MULTIPLE-SEAM LONGWALL MINING IN THE UNITED STATES: LESSONS FOR GROUND CONTROL

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ABSTRACT

Relatively few longwall mines in the United States operate under multiple-seam conditions where the two seams are less than 200 ft apart. This paper describes the experience of six that do. These operations are located in Pennsylvania, West Virginia, and Utah and include examples of both undermining and overmining. Some operate above or beneath their own workings; others are in historic mining districts and must contend with abandoned mines that are decades old. The lessons learned by these mines cover a broad range of topics, including:

- Whether to stack gate roads or place them under old gob areas;
- How to size pillars and select artificial support to cross longwall stop lines;
- How to use yield pillars to minimize multiple-seam stresses and coal bump potential; and
- When to anticipate the creation of pathways for gas, water, or oxygen between current and abandoned gobs.

INTRODUCTION

Multiple-seam interactions can cause roof falls, rib spalling, and floor heave, disrupting mining operations and threatening the safety of miners. In early 2006, a West Virginia coal miner was killed by rib roll that occurred in a high-stress zone beneath a remnant pillar structure in an overlying mine [MSHA 2006]. Longwalls may be uniquely vulnerable to multiple-seam interactions because they tend to operate under deep cover, generate large abutment stresses, and have little flexibility to avoid localized zones of difficult conditions.

For the past several years, the National Institute for Occupational Safety and Health has been conducting research to develop better techniques for predicting the location and severity of multiple-seam interactions. During this research, more than 40 mines were visited across the U.S. coalfields, including a number of longwalls. The study also drew upon past studies conducted by the author and an extensive literature review. The purpose of this paper is to discuss the potential impacts of multiple-seam mining on longwalls based on an evaluation of the different geologic environments in which longwall mining is conducted, combined with analyses of past case histories.

OVERVIEW

Figure 1 shows the five major underground coal mining regions in the United States. Also shown are the numbers of operating longwall faces in each region [Fiscor 2006].

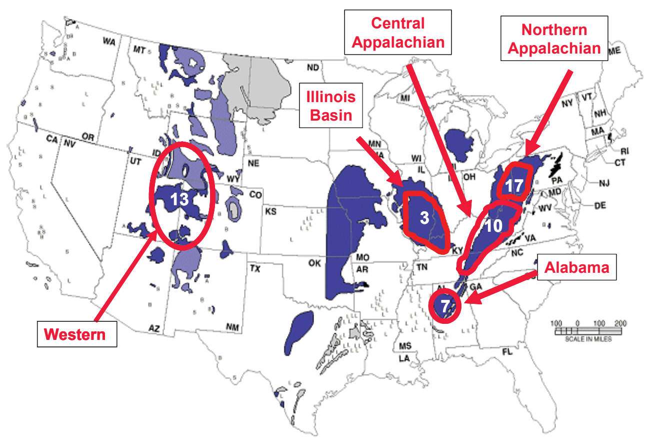

Figure 1.—The five major underground coal mining regions in the United States and the number of longwall faces in each [Fiscor 2006].

The central Appalachian region of southern West Virginia, eastern Kentucky, and southwestern Virginia is the most significant coalfield from the standpoint of multiple-seam mining. Mining has been ongoing in central Appalachia for nearly 150 years. Recent studies have indicated that perhaps 70% of the ultimate reserve base in the region has already been mined [Bate and Kvitkovich 2004]. One consequence of the maturity of the central Appalachian coalfields is that most underground reserves have been impacted by past mining activity. The mountains of the central Appalachian coalfields are honeycombed with worked-out mines located above, below, and adjacent to today's and tomorrow's operations.

Although longwall mining has a long history in central Appalachia, including the first mechanized faces in the

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United States [Barczak 1992], the 10 longwalls active there today account for less than 20% of the region's underground production [EIA 2006; Fiscor 2006]. Of these, three are extracting the very deepest minable seam in the area—the Pocahontas No. 3—without any significant mining above or below. The others are operating in multiple-seam environments, and two case histories are discussed in some detail later in this paper.

The Western United States is the next most important area for multiple-seam mining. In Utah, Colorado, Wyoming, and New Mexico, nearly 95% of underground production comes from the 13 longwall operations [EIA 2006; Fiscor 2006]. Approximately half of these are operating in multiple-seam configurations, including several mines in the Price, UT, area and three others in the North Fork Valley near Paonia, CO.

In contrast to central Appalachia, in the West the same mining company is usually responsible for all the mining on a property. As a result, a greater degree of multiple-seam planning is normally possible. Recently, however, one North Fork Valley mine was forced to abandon a panel prematurely when an interaction associated with an abandoned mine resulted in roof falls in the headgate [Buchsbaum 2006].

Multiple-seam interactions in western longwalls can also contribute to the deadly bump hazard because of the deep cover and strong roof and floor rock [Peperakis 1968]. To minimize the hazard, many western longwalls employ yield pillar gate entry designs. Some of the lessons that have been learned from their experience are discussed later in this paper.

