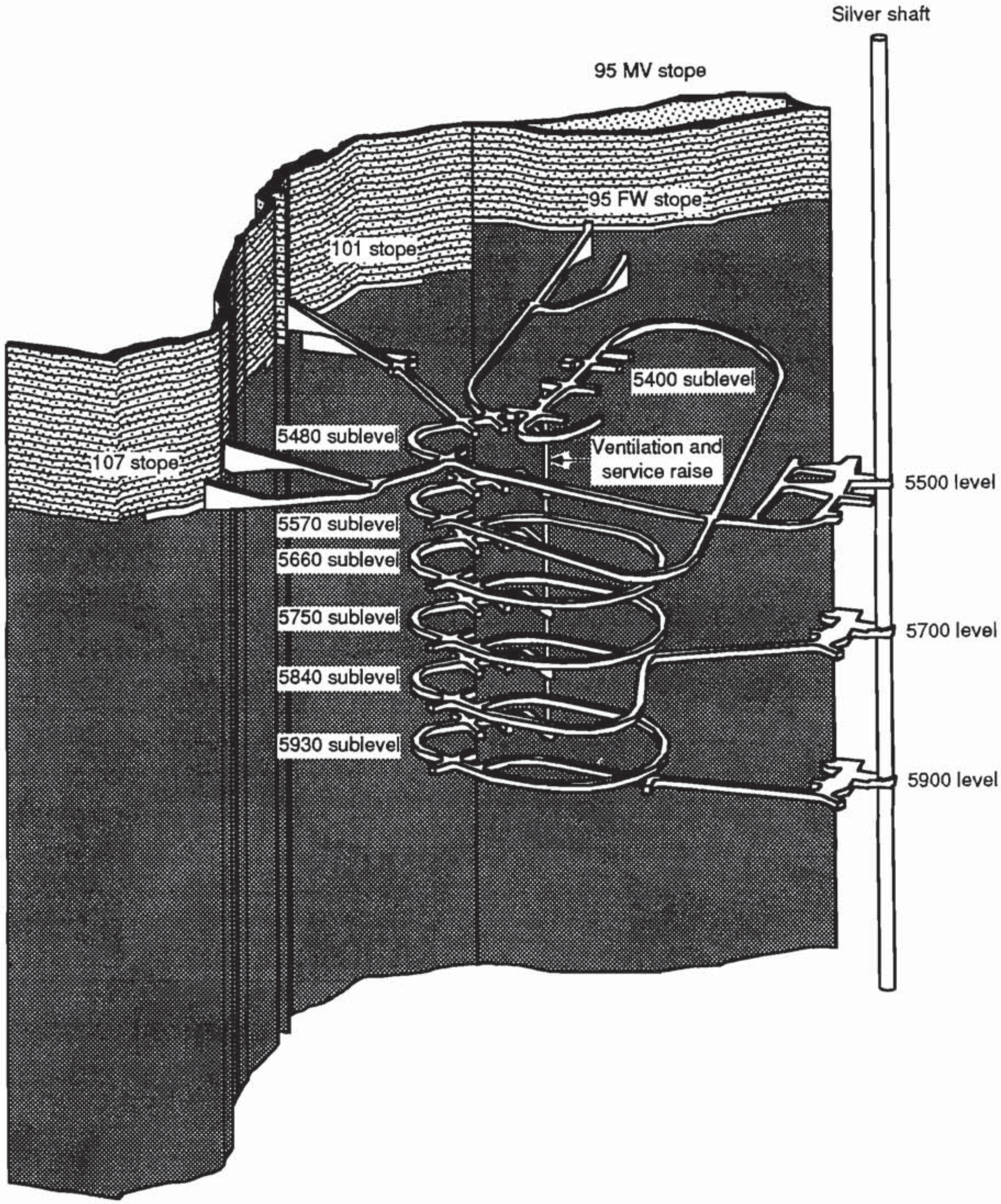


Figure 8
Sublevel Plan at Lucky Friday Mine.



MV = Main vein. FW = Footwall.

DISCUSSION

The Lucky Friday Mine is considered to be the most seismically active mine in the Coeur d'Alene district and among the most seismically active mines in North America (Jenkins and others, 1990). Sprenke and others (1991) estimate that the Lucky Friday Mine experiences a rock burst of local magnitude (M_L) of 2.5 or greater on the average of once every 15 weeks.

