FIGURE 23.6 Timber support being set on a retreat mining section

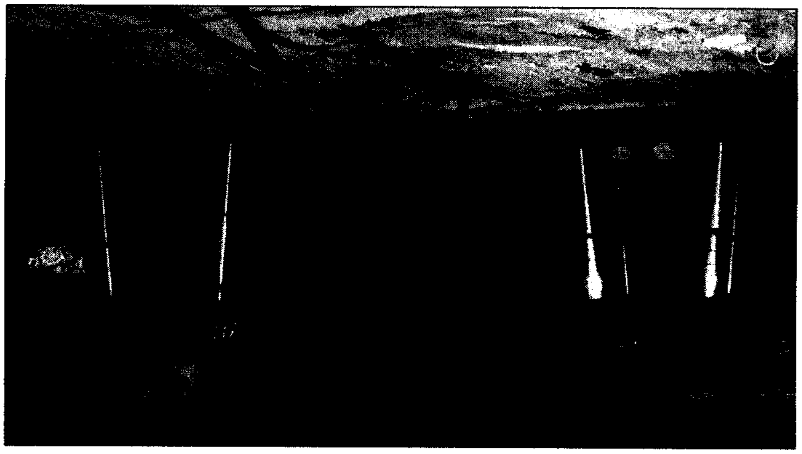

FIGURE 23.7 Mobile roof support (MRS) for retreat mining (photo by Chase 1992)

The recovery of the final stump, or pushout, is the most hazardous aspect of pillar recovery operations. During the past 20 years, nearly half of all fatalities during retreat mining have occurred while the pushout was being mined. The pushout should never be mined if conditions do not look safe or if adverse conditions arise during mining. All unnecessary personnel should remain outby the intersection at all times during pillar recovery, but especially while the pushout is being mined.

Many fatal investigation reports cite geologic features, especially slips, as contributing to the accident. Geologic features should be carefully supported and observed during retreat mining. Special precautions need to be taken near the outcrop, where the presence of groundwater and weathered joints (sometimes called "hill seams") can reduce roof competence. In general, pillar recovery should not be conducted when the distance to the outcrop is less than 45 m (150 ft).

Pillar recovery can also be difficult under deep cover. Between 1996 and 1998, nearly half of the pillar recovery fatalities occurred where the depth of cover exceeded 200 m (650 ft). Under deep cover, barrier pillars and special mining sequences may be required.

Extended Cuts and Remote Control Mining

Extended (deep) cut mining is where the continuous mining machine advances the face more than 6 m (20 ft) beyond the last row of permanent supports. The development of remote control for continuous miners (Figure 23.8), spray fan systems, and flooded-bed scrubbers has provided the technology to

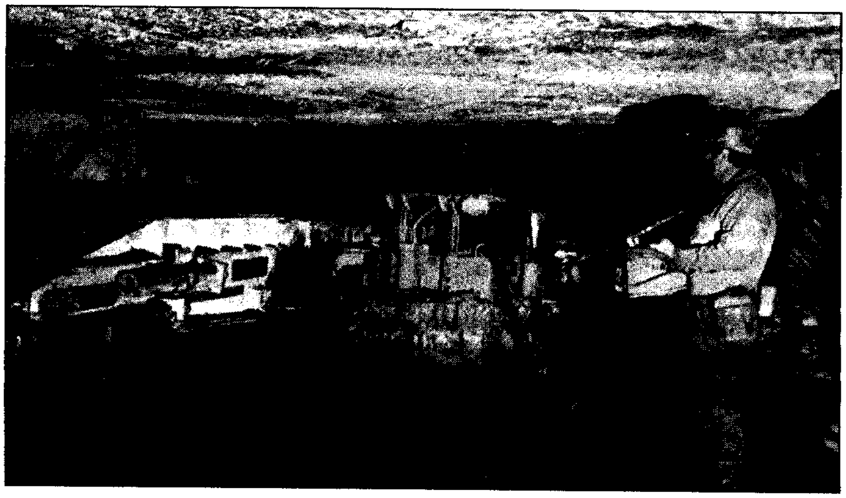

FIGURE 23.8 Miner operating a continuous mining machine by remote control (photo by E.R. Bauer)

enable deep cuts. By 1997, about 75% of all underground labor hours were worked at mines with extended cut permits. However, extended cuts raise a number of ventilation, ground control, and human factor issues. Between 1988 and 1995, extended cuts may have been a factor in 26% of all roof fall fatalities in underground coal mines (Bauer et al. 1997).

In practice, many mines with permits only take extended cuts when conditions allow for them. Where the roof is competent, extended cuts are routine. At the other extreme, when the roof is poor, miners may not even be able to complete a 6-m (20-ft) cut before the roof collapses. A premature roof collapse can trap the continuous miner or endanger the crew, or it can create uneven and hazardous conditions for the roof bolters. Where premature collapses are likely, additional roof supports (extra bolts, planks, mesh, or straps) should be used within the last two rows of supports to prevent the fall from overriding these supports.