The northern Appalachian region is home to nearly one-third of the nation's longwalls—17 faces producing 87 million annual tons [EIA 2006; Fiscor 2006]. Currently, all but one of these longwalls is extracting the Pittsburgh Seam. The Freeport Seam, the nearest minable coalbed beneath the Pittsburgh, is over 600 ft below, and it has never been extracted beneath any Pittsburgh longwall. There has been some mining in the Sewickley Seam that overlies the Pittsburgh. In the distant past it caused some disruption in the Pittsburgh [Zachar 1952], but it has not been known to impact the modern longwall mines.

Although none are operating today, in the recent past longwalls have operated in the Sewickley Seam and other seams in central Pennsylvania. These operations provide two examples of longwall mining above abandoned works that are discussed below.

More than 90% of the underground coal produced in the Illinois Basin comes from two seams: the Springfield 5/Kentucky 9 and the Herrin 6/Kentucky 11 [EIA 2006]. These seams are often less than 80 ft apart, so there is significant potential for multiple-seam interaction. However, today there are just two longwall mines operating in the Illinois Basin. One of these does work both seams, but the mining has been planned so that the workings in one seam have never crossed previously mined gob areas in the other seam.

Seven longwalls are currently active in the Alabama coalfields. Six of these are extracting the Blue Creek Seam, which is again the deepest minable seam in the section, lying hundreds of feet below the nearest minable overlying seam. The only non-Blue Creek longwall is also free of multiple-seam interactions.

HAZARDS ASSOCIATED WITH MULTIPLE-SEAM MINING

Ground instability is usually the greatest hazard due to multiple-seam interaction. Interactions may be classified into four major categories depending on the mining method, mining sequence, and thickness of the interburden. Other potential hazards are associated with water, gas, and oxygen-deficient air.

Undermining, the first category of interaction, occurs when the upper seam has been mined first and the lower seam is the active seam (Figure 2). In an undermining situation, damage is caused by load transfer from highly stressed structures associated with full-extraction mining in the overlying seam.

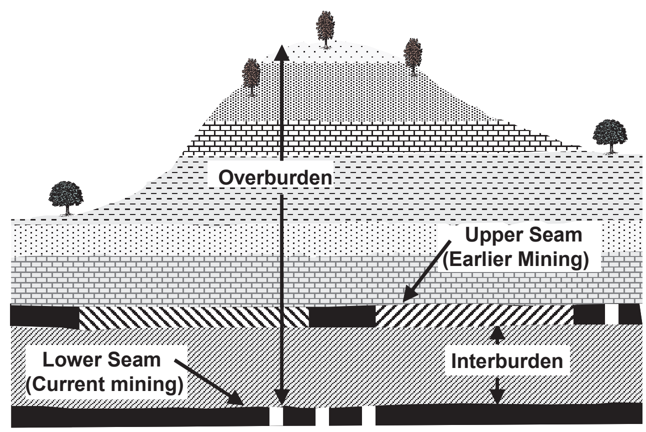

Figure 2.—Undermining interaction.

Overmining, the second type of interaction, occurs when the upper seam is extracted after mining is complete in the lower seam (Figure 3). Load transfer occurs in this situation just as it does in undermining (in other words, gob-solid boundaries and remnant pillars cause stress concentrations both above and below). In addition, however, full extraction of the lower seam normally results in subsidence of the overlying beds, potentially damaging the roof.

Dynamic interactions occur whenever active mining occurs above or beneath open entries that are in use. The most severe dynamic interactions occur when a lower seam is longwalled or pillared, resulting in subsidence of the overlying workings. Although there have been several relatively recent cases in which longwalls were extracted as far as 550 ft beneath open main entries, causing

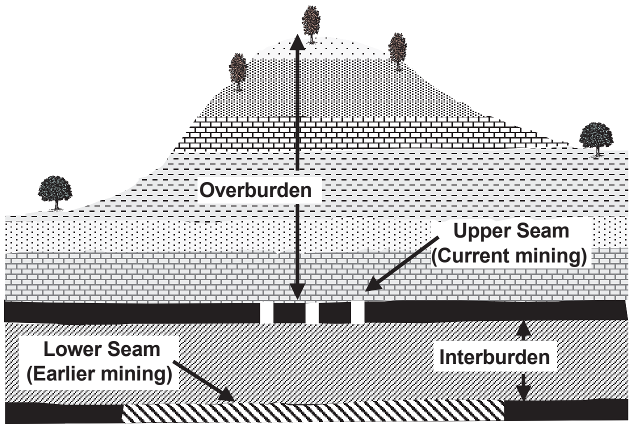

Figure 3.—Overmining interaction.

extensive damage to the upper mine [Ellenberger et al. 2003; Mark 2006], there do not seem to be any instances in the United States where a working longwall was the victim of a dynamic interaction.

Ultraclose mining is the fourth type of interaction and the only one that applies to development mining. The main concern is failure of the interburden between the two seams. Ultraclose interactions are unlikely when the two seams are more than 20–30 ft apart.

Other hazards include the potential for inundation from an overlying flooded mine, particularly where full extraction in the lower seam can create a direct pathway between the upper- and lower-seam gobs. In one example, the first longwall panel at a Kentucky mine encountered a major inflow from workings 150 ft above. In this instance, the water posed no hazard to the miners, but the lack of pumping capacity in the lower seam resulted in major mining delays [Mark et al. 1998]. Fractures in rock above subsided gob areas can also fill with methane or oxygen-deficient air, resulting in inflows of gas or blackdamp when they are intersected by overmining.

