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Room-and-Pillar Mining in Bump-Prone Conditions and Thin Pillar Mining as a Bump Mitigation Technique

By Thomas P. Mucho, Timothy M. Barton, and Craig S. Compton

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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CONTENTS

ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot
psi	pound per square inch

ROOM-AND-PILLAR MINING IN BUMP-PRONE CONDITIONS AND THIN PILLAR MINING AS A BUMP MITIGATION TECHNIQUE

By Thomas P. Mucho,[1] Timothy M. Barton,[1] and Craig S. Compton[2]

ABSTRACT

Retreat or pillar recovery mining redistributes the overburden weight onto the adjacent coal pillars in a room-and-pillar section. The additional stress and the resultant energy stored in the remaining pillars can become so great that pillars may bump or violently fail. An investigation at the Gary No. 2 Mine was conducted to examine the effectiveness of the thin pillar mining method for mitigating bump occurrences. Field observations were made and instruments were installed to monitor pillar behavior during extraction. Stress monitoring instruments and roof-to-floor convergence stations were installed in pillars and entries and crosscuts, respectively. Results indicated that high pillar stress concentrations occurred in these bump-prone geologic conditions. The thin pillar mechanism, the creation and progressive outby movement of an expanded yield zone, was also monitored through the instruments. The expanded yield zone, a result of using thin pillars in a highly stressed pillar line area, mitigates bump risk.

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INTRODUCTION

COAL BUMPS

Over the past several years, research to eliminate coal mine bumps has been conducted by the U.S. Bureau of Mines (USBM). Efforts have been directed towards understanding the causes and prevention of coal mine bumps. These endeavors have taken the form of field investigations of the geological and mining parameters that are major contributors to bumps. A thorough documentation of stress and displacements in bump-prone environments was also conducted (*1-6*).[3] Numerical models of various bump-prone mines were developed and calibrated with the actual field data. Geologic strain energy dissipated during mining was calculated. This information was used to increase the operators' awareness of potential bump conditions and to help reduce bump-related accidents through effective cut sequencing and mine layout (*7-10*).

Coal bumps have been reported in U.S. literature since 1935 (*11*). By the mid-1950's, preliminary research had identified several conditions that contributed to coal bump events (*12*). These and subsequent studies have indicated that certain geologic conditions, such as stiff competent associated strata and relatively thick overburden (>500 ft), and the concentration of high stresses, especially those resulting from retreat mining, increased the probability of bumps (*1, 12-14*). Several bump related fatalities in 1984 and 1985 prompted intensive coal mine bump research to be initiated by the USBM (*1*).

Coal bumps have been a problem at the Gary No. 2 Mine since the 1930's. However, in the late 1940's as mining changed from hand loading to mechanical loading and as overburden depth increased, the bumps became more severe (*15-16*). For example, from June 1945 to April 1951 there were 32 separate bump accidents resulting in 66 injuries and 7 fatalities at the mine (*1*). In response, considerable resources were employed in the Gary division in an attempt to understand and cope with bumps. In studying the problem, management noted the conditions that were conducive to bumping. They observed that the high concentration of stresses in and around gob lines and barrier pillars led to bumps. One technique used at the Gary Mine during this period was to destress the pillars by auger drilling. This approach was time-consuming, expensive, and somewhat dangerous though extensive safety precautions were taken (*17*).

Another approach developed during the early 1950's by U.S. Steel, the mine operator at that time, evolved from the observation of the effect of pillar dimensions on bump occurrence. U.S. Steel determined that rather large pillars, equal to or greater than 160 by 160 ft, would not bump and could help carry the loading being created by the retreating gob line. These large pillars, highly stressed, were left in place and called "bump blocks." It also became apparent that very small pillars (i.e., less than 45 ft) would yield, and therefore, not bump (*15*). In addition, they also observed that between these very small pillars and the large pillars were "critical" size pillars that were highly stressed and prone to bumping (*1*). Using this yielding concept and the resultant stress redistribution, the thin pillar method was developed.

The thin pillar mining method is similar in concept to one developed at a neighboring Pocahontas No. 4 Mine that was also in bump-prone conditions. At the nearby Olga Mine, a novel retreat mining method was originated that redistributed stress away from the gob line by systematically splitting the pillars in the immediate gob area (*4, 18*). This current study of the thin pillar mining method, added to the study of that novel retreat method at Olga Mine, furthers the USBM long-term objective to develop design criterion that can reduce bump hazards (*5*).

THIN PILLAR MINING METHOD

Presently, room-and-pillar mining is being used at Gary No. 2 Mine to retreat the mine toward the drift mouth in workings developed as early as the 1900's. The thin pillar mining method developed at the Gary No. 2 Mine, is employed to mine areas that management anticipates will bump, or upon inspection, exhibit signs of bumping. This generally includes the rather large barrier pillars that were left to protect the main entries from the concentrated stress of pillared production sections. These barrier pillars are highly loaded from the mining-induced stresses of the main entry development and the pillaring operations of the old gob. The additional loading from the current pillar line only compounds this situation.

To mine these highly stressed barriers, thin pillars, approximately 25 ft wide were developed in the area immediately next to the new, retreating gob line. These pillars have a width-to-height ratio of approximately three, and are incapable of confining the pillar core to a point where excessive stress may exist. This, and the fact that they are weak, interlaced with closely spaced fractures, subjected to high loading from the approaching pillar line, and situated between strong competent strata, causes the thin pillars to yield quickly. As a consequence of the

[3]Italic numbers in parentheses refer to items in the list of references at end of this report.

yielding, the gob abutment loading is cast further outby to larger chain and barrier pillars. The pillar yielding results in a zone that has much lower levels of stresses and stored strain energy. It is then possible to mine in this area relatively free of the hazards of bumps.

Critical to this method is the continued systematic outby expansion of the yielded zone. The zone movement is accomplished by the alternate extraction of the thin pillars and the nearly simultaneous creation of more thin pillars outby. This procedure maintains an evolving "buffer zone" for pillar extraction. A typical thin pillar mining sequence is shown in figure 1.

During thin pillar mining, it is extremely important that the development of the thin pillars is not in an area that is highly stressed, but rather in an area that has undergone some softening due to the pillar line loading. Therefore, outby thin pillar development must remain near the gob line. Usually, the first cut into the barrier pillar that begins to outline a new thin pillar, encounters the most critical stresses. Thereafter, as the mining continues to outline the thin pillar, the developing thin pillar will yield, causing the load to be distributed on outby pillars. The balance between the pillaring along the gob line and the outby development is of great importance, and the mine continually assesses the progression of the yielded zone. The working area is examined daily for signs of excessive roof, floor, or pillar deformation indicating a higher than normal stress concentration. If such conditions are observed, inby pillars must be pillared or split to "soften" the area. Based on years of experience with this technique, the mine can become adept at evaluating conditions and develop a systematic approach to control coal bumps.

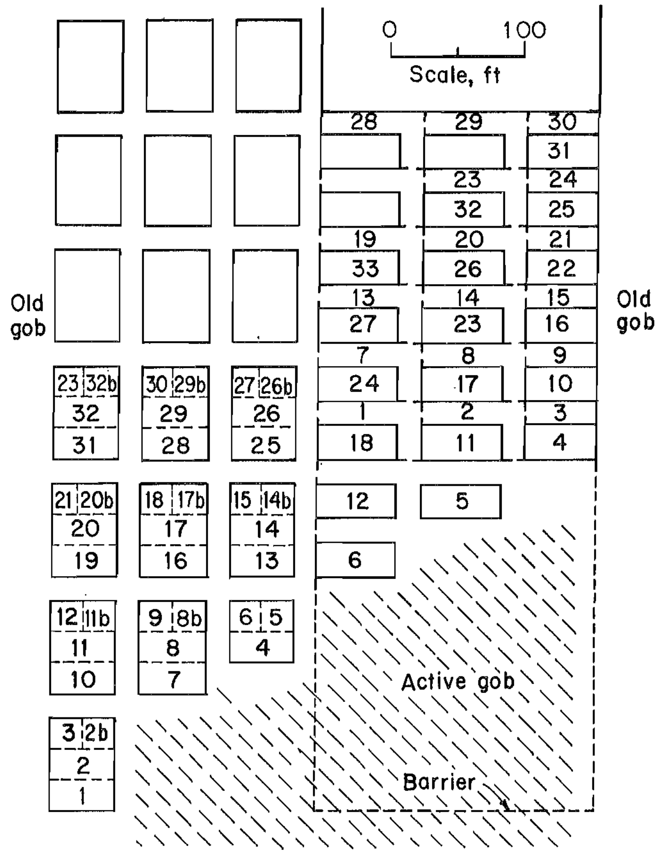

Figure 1.—Typical mining sequence utilizing thin pillar method. Numbers indicate mining sequence order. Dual numbers such as 1, 1; 2, 2 - indicate areas mined simultaneously. (After Talman, 1958)

GEOLOGIC SETTING AND PHYSICAL PROPERTIES

The Gary No. 2 Mine was one of a group of mines that were part of the former U.S. Steel Gary Mining District. It is located in southern West Virginia near Gary, McDowell County in an area of the southern Appalachian Basin known to be bump-prone (fig. 2). The mine operates in the Pocahontas No. 4 coalbed that was 6 to 8 ft in thickness in the study area. The study area of the mine is shown on figure 3. The Pocahontas No. 4 coal seam is friable, soft, and crushes easily. Clay binders separate the coal into three distinct benches that were consistent through out the portion of the mine investigated. The generalized stratigraphy of the mine and the stratigraphy in the study area and in the immediate area of the seam is shown on figure 4. The locations of the drill holes used for this stratigraph are shown on figure 3.