Design studies of the LFUL projected an increase in *overall* seismicity but a decrease in the *magnitude* of the largest events. Demonstrating that this has indeed happened is important for evaluating and improving the underhand longwall method.

A plot of annual rock burst activity normalized to metric tons of ore mined for the 10-year period between 1983 and 1993 was prepared (figure 9). An initial increase in seismic activity (1983 to 1987) reflected the progress of mining from the relatively soft Middle Revett Formation to the harder (and more rock-burst-prone) Lower Revett. This number dropped as pillar recovery operations were reduced and the longwall stopes initiated. As the stopes approached a full longwall configuration (1993), the number of rock bursts is again increasing. Lucky Friday Mine personnel have determined that seismic events registering 300 mm or more on the mine's seismograph have the potential to cause damage.

The most dangerous rock bursts, those with M_L greater than 1.5, are plotted in figure 10 for the 8-year period between 1985 and 1993 (without normalization to production): This plot shows that while large bursts occurred at a rate roughly proportional to the entire class of bursts, there was a decoupling after 1990. Initiation of pillar mining increased the relative propensity for large bursts in 1991. This trend reversed in 1992 and 1993 as the mining pattern finally began to resemble a longwall with a single advancing face, and the frequency of large rock bursts fell dramatically, even as the number of small rock bursts increased.

The underhand cut-and-fill method is proving to be a much safer way to mine in rock-burst-prone ground. Many of the large rock bursts that were caused by pillar recovery are being eliminated as the primary stopes progress away from previously mined areas. The cemented backfill has proven to be a reliable and competent roof above the worker.

This is not to say that rock bursts are not a problem in the mine, however, because they are also caused by unfavorable geologic conditions and high stress levels, which are expected to remain.

The underhand cut-and-fill method is also proving to be a more efficient way to mine, and production now averages 33 t (36 st) per crew member per shift. This includes the time spent in a typical 8-week cut cycle to mine the vein, backfill, and reaccess the following cut. Overall mine production is limited to four primary stopes, one or two secondary stopes working on remnant pillars left over from the overhand method, and one Silver vein stope. The number of stopes mined still must be limited because of the danger of rock bursts, and the full implications of the new LFUL mining method are still being evaluated.

Figure 9
Rock Burst Activity Related to Production.

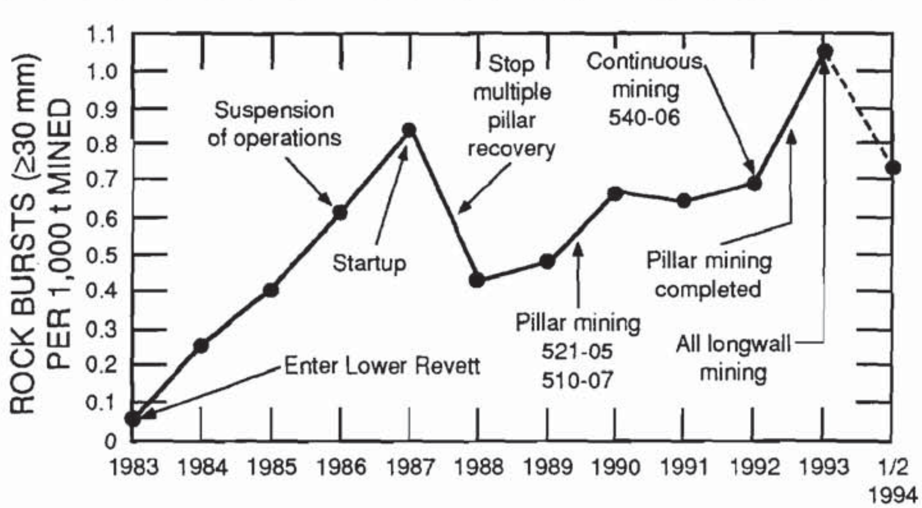
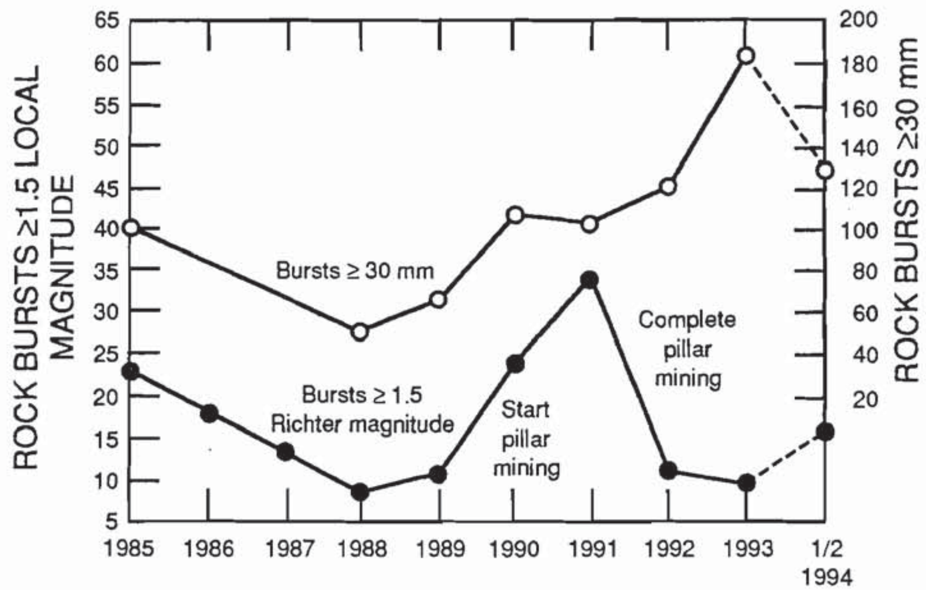


