Proceedings of the New Technology in Mine Health and Safety, SME Annual Meeting, Phoenix, AZ, February 17, 1992

OPTIMUM MINE DESIGNS TO MINIMIZE COAL BUMPS: A REVIEW OF PAST AND PRESENT U.S. PRACTICES

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ABSTRACT

Coal bumps have presented serious mining problems in the U.S. throughout the 20th Century. Fatalities and injuries have resulted when these destructive events occur at the working face. Persistent bump problems can result in abandonment of large reserves or lead to premature mine closure. Through the years, alternative techniques such as artificial supports, extraction sequencing, destressing, pillar design changes and specific pillar retreat practices have been successfully implemented to mitigate coal mine bumps. Several techniques have evolved for room-and-pillar operations that control the way the roof rock breaks, regulating the manner in which stresses are redistributed in the mined section. Special mine layouts employed in longwall mines have also proved to be successful in safely redistributing or containing excessive loadings. However, with ever increasing production rates, greater overburdens and new mining systems, the need to evolve even more effective bump control designs will continue to challenge the U.S. coal mine industry.

INTRODUCTION

An understanding of past bump control methods provides a useful perspective for evaluating present designs and may show how future innovative engineering solutions will evolve. This paper reviews various design techniques in chronological order to illustrate how the bump hazard in the U.S. has changed as mining methods have evolved and where the U.S. may direct future bump hazard reduction efforts. In some cases the solutions have been site specific; while in other cases the solutions have been applied over a wide range of geologic and mining conditions.

Background

Almost all U.S. coal mine bumps have occurred either in the southern Appalachian Basin of West Virginia, Kentucky and Virginia or the Uinta and Piceance Creek Basins of Utah and Colorado as shown in Figure 1. One of the principal mining districts within the southern Appalachian Basin is the Pocahontas Field shown in Figure 2. Coalbeds within this field occur in the Pocahontas, Lee and New River Formations of the Lower to Middle Pennsylvanian System. Massive sandstone members, many with compressive strengths ranging from 140 to 210 MPa, are prevalent. Many of the coalbeds found in the southern Appalachian Basin are under considerable overburden and have high horizontal and vertical stress conditions. Over the last 13 years, bumps have occurred at eight different mines with four fatalities and several injuries in both room-and-pillar and longwall mining systems. Prior to this point in time, most bump occurrences were restricted to three locations, the Gary mining district of West Virginia, deep Pocahontas No.4 Coals near Grundy, Virginia and the Cumberland mining district of Kentucky and Virginia.

Many of these same geologic and mining conditions occur within the Uinta and Piceance Creek Basins in the western portion of the U.S. shown in Figure 1. Bumps have been principally experienced in several coal fields within the Book Cliffs and Grand Hogback structures of Utah and Colorado (Figure 3). The Upper Williams Fork and the Blackhawk Formations of the Mesaverde Group, Upper Cretaceous System contain the principal bump prone coalbeds. Both of these areas have significant quantities of massive, stiff sandstone, large and small displacement faults and intrusions caused by igneous dikes. These geologic structures have been associated with bumps which are related to past fatalities and injuries. The potential for further bump problems from the southern Appalachian, Uinta, and Piceance Creek Coal Basins is extremely high due to the extensive reserves of deep, high quality (low sulfur) coal.

Historical review

Watts reported one of the earliest incidents of bumps in the U.S. (Watts, 1918). These bumps occurred at the Sunnyside No.1 Mine, Sunnyside Field in the state of Utah, in development sections under a thick overburden of principally sandstone. Watts indicated the bumps were apparently greatly influenced by faults, not more than 300 m away.

Bryson (1936) indicates that bumps occurred in the Cumberland Field of Kentucky and Virginia as early as 1923 and became very troublesome from 1930 to 1934. Rice (1934) classified bumps as two general types, namely excessive pressure bumps and shock bumps. According to Rice (1934), pressure bumps are caused when pillar stress exceeds bearing strength. Shock bumps are induced by the breaking of thick, massive strata at a considerable distance above the coalbed, causing the immediate roof to transmit a shock wave to the coal. To this day, these categories still provide a practical means of classifying bumps. Rice also designed a rock filled crib system to control the fracturing of the roof rock which in turn minimized the occurrence of shock bumps.

Holland and Thomas (1954) examined 177 instances of bumps from the states of West Virginia, Kentucky, Utah and Virginia that occurred between 1925 to 1950. They deduced that the primary cause of bumps was unfavorable mining practices in abutment areas. They also noted the importance of a strong floor rock, which does not heave readily.

Peperakis (1958) noted the occurrence of bumps in the Sunnyside Field of Utah between 1944 and 1957. In particular, the Sunnyside No.1-2-3 Mines had several large bumps while advancing under cover deeper than 600 m with multiple-entry systems associated with room-and-pillar mining. Several of these bumps occurred in development sections as faults were approached. Unique control designs attempted during this era included: volley firing to