OVERMINING INTERACTIONS: TWO CASE HISTORIES FROM PENNSYLVANIA

Two Pennsylvania longwalls, both of which are now closed, provide examples of the potential for overmining previously extracted areas. The first example was a successful one, the second less so.

In Cambria County, PA, Bethlehem Mines Corp.'s No. 33 Mine employed longwall methods to extract the B Seam (Middle Kittanning) and the overlying C-prime Seam (Upper Kittanning). The mining was sequenced so that extraction was completed in the B Seam first. More than 25 longwall panels were later recovered in the upper seam over almost 2 decades [Bauer et al. 1992].

The B Seam averaged about 5 ft in thickness, and its depth of cover was 500–800 ft. High horizontal stresses were typical of the lower seam, where they caused extensive damage to the gate entries during both development and longwall retreat [Mark and Mucho 1994].

The C-prime Seam was typically 3.5 ft thick, with an additional 1 ft of drawrock normally extracted. The immediate roof consisted of interbedded sandstone and shale, with a Coal Mine Roof Rating (CMRR) of about 50. The interburden between the seams averaged 105 ft and consisted mainly of shales and sandy shales. Typically, at least 10 years was allowed to elapse between the completion of mining in the lower seam and development in the upper. Contrary to usual multiseam practice, the gate entries in the C-prime were superpositioned above the gates in the lower seam (Figure 4). In general, conditions were quite good both on development and longwall retreat. Six-ft-long fully grouted resin bolts, supplemented in the tailgate by two rows of wooden posts, provided adequate roof support. In only one instance, when an attempt was made to develop a gate road slightly over the gob, were poor ground conditions attributed to multiple-seam interactions. Conditions along the longwall face were also benign and were not noticeably different near the panel edges than they were in the center of the subsidence trough.

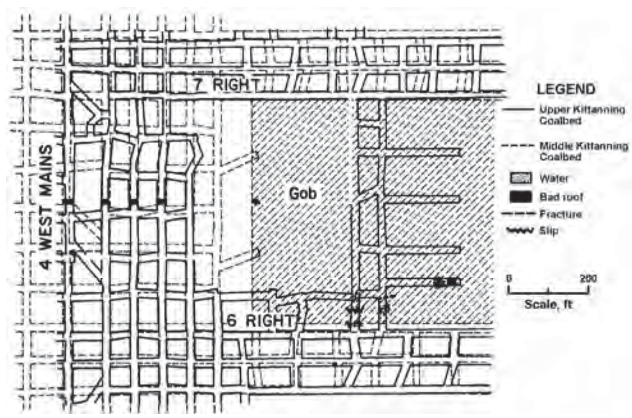

Figure 4.—Stacked gate road layout at Bethlehem Mines Corp.'s No. 33 Mine [Bauer et al. 1992].

Interestingly, ground conditions in the upper seam actually seemed to be worse above virgin, undisturbed B Seam areas than above areas where the B Seam was mined out. Above the virgin areas, C-prime workings encountered severe ground conditions and methane emissions. It seemed that perhaps the subsidence associated with the extraction of the B Seam relieved the horizontal stresses and removed the methane that would otherwise have been present.

The second example of overmining is provided by New Warwick Mining Co.'s Warwick Mine in Greene County, PA. The Warwick Mine worked the Sewickley Seam beneath 500–900 ft of cover. The Sewickley roof was a dark sandy shale with a CMRR of about 40.

The Pittsburgh Seam was approximately 100 ft below the Sewickley, and underneath one panel it had been worked by high-extraction room-and-pillar methods (Figure 5). Analysis indicated that many of the small fenders that had been left in the Pittsburgh Seam had probably yielded, transferring much of their load to a few large, isolated remnant pillars [Heasley and Chekan 1999]. Severe pillar spalling and poor roof conditions were encountered when developing gate entries above these remnants.

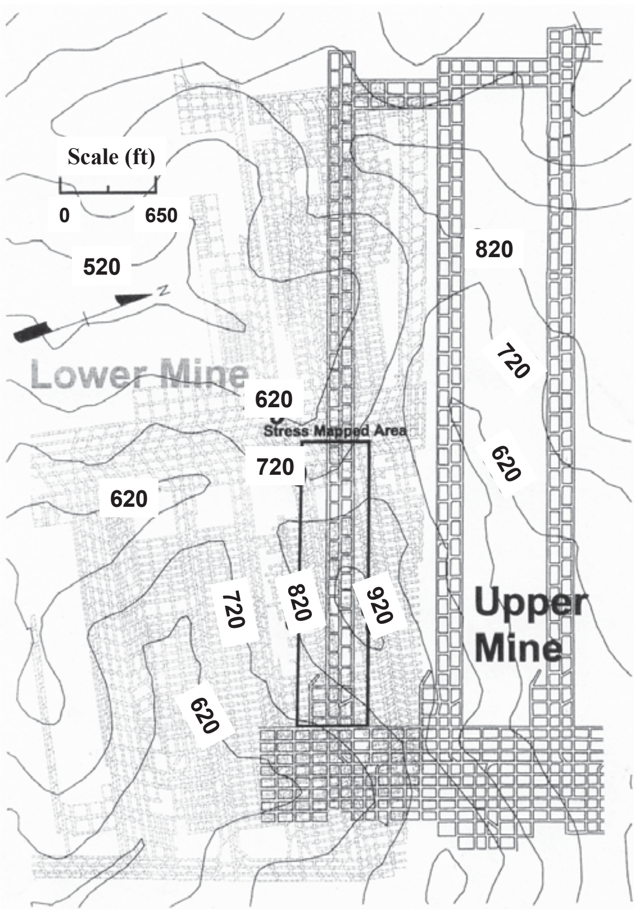

Figure 5.—Map of the Warwick Mine in the Sewickley Seam and the underlying Pittsburgh Seam workings [Heasley and Chekan 1999].