A study conducted at 36 mines found that in 50% of all underground coal operations, extended cuts were routinely used nearly all the time (Mark 1999). In 22% of the mines, extended cuts were rarely feasible. In the remaining mines, extended cuts were sometimes stable, sometimes not. The prevailing conditions were found to be determined by the roof quality, the entry width, and depth of cover. Another study found that extended cut mines were no more prone to roof falls after bolting than non-extended cut mines (Bauer et al. 1997).

Remote control mining allows the operator to stay further back from the unsupported roof, but it also removes him from the protection provided by the canopy. The freedom of movement, combined with a lack of visibility, can tempt the operator to stray into dangerous locations. Several fatalities have occurred during the mining of the first cut in a 90-degree crosscut to operators who had gone inby permanent supports (Figure 23.9). In response, some companies have limited the length of the initial cuts in a crosscut to 20 ft, and others have angled the crosscuts to provide better visibility.

Training is an essential element in safe deep cut mining. Other workers on the section should know not to go in by the continuous miner operator unless they are operating coal haulage equipment at the face. If the continuous miner breaks down inby permanent roof support, the roof must be properly supported before repairs are made. Finally, all crosscuts must be supported before a cut is taken inby or the opposite crosscut is started.

Intersection Stability

In underground coal mines, tens of thousands of intersections are driven each year. Intersections create diagonal spans of 8 to 12 m (25 to 40 ft), well over the normal width of an entry. The hazards of wide spans can be increased when pillar corners are rounded for machine travel (turnouts), or when rib spalling increases the span.

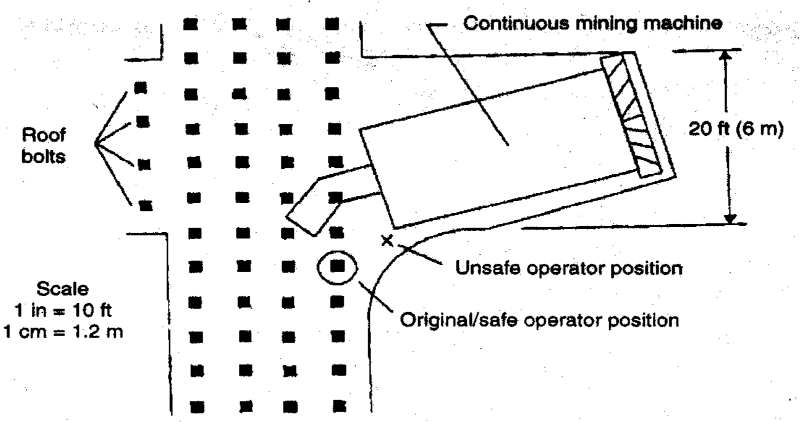

FIGURE 23.9 Unsafe location for a continuous mining machine operator while mining a crosscut (Bauer et al. 1997)

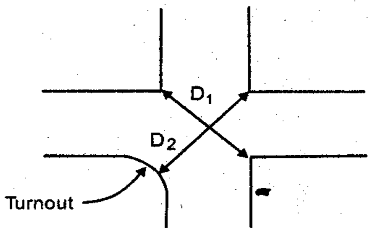

FIGURE 23.10 Sum-of-the-diagonals for intersection span measurement (G. Molinda et al. 1998)

Subsection 50.20-5 requires every roof fall in the active workings that occurs above the roof bolt anchorage, impairs ventilation, or impedes passage be reported. In 1996, there were 2,105 noninjury reportable roof falls. More than 71% of these occurred in intersections, despite the fact that intersections probably account for less than 25% of all drivage underground.

Intersection spans are often measured as the sum of the diagonals (Figure 23.10). Because the rock load increases in proportion to the cube of the span, even a small increase in the span can greatly reduce the stability of an intersection. For example, widening the entry from 5.5 to 6 m (18 to 20 ft) increases the rock load from 82 to 120 tonnes (96 to 132 tons)! A study conducted at one mine in western Pennsylvania found that 83% of the roof falls occurred in 13% of the intersections where the sum of the diagonals exceeded 22 m (70 ft) (Molinda et al. 1998).

Many roof control plans specify the maximum spans that are allowed. Mining sequences can also be designed to limit the number, location, and size of turnouts, and to restrict turnouts to specific entries. Extra primary support, such as longer roof bolts, installed within intersections can also be very effective in reducing the likelihood of roof falls. On the other hand, replacing four-way intersections with three-ways may be not be an effective control technique. Three-way intersections are more stable, but since it normally takes two three-ways to replace one four-way, the total number of falls is likely to increase (Molinda et al. 1998).