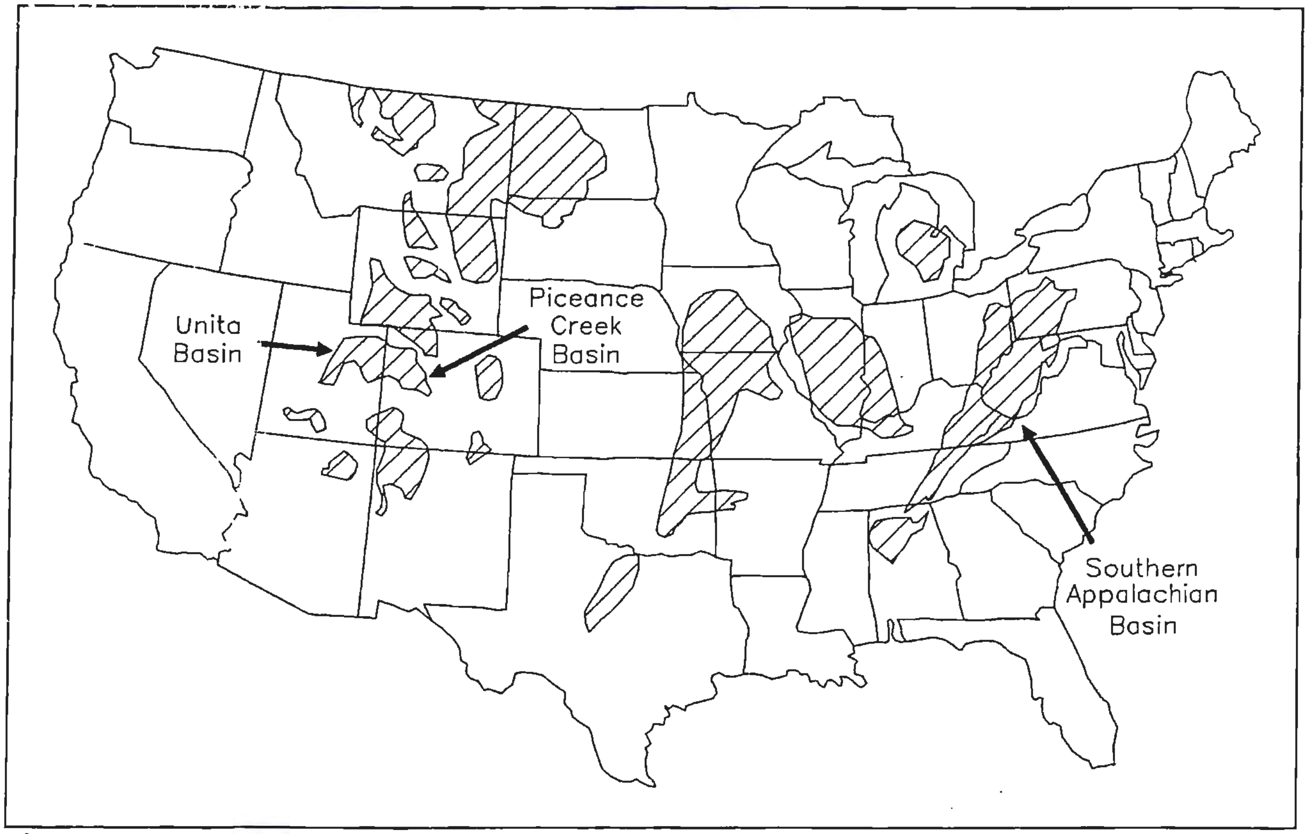

Figure 1. - Geographic distribution of major U.S. coal basins.

destress the coal, yielding arch supports to minimize associated roof fall damage and hydraulic backfill to support the main roof above the gob.

During this same period a novel barrier pillar splitting technique called the thin-pillar method (Talman and Schroder, 1958) and an auger drilling destressing technique (Talman, 1955) were introduced in the Gary Mining District of southern West Virginia. The thin-pillar method is a design concept which segments the barrier into a series of yield pillars too small to hold significant stress levels (> 10 Mpa). The pillar destressing practice consisted of drilling 61 cm auger holes from one side of the stressed pillar to the other. The use of this system was curtailed when several miners were injured by a bump induced during a destressing operation.

Goode et al. (1984) analyzed the records of bump events from 1950 until 1984 and found that bumps were still occurring at disturbing rates. Twenty-eight fatalities occurred during this time: fourteen in the eastern U.S. and another fourteen in the west. Continued bump problems were probably due to the same unfavorable mining conditions and practices discussed by Holland and Thomas (1954); however, the advent of the continuous mining machine brought about different problems which required new control solutions. The mobility and versatility of the continuous miner led to the development of novel pillar splitting and extraction sequencing designs for bump control.

With the widespread utilization of the longwall mining technique over the last 15 years, bump problems have again surfaced to threaten the safe and efficient mining of coal. One fatality on a advancing longwall face, several injuries on retreating longwall faces and at least one mine closure have been attributed to bumps. However,