The inby portion of the Sewickley longwall panel, where the cover was shallowest, was developed and longwalled with little difficulty. However, stress mapping and LaModel analysis indicated that the most severe interactions would occur beneath the deepest cover, near the mouth of the panel [Heasley and Chekan 1999]. When the longwall face reached this area, ground control problems included face spalling and headgate roof instability. The conditions were so severe that the longwall face had to be stopped 50 ft short of the recovery chute, which greatly complicated recovery of the longwall.

UNDERMINING INTERACTIONS: TWO CASE HISTORIES FROM CENTRAL APPALACHIA

Two mines in southern West Virginia provide examples of longwalls undermining full-extraction workings in an upper seam. The first, the Harris No. 1 Mine, is operated by Peabody Energy. During the past 30 years, Harris has mined more than 60 longwall panels in the Eagle Coal Seam. The depth of cover exceeds 1,400 ft beneath the highest ridges. The roof is fairly typical of central Appalachia and consists of strong shale and sandstone, with CMRR values normally in the 45–60 range.

The Eagle is located 180–200 ft beneath the No. 2 Gas Seam. Figure 6 is a generalized stratigraphic column of the interburden that shows it contains a high percentage of massive sandstone. The No. 2 Gas has also been extensively mined. The longwall panels in the upper seam were much smaller than the recent Harris panels, and they lie in several different orientations. As a result, in many cases it has not been possible to plan the lower-seam workings to minimize the potential for interaction.

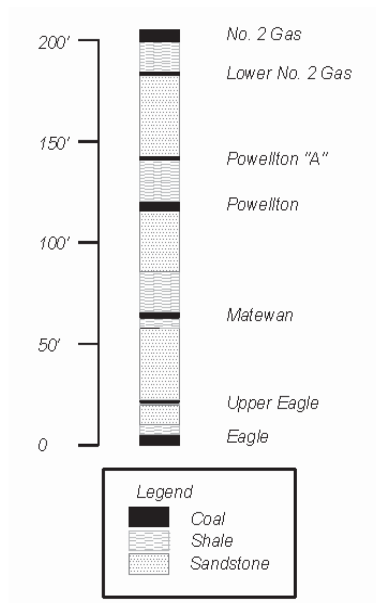

Figure 6.—Stratigraphic column from the Harris Mine, Boone County, WV.

Chase et al. [2007] evaluated 17 locations where gate entries at Harris crossed beneath remnant pillar structures in the upper seam. In about 60% of these cases, development and retreat mining were successful, although it was often necessary to install cable bolts or other secondary support to control the ground conditions. In seven cases, however, the interactions were serious enough that the headgate or tailgate squeezed shut during panel recovery.

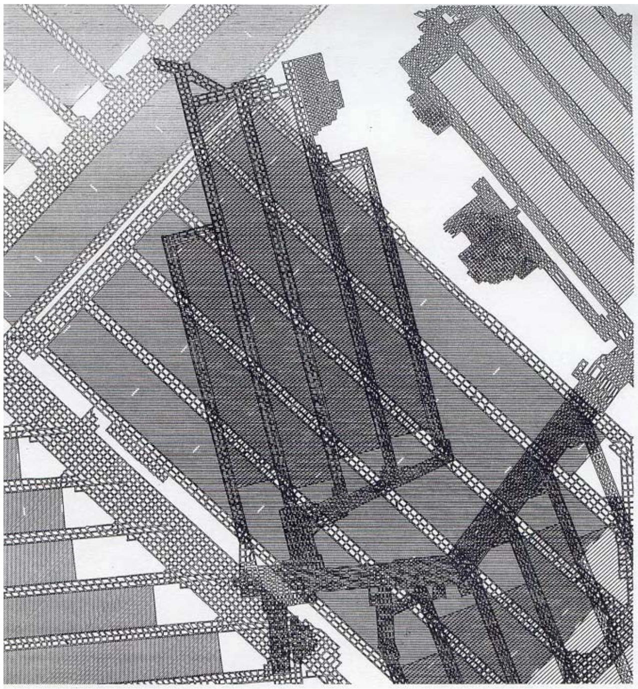

Figure 7.—Harris Mine longwalls in the underlying Eagle Seam (light gray) crossing beneath upper-seam chain pillars (dark gray).

Most of these cases occurred beneath chain pillars where the depth of cover exceeded 1,000 ft (Figure 7).