Hazards in Underground Metal and Nonmetal Mines

Between 1996 and 1998, nine fatal fall of ground injuries from eight different accidents occurred in underground metal and nonmetal mines (Table 23.6). Two major contributing factors were the failure to conduct proper roof and rib examinations and problems with removing loose rock. Both of these activities are more difficult in large mine openings. Overall, metal and nonmetal underground mines have lower ground fall injury rates than coal mines. For example, a study by Iannacchione et al.

TABLE 23.6 Factors associated with nine metal/nonmetal underground fatalities, 1996–1998

Date	Commodity	Factor	State	Type of Fall	Job	Mining Height (m)
11/4/98	Metal	Inadequate examination/failure to remove loose ground	CO	Rib	Driller	3
3/4/98	Metal	Failure to remove loose ground	AZ	Roof	Installing support	Not applicable
1/19/98	Metal	Failure to support or remove loose ground	MO	Roof	Surveying	4.9
4/1/97	Stone	Inadequate examination/ geology	TN	Rib	Driller	7.6
2/5/97	Metal	Unsafe location	NV	Roof	Scaling	2.4
2/3/97	Metal	Large span/geology	TN	Roof	Driller	5.5
7/24/97	Metal	Unsafe practice/loose ground	NV	Rib	Driller	12.2
5/10/96 (double fatal)	Stone	Failure to support loose ground	MO	Roof	Blasters	7.6

(1999) found that 92 falls of ground injuries from 1990 to 1996 were reported from the underground stone mining industry, which employs approximately 2,000 miners. This high groundfall rate is certainly related to the large size of the openings in stone mines, and to the problems of scaling them.

Large Openings

Many metal/nonmetal mines have large openings, especially nonmetal stone and salt mines and metal mines with stopes. Large mine openings have roof or back greater than 5 m (16 ft) high, with spans greater than 10 m (30 ft) wide. When the back is high, a miner's ability to observe the ground conditions is greatly reduced. Additionally, many metal/nonmetal mines use roof bolts on an infrequent basis. Ventilation of large openings is sometimes poorly controlled, promoting dramatic fluctuations in humidity, and sometimes fog. High humidity can cause even strong rocks to split and crack, creating hazards for miners. Because of these factors and others, mines with large openings rely on mining both a stable roof beam and a stable roof line to reduce ground control hazards (Iannacchione and Prosser 1998).

A stable roof beam is generally massive, strong, thick, and persistent. Additionally, a persistent, smooth roof profile at the bottom of the stable roof beam is very helpful in creating a stable roof. Natural laminations, bedding planes, or interfaces between rock layers often providing the best roof lines (Figure 23.11). Too many bedding planes or rock layer interfaces can allow the roof to separate with time into many thin layers that are inherently unstable. Thicker roof beams sag less than thinner beams and therefore are less likely to fail (Figure 23.12). A meter or more of competent rock has been observed to form a stable beam in rooms up to 15 m (50 ft) wide.

However, as more joints intersect the roof beam or the associated room is widened, the chances for instabilities increase.

If a natural smooth roof plane does not exist, special blasting procedures like presplitting or smooth blasting can be used to produce an artificial smooth roof plane. Pre-splitting requires additional drill holes along the roof and rib line. Postsplitting or trimblasting is another technique used to produce an even, stable roof line. Conversely, poor blasting practices often have a negative influence on roof and rib stability. Overbreak can damage the roof and rib rock, while bootlegs (poor rock breakage at the end of a blasthole as a result of inadequate explosive burn) can leave broken rock along uneven rib and face surfaces.

Scaling

Scaling is necessary to remove loose rock from the sidewalls (rib) and hanging walls (roof) of mine openings. It is particularly important when the rock and ore is removed by blasting, as in most underground metal and nonmetal mines.

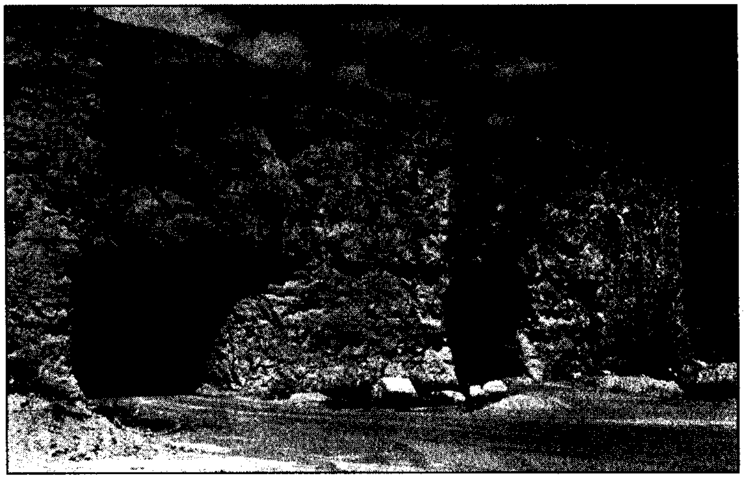

FIGURE 23.11 Smooth roof line produced by a persistent bedding plane lamination within the roof rock beam