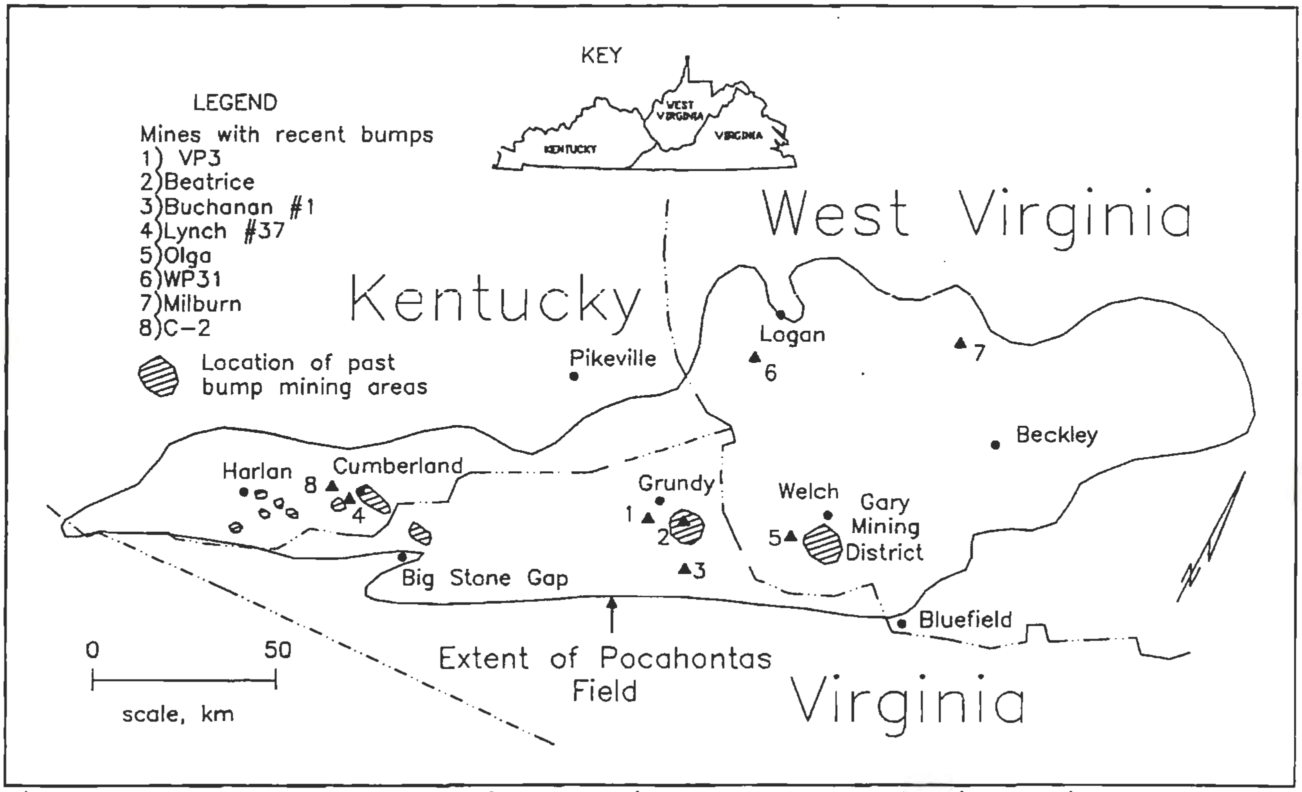

Figure 2. - Location of past and present bump prone areas in the southern Appalachian Basin.

ingenuity and experience have prevailed and several innovative designs for controlling bumps in longwall mines have been developed. One technique is the advancing longwall method which was first used at the Mid-Continent Coal Mines in the 1970's. In coalbeds where bump problems occur on development of gate entries, the advancing longwall design can be effective. Two other designs are centered around altering the size and shape of the gate entry pillars. One method consists of increasing the gate entry pillar size, so that the pillars will prevent abutment load ride-over onto the active longwall face. The other method consists of reducing the gate entry pillar size, so that pillars will yield in a controlled fashion, aiding in the controlled fracturing of the main roof rock. All of these methods have some drawbacks but in general represent innovative design philosophies for controlling bumps.

In the U.S., coal pillar bumps have been associated with several primary characteristics: 1) stiff, massive strata, 2) high overburden stresses, 3) full extraction mining, 4) multi-seam mining, and 5) mining near geologic structures such as faults, igneous dikes and sandstone channels. Unique combinations of geology and mining systems have required many site specific bump control designs. Therefore, a continual development of improved bump control designs is needed as new geologic and mining scenarios are encountered. Each of these new challenges can be overcome by evaluating past experiences, analyzing current and projected conditions and investigating new design techniques in the field. This paper will discuss past and present experiences in retreat mining, barrier splitting, chain pillar extraction and longwall mining methods.

ROOM-AND-PILLAR MINING

When coal pillar bumps first began to occur in eastern Kentucky (Bryson, 1936), local mine officials, workmen,