There have also been several instances when poor ground conditions on the face were attributed to overlying structures. Most often the problem was severe floor heave, although in two instances roof control was lost at the face. All but one of these incidents occurred more than a decade ago, when the longwall hydraulic face supports were much less capable than they are today.

Based on past experiences, mine planners at Harris try to adhere to the following rules of thumb: (1) the long axis of the panel to be mined should parallel that of the upper-seam panel; (2) the future headgate should be positioned under and as close to the center of the gob as possible; and (3) avoid advancing the longwall face under a gob/solid boundary [Hsiung and Peng 1987a,b].

The engineers at Harris also use the LaModel program to identify high vertical stress areas that are caused by deep cover, abutment loads, and/or multiple-seam stress transfer [Heasley and Agioutantis 2007]. Once multiple-seam stress transfer magnitudes are obtained, they can be incorporated into the Analysis of Longwall Pillar Stability (ALPS) or the Analysis of Retreat Mining Pillar Stability (ARMPS) programs to obtain more realistic pillar stability factors.

At West Virginia Mine B, longwall mining was initially conducted in the Lower Cedar Grove Seam before moving to the underlying Alma Seam. The interburden between the two seams was only 60–90 ft and consisted largely of sandstone. In the highly mountainous terrain the cover varied from 300 to 1,100 ft [Vandergrift et al. 2000]. The lower-seam roof is typically a strong silt-stone or fine-grained sandstone, with a CMRR in excess of 55.

Following an extensive LaModel study, the lower-seam layout was planned to minimize the potential for interactions. Particular care was taken to ensure that no development crossed beneath the heavily loaded upper-seam chain pillars. The lower-seam mains were developed beneath the overlying ones, but the longwalls were laid out so that the gates were offset by approximately one-quarter of a panel width (Figure 8). Because the lower-seam panels were longer than the overlying ones, the gates crossed both the upper-seam start and stop line barrier pillars. At both crossings, the entry widths were reduced to 18 ft and the crosscut spacing was increased. Extra support, including truss bolts and steel props, were installed in the belt entry.

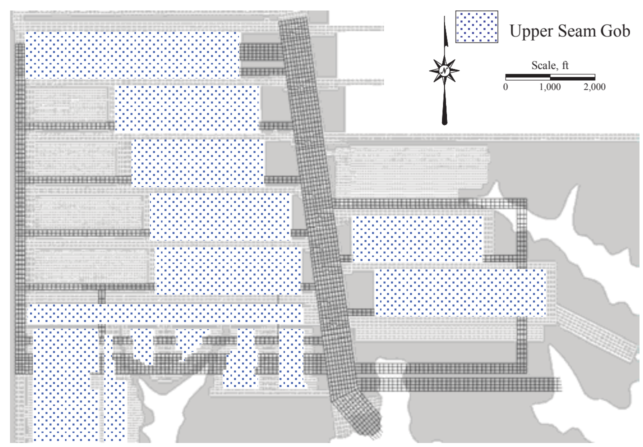

Figure 8.—Multiseam longwall layout employed in the Lower Cedar Grove Seam [Vandergrift et al. 2000].

The first panels were retreated in the lower seam (see Figure 8). No serious gate entry stability problems were encountered, although the high stress zones beneath the stop and start lines were clearly visible, particularly when the depth of cover exceeded 800 ft. Although the upper-seam chain pillars were located above the longwall face, they did not seriously impact ground conditions either. As one miner put it: "Beneath the chain pillars, the coal was so broken that the shearer didn't have to cut anything; all it had to do was load." Several of these faces were also successfully retreated across the upper-seam start pillars.

The next two panels were not as successful, however. They were oriented perpendicular to the initial panels and crossed a 110-ft-wide remnant barrier pillar located under about 800 ft of cover between two pillared areas in the upper seam. It was difficult to develop the gates across this structure, but when the longwall face approached it, the conditions on the face became so severe that the panel was abandoned early. To prevent a similar event, the second panel was also recovered before it reached the remnant barrier.

Subsequently, eight additional longwall panels have been extracted in the lower seam. The most serious difficulties have been associated with an unsuccessful attempt to stack the gate roads. The roof in this area consisted of an unusually thick shale, and the conditions became so severe once the depth of cover exceeded 800 ft that the development was abandoned.

MULTIPLE-SEAM LONGWALL MINING WITH YIELD PILLARS IN UTAH

Longwall mines in Utah work in a region characterized by rugged canyon and mesa topography, where cover depths can reach 3,000 ft. The roof and floor strata tend to be relatively strong (15,000–25,000 psi), and the overburden consists largely of massive sandstone units that can be as much as 500 ft thick. Many of the mining properties also contain two or more thick coal seams in close proximity [Barron et al. 1994].

Unique among U.S. coal operations, Utah longwalls rely almost exclusively on yielding pillar gate entry designs. According to DeMarco [2000], yielding pillar gate systems were developed to—

1. Mitigate the severe coal bumps (dynamic coal seam failures), most commonly experienced in the tailgate entries; and
2. Abate the high-stress concentrations associated with remnant gate pillars during close-proximity multiseam mining.

Based on his comprehensive study of yielding pillar case histories, DeMarco [2000] concluded that successful gate entry systems—

- Are largely limited to settings where the immediate roof is strong enough to withstand large deformations (the CMRR in every successful case history exceeded 50);
- Employ chain pillar width-to-height ratios of less than 5 to ensure that timely, nonviolent yielding occurs during first panel mining; and
- Normally require that artificial roof support plays a major role.