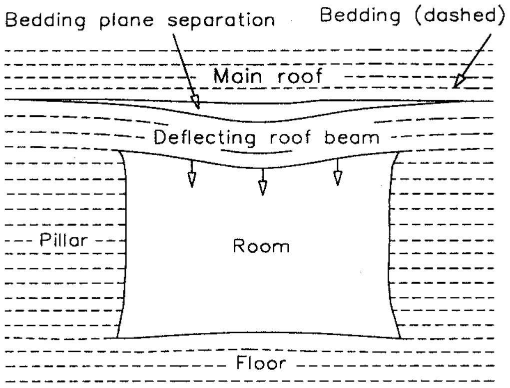

FIGURE 23.12 A common mode of roof rock failure in underground stone mines

Scaling may be conducted either with a hand-held pry bar or with mechanical equipment. Mechanical scalers usually remove the greatest portion of the loose rock, using an assortment of prying, hammering, or scraping attachments. Hand scaling is often conducted by a worker mounted in a lift basket in high openings. It can be the primary means of scaling or it can be done on an as-needed basis before any mining operation (drilling, blasting, mucking, haulage, etc.). Periodic reexamination of working areas is essential to identify new loose rock.

A study of accidents in underground stone mines between 1985 and 1994 found that nearly one-third of the ground control injuries involved scaling (Grau and Prosser 1997). More than 90% of these involved hand scaling. Mechanical scaling generally affords greater protection, because the miner is positioned in a protective cab at a greater distance from the loose rock. The data from this study also showed that the extremities and limbs were the body parts most often injured during scaling. Arm and leg padding, such as worn by athletes, may be one way to cushion the blow from falling rock and may also lessen the severity of an accident.

Although nearly two-thirds of the scaling accidents were caused by a direct hit from falling rock, many are related to loss of balance of the worker because of machine movement or a loss of bar control. Scaling bars that are too short can put workers in danger, but longer bars can be too heavy. A scaling bar experiment in 1988 indicated that a counterbalanced bar might be a better ergonomic design. At one coal mine, workers welded a 0.6-m (2-ft) end piece of a scaling bar to the end of an 2.4 m (8-ft) metal pipe, creating a bar that was relatively lightweight and strong (Klishis et al. 1992).

Training is a basic consideration for reducing scaling accidents. The stone mine data cited above indicated that nearly two-thirds of the accidents occurred to miners with less than two years of scaling experience (Grau and Prosser 1997). Workers should stand under supported top whenever it is available. To prevent hand injuries when using a scaling bar, one method suggested by MSHA is to slip a piece of water hose about half way down the bar. If the material being pried away slides down the bar, it will then be deflected away from the hands. Finally, miners should always pry *up* when scaling, so that if they lose their balance they do not fall underneath the loose rock.

Global Safety Strategies

Best practices, as discussed in the previous section, generally address ground control safety in the immediate vicinity of the miner. Creating a stable mine environment begins much earlier, however, during the process of mine design. Ground monitoring can also be central to the creation of a ground control safety culture at a mine.

Safe Mine Design

Mine design includes pillar sizing, layout of drifts and entries, dimensions of openings, and artificial support. Mine planners seek optimum designs that balance the competing goals of ground control, ventilation, equipment size, production requirements, and costs. In recent years, a number of design aids have been made available to assist with the ground control aspects of design.

The role of pillars is to support the great weight of the overburden above the mine. No manmade supports (except filled stopes in metal mines) have anything near the tremendous load-carrying capability of mine pillars. The tributary area concept is often used to estimate the loads applied to pillars. Mine designers must consider all of the loads the pillars may be required to carry during their service lives, however. Longwall panel extraction, pillar recovery, and multiple seam operations can all increase pillar loads, and benching can reduce pillar strength. Design aids for coal mines include the Analysis of Longwall Pillar Stability (ALPS), the Analysis of Retreat Mining Pillar Stability (ARMPS), and LAMODEL (Mark 1999b; Heasley and Chekan 1999). Guidelines for sizing limestone pillars were recently published (Iannacchione 1999).

Mining layout can often be used to minimize the effects of geologic hazards. Traditionally, features such as joints, cleats, and faults have been considered in design. More recently, horizontal stress has become an important concern. Global plate tectonics are the primary source of horizontal stress in mines, and measurements have shown that horizontal stresses are often three times as great as vertical overburden stresses. Horizontal stresses have caused roof potting, cutter roof, and roof falls in coal and limestone mines (Mark and Mucho 1994; Iannacchione et al. 1998). Their destructive effects can be reduced by orienting the mine so that most of the drivage parallels the direction of the maximum horizontal stress.