Figure 10
Rock Burst Activity Greater Than Local Magnitude of 1.5.



ACKNOWLEDGMENTS

As the extensive list of references demonstrates, this research was the product of a community of people from the USBM, University of Idaho, and Hecla Mining Co. Among the people who made key contributions to this program are Fred Brackebusch, manager of Mining Research for Hecla (now president of Mine Systems Design, Kellogg, ID) and Wally Crandall, vice-president of Research for Hecla (now retired), who were responsible for organizing research efforts. Dave Cuvelier, mining engineer with Hecla, and Mike Werner, mining engineer (now with TUX, Toronto, ON), coordinated mine access. The Department of Mining and Metallurgy of the University of Idaho committed graduate students and expertise. Mark Board, a mining engineer formerly with the USBM and now at Itasca Consulting Service, Minneapolis, MN, planned the monitoring and instrumentation phase. Wilson Blake, mining consultant, Hayden Lake, ID, deserves thanks for providing his expertise in seismicity and rock-burst analysis. Mike Jenkins, Terry McMahon, and Ted Williams, mining engineers, and Doug Scott, geologist, from the USBM, James Vickery, mining engineer for Kennecott Mining Co., Salt Lake City, UT, and William Pariseau, professor of Mining Engineering, University of Utah, Salt Lake City, UT, assisted with mapping, instrument installation, and monitoring and analysis. Most significantly, the employees at the Lucky Friday Mine are acknowledged for their commitment and ingenuity in successfully implementing the underhand cut-and-fill mining method.

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Special Publication 01-95

Proceedings: Mechanics and Mitigation of Violent Failure in Coal and Hard-Rock Mines

Edited by Hamid Maleki, Priscilla F. Wopat, Richard C. Repsher, and Robert J. Tuchman

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BUREAU OF MINES
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Library of Congress Cataloging in Publication Data:

Maleki, Hamid N.

Proceedings : mechanics and mitigation of violet failure in coal and hard-rock mines / edited by Hamid Maleki ... [et al.].

p. cm. — (USBM special publication; 01-95)

Includes bibliographical references.

Supt. of Docs. no.:I 29.151 : 01-95.

1. Rock bursts—Congresses. 2. Mine roof control—Congresses. 3. Coal mines and mining—Safety measures—Congresses. 4. Mines and mineral resources—Safety measures—Congresses. I. Title. II. Series: Special publication (United States. Bureau of Mines); SP 01-95.

TN317.M35 1995 622'.28—dc20 95-7138 CIP