At Utah Mine A, approximately 20 lower-seam longwalls have been extracted beneath upper-seam panels. The interburden has ranged from 60 to 90 ft, with maximum depths of cover from 1,400 to 2,100 ft. Upper-seam mining was typically completed 3–5 years before development began beneath it. Both seams employ two-entry gate systems with 30-ft-wide yield pillars. The roof in the lower seam is variable, but typically a strong sandstone either lies directly on the coal or can be reached with roof bolts, so the CMRR is usually near 70.

In the very first multiple-seam application at this mine, the gate entries were stacked. A 160-ft massive roof fall ensued, and the gate had to be redriven. Since then, all gate entries have been driven beneath the upper-seam gob, normally offset at least 100 ft from the upper gate. Lower-seam panels have usually been designed so that they begin and end under the upper-seam gob. However, Figure 9 shows a multipanel layout where several of the longwall faces did cross the stop lines of the overlying panels. The depth of cover at the crossings was less than 1,400 ft in every case.

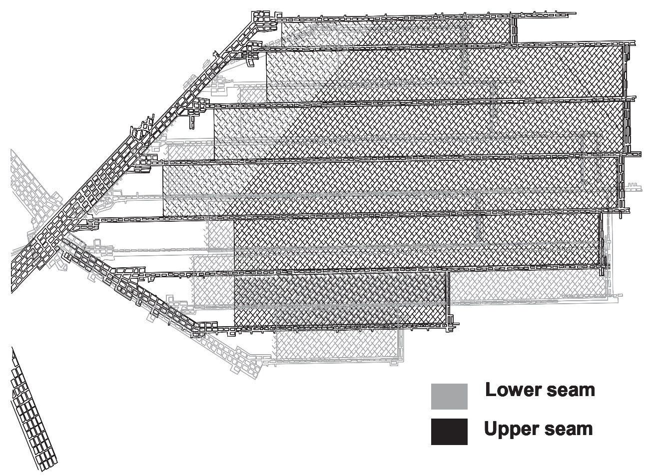

Figure 9.—Layout of yield pillar longwall panels at Utah Mine A.

No special support is normally required to develop the gates underneath the upper-seam stop lines. However, when the cover exceeds about 1,600 ft, bumps are more likely to occur if the gate crosses the stop line near the middle of the overlying panel rather than near the edge where the upper-seam stop line barrier pillar has been slightly "softened" by the presence of the upper-seam gates.

One of the big advantages of a two-seam longwall mine is that, other than the chain pillars, there should be no isolated remnant pillars in the overlying gob. One incident at Mine A illustrates just how important this advantage is. A "barrier pillar" was created in the upper seam between the longwall start line and some bleeder entries. When the lower-seam longwall had mined beneath the bleeders and partially beneath the barrier, a major bump occurred along approximately 80% of the face (Figure 10). The depth of cover at this location was in excess of 2,000 ft. Subsequently, the setup rooms in the lower seam were always placed under the gob if the cover exceeded 1,400 ft.

In general, face conditions have been excellent in the lower seam. Although the imprint of the overlying yield pillars could clearly be seen in the roof and coal face,

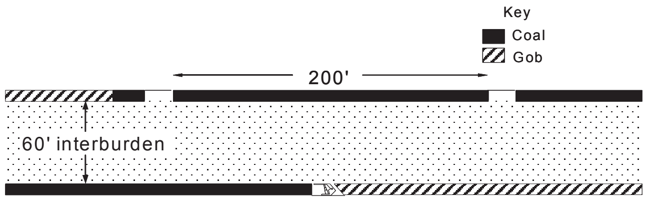

Figure 10.—Cross-section showing panel geometry at the time of a large face bump at Utah Mine A.

it caused no problems. Under deep cover, the panels start outby the upper setup rooms and stop inby the upper-seam stop line, so nearly all the longwall mining has been beneath gob.

With a 10-ft extraction height in the lower seam and as little as 60 ft of interburden, it seems likely that subsidence fractures can create hydraulic connections between the gobs of the two seams. Nonetheless, there has been just one instance where water from an insufficiently dewatered area entered the lower-seam mine in sufficient quantities to obstruct production.

At Utah Mine B, the two seams are 50–75 ft apart. The cover is lighter than at Mine A, reaching a maximum of about 1,100 ft, but the roof is weaker, with a CMRR averaging about 50. Bumps have not been a problem at this operation, but roof control is a significant concern.

The upper-seam panels at Mine B have all employed three-entry gates with 30-ft-wide yield pillars. A total of nine lower-seam panels have been extracted. As was the case in Utah Mine A, it is possible to "see" the upper-seam pillars on the face and in the setup rooms of the lower seam, but they have never caused problems.

The lower-seam panels at Mine B have been planned so that they are set up, mined, and stopped all under the gob of the upper seam. The critical zone of interaction has been where the gates cross the upper-seam stop line barriers. These have been troublesome and require substantial artificial support. Currently, cable bolts are installed in these areas as primary support on development in a pattern of four 12- to 16-ft-long cables per row, with rows on 4-ft centers. Over time, Mine B has also found that conditions are better if larger pillars (currently 100-ft centers) are used to cross the barriers (Figure 11).