The maximum stable size of mine openings depends greatly on the geology. The back in some stone and salt mines is so competent that it can routinely maintain spans of 15 m (45 ft), while 5-m (15-ft) spans may be unstable in the weak, fractured ground found in some coal and hard rock mines. Rock mass classification systems can be especially helpful in estimating the safe span. In hard rock mines, examples include the RMR system, the Q system, the MBR system, and the Stability Graph System (Hoek et al. 1995). The Coal Mine Roof Rating System is increasingly used for many aspects of coal mine design (Molinda and Mark 1994).

U.S. mines use more than 100 million roof bolts every year. Only mines with exceptionally competent country rock can do without pattern roof bolting, and even they require some spot bolting. A wide variety of rock bolts are available, but matching the proper bolt type and pattern with the ground conditions remains as much an art as a science (Peng 1999).

Controlling Catastrophic Failures in Underground Mines

One of the most difficult and longstanding ground control issues is the catastrophic failure of mine structures. Catastrophic failures that create hazards for miners in coal, metal, and nonmetal underground mines include coal mine bumps, hard rock bursts, large collapses, and outbursts. The driving mechanisms include both excessive stresses from geologic forces like faults or from mining induced situations. Catastrophic failures of mine structures range in size from small pieces of ribs or roofs to entire mining sections. When gases under elevated pressures are present in the strata, outbursts of rock and gas can occur. Hazards to miners range from injuries associated with flying rocks to complete burial in ejected rock. Pressure waves from large collapses can throw miners into natural and manmade structures. When large quantities of gas are instantaneously released, gas ignition or asphyxiation can occur.

"Coal mine bumps" have presented serious mining problems since the early 1900s. Iannacchione and Zelanko (1995) compiled a coal bump database that included 172 specific events. The database was constructed from USBM and MSHA coal bump accident and incident reports written between 1936 and 1993. A total of 87 fatalities and 163 injuries were identified. The 1980s witnessed the greatest outbreak of bumps, accounting for 31% of the total. In 1996, three miners were killed in two different bump events. Two Kentucky miners were fatally injured when six pillars suddenly failed violently during pillar recovery operations. The second event claimed the life of a Utah miner when coal along a longwall face violently ejected into the shields. Both of these events occurred in characteristic settings for coal bumps, with elevated overburden, proximity to a gob area, and a strong hanging roof.

Many recommendations have been proposed to mitigate bump hazards. Special mining techniques like the Olga pillar extraction technique and U.S. Steel's thin-pillar method have the ability to reduce stresses around pillar extraction areas. Longwall mines can use techniques like abutment and yielding pillars. Finally as a last resort, several destressing techniques, such as shot firing, auger drilling, water infusion, hydraulic fracturing, and partial pillaring, have proven useful in combating the most hazardous conditions.

"Hard rock bursts" have been occurring in deep metal mines for as long as records have been kept (White et al. 1995). Federal regulations have been developed mainly in the form of administrative controls (Subsection 57.3461). When a rock burst causes miners to withdraw, impairs ventilation or impedes passage, MSHA must be notified. A rock burst control plan should then be developed and implemented. This plan is required to reduce the occurrence of rock bursts through monitoring and minimizing exposure. Monitoring can range from simple deformation measurements to mine-wide microseismic monitoring systems. Minimizing exposure can range from administrative controls to the use of remote controlled equipment.

A "pillar collapse" is a sudden, violent event that can pose a serious hazard in a room and pillar mine. A collapse occurs when one pillar in a mining layout fails, transferring its load to neighboring pillars, causing them to fail, and so on in a domino fashion. A pillar collapse can induce a devastating airblast that can disrupt the ventilation system and send flying debris that can injure or kill miners. In recent years, at least 13 coal mines and 6 metal/nonmetal mines in the United States have experienced pillar collapses. Fortunately, only one fatality has resulted, following a collapse of hundreds of pillars at a Wyoming trona mine (Zipf and Mark 1997).

The mechanics of pillar collapses are very different from either coal bumps or the more common slow pillar failure. Collapses occur when the pillars are so thin that they cannot carry any weight once they fail. Pillar collapses can be *prevented* by increasing the stability factor of the pillar design, or *contained* by conducting high extraction in localized compartments that are protected by barrier pillars.