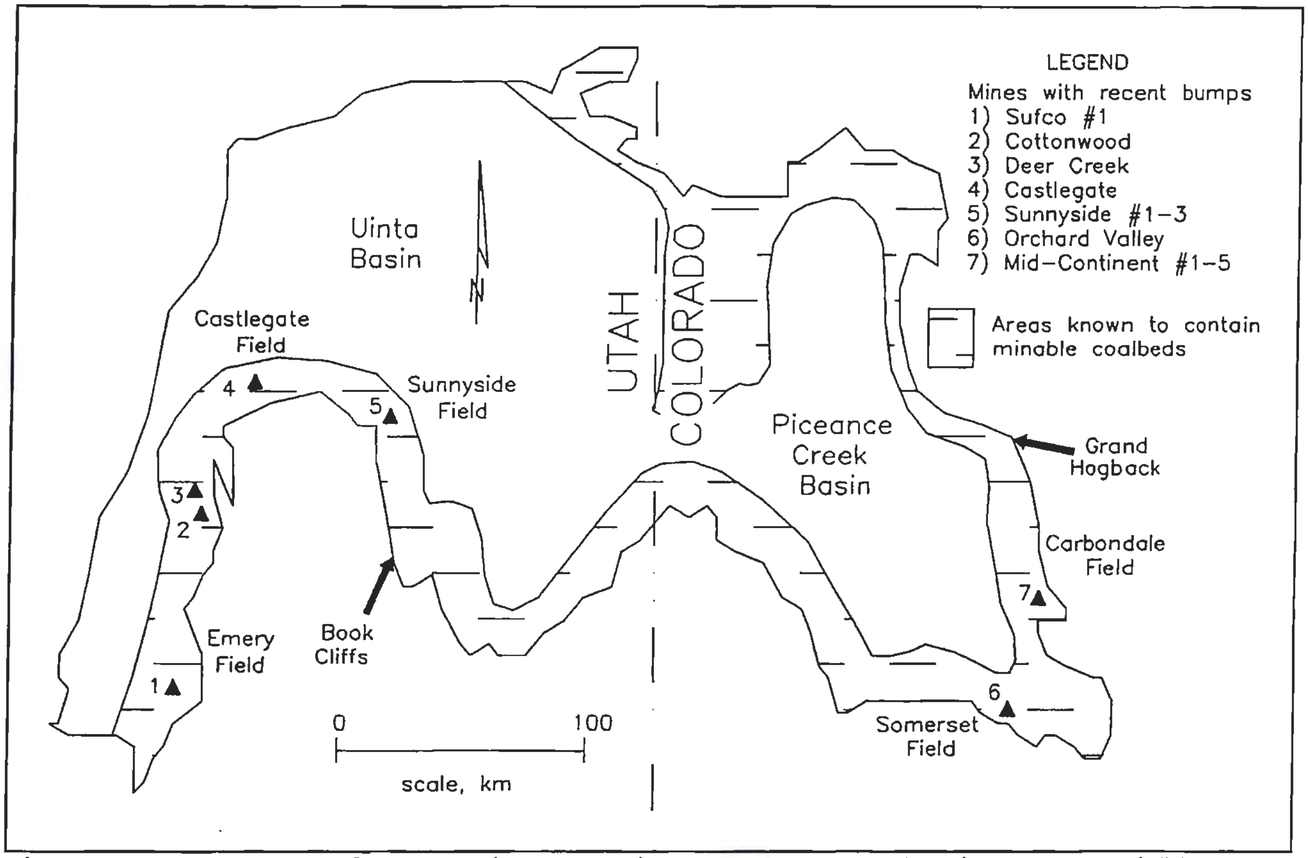

Figure 3. - Location of past and present bump prone areas in the Uinta and Piceance Creek Basins.

mining engineers and many others offered many ideas as to their cause. Numerous methods of prevention were suggested and tried without success. Most of the bumps were occurring along the retreating pillar line where several of the following conditions existed: 1) uneven pillar lines, 2) irregular pillar sizes, 3) overburden in excess of 300 m, 4) strong roof and floor strata, and 5) overhanging or cantilevering gob. Several prominent mining personnel were influential in developing recommendations which led to a series of rules used to mitigate the bump hazards in room-and-pillar mining.

Rice's recommendations

Rice (1934) developed the premise that two types of bumps, termed pressure and shock bumps, caused the observed mining problems. Pressure bumps are caused by stress on moderate sized pillars too great for their bearing strength. Shock bumps are induced by breaking of thick, massive strata above the coalbed, which transmits a shock wave through the rock to the stressed coal pillars. Faulty mining methods were then identified which included: 1) pillars too small, 2) leaving projecting pillars behind retreat line, 3) narrowing pillars to points, and 4) extracting pillars in separate groups without any attention to a long continuous retreat line.

Based on these observations, Rice recommended two operational methods for controlling bumps: 1) straight retreat lines and 2) rock-filled cribs. Keeping retreating pillar lines straight eliminated pillar points projecting into the gob. This practice was fairly easy to initiate and had favorable results. Rock-filled cribs, for a cushioned support of the roof rock, were also tried with positive results. Generally the cribs were comprised of ordinary mine post timbers. These were 1.1 m long, not less than 0.2 m thick and generally set on 6 m centers. A tight packing of each crib was obtained with a fill of rock material. The cribs were designed and placed in such a manner so that the roof was allowed to converge gently without rupture of the immediate strata. This action lessened the potential for sandstone breaks within the gob which were thought to be the cause of so many shock bumps.

Bryson (1936) described a detailed field test of this design method at a deep mine in the Harlan Coalbed, Cumberland Mining District under 430 m of cover. Bumps had killed five men at this particular site. Figure 4 shows the test area located off two support entries, approximately 210 m wide, adjacent to a large gob area. Rooms were driven approximately 91 m between the support entries about 10.7 m wide. Prior to the extraction phase, the study area was comprised of a series of narrow (10.7 m wide) and large (43 m wide) pillars. As the section was mined, sixteen roof-to-floor convergence stations and sixty-four rock filled cribs were installed.

Once the area was extracted, convergence began and continued almost continuously (Figure 4). Bryson reported that a few roof rock cracks gradually widened to as much as 41 cm without causing roof collapse. Convergence continued until the roof and floor came almost in contact. In general the strata settled by cracking and grinding with much noise but without developing many large breaks. Bumps did not occur during the extraction of coal from this section except for one incident when the pillar line was not kept straight.

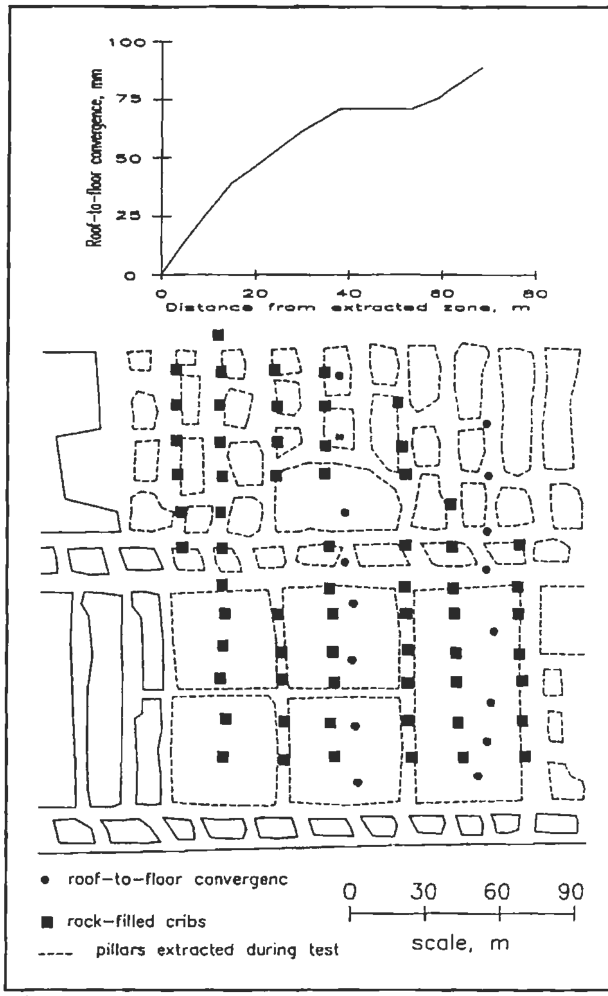

Figure 4. - Location of roof-to-floor convergence stations and rock-filled cribs placed during retreat mining. Graph shows the convergence trend from one station.