Another design issue is the location of the lower-seam setup room. In the first lower-seam panels, the setup was developed just 40 ft inside the gob from the edge of the upper-seam setup (Figure 12). Conditions were less than favorable. They improved considerably when the offset was increased to 100 ft.

A mine planner at Mine B observed that one undesirable characteristic of multiple-seam interactions is that "they just keep coming." In one instance, a long-term mains crossed beneath an upper-seam gob line. Over 4 years, more than 4 ft of floor heave developed, and the roof was cable-bolted three times but still eventually failed.

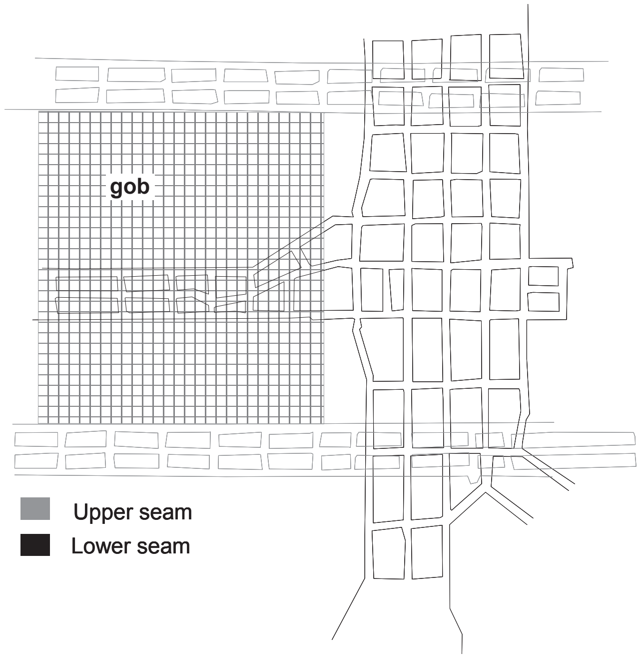

Figure 11.—Layout of stop line crossings employed at Utah Mine B.

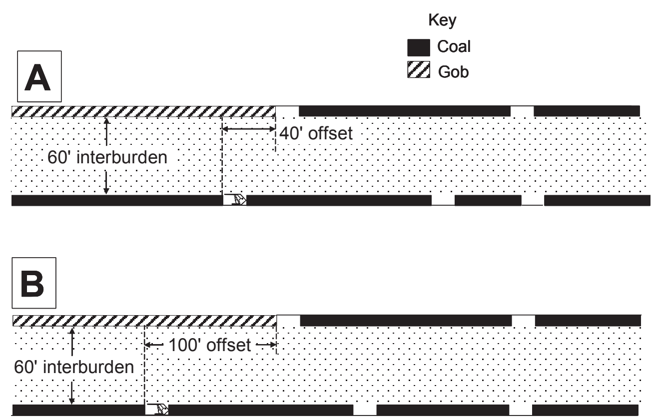

Figure 12.—Setup room offset at Mine B: (A) 40-ft offset; (B) 100-ft offset.

Spontaneous combustion is another safety concern at Mine B. In one of the panels where the setup was developed with a 40-ft offset, the caving behind the longwall created a connection that allowed oxygen to reach the upper-seam bleeder system. A heating developed, which was fortunately detected and quickly extinguished. There have also been several instances of large water inflows to the lower seam despite numerous holes drilled from the lower seam into low areas of the upper-seam gob to drain water pools from the upper-seam workings before undermining.

CONCLUSIONS

Although few U.S. longwalls face serious multiseam challenges, some valuable lessons can be learned from those that do. These include the following:

- Gate entry configuration: The first question that often faces mine planners is whether to stack the gate roads or offset them. Most of the U.S. longwall mines have preferred to offset their gate roads at least 100 ft from the gates in the previous seam. Some have had bad experiences when they tried stacking. However, the No. 33 Mine successfully employed a stacked gate configuration for many years, and the Harris Mine has used stacked pillars on occasion.
- If the offset design is employed, then the gate entries must be developed across the gob-solid boundary at the stop line of the previous seam longwall. The experience of the mines described in this paper is that this crossing may require a special pillar design or extra roof support, but it has not usually been a major concern.
- Panel layout: The preferred layout is one in which the panel start positions are set up outby the overlying or underlying setup room and stop before they reach the stop line of the previous panel. This way all longwall mining is beneath the old gob area (except for the coal beneath the chain pillars). However, there are a number of instances where these mines have successfully brought their faces across old stop lines or setup rooms, at least occasionally.
- Longwall face conditions have rarely been a problem at any of these mines, whether they are overmining, mining underneath large chain pillars, or crossing gob-solid boundaries. The most difficult interactions have been associated with large remnant pillars that were left in the previously mined seam, particularly when the remnant barrier was oriented parallel with the longwall face.
- Roof strength: The experience of these mines is that roof strength is a major factor determining the success of multiple-seam mining. For example, the weaker roof at Utah Mine B has caused it to generally have more trouble than Utah Mine A, even though Mine A's cover is significantly greater. Similarly, the Warwick Mine has weaker roof than the No. 33 Mine and also encountered greater difficulties.
- Planning: The ability to preplan the multiple-seam mining on a property is a major advantage. Mines that overmine or undermine their own longwall panels can more easily overlap the panels, offset the gates, and longwall almost entirely under gob areas. Most importantly, they can ensure that isolated remnant pillars are not left in the gob. The experience of the Utah mines also shows that yield pillars can also be a very useful planning option as long as the roof strength is adequate.
- Mines like Harris and Warwick that do not have the luxury of preplanning all the mining in advance have been forced to deal with remnant structures and gob areas at odd angles. For instance, it seems that perhaps the extra 100 ft of interburden at Harris compared to West Virginia Mine B may have compensated for Harris' more difficult remnant structures.