The bump-proneness of the mine is caused by its local geology. Although the topographical relief in this area is usually high due to the rugged, mountainous terrain, the overburden was consistent over the particular study area. It ranged from 650 ft to more than 700 ft (fig. 5*A*). Overlying the Pocahontas No. 4 seam is the Eckman sandstone. This stiff, competent roof member ranges from 140 to 180 ft in thickness over the study area (fig. 5*B*). Between the thick Eckman sandstone and the coal seam, a thin roof shale may be present. When shale is present, especially if it is thick, this roof may act as a weaker layer that reduces bumping. However, as shown on figure 5*C*, this intervening layer was relatively absent in the study area and only a few sporadic pockets of roof shale were actually observed.

The floor rock is a strong, competent sandstone layer. An intervening layer of shale may be present immediately beneath the coal. This softer layer, like the shale in the roof, may mitigate bumps. However, as can be seen from figure *5D*, this weaker floor shale layer was minimal in this area.

No rock property tests were conducted at the Gary No. 2 Mine. However, rock tests were conducted at the adjacent Olga Mine located west of the study area and mining the same coalbed. The roof and floor sandstones have an average compressive strength that ranges from 21,900 to 24,200 psi with a Young's Modulus of 5.16 - 5.45 × 10^6 psi. The compressive strength and the Young's Modulus of the Pocahontas No. 4 coal specimens tested were found to be 2,400 psi and 0.61 × 10^6 psi (*4*).

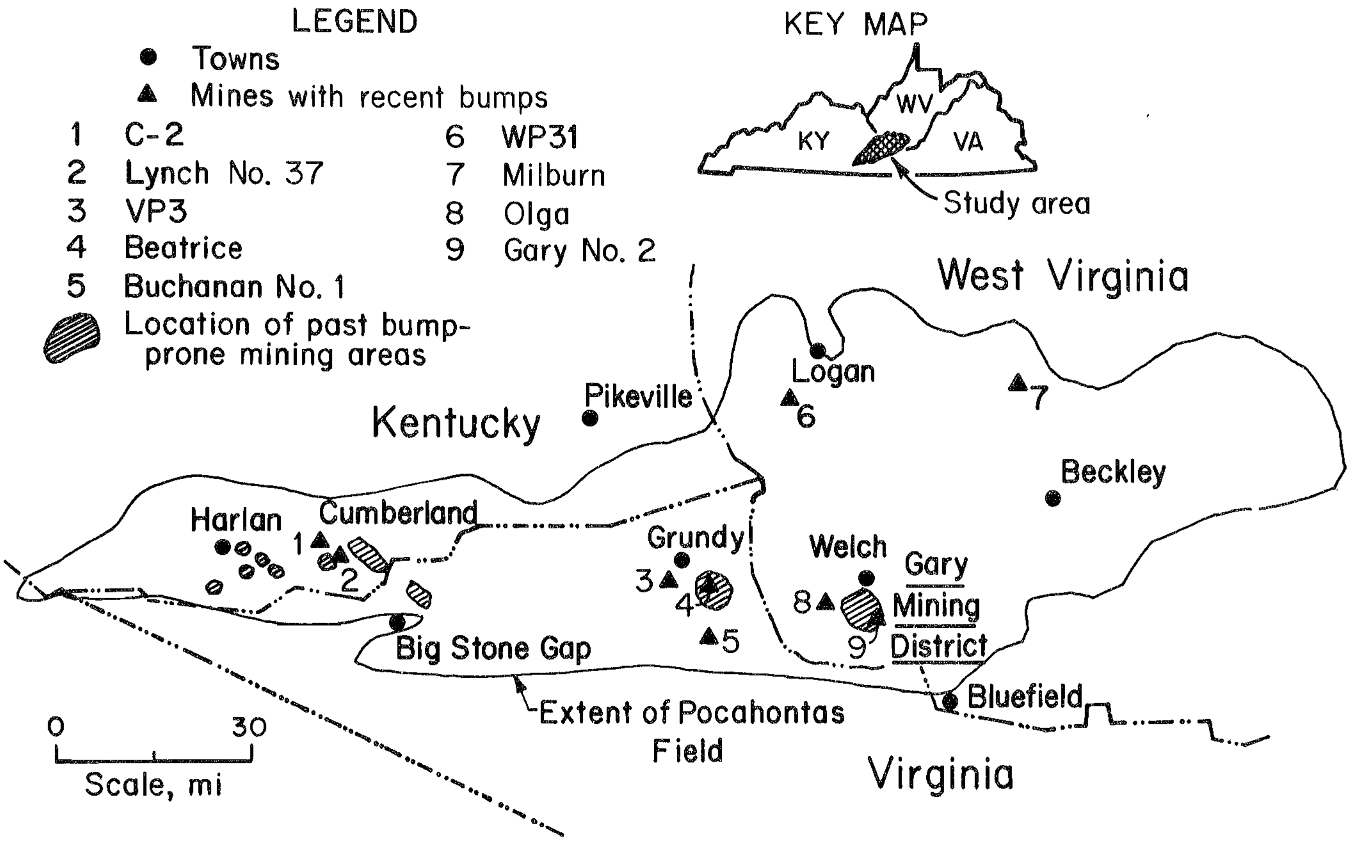

Figure 2.—Location of bump-prone areas in southern Appalachian Basin. [After Iannacchione and DeMarco, 1992 (*19*)]

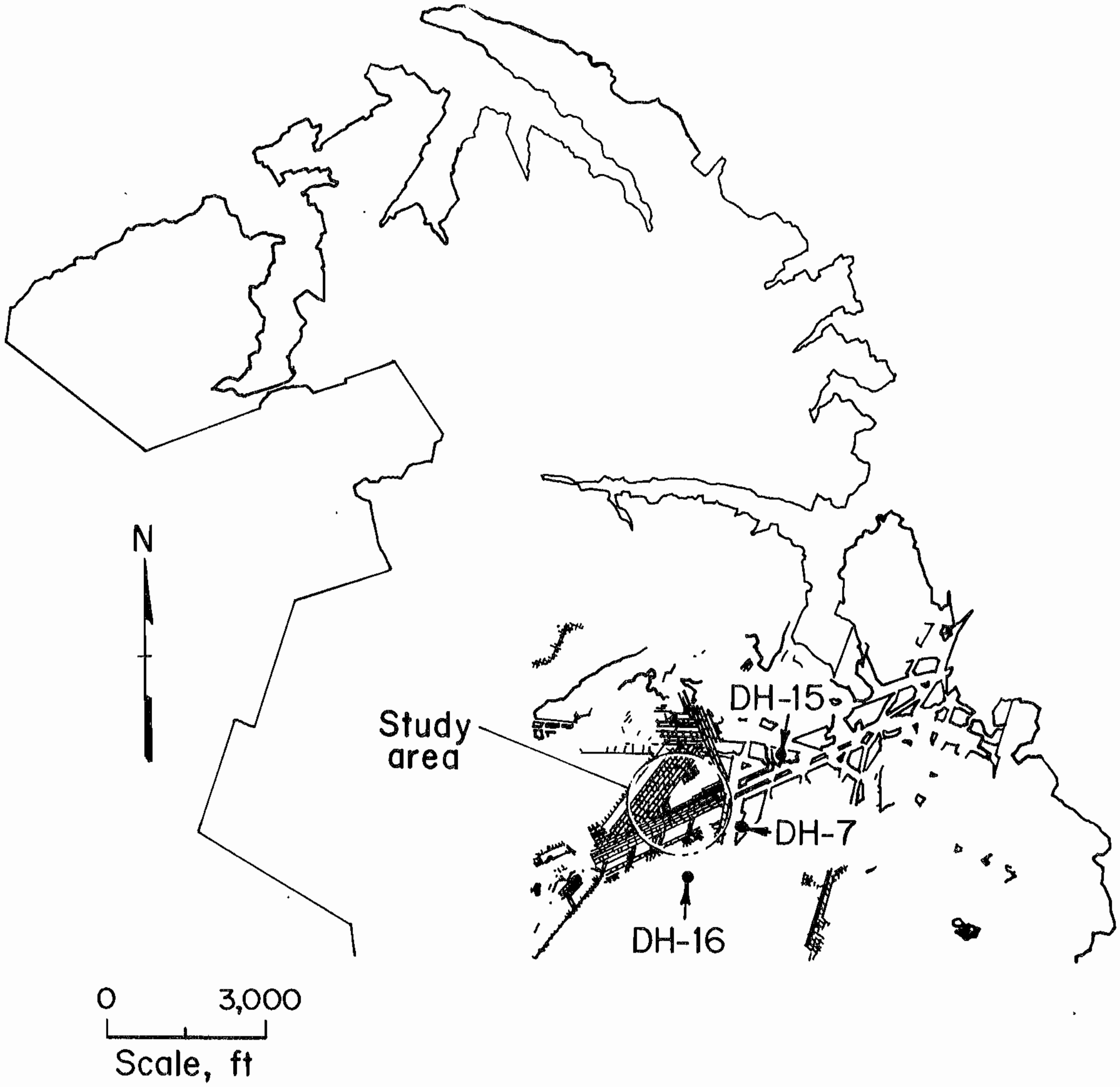

Figure 3.—Study area of Gary No. 2 Mine. DH is drill hole location.