"Outbursts" of gas and rock have occurred mainly in evaporite and to a lesser degree coal mines. With the occurrence of the multiple fatal explosion at the Belle Isle Salt Mine in 1981, domal salt mines in Louisiana and Texas were recognized as potential locations for large outbursts. Modifications to mining regulations were made in 1984 creating special levels of gassy metal/nonmetal mines (Subcategory II-A and II-B, 57.22003). Each advance in the gassy level requires additional operational safeguards. Outbursts in Canadian bedded salt and New Mexico potash mines have periodically created serious safety hazards. Outbursts in coal have been relatively rare, occurring most frequently along the grand hogback of Colorado. However, the most deadly outbursts in the recent U.S. history occurred in 1981 at the Dutch Creek No. 1 Mine in Colorado where 16 miners were killed. It is commonly felt that outbursts will become much more prevalent as average mining depths increase below 600 m (2,000 ft).

Roof Monitoring

Roof falls seldom occur entirely without warning. Often, however, miners are not aware of the warning signals until it is too late. Most underground mines use observational techniques, primarily visual inspection, as a means of determining roof stability. Traditionally, miners have sounded the rock, listening

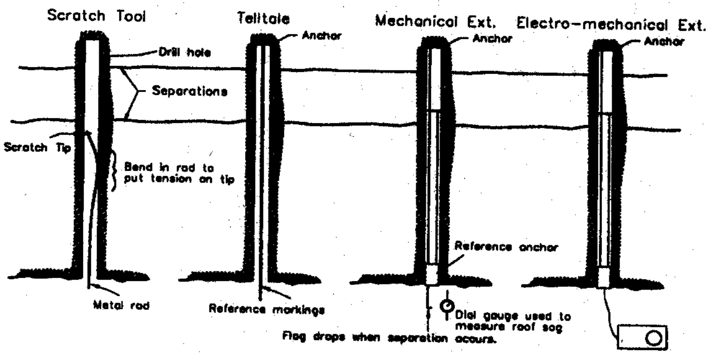

FIGURE 23.13 Four types of mechanical tools

for the drummy sounds that signal loose rock. Also, the act of drilling exploration roof bolt or blast holes can provide much information about the rock. During drilling, blasting, and scaling operations, additional knowledge related to roof conditions can be gained. For example, a driller preparing to bolt may notice a sudden increase in the penetration rate, and then realize that possibly a gap or clay seam was encountered. Much of this "hands-on" information provides an overview of the general conditions related to roof stability. Observational techniques can be extended by monitoring the movement of the mine roof in boreholes using mechanical tools (Figure 23.13). Four types are available (Iannacchione et al. 1999):

- *Scratch tools* can detect separations and provide an indication of loose rock layers or roof beam deflection. Information on the location and size of the separation can be marked on the roof and used to assess potential future roof degradation.
- *Telltales* are rigid bars, possibly just a roof bolt, anchored into the roof. A small section of rod protruding from the borehole is covered with three bands of reflective tape. The portion of the bar closest to the roof is generally green, followed downward by yellow and then red. As the roof deflects downward, the roof line can easily be seen to move through the green, yellow, and finally red tape zones. Telltales are required by law in British and Canadian coal mines (Altounyan et al. 1997).
- *Mechanical extensometers* consist of a top and bottom anchor, steel wire or rigid tubing, and some kind of micrometer or dial gauge. These devices have been used for decades in metal mines in Michigan, Missouri, and Idaho. The most common commercially available mechanical extensometer monitoring devices are the Miners Helper and the Guardian Angel. These monitors generally have one or two anchor points that measure the overall separation of rock layers in the immediate roof. If roof deflection is detected, a reflecting flag drops from the roof line, signaling the potential for imminent roof failure. In some cases, this information has been used to indicate a need to add roof support, remove roof rock, or mark off affected areas.
- *Electromechanical extensometers* include sonic probes that allow for up to 20 permanent anchors up to a 6-m (20-ft) height. The probes have the added benefit of being remotely read by portable devices or by connection to a data acquisition system. Recently, NIOSH introduced an easy to fabricate and install extensometer called the Remote Monitoring Safety System (RMSS). This instrument can be read remotely with a multimeter or can be connected directly to a data acquisition system.

A comprehensive ground control plan not only includes the basic observational, visual, and hands-on components, but also uses supplemental observational and monitoring techniques and regularly reads, analyzes, and displays information gained from these efforts. When this type of information is logged or mapped, it provides a documented history of ground conditions. Data from monitoring can be analyzed and prepared either by consulting firms or with in-house expertise. The information is extremely useful in deciding a course of action or alteration of the mining plan at the time of a major groundfall or when unstable geologic conditions are encountered. Mines that follow these practices and promote open communication and participation from everyone at the site are the mines with the most proactive approaches towards ground control safety.

SURFACE HIGHWALLS AND SLOPES

Surface mines have relatively few serious falls of ground, with six fatalities in the period from 1996 to 1998. However, six additional fatal falls of highwalls and slopes fatalities occurred in the first half of 1999. Two of these six were initially classified as powered haulage, but they were actually caused by slope failure beneath haulage equipment. The large jump in fatalities in 1999 is hopefully an aberration, but it may signal a new safety issue caused by a change in mining method or equipment, different enforcement practices, or a social issue such as the experience level of the mining workforce.