Holland and Thomas's recommendations

Holland and Thomas (1954) expanded on Rice's general recommendations concerning pillar extraction procedures and produced the following ten rules to minimize pillar bumps: 1) Recover all coal in a pillar operation; 2) Avoid pillar-line points; 3) Keep roof spans projecting over the gob as short as possible or else provide support so that the roof beds do not fracture; 4) Do not do development work in abutment areas; 5) Do not split pillars on or near the extraction line;
6) Use the open-ending extraction technique with lifts of not more than 4.3 m; 7) Leave one to two rows of pillars adjacent to old gob areas; 8) Maintain pillars the same size and shape; 9) Keep development entries narrow, approximately 4.3 m; and 10) Note areas of rolls, change in dip, change in coal thickness and hardness. Use this information in designing the mining system.

Although many of the rules still apply to modern room-and-pillar operations, several rules no longer apply by today's standards but may again be useful as new mining methods are developed. For instance, continuous mining machines require regular mining patterns and entries larger than 4.3 m to operate. It is also necessary to conduct development work in abutment areas during the final stages of a mines life. This is a necessary procedure as the mine pulls back along main entries, extracting the remaining large barriers. The practice of a retreating longwall through existing openings may change this assumption.

Peperakis's recommendations

Peperakis (1958) summarized the cumulative experience utilizing novel engineering designs at the Sunnyside Mines prior to the introduction of longwall mining techniques in the early 1960's. Many of Sunnyside's bumps initiated roof falls of the immediate shales and thin laminated sandstones beneath the massive main sandstone roof rock. Bumps initiated on development were associated with a series of faults trending along strike with displacements ranging from 1 to 8 m. Peperakis identified the following seven measures taken to minimize the bump hazards: 1) long hole shooting; 2) cutting up large blocks into smaller more uniform pillars ahead of the retreating pillar line; 3) do not split large blocks on development;
4) break large development blocks ahead of retreat pillar lines into uniform size blocks; 5) substantial supplemental support can reduce the severity of bumps;
6) steel yieldable arch supports minimize roof falls following bumps; and 7) hydraulic backfill reduces stress transfer during bump events.

Osterwald (1962) noted that many other oriented structural features, such as shatter zones, cleavage, pyrite veins, and cylindrical and smooth fractures, were found in the bump prone areas. He suggested that mine layouts could take advantage of these features to reduce stress concentrations thereby decreasing the incidence of bumps.

BARRIER SPLITTING OPERATIONS

Coal bumps can often occur during extraction of the large barriers adjacent to the main entries. Violent bumps during barrier splitting appeared to be especially troublesome during the 1950's in southern West Virginia. Engineers working for the US Steel Coal Corp., a major coal producer in the region, developed a method of splitting large barriers adjacent to main entry systems (Talman and Schroder, 1958). They had found through experience that pillars smaller than 14 m or larger than 49 m almost never bumped. An extraction method known as thin-pillar mining was developed which systematically cuts the large barriers into pillars with widths smaller than 14 m, leaving a barrier pillar remnant, which was either destressed or left in place.

When implementing a thin-pillar mining system for barrier extraction, multiple entries are first driven within the barrier directly adjacent to the main entries. The remaining solid barrier located between the newly advanced headings and the stabilized

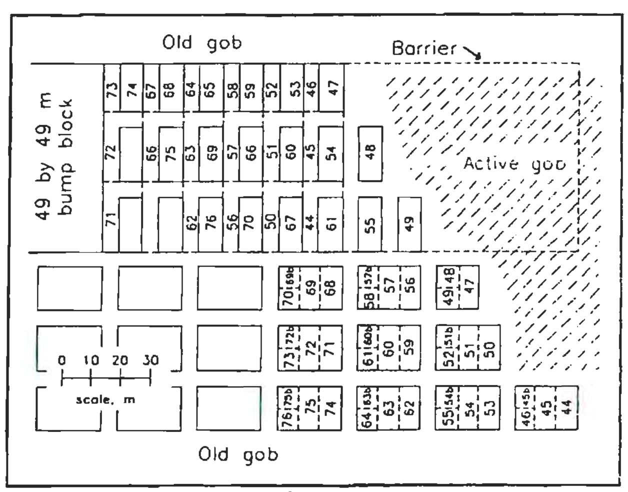

Figure 5. - Typical mining sequence utilizing the thin-pillar method. Numbers indicate cut sequence order.

gob. Mining of barrier and predeveloped chain pillars proceed simultaneously (Figure 5). Splitting of the barriers occurs from the recently driven headings adjacent to the active gob and back towards the next solid barrier. These headings are very close together, isolating yield pillars about 6.1 m wide. These yield pillars fail in a controlled manner, shedding the high stresses both to the active gob areas and further into the solid barrier. When the remaining barrier approaches 49 by 49 m, a critical size pillar is formed. This large abutment pillar is called a bump block and left to avoid a potential bump. These large blocks aid in breaking the roof at the pillar line and protect the remainder of the section from excessive convergence.