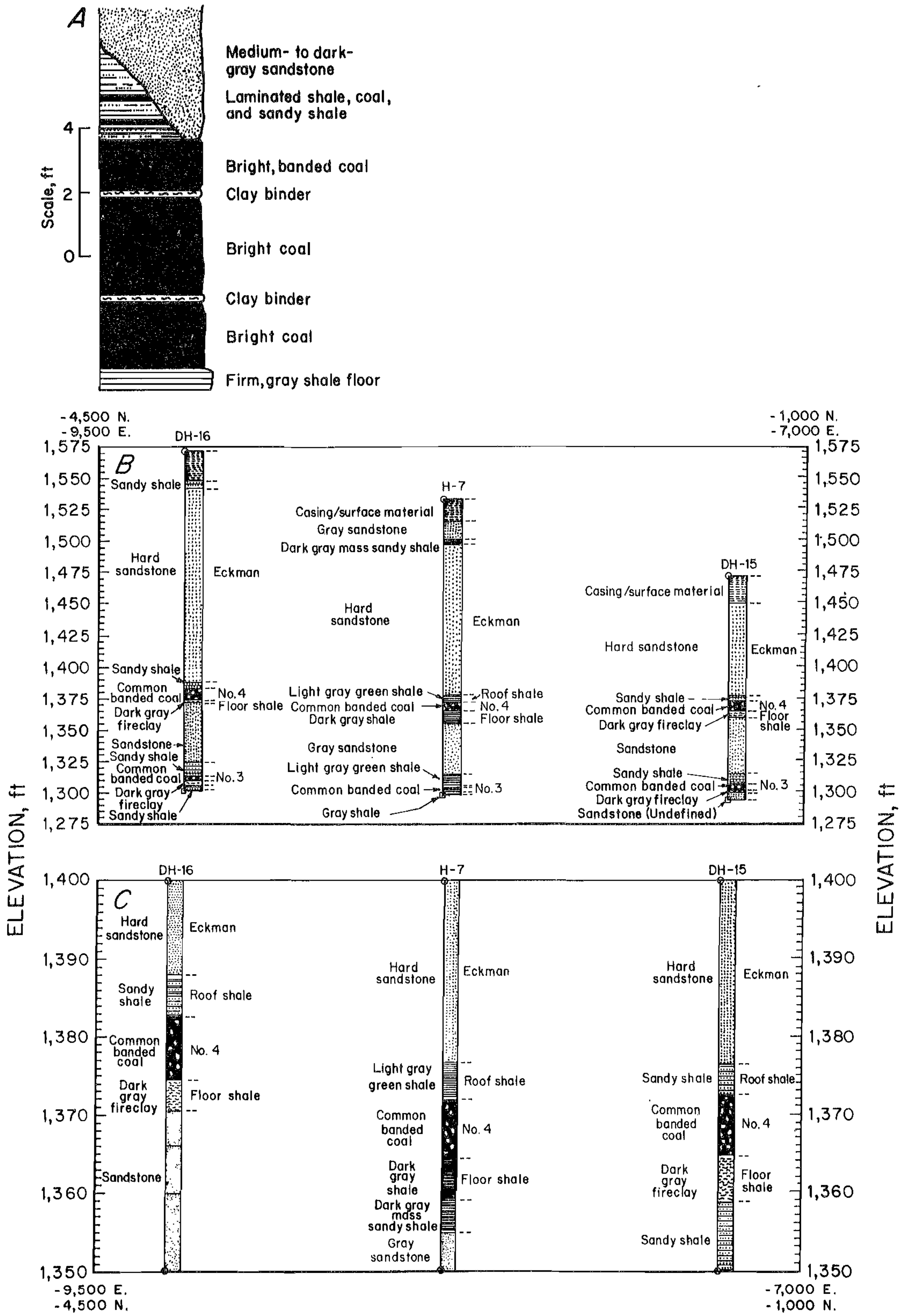

Figure 4.—Stratigraphy. *A*, Generalized stratigraphic column. (After Campoli, 1987); *B*, general stratigraphy in study area; *C*, stratigraphy in the immediate area of the seam.

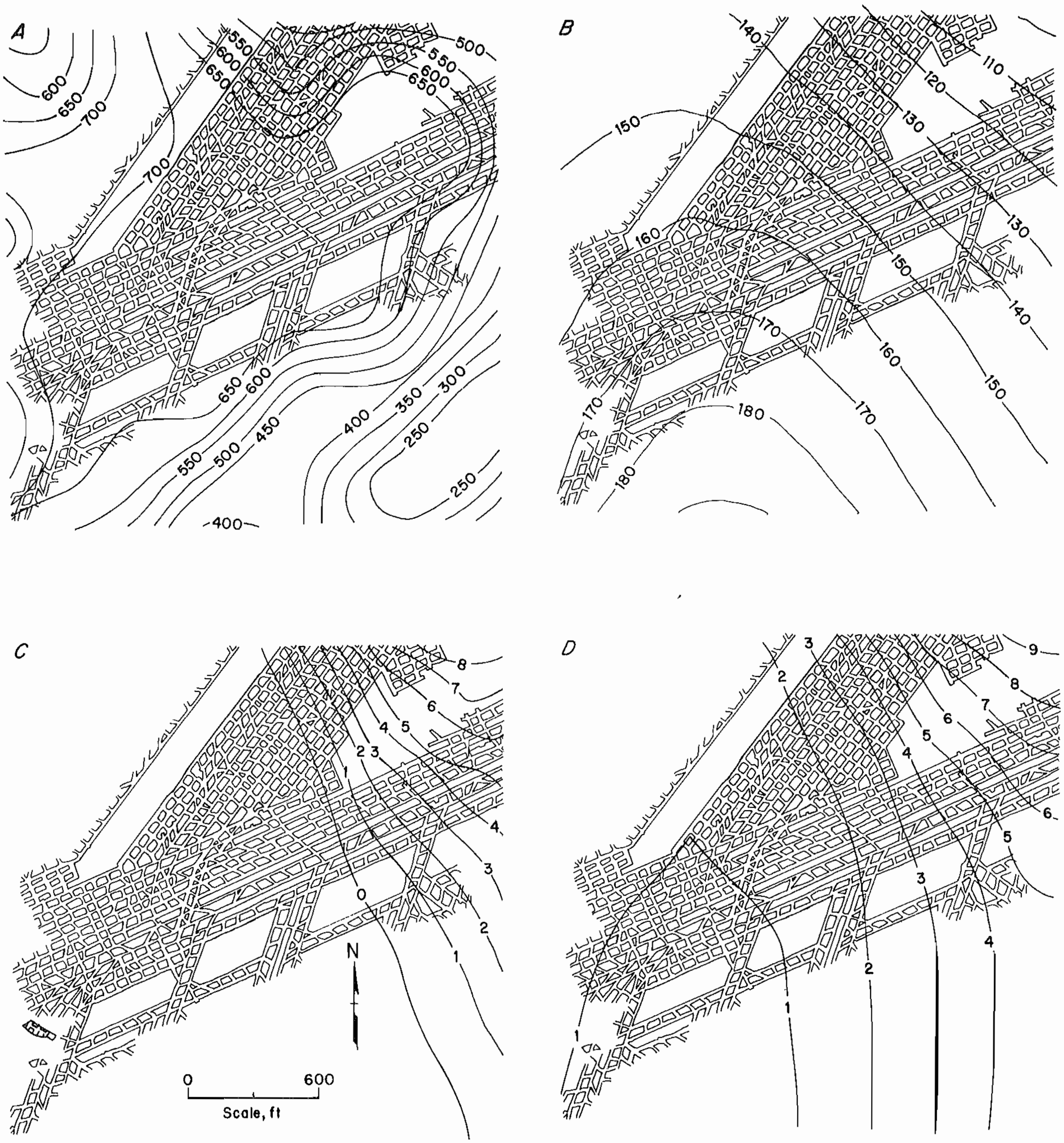

Figure 5.—Study area structure contours. *A*, Overburden thickness, 50-ft contour interval; *B*, thickness of Eckman sandstone, (main roof) 10-ft contour interval; *C*, immediate roof shale thickness, 1-ft contour interval; *D*, immediate floor shale thickness, 1-ft contour interval.

INSTRUMENTATION PLAN

To study pillar-strata behavior and the thin pillar mining method, instruments were placed in three areas that were near each other. These three areas are shown on figure 6. Also included on this figure are numbers that correspond to pillars in which instruments were installed. The instruments in area A, the Mule Barn section, were to observe the behavior of the pillars and strata to both development and pillaring induced stresses in that immediate area. In area B, three pillars, developed in the 1970's, were instrumented to monitor pillar and strata response to the nearby development and retreat operations in the Mule Barn section. The instruments in area C, the Bailey section, were installed to document the thin pillar mining method and to provide insights into its mechanics.