Most highwall injuries occur when loose pieces of rock fall on workers located below. Small pieces of rock can be dangerous when they fall from great height; even a fist-sized rock caused one recent fatality. At the other extreme, an entire section of a highwall or spoil pile may collapse, endangering miners working either on or beneath it.

Good basic design is essential to highwall safety. The height should be limited for stability and to allow scaling. Where the pit is deep, benches should be used to limit the slope height. Angling the highwall back from vertical also increases stability. Good blasting practices make for a smoother wall and reduce the need to scale. Drainage ditches should be used to divert springs and groundwater away from slopes.

Geologic features have contributed to many rockfall injuries from highwalls. Faults or "hill-seams" (weathered joints) can create wedges of unstable ground that can slide into the pit. In dipping strata, the rock can also be prone to slide along bedding planes. Freeze-thaw action acts to loosen rocks, and has been cited in several fatality reports. A review of accident records indicates that highwall accidents are twice as likely to occur in December and January than they are in the summer months. The presence of abandoned underground mine openings in the highwall has contributed to three of the recent fatalities.

Rock faces should be monitored frequently to check for loose rocks, and scaling should be conducted as needed. As highwalls age, weathering may cause additional loosening. The surface at the top of the highwall should also be checked for tension cracks that could indicate pending massive slope failure. In very large pits, various kinds of electronic surveying and monitoring systems are in use to provide early warning.

Good work practices can also help reduce rockfall hazards. Workers should not position themselves beneath highwalls except when absolutely necessary to perform their duties. Where possible, equipment cabs should be designed for object protection, and equipment should be positioned with the cab away from the highwall.

The stability of spoil piles can be reduced by extra surface loads ("surcharges") or by removing the bottom ("toe") of the slope. One recent fatality occurred when an uncompacted spoil pile gave way beneath the weight of a loaded truck. Another miner was killed when he excavated material at the base of the slope to widen a road, causing the pile to collapse.

CONCLUSION

This chapter has presented an overview of the most significant ground control hazards facing today's mineworkers. Underground miners, particularly in coal mines, are at the greatest risk from ground falls. The six highwall and slope fatalities that occurred in the first half of 1999 show that surface miners are at risk as well.

The analysis of recent fatality investigations and accident statistics identified certain job categories, mining techniques, and geologic environments that appear to pose the greatest hazards. Best practices have been developed through experience and research to reduce these risks. They combine engineering design, roof support, equipment, mining methods, and human factors to create safer workplaces and work practices. The roof control plan is another valuable tool in this effort.

Unfortunately, recent trends indicate that ground fall injury rates have stopped decreasing, and may even be on the increase. A renewed effort by the entire mining community will be necessary to finally eradicate the groundfall hazard.

REFERENCES

Altounyan, P.F.R., D.N. Bigby, K.G. Hurt, and H.V. Peake. 1997. Instrumentation and procedures for routine monitoring of reinforced mine roadways to prevent falls of ground. Paper presented at the 27th International Conference of Safety in Mines Research Institute. New Delhi, India. 759–766.

Bauer, E.R., D.M. Pappas, D.R. Dolinar, F.E. McCall, and D.R. Babich. 1999. Skin failure of roof and rib in underground coal mines. In *Proceedings 18th International Conference on Ground Control in Mining*. West Virginia University, Morgantown, WV. 108–114.

Bauer, E.R., G.J. Chekan, and L.J. Steiner. 1997. Stability evaluation of extended cut mining in underground coal mines. *International Journal of Rock Mechanics and Mining Science* 34(3-4): Paper No. 302.

Chase, F.E. 1992. Geologic structures that affect Appalachian coal mines. In *Preventing Coal Mine Groundfall Accidents: How to Identify and Respond to Geologic Hazards and Prevent Unsafe Worker Behavior*. USBM IC 9332. 3–14.

Chase, F.E., A. McComas, C. Mark, and C.D. Goble. 1997. Retreat mining with mobile roof supports. In *New Technology for Ground Control in Retreat Mining: Proceedings of the NIOSH Technology Transfer Seminar*. NIOSH IC 9446. 74–88.

Grau, R.H. III, and L.J. Prosser. 1997. Scaling accidents in underground stone mines. *Rock Products* 1: 39–41.

Grayson, R.L., L.A. Layne, R.C. Althouse, and M.J. Klishis. 1992. Risk indices for roof bolter injuries. *Mining Engineering* 44(2): 164–166.

Heasley, K.A., and G.J. Chekan. 1999. Practical boundary element modeling for mine planning. In *Proceedings of the Second International Workshop on Coal Pillar Mechanics and Design*. Vail, CO. NIOSH IC 9448. 73–88.