The thin pillar mining system has many forms but is generally employed when extracting the barriers left to protect main entries. The smaller pillars tended to yield to the high stresses imposed on them by the overburden and normal mining. The adoption of this technique greatly reduced the occurrence of bumps.

CHAIN PILLAR EXTRACTION

Even with the previously discussed designs, numerous bumps occurred in room-and-pillar sections throughout the 1980's (Campoli et al, 1988). Many recent bump occurrences have occurred on continuous miner sections where rows of chain pillars (15 to 30 m wide) are extracted next to the gob. Individual chain pillars are extracted very rapidly, causing the loads to shift swiftly without allowing the adjacent pillars to redistribute the load in a controlled fashion. These pillars have difficultly accommodating excessive amounts of strain energy, increasing their potential to bump. In response to this problem, a novel pillar splitting method utilizing the stress-reduction principles of thin-pillar mining was devised by the operations staff at the Olga Coal Company, near Welch, West Virginia.

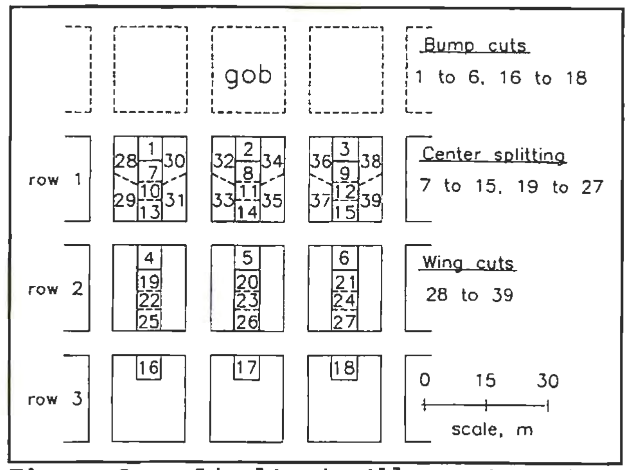

Figure 6. - Idealized pillar extraction sequence for bump control during room-and-pillar mining.

This novel retreat mining technique involves the sequential mining of numerous places over three to four rows of pillars in order to gradually direct the overburden loads away from the pillar line, where most of the men and machines are located. An idealized schematic of the extraction sequence is shown in figure 6. By design, all coal pillars three rows away from the retreating pillar line have at least a "bump" cut. This bump cut is a 6.1 by 6.1 m cut of coal taken from a regular sized chain pillar (18.3 by 21.3 m). The frequent occurrence of audible events or thumps during extraction are responsible for the terminology. Two pillar rows closest to the gob line are split in half by extending the bump cut entirely through the pillar. Finally, the pillar wings or fenders are extracted in the row closest to the gob line.

This novel design was further evaluated by the Bureau of Mines with an extensive rock mechanics instrumentation array to determine how the strata responded during mining (Campoli et al, 1989). The response of the strata was measured by 44 coal cells (Borehole Platened Flatjacks) and over 70 convergence stations. Observations from this field site indicated the technique did indeed redistribute stress in an effective manner (Figure 7). The pressures were transferred greater distance than normally expected, up to eight pillar rows away from the pillar line. This redistribution effectively transferred the load over a very large area, greatly minimizing the bump hazard.

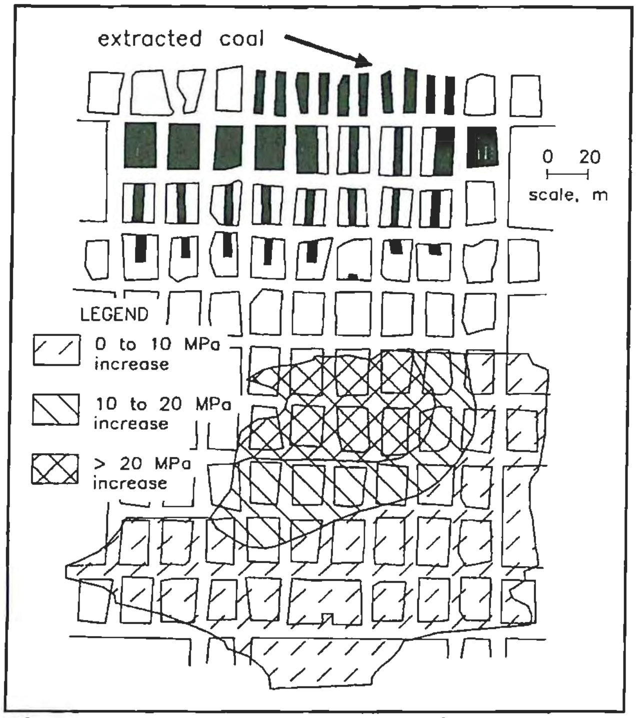

Figure 7. - Isopach map of the pressure changes around an instrumented portion of a multi-place retreating pillar line over a four week period.

Recently, an attempt has been made to evaluate this extraction philosophy using numerical modeling techniques (Zipf and Heasley, 1990). Several idealized mining scenarios were modeled by a boundary element program developed by the Bureau of Mines with non-linear material types and an energy release rate subroutine. The study found this novel pillar splitting and extraction sequencing method superior in reducing the potential for bump occurrence than more traditional techniques such as single split-and-fender, pocket-and-wing and open-ending.

LONGWALL GATE ENTRY DESIGN

More recently, coal bumps have occurred within the multiple entry tail gate systems and, in some instances, along the faces of several U.S. longwalls. Currently, several high production, deep longwall mines (two in Virginia, two in Utah, one in Colorado and one mine in Kentucky) have experienced bumps. In several cases these bumps have occurred where the gate entry pillars were unable to prevent abutment loads from "riding-over" onto the mined longwall panel (Iannacchione, 1988). In other cases, the bumps occurred in response to either gob caving characteristics adjacent to the longwall face or in association with excessive gas pressures. It should also be noted here that at one mine the bump problems on development were severe enough to warrant the elimination of gate entries by employing the advancing longwall system.