The instrumentation consisted of stainless steel borehole platened flatjacks (BPF's) for indicating coal pillar stress changes and convergence stations for measuring roof-to-floor closure. The BPF's were installed at mid-seam height to depths ranging from 5 to 28 ft in existing coal pillars or in barrier pillars that were being developed into smaller pillars. A data acquisition system was used to remotely and continuously monitor the BPF's within the three instrumentation sites. The conversion of the hydraulic pressure change in the BPF's to an approximation of actual in situ stress change was accomplished with a computer program Borehole Platened Flatjack Calibration (BPFCAL) (*20*). For the total stress state to be calculated, the original state of stress, plus the development stresses, would need to be known. These would then be added to the stress change data obtained by the BPF's. Since the original state can only be estimated, the data in this report will be limited to the calibrated stress change

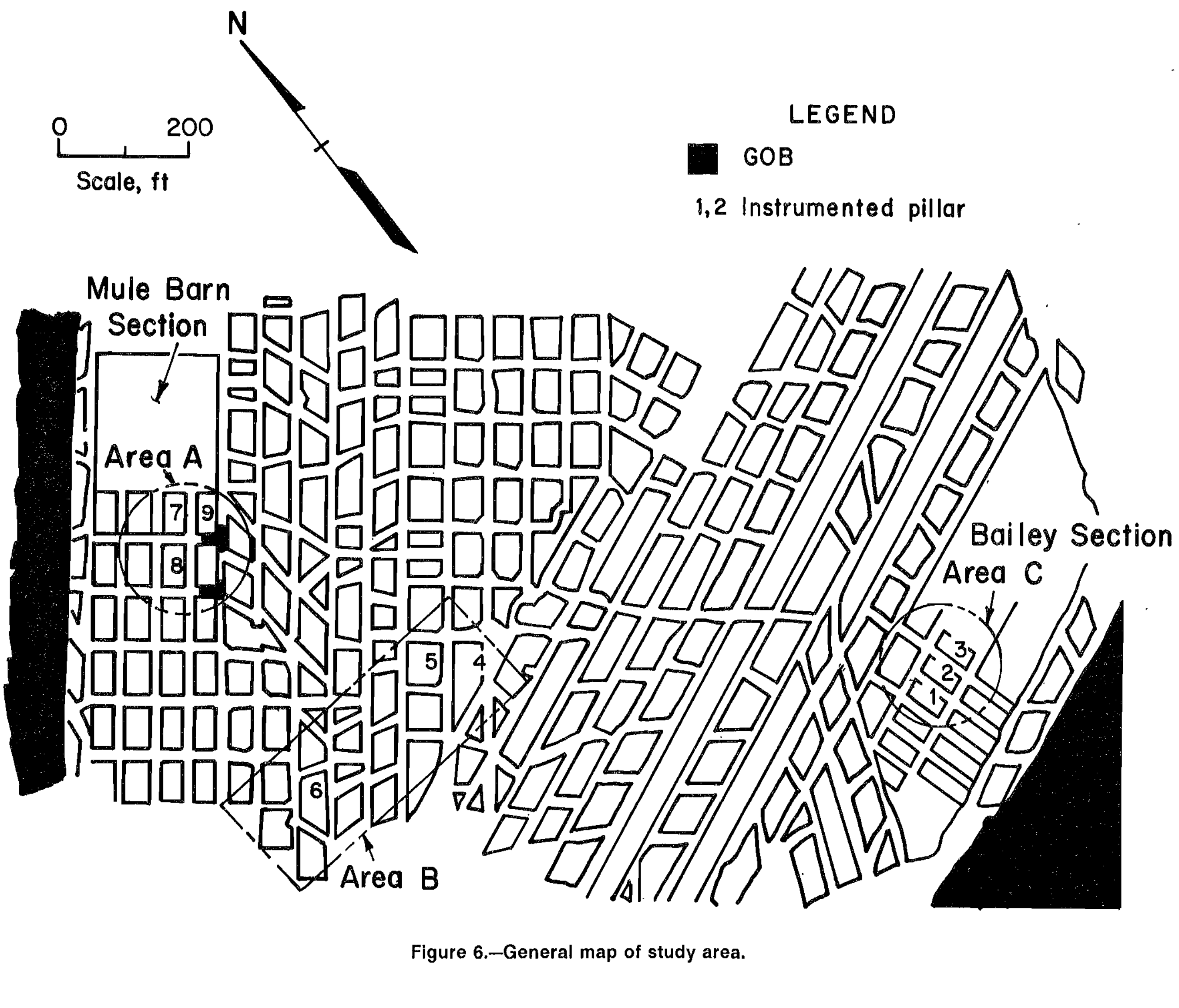

Figure 6.—General map of study area.

after the cells were installed. The cells were installed at a pressure calculated to approximate in situ vertical stress.

The convergence stations consisted of metal pins in the roof and the floor. They were generally installed near the center of the entry and were normally next to instrumented pillars. A portable telescoping rod, capable of a precision of a few thousandths of an inch was used to measure entry closure. No means of differentiating between roof sag or floor heave was provided. However, other work has shown that the relative closure of the strata is a reliable indicator of strata response to stresses and usually confirms stress meter data (*4*). The convergence stations were manually read on a periodic basis.

RESULTS

AREA A

Area A was a barrier pillar left to protect the former main haulageway from the adjacent gob. This barrier was being developed into smaller pillars. The most inby new pillars were alternately being retreated while the outby portion of the barrier pillar was being developed. Figure 7 shows area A mining at selected times from early January 1991 through the end of March 1991. For consistency, the dates of the selected mining status figures roughly correspond to data lines shown on other figures for areas A and B.

The instrument array installed in area A is shown on figure 8. BPF's were installed across the width of pillar 8 at pillar midlength. These cells were installed to observe pillar behavior in response to the approaching pillar line and to capture development stresses. BPF's in pillars 7 and 9 were installed prior to these pillars being fully developed in an attempt to record development stress increases and the abutment loading from the approaching gob line. In addition to BPF's, convergence stations were installed around pillar 8 to supplement BPF data. However, water accumulations made it impossible to totally surround the pillar.

BPF data for pillar 8 is shown on figure 9. When the cells were installed on December 21, 1990, pillar 8 had just recently been developed. Periodic stress changes from January 3, 1991 to February 23, 1991 are depicted for the BPF cells identified by the location in the pillar as the distance from the left rib (note: left and right directions noted in this report are facing the pillar looking inby toward the pillar line). From January 3, 1991 to January 14, 1991, development mining was being done to create the next immediate pillar row outby pillar 8. During this period, pillars were also being retreated in the third row inby this pillar (see figure 7). This alternating from development outby pillar 8, to pillaring inby, continued throughout the period of the data collection shown on figure 9, except five days beginning on January 30, 1991. On that day, a fall occurred in the intersection between pillars 8 and 9, interrupting mining and severing the data lines. Data collection resumed on February 4, 1991.

By February 23, 1991, the last day stress readings were taken, the pillaring phase had begun to split two of the blocks of the row immediately inby pillar 8 and the development work had created three rows of pillars outby pillar 8. The recording of readings ceased in late February in the Mule Barn section due to the approach of pillar mining, and later, due to a water inflow from the adjacent gob. The water inflow eventually caused mining to cease for the next few months, except a small amount of outby development mining for a few days near the end of March.

The stress profile of pillar 8 on figure 9 shows that the BPF 28 ft from the left rib, or 7 ft from the right rib, returned to zero stress change following a slight increase shortly after installation. This BPF may indicate the propagation of the yield zone of the pillar. Pillar 8 was being subjected to increasing development loading, retreat mining stresses, and the entire barrier pillar was loaded by the adjacent gob. The performance of this cell, in-mine observations, and other instrumented data indicated that a yield zone of 7 to 10 ft was normal around the perimeter of the chain pillars under abutment loads.

The 16 ft BPF near the center of the pillar and the BPF 9 ft from the left rib provide an apparently reliable portrayal of the pillar core and core-yield zone area response to the development and retreat mining. The stress change of these two cells versus time are shown on figure 10. For the 16 ft BPF, the stress levels generally continued to rise from the time of installation. When connected after the January 30, 1991 roof fall, this cell showed higher stress levels and was again rising until February 10, 1991 when it began to decline. Notably, pillar 2 in area B next to this area, also recording stress changes due to this mining, recorded a drop in stress on February 10, 1991. This stress drop may have been due to substantial caving of the cantilevered competent roof in the new gob of the Mule Barn section. Another possible explanation for this drop is that, this area of the pillar core could have been at or near yield, and was redistributing load (note the continued rise in the 9 ft cell). The 16 ft cell continued to decline until readings were discontinued in late February.

The 9 ft BPF of pillar 8 lost pressure upon installation and was repumped on January 9, 1991. Thereafter, this