Hoek, E., P.K. Kaiser, and W.E. Bawden. 1995. *Support of Underground Excavations in Hard Rock*. Rotterdam, Netherlands: Balkema.

Iannacchione, A.T., and J.C. Zelanko. 1995. Occurrence and remediation of coal mine bumps: a historical review. In *Proceedings: Mechanics and Mitigation of Violent Failure in Coal and Hard-Rock Mines*. USBM Special Publication 01-95. 27–67.

Iannacchione, A.T., and L.J. Prosser. 1998. Roof and rib hazards assessment for underground stone mines. *Mining Engineering* 50(2): 76–80.

Iannacchione, A.T., D.R. Dolinar, L.J. Prosser, T.E. Marshall, D.C. Oyler, and C.S. Compton. 1998. Controlling roof beam failures from high horizontal stress in underground stone mines. In *Proceedings of the 17th Conference on Ground Control in Mining*. West Virginia University, Morgantown, WV. August 4–6. 102–112.

Iannacchione, A.T., L.J. Prosser, R. Grau, D.C. Oyler, D.R. Dolinar, T.E. Marshall, and C.S. Compton. 1999. "Preventing Injuries Caused by Unrecognized Stone Mine Roof Beam Failures with a Proactive Roof Control Plan." Presented at the Society of Mining Engineering Annual Meeting Preprint 99-87. Denver, CO. March 1–3.

Iannacchione, A.T. 1999. Pillar design issues for underground stone mines. In *Proceedings of the 18th Conference on Ground Control in Mining*. West Virginia University, Morgantown, WV. 271–281.

Klishis, M.J., R.C. Althouse, L.A. Layne, and G.M. Lies. 1992. Increasing roof bolter awareness to risks of falling roof material during the bolting cycle. In *Preventing Coal Mine Groundfall Accidents: How to Identify and Respond to Geologic Hazards and Prevent Unsafe Worker Behavior*. USBM IC 9332. 69–78.

Mallett, L.G., C. Vaught, and R.H. Peters. 1992. Training that Encourages Miners to Avoid Unsupported Roof. In *Preventing Coal Mine Groundfall Accidents: How to Identify and Respond to Geologic Hazards and Prevent Unsafe Worker Behavior*. USBM IC 9332. 32–45.

Mark, C. 1999. Application of the coal mine roof rating (CMRR) to extended cuts. *Mining Engineering* 4: 52–56.

——. 1999. Empirical methods for coal pillar design. In *Proceedings of the Second International Workshop on Coal Pillar Mechanics and Design*. NIOSH IC 9448, 45–154.

Mark, C., F.E. McCall, and D.M. Pappas. 1997. A statistical overview of retreat mining of coal pillars in the U.S. In the *Proceedings of the 16th International Conference on Ground Control in Mining*. West Virginia University, Morgantown, WV. 204–210.

Mark, C. and T.P. Mucho. 1994. Longwall mine design for control of horizontal stress. In *New Technology for Longwall Ground Control: Proceedings of the USBM Technology Transfer Seminar.* USBM SP 94-01. 53–76.

Mazzoni, R.A., G.J. Karabin, and J.A. Cybulski. 1996. *A Trouble Shooting Guide for Roof Support Systems*. MSHA IR 1237. 101 pp.

MSHA. Best Practices. Series of cards available on the Internet at www.msha.gov/s&hinfo/prop/prophome.htm.

Molinda, G., and C. Mark. 1994. *The Coal Mine Roof Rating (CMRR)–A Practical Rock Mass Classification for Coal Mines*. USBM IC 9387. 83 pp.

Molinda, G., C. Mark, E. Bauer, D. Babich, and D. Pappas. 1998. Factors influencing intersection stability in U.S. coal mines. In *Proceedings 17th International Conference on Ground Control*. West Virginia University, Morgantown, WV. 267–275.

Peng, S.S. 1999. Roof bolting adds stability to weak strata. *Coal Age* 12: 32–38.

Peters, R.H. 1992. Miners' views on how to prevent people from going under unsupported roof. In *Preventing Coal Mine Groundfall Accidents: How to Identify and Respond to Geologic Hazards and Prevent Unsafe Worker Behavior*. USBM IC 9332. 25–31.

White, B.G., J.K. Whyatt, and D.F. Scott. 1995. Geologic factors in rock bursts in the Coeur d'Alene mining district. In *Proceedings Mechanics and Mitigation of Violent Failure in Coal and Hard Rock Mines*. USBM SP 01-95. 217–230.

Zipf, R.K., and C. Mark. 1997. Design methods to control violent pillar failures in room-and-pillar mines. *Transactions of the Institution of Mining and Metallurgy* 106 (September–December): A124–A132.