As a result of the gate entry bump problems, two different design philosophies have emerged in the U. S. based primarily upon regional geologic conditions and mining preferences, to address these largely stress-related problems. Standard gate entry designs in the southern Appalachian Coal Basins consist of three or more entries with at least one row of abutment pillars; whereas, two and three entry systems with yield pillars are a more common gate entry design in the Uinta and Piceance Creek Basins. Many of the mines in the southern Appalachian Basin require multiple gate entries because of methane emission problems. Three of the bump prone longwall mines operating in the southern Appalachian Basin employ three and four entry designs with a combination of yield and abutment pillars. The most common designs used in the Uinta and Piceance Creek Basins consist of one or two yield pillars.

Abutment gate entry design

A well designed abutment gate entry design will support a considerable amount of the abutment loads generated from both the adjacent gob and the approaching longwall face. This method is well suited for longwalls of

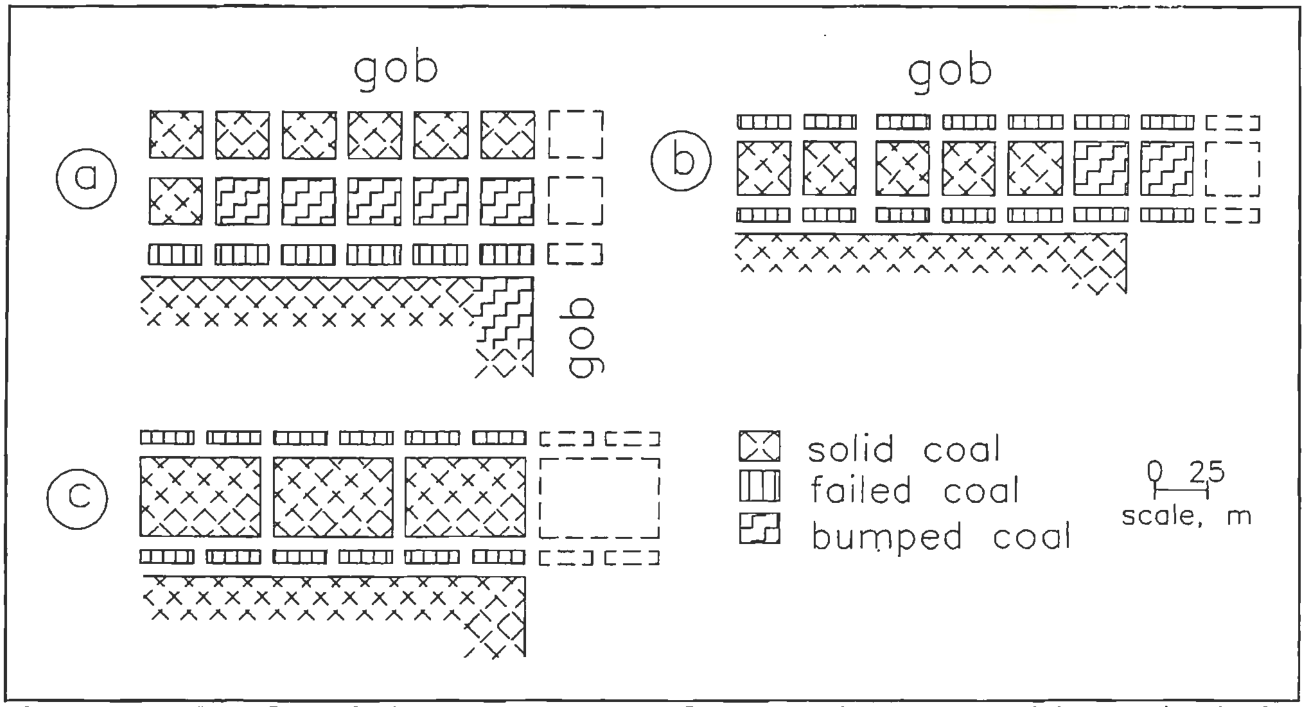

Figure 8. - Examples of abutment gate entry layouts: a) experienced bumps ahead of the passage of the face, b) experienced bumps as the face passed, while c) did not experience bumps until after the face had passed.

moderate depth (300 to 600 m) with substantial gas emission problems. In bump prone ground massive strata often cause excessive stress levels, causing the gate entry pillars to fail prior to the passage of the longwall mining face. As a means of controlling the abutment load ride-over problem, engineers at the Island Creek Coal Company in southwestern Virginia redesigned the gate entry pillars so that they would not fail during panel extraction. Redesign of the gate entry was accomplished by increasing the width of the center abutment pillar from 25 to 36.6 m (Figure 8). An extensive field study was conducted by the Bureau of Mines at this mine to identify the effects of different pillar sizes and configurations on the occurrence of bumps (Campoli et al. 1990). Rock mechanics instrumentation placed in the gate entries showed the redesigned pillars had reduced the stress levels. This caused the abutment pillars to fail at a much later point in the mining sequence (Heasley and Barron, 1988). Observations have shown this design eliminated abutment load ride-overs from the adjacent gob panels onto the actively mined panel. As a result of this implementation, the incidence of bumps at the mine has been greatly reduced. Although this method has proven successful at this mine, it may have limitations when the overburden is extreme or when the coalbed is thick. These conditions may require extremely large abutment pillars which may not be practical.