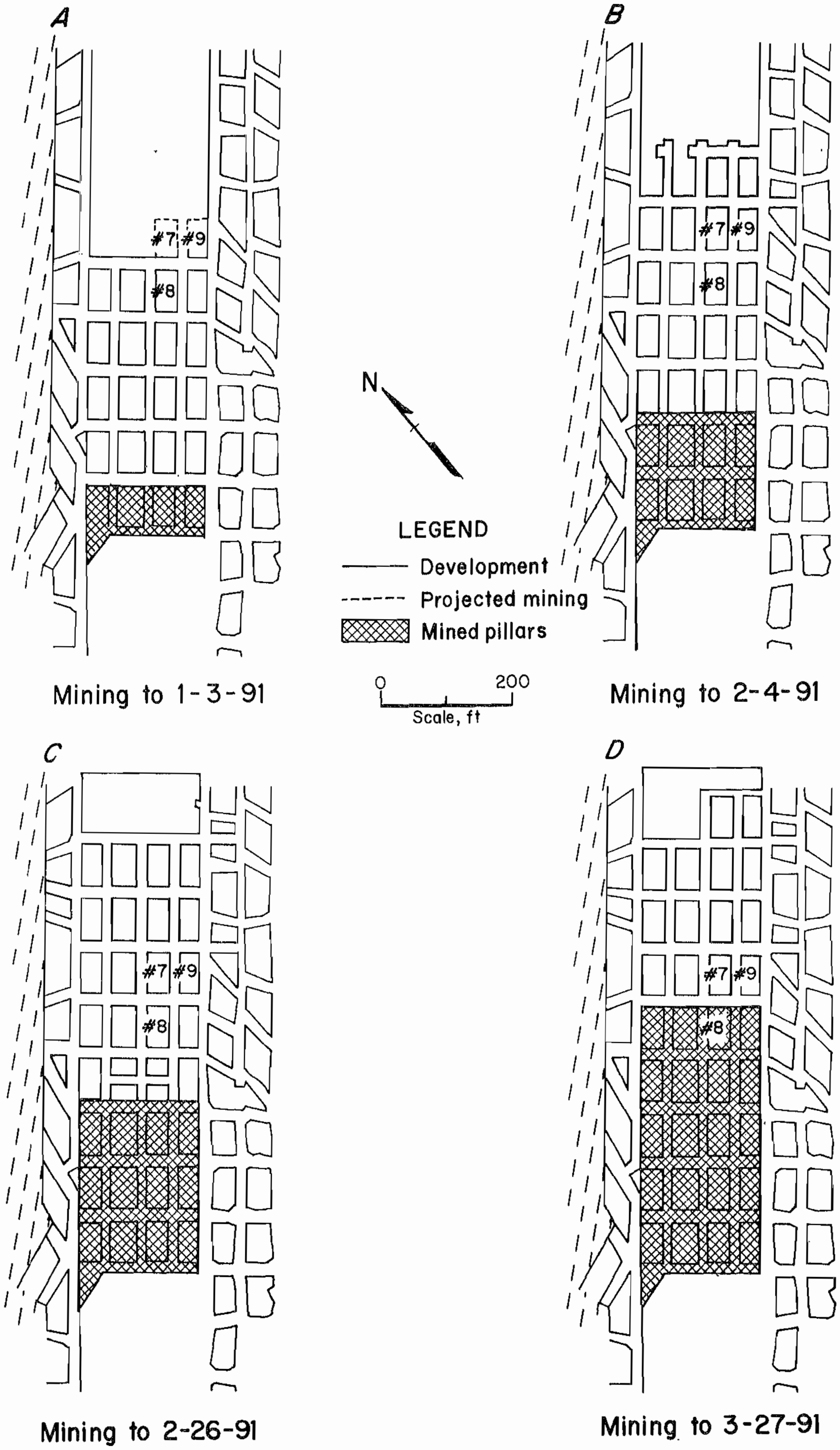

Figure 7.—Mining sequence in area A. *A*, Mining to 1-3-91; *B*, mining to 2-4-91; *C*, mining to 2-26-91; *D*, mining to 3-27-91.

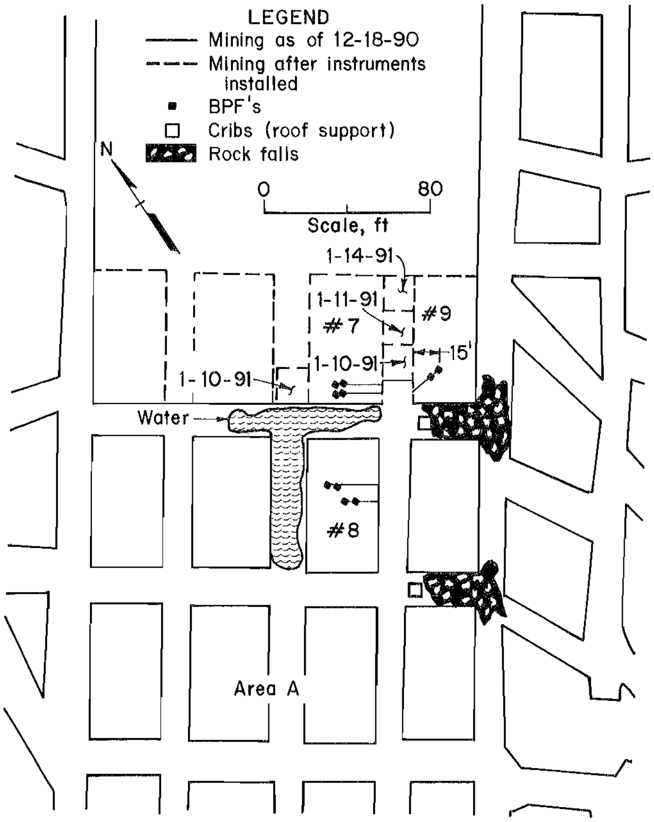

Figure 8.—Area A mining and instrumentation.

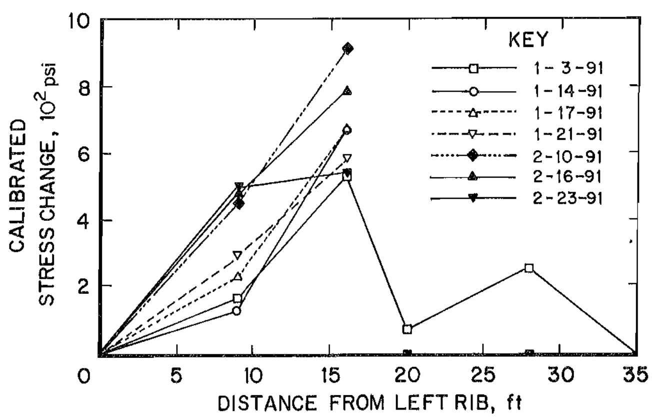

Figure 9.—Calibrated stress change of pillar 8 BPF's.

cell generally displayed a continual rise in stress change as the pillaring approached pillar 8. Although the general behavior pattern of the cells in pillar 8 was similar to other investigations, they did not attain the magnitudes of other BPF's at Gary. However, full extraction mining was still two rows of pillars inby this location (approximately 120 ft) when the readings were suspended. In addition, while an attempt was made to capture the pillar loading from the new development mining and the newest pillar line gob

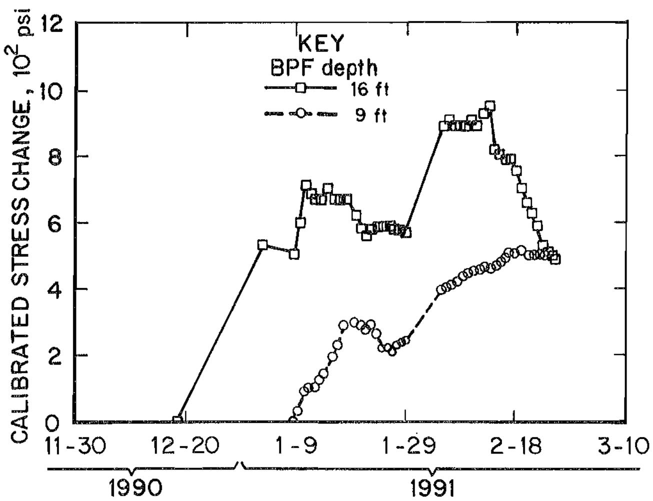

Figure 10.—Pillar 8 calibrated stress change versus time.

loading, these stress changes do not account for the loading that this barrier pillar had been subjected to from the original development of this wide main line juncture in the late 1930's and from the adjacent gob area retreated in the 1940's. The history of mining at this mine has always indicated high-stored energy and stress in these bump-prone barrier pillars as a result of previous high loading.

A contributing factor to the lower levels of the readings may be pillar size. The pillars being developed in this area were relatively small (35 ft wide by 70 ft long). The combination of the high preloading prior to instrument installation and a relatively small, possibly quick-to-yield pillar, as indicated on figure 9 by the decrease in stress after February 10, 1991, may be the reasons for the smaller magnitudes.

Four BPF cells were located in pillar 7 as shown on figure 8. The four cells were installed near each other, two each at 25 and 30 ft into what was then solid coal. This location was approximately 8 ft from the existing crosscut coal rib. The stress changes of the cells over time are shown in figure 11. From the date of the installation on December 20, 1990, these cells displayed a decline in stress through January 9, 1991 (although one 25 ft cell had some erratic readings). This decline could be anticipated due to their proximity to the mine opening as the pillar yield zone evolved. Except for the cell at 25 ft, all the cells dramatically dropped to zero on January 10, 1991 when the first cut was taken to continue to form pillar 7. This first cut (fig. 8) placed these cells 5 and 10 ft from the newly created coal rib, and this, in addition to being 8 ft from the crosscut coal rib, located them in the newly created corner of the pillar. The corner of the pillar is an area that would be expected to yield quickly under these particular loading conditions. The cell at 25 ft continued to show a decline in stress although at a reduced level after the cut taken on January 10, 1991. Although, near the other cells, it may not have been in the yielded area of the pillar.

Two BPF's were located in what would become pillar 9 as shown on figure 8. The boreholes were drilled at an angle to and ahead of the face in an attempt to record the stress changes due to development mining, and pressure increases due to pillar mining. These cells were installed on December 20, 1990. On January 10, 1991 mining resumed to continue to create pillar 9. The BPF's, located 20 and 25 ft from the left rib of the pillar, were now 15 and 10 ft laterally from the newly created right edge of pillar 9. As can be seen on figure 12, these cells began to rise immediately in response to the developmental mining of January 10, 1991. The 25 ft cell rose rapidly and attained a stress increase of over 4,000 psi when the pillar was fully outlined. At this point, either cell failure or the creation of the pillar yield zone (since the cell was approximately 10 ft into the pillar) caused a rapid decline in the readings.

The 20 ft cell, located 15 ft from the right pillar edge, and therefore, more in the core of pillar 9, displayed a slower but steady increase in stress, as it, and the pillars immediately outby were being developed. However, the January 30, 1991 fall that severed the data lines also prohibited these cells from being reconnected to the recorder. While the later pillaring stresses were not recorded, these cells provide insight to the response and behavior of this pillar to initial developmental stresses in bump-prone strata.

AREA B

The second area instrumented at Gary No. 2 Mine, area B, was next to the Mule Barn section (fig. 6). This area, the original junction of two sets of mains, had been developed in the 1940's. Additional mining had been done in this junction in 1974. Three of these older pillars were instrumented. Pillars 4 and 5 had BPF's installed, and all three pillars were surrounded by convergence stations (fig. 13). The purpose of this instrumentation was to observe the reaction, interaction, and behavior of pillars and strata in a known bump-prone environment to nearby development and retreat mining in the Mule Barn section.