As the demand for coal continues to expand, mining companies are considering a number of new multiseam longwall mines in such areas as central Illinois and the Hunter Valley in Australia. Hopefully, these future operations will be safer because they have benefited from the experience of the operations described in these case studies.

REFERENCES

Barczak TM [1992]. The history and future of longwall mining in the United States. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 9316.

Barron LR, DeMarco MJ, Kneisley RO [1994]. Longwall gate road stability in four deep western U.S. coal mines. Denver, CO: U.S. Department of the Interior, Bureau of Mines, IC 9406.

Bate RL, Kvitkovich JF [2004]. Quantifying the coal reserve dilemma in the central Appalachian mining region. SME preprint 04–108. Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc., 8 pp.

Bauer ER, Chekan GJ, Sames GP [1992]. Influence of subjacent gob on longwall development mining in the upper Kittanning coalbed of south-central Pennsylvania. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, RI 9403.

Buchsbaum L [2006]. Longwall mining thrives in Colorado's North Fork Valley. Coal Age *111*(8):28–34.

Chase FE, Worley P, Mark C [2007]. Multiple-seam mining interactions: case histories from the Harris No. 1 mine. Paper in these proceedings.

DeMarco M [2000]. Review of current yielding gate road design approaches and applications in U.S. longwall operations. Published as Appendix 11 to Volume 1 of University of New South Wales/SCT Collaborative ACARP Project C9018 – Final Report, Australian Coal Association Research Program (2005).

EIA [2006]. Annual coal report, data for 2005. Washington, DC: U.S. Department of Energy, Energy

Information Administration. [http://www.eia.doe.gov/cneaf/coal/page/acr/acr_sum.html]. Date accessed: January 2007.

Ellenberger JL, Chase FE, Mark C, Heasley KA, Marshall JK [2003]. Using site case histories of multiple-seam coal mining to advance mine design. In: Peng SS, Mark C, Khair AW, Heasley KA, eds. Proceedings of the 22nd International Conference on Ground Control in Mining. Morgantown, WV: West Virginia University, pp. 59–64.

Fiscor S [2006]. Coal companies invest in more long-wall capacity: leading American longwall operators report record production. Coal Age *111*(2):26–30.

Heasley KA, Chekan GJ [1999]. Practical boundary-element modeling for mine planning. In: Mark C, Heasley KA, Iannacchione AT, Tuchman RJ, eds. Proceedings of the Second International Workshop on Coal Pillar Mechanics and Design. Pittsburgh, PA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 99–114, IC 9448, pp. 73–87.

Heasley KA, Agioutantis ZG [2007]. LaModel: a boundary-element program for coal mine design. Paper in these proceedings.

Hsiung SM, Peng SS [1987a]. Design guidelines for multiple-seam mining, part I. Coal Min *24*(9):42–46.

Hsiung SM, Peng SS [1987b]. Design guidelines for multiple-seam mining, part II. Coal Min *24*(10):48–50.

Mark C [2006]. Extreme multiple-seam mining in the central Appalachian coalfields. SME preprint 06–060. Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc., 7 pp.

Mark C, Mucho TP [1994]. Longwall mine design for control of horizontal stress. In: Mark C, Tuchman RJ, Repsher RC, Simon CL, eds. New Technology for Longwall Ground Control. Proceedings: U.S. Bureau of Mines Technology Transfer Seminar. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, SP 01–94, pp. 53–76.

Mark C, Mucho TP, Dolinar D [1998]. Horizontal stress and longwall headgate ground control. Min Eng *Jan*: 61–68.

MSHA [2006]. Report of investigation, underground coal mine, fatal rib roll accident, February 1, 2006, #18 Tunnel mine, Long Branch Energy, Wharton, Boone County, West Virginia, ID No. 46–08305. Mount Hope, WV: U.S. Department of Labor, Mine Safety and Health Administration. [http://www.msha.gov/fatals/2006/ftl06c18.asp]. Date accessed: January 2007.

Peperakis J [1968]. Multiple-seam mining with long-wall. Min Congr J *Jan*:27–29.

Vandergrift TL, Ross TR, Hawley CW, Rusnak JA [2000]. Mine planning for longwall and pillar retreat panels subject to seam interaction effects. In: Peng SS, Mark C, eds. Proceedings of the 19th International Conference on Ground Control in Mining. Morgantown, WV: West Virginia University, pp. 204–212.

Zachar FR [1952]. Some effects of Sewickley seam mining on later Pittsburgh seam mining. Min Eng *Jul*: 687–692.

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