Yielding gate entry design

Yield pillar designs allow the gate entry system to deform under the weight of the approaching panel abutments, thereby diverting substantial load to the nearby solid coal panel. This method of stress control for gate entries is well-suited for two-entry designs. The first U.S. applications of which were pioneered in the early 1960's at the Sunnyside Mine, Uinta Basin (Huntsman and Pearce, 1981). Longwall mining had just been introduced to the U.S. coal industry at that time, and entry design methods for bump-prone ground were not well developed. Perhaps without fully realizing the advantages of a two- versus multiple-entry yielding system, the decision to develop only two entries was primarily based on limiting the amount of ground to be opened-up prior to panel retreat. Nearly thirty years later, this system has continued to successfully eliminate entry pillar bumps during panel development and retreat operations, especially in areas of the operation overlain by up to 610 m of mesa-forming sediments.

Although a yield pillar design has worked very well at the Sunnyside operation, not all mines have experienced this level of success. A nearby mine attempting to emulate the very profitable yield pillar design had difficulties in developing small pillars without serious bumps occurring, and routinely lost significant portions of tailgate entries to large bump events. It soon became clear that the successful application of yielding designs was dependent, in part, on the immediate geology surrounding the pillar system. Soft roof and floor units aggravate ground conditions in yielding systems because 1) the roof cannot sustain the large deformations that accompany pillar yielding, and 2) the floor cannot withstand the additional bearing load of supplemental support required to hold the entry. Competent roof and floor conditions are necessary to maintain stability during entry closure and not impair subsequently installed secondary support. On the other hand, strong roof and floor conditions, like those at the neighboring mine described above, enhance the strength characteristics of the coal by offering high degrees of confinement at the coalbed interface. This may in turn require a very narrow pillar design to initiate yielding. It may also not be possible to develop such a narrow structure under highly stressed conditions without some form of costly ground preconditioning.

An additional consideration when employing yield pillar designs concerns the effect that redistributing stress from the gate entries onto the active longwall may have on face cutting operations, particularly near the tailgate. Employing a yielding entry system may eliminate bumps in the gate entries, but may also escalate the incidence of bumping during face shearing due to increased abutment loading. Coal stress measurements at the Sunnyside No.1 Mine showed the peak face abutment to commonly reside within 3 to 6 m of the standing longwall (Haramy and McDonnell, 1988). The extent of yielding was even greater along the panel rib-line, extending to nearly 15 m at two measurement locations. This characteristic of side and front abutment stress distribution about the panel explains why bumps are very infrequent at this operation. Moderately stiff immediate roof and floor units, in conjunction with a low-to-moderate strength coal, do not allow coalbed confinement to generate high, bump-initiating stresses near the face. In contrast, measurements at the neighboring Castlegate Mine, which employed a non-yielding two-entry gate design, showed peak face abutments to exist within 0.3 to 0.7 m of the standing wall (Barron, 1990). Bumps were common to this operation, requiring routine face destressing to avoid serious injury to mine personnel and damage to the longwall equipment. Employing a yielding design would almost certainly have aggravated the occurrence of bumps in both the headgate and tailgate entries, as corroborated by previous attempts to implement yield designs on earlier panel gates. This mine was eventually forced to close, largely due to coal bump complications.

In general, two-entry gate entry systems more commonly employ pillar designs that yield during or shortly after development. By design, the narrower gate entries typically generate significant side abutment stresses, and thereby lower the risk of bump occurrence. In situations where two-entry systems are not practical, yield pillars have been used effectively in multi-entry systems, but are more commonly used in conjunction with abutment pillar designs, as shown in the previous section. In either application, yield pillar designs have proven to be an effective alternative in mitigating bump hazards in deep U.S. coal mines.

SUMMARY AND CONCLUSIONS

In summary, many useful designs have been developed in the U.S. to reduce the severity and occurrence of coal mine bumps. This paper has listed the most successful of these designs in chronological order for both room-and-pillar and longwall mining. The following is a list of major observations and recommendations developed from mining in bump prone strata:

1) The potential for bump occurrence increases when mining in stiff roof and floor rock. Strata of this nature are frequently found within the southern Appalachian, Uinta and Piceance Creek Basins.

2) Bumps can occur a) in development sections when faults and igneous dikes are approached, b) in room-and-pillar sections when cantilevering gob is encountered, c) in longwall sections when geologic structures are encountered, and d) in either room-and-pillar or longwall sections when overburden, abutment or shock loads are excessive.

3) Supplemental support has been useful in minimizing bump damage. Rock-filled cribs allow gob to converge gently without rupture. Combinations of cribs, crossbars and props reduce the severity of bumps in main entries. Wood cribs and yielding arches in combination with rock bolts helped support weak, immediate roof during bumps which reduce the associated occurrence of roof fall.

4) The use of straight retreating pillar lines and total extraction of all coal can eliminate projections of bump prone material into the gob.

5) Developing or splitting large blocks of coal into smaller, uniform blocks ahead of the retreating pillar line, causes the coal to yield in a controlled fashion prior to extraction and allows the roof to bend gently.

6) Sequential splitting of pillars away from the retreating pillar line can effectively move excessive stress conditions in a controlled manner away from the working face.

7) Sizing gate entry pillars large enough to contain induced stresses can effectively reduce bump occurrence.

8) Sizing gate entry pillars to yield in a controlled fashion can assist fracturing of the main roof and in some cases lessens the magnitude of abutment and/or shock loads onto the longwall face.

Most of the past and present U.S. bump control designs have helped to control the way the roof rock breaks and regulated the manner in which stresses are redistributed. For the most part, these techniques have been very successful, but have not been applied over a wide range of geologic and mining conditions. As production rates and overburdens increase and new mining systems are developed, the mining industry will be required to develop new bump control designs. Evaluating past experiences, analyzing current and projected conditions and investigating innovative design techniques in the field will help develop the needed technology to keep bump prone U.S. mines safe and productive.

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