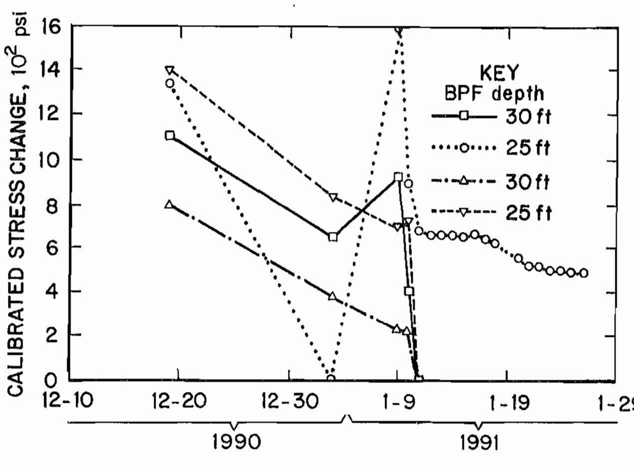

Figure 11.—Pillar 7 calibrated stress change versus time.

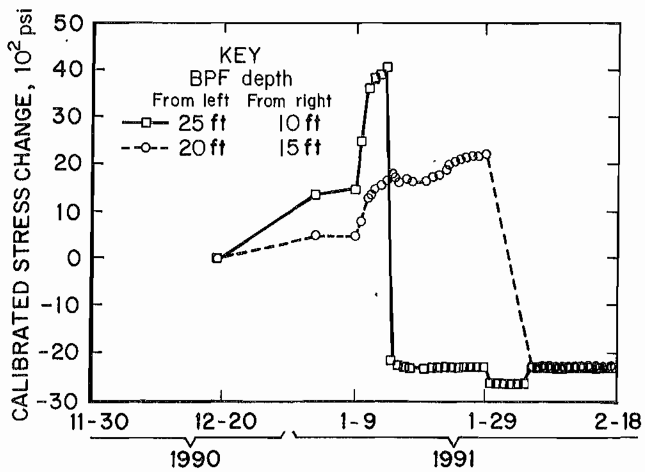

Figure 12.—Pillar 9 calibrated stress change versus time.

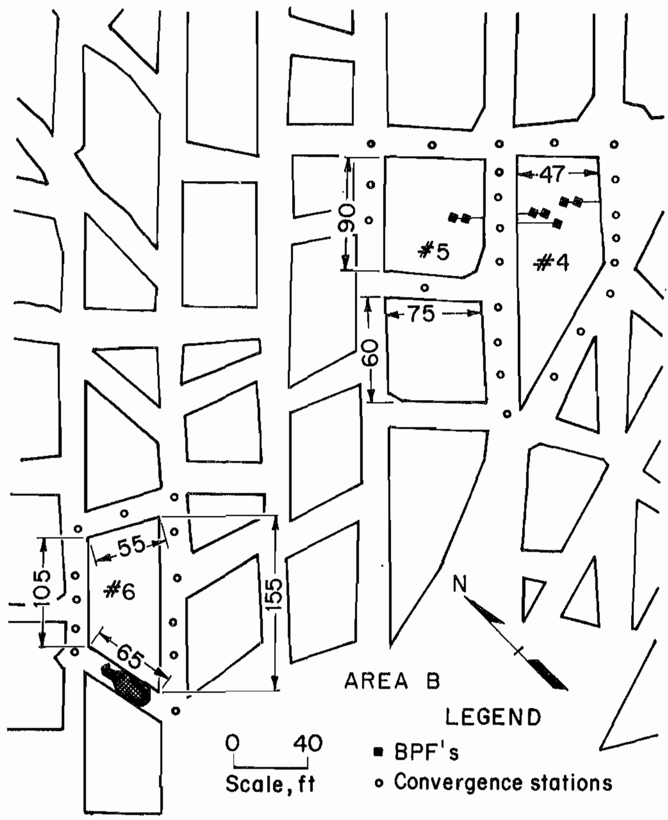

Figure 13.—Area B instrumentation.

A history of the stress change profile across the width of pillar 4 is shown on figure 14. These profiles were created from data from five BPF's located at distances of 15, 20, 22, 27, and 32 ft from the left rib (looking inby) of the 47-ft-wide pillar. The BPF's in pillar 4 were installed on December 18, 1990. The dates of the stress profiles generally correspond to the mining stages in the Mule Barn section previously displayed on figure 8 for area A.

The pillar 4 readings show a steady increase in response to development and pillar mining in the neighboring Mule Barn section. Though the Mule Barn pillar mining and gob came no nearer than about 400 ft to the right of pillar 4, the cells in the pillar core exhibited stress increases in excess of 6,000 psi. Also, the BPF's in the right side and center of this pillar increased to higher levels than the pressure cells on the left side of the pillar.

This right skew of the stress change profile of pillar 4 may be a result of each cells' proximity to the Mule Barn mining. The BPF's located 15 and 20 ft from the left rib did not increase as rapidly or to the magnitudes of the cells in the center and right side of pillar 4. The BPF located 20 ft from the left rib attained a maximum increase of a little over 2,000 psi, and the 15 ft cell increased approximately 1,000 psi. However, the stress change that did occur in the left side of the BPF's indicated this section of the pillar was not totally yielded prior to instrument installation.

Another possible explanation for the performance of the cells in the left pillar edge is that they were in an already highly loaded area of the pillar and were unable to accept significant additional loading. It is possible that the yield zone of this pillar could approach 20 ft in width in this area due to: the very wide entry to the immediate left of pillar 4 (fig. 6), the age of the pillar, and the developmental loading.

Pillar 5, adjacent and to the right of pillar 4, had two BPF's installed at 15 and 20 ft from its left ribline. However, the 20 ft cell failed soon after installation and would not maintain positive pressure. The plot of the 15 ft BPF readings from installation on December 20, 1990 until March 28, 1991 is shown on figure 15. This cell, like the BPF's in pillar 4, steadily rose from its installation pressure until it reached a maximum in early February of over 6,000 psi. It reached its highest reading earlier than pillar 4, probably due to its closer position to the mining. Also, pillar 5, like pillar 8 in the Mule Barn section, recorded a drop in stress on February 10, 1991. At that time, the stress readings dropped into the low 5,000 psi range and remained fairly constant until readings were stopped near the end of March. Possible reasons for this drop on February 10, 1991, as noted previously during the discussion of pillar 8, are substantial caving of the cantilevered gob or pillar core stress redistribution.

Selected convergence contour trends of area B corresponding to the mining periods of the adjacent Mule Barn section are shown on figure 16. In this report, convergence contours are shown as though the contour lines would extend through the pillars. While this may not be physically correct, the intent of the convergence data is to confirm and supplement the BPF data. Since the interest is in stress or pressure profiles and patterns, it is felt that the connected contour lines through the coal pillars provides an easy method to represent the data. The convergence contours depict the relative response of the strata and mine structures to the increased loading due to pillar mining. The convergence contours shown are computer generated first order trends of the convergence data. This was done to demonstrate strata response to the developmental and retreat mining in adjacent area A.

The convergence patterns and magnitudes were as expected, given their physical relationship to the Mule Barn section mining and the results of the BPF readings already discussed. The edge of the Mule Barn gob passed 150 ft to the right of pillar 6 and an average of 350 ft to the right of pillars 4 and 5. The magnitudes of the roof-to-floor

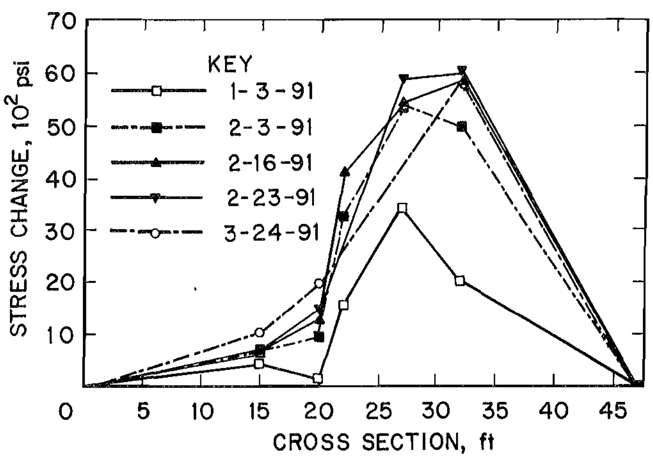

Figure 14.—Calibrated stress change of pillar 4 BPF's.

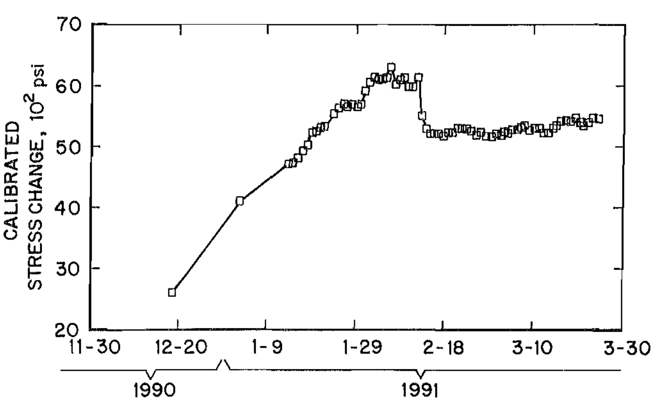

Figure 15.—Pillar 5 calibrated stress change versus time for 15 ft deep BPF.

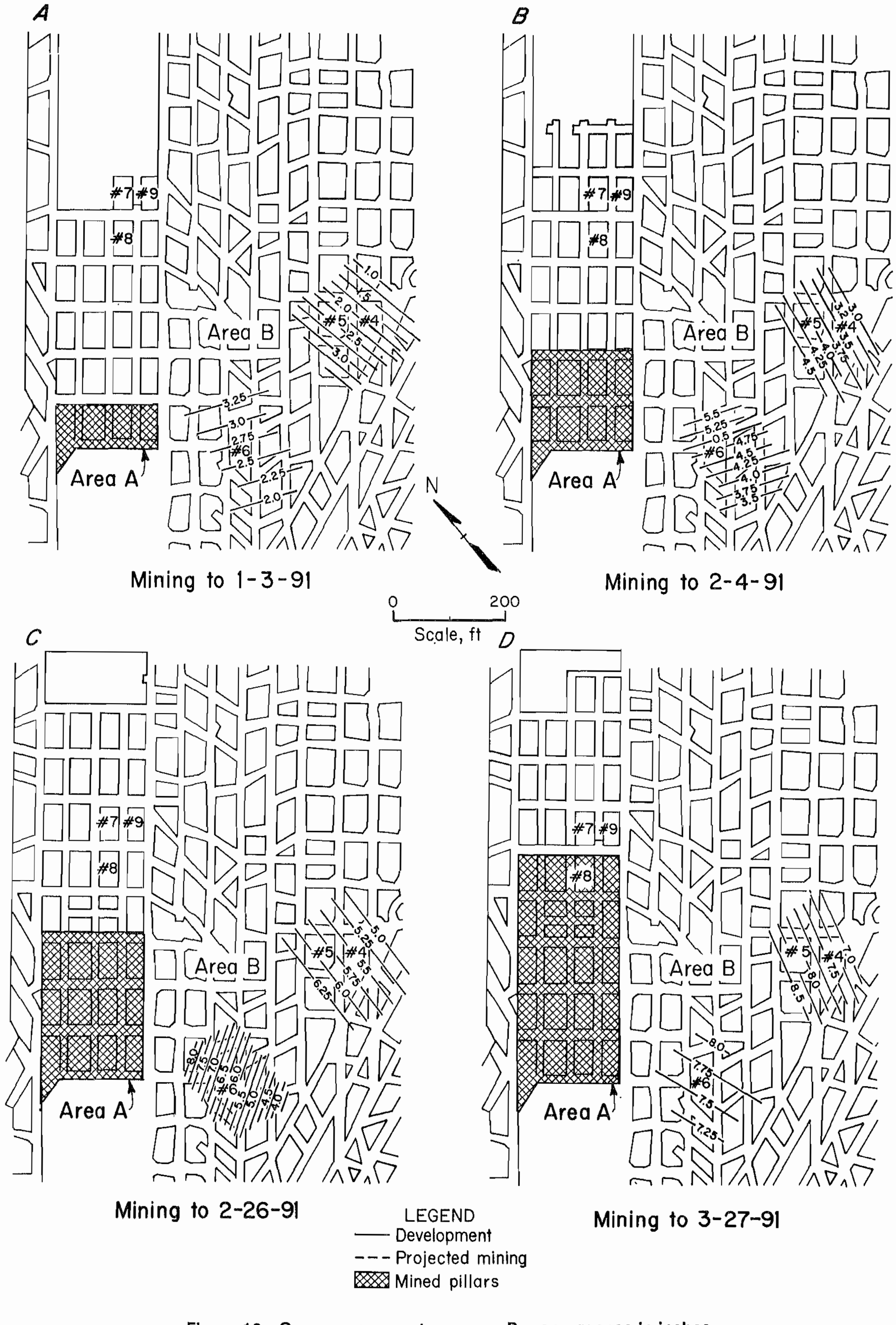

Figure 16.—Convergence contours area B—convergence in inches.

convergence increased from inby to outby as the mining passed these stations from inby to outby. The convergence magnitudes were also greatest on the right side of the pillars and less on the left side that was further from the active mining gob. The computer generated trend lines also pivoted with the mining movement. This was especially evident from pillars 4 and 5 data that had twice as many stations as pillar 6 and covered a greater area. The convergence data confirm and reinforce the BPF data and are therefore, a reliable gauge of the response of this strata to the high loading as a result of the pillar mining.

AREA C

Area C was known at the mine as the Bailey section (fig. 6). This production section was mining barrier pillars to the left of the main's junction where instrumented pillars 4, 5, and 6 (area B) were located. From underground observations of the area, the stresses observed in area C were higher than those encountered when mining the barrier to the right side of the junction (area A). As a result, management employed the thin pillar mining technique to minimize the potential for coal bumps. The higher roof stresses may have been related to the thickness of the Eckman sandstone, which increases in the direction of the Bailey section (fig. *5B*). The instrumentation in this area consisted of two BPF cells installed at 15 and 20 ft depth into the barrier pillar along the centerline of three projected 25 ft wide thin pillars (fig. 17). Convergence stations were also installed along the entry from which the thin pillars were to be driven.

The purpose of the instrumentation in the Bailey section was to investigate the thin pillar mining method. In particular, the intent was to document how and why this method works as a coal bump control technique. The mining in this area began with developing pillars in the most inby southwestern barrier pillar and proceeded toward the instrumented area, alternatively developing and retreating pillars as discussed earlier in describing the thin pillar method. From mid-June 1991 until August 1991, retreat mining progressed toward the instrumented area. By late August, the thin pillars in the immediate area of the instruments had been created and their pillaring begun. Figure 18 shows three stages of the mining as it approached the instrumented thin pillars.

The pressure change plots of BPF readings of the two cells installed along the projected centerlines of thin pillars 1 and 3 are shown on figures 19*A* and 19*B*. The BPF's in thin pillar 2 were erratic in their performance. The 15 ft BPF was unresponsive until mining approached very close, and the 20 ft BPF had a negative reading soon after installation and continued to read negatively until mining approached this pillar. Therefore, the magnitudes of the readings in thin pillar 2 are questionable and not reported in this figure. However, the basic trends follow the same pattern as those in thin pillars 1 and 3, and they are shown on the following figure for completeness.

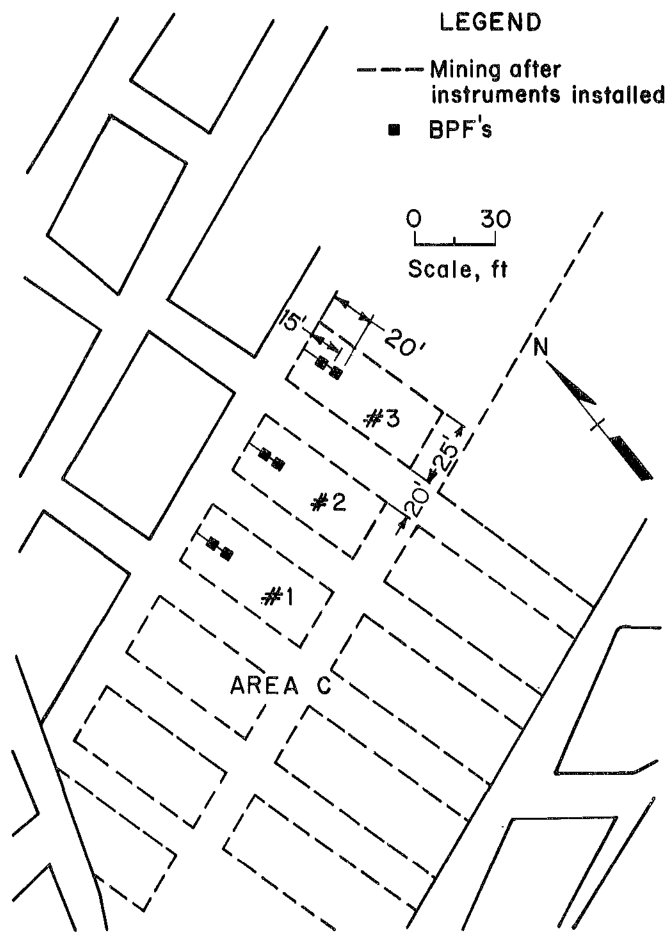

Figure 17.—Area C mining and instrumentation.

The cells in pillar 1 (fig. 19*A*) increased slowly as the development and pillar line approached and then began rising rapidly when the pillar line and thin pillar creation were within 200 ft of the instruments. By August 14, 1991, these cells reached their maximum stress change of 4,551 psi for the 15 ft BPF and 5,567 psi for the 20 ft BPF. The mining as of August 14, 1991 is shown on figure 19*B*. However, as mining came even closer to pillar 1, the BPF's readings dropped quickly to or near the original stresses as shown by the August 20, 1991 readings. It is believed that this is due to the coal yielding in pillar 1.

Meanwhile, the BPF's in pillar 3 (fig. 19*B*) were following the same trend as pillar 1, although not attaining the same magnitudes since they were further from the gob line and the thin pillar development. When the cells in

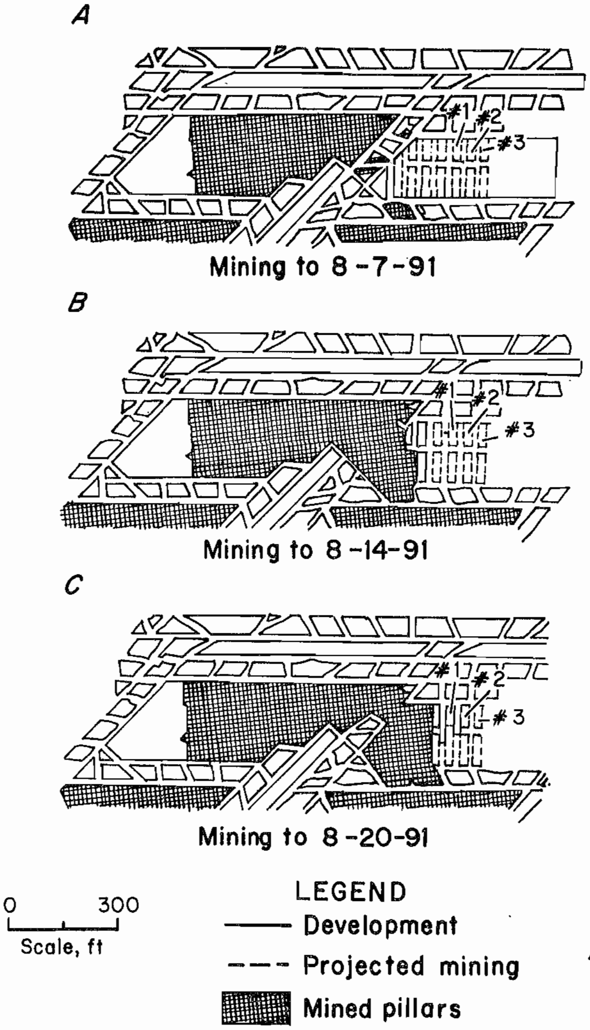

Figure 18.—Mining sequence in area C.

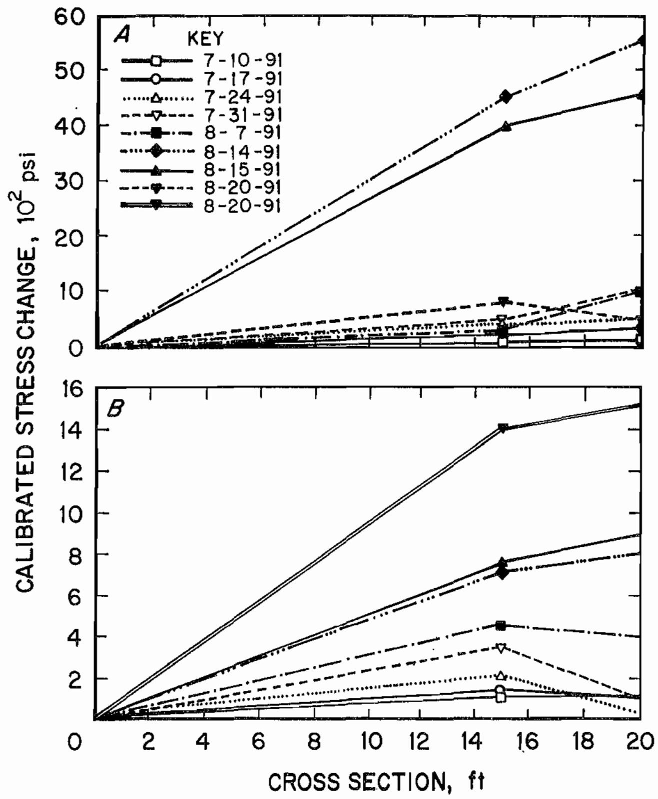

Figure 19.—Calibrated stress change of area C pillars. *A*, Pillar 1 BPF's at 15 and 20 ft; *B*, pillar 3 BPF's at 15 and 20 ft.

pillar 1 reached their maximum and began to drop on August 14, 1991, the pillar line was slightly more than 100 ft away from pillar 1 and the mining to develop the inby side of pillar 1 had begun (see figure 18). As the development of pillar 1 progressed, alternating with periodic inby pillaring, the cells in pillar 1 continued to drop. By August 20, 1991, pillar 1 (fig. 18) was fully outlined and the BPF cells had almost returned to the original installation pressures. At this time, the pillar line was 60 ft away from pillar 1 and the cells in thin pillars 2 and 3 were still rising from the transferred loads.

This process of rapid stress increase and then decline due to the yielding of the coal is best demonstrated as a function of the approaching pillar line as shown on figure 20. This figure shows the stress change of the 15 ft (fig. 20*A*) and the 20 ft (fig. 20*B*) BPF's of all three thin pillars versus distance to the pillar line. The negative numbers indicate the distance to the approaching pillar line. Unfortunately, the BPF's in thin pillars 2 and 3 failed prior to recording the entire cycle. However, ample data were given by the functioning cells in thin pillar 1 to demonstrate the high stress increases and then the decline in stress due to the coal yielding from the loading. The coal yielding is due to the dimensions of the thin pillar and the high loads imposed on this area. This high loading is the result of: (1) development stresses of the original mains; (2) the load from the adjacent old gob; and (3) the stresses from the new gob line and from thin pillar creation. Figure 20 also shows the progression of the process of increasing load, yielding, and load transfer to the remaining outby chain and barrier pillars. The instruments in area C documented the thin pillar mechanics, including, the high stresses from the approaching pillar line, the yielding of the thin pillars as they were being created, and the resulting redistribution of the abutment loads. Indications were that the yield zone in this instance was about 100 ft ahead of the pillar line. Mining can then be conducted within this destressed zone and the possibility for coal bumps is minimized.

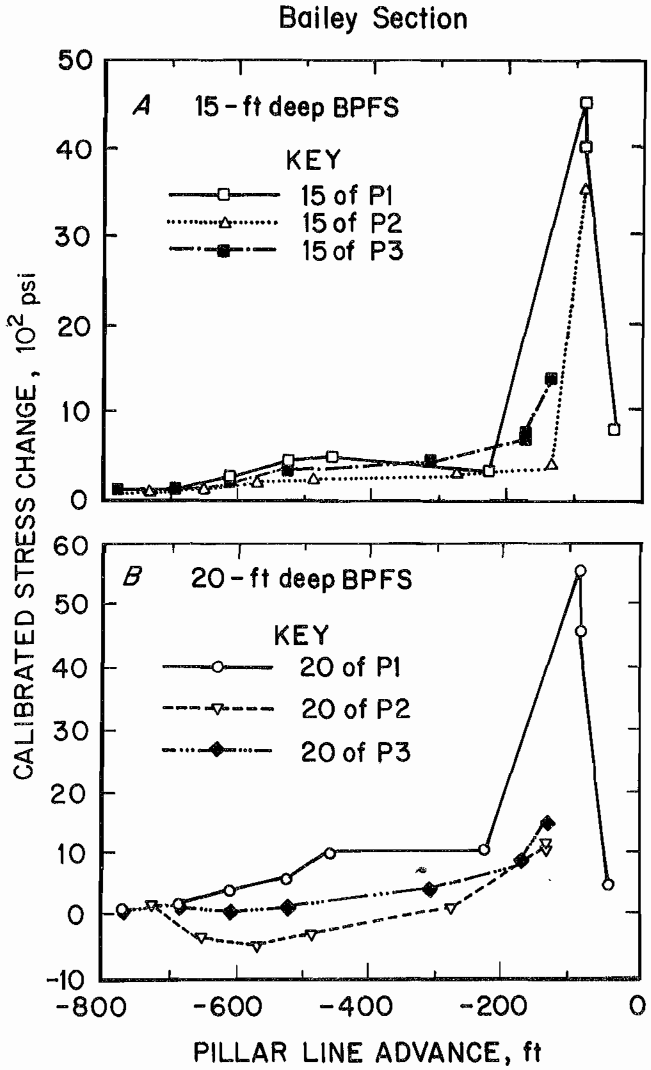

Figure 20.—Calibrated stress change of area C pillars versus pillar line advance. *A*, Bailey section 15 ft deep BPF's; *B*, Bailey section 20 ft deep BPF's.

SUMMARY AND CONCLUSIONS

In ongoing efforts to develop design criteria and approaches to reduce or eliminate the hazard of coal bumps, the USBM studied pillar and strata behavior in a known bump-prone environment and a bump mitigation technique, thin pillar mining. Instrumentation recorded stress histories of coal pillars, as these, and nearby pillars were developed and of coal pillars impacted by nearby and encroaching pillaring. The pillar information was not unlike other pillar data and reconfirms earlier work on pillar behavior during retreat mining.

When higher stresses are encountered, management employs the thin pillar mining technique to minimize the potential for coal pillar bumps. The combination of high abutment stresses encountered near to the gob line and the technique's method of developing thin yielding pillars near the gob line, create a "buffer" zone along the pillar line where the coal has yielded and redistributed its loading to the outby pillars. The progression of this yield zone toward the outby areas is controlled by the systematic development of the thin "yielding" pillars. The yielding and stress redistribution permits the dissipation of the stresses in the pillars and the potential for coal bumps is minimized or eliminated.

Observation and instrumentation results revealed that the pillar perimeter yield zone, under these conditions, were 7 to 10 ft. In addition, readings indicated: (1) that the yield zone could even be greater depending on loading and age; (2) that the yield zone could form quickly under development load; and (3) that perimeter yielding increases pillar core load. BPF readings also implied that high loading was experienced by pillars at some distance (300-400 ft) from mining activities in this bump-prone strata, although pillar age and previous load history also may have influenced these readings. Data from roof-to-floor convergence stations, when installed in sufficient numbers over a large area, generally confirmed stress readings and were reliable indicators of pillar response to high abutment stresses.

Since this study, areas A, B, and C have been combined into one continuous pillar line as the mine continues to retreat the original workings. To counteract the inclination for bumps, the thin pillar method is used to develop barrier pillars and other unmined coal blocks. In addition, the thin pillar concept is utilized where the older pillars are being retreated. The older pillars are split to form "thin pillar fenders" in a systematic method very similar to utilizing the thin pillar method in undeveloped areas. These "fenders" yield, and thereby, maintain a destressed or softened area near the pillar line, while the gob load is transferred inby and outby. As a result, mining within the destressed area mitigates the potential for coal bumps.

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