Bulletin 535
BUREAU OF MINES

COAL-MINE BUMPS:

SOME ASPECTS OF OCCURRENCE, CAUSE AND CONTROL

By Charles T. Holland and Edward Thomas

UNITED STATES GOVERNMENT PRINTING OFFICE • WASHINGTON : 1954

UNITED STATES DEPARTMENT OF THE INTERIOR
Douglas McKay, Secretary

BUREAU OF MINES
J. J. Forbes, Director

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Washington 25, D. C. - - - Price 35 cents

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COAL-MINE BUMPS:

SOME ASPECTS OF OCCURRENCE, CAUSE, AND CONTROL[1]

By

Charles T. Holland[2] and Edward Thomas[3]

Summary

ANALYSIS of 117 occurrences of bumps in coal mines shows that 67.6 percent are associated with pillar-line points.[4] Slabbing and splitting pillars, development, and other unfavorable mining practices in abutment areas may be a contributory or the primary cause of bumps.

The cure for pillar-line bumps is to recognize areas that can be expected to become highly stressed and to project the mining plan and operations to eliminate such areas insofar as possible. If such areas cannot be eliminated, then the mining plan and operations should be projected to avoid the necessity of disturbing these areas before the stresses have been dissipated.

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[3] Chief, Roof Control Section, Health and Safety Division, Bureau of Mines, Washington, D. C.
[4] The word "point" is used in a geographical sense.

INTRODUCTION

The problem of bumps in coal mines is one that has attracted the interest of mining engineers for many years. Several comprehensive papers and reports on the subject have appeared in English and American mining literature (*1, 2, 3, 4, 5, 6, 7*).[5] Serious accidents involving loss of life and extensive damage to mining properties, however, have continued to occur.

The purpose of this report is to analyze the coal-mine bumps that have occurred on pillar lines during the past 25 years in the hope that the analyses and the conclusions drawn will aid mining engineers and other mine officials in improving mine layouts and face mining methods in mines where bumps reasonably may be expected to occur.

The attempt is made to rationalize the causes of bumps with the published material on stress analysis as applied to mining; however, the bulk (and probably the more valuable material) is based on the personal observations of the authors in underground investigations of actual occurrences.

Bump occurrences that are not associated with the extraction of pillars are not mentioned because information on stresses of tectonic origin is lacking and such occurrences, as indicated by the information assembled, are comparatively rare in the United States (less than 1 percent of the total).

[5] Italicized numbers in parentheses refer to items in the bibliography at the end of this report. Page references represent those in the citation and not in this bulletin.

ACKNOWLEDGMENTS

The cooperation of the several mining companies and their engineers who have furnished material for this report is gratefully acknowledged. Acknowledgment is also made to L. A. Panek, mining engineer, Bureau of Mines, College Park, Md., for his helpful criticism of the manuscript and to James L. Gilley, mining engineer, Bureau of Mines, Welch, W. Va., for assistance in assembling part of the data analyzed.

DEFINITION OF BUMP

Coal and adjoining rock when subjected to a gradually increasing load, such as imposed by an approaching pillar line, usually adjust gradually by slow failure of the pillar or by slow flow of the bottom and/or top shales. Occasionally, however, the failure is sudden and explosivelike; a mass of coal may be expelled violently from the pillar, or the whole pillar may crush. In some areas the floor may heave suddenly. The failure is usually accompanied by a very loud report, and tremors or vibrations are set up in the earth and in the mine atmosphere that can be detected some distance away. A failure of this kind may affect only a single pillar, part of a pillar, or several pillars, with varying degrees of violence. Such failures usually occur in the vicinity of a pillar line in room-and-pillar work, at or near the wall face in retreating longwall work, or at the wall face in advancing longwall mining. Many names have been applied to these occurrences, such as bump, bounce, crump, mountain shot, pillar burst, pressure burst, rock burst, pounce, quake, and several others. Inasmuch as "bump" is the designation most commonly used not only in the United States but also in many foreign countries, this term is used to describe such phenomena in this report.

NATURAL CONDITIONS FAVORING BUMPS IN COAL MINES

Bumps in coal mines have occurred under a rather definite set of natural conditions. These are:

1. The cover over the bed is approximately 500 feet or more thick.
2. A strong, overlying stratum, usually a massive sandstone or a conglomerate, occurs immediately above or close to the coal bed.
3. The floor is strong and does not heave readily.
4. The thickness and physical and chemical characteristics of the coal bed apparently are not critical factors, as rock bursts have occurred in coal beds as thin as 34 inches and as thick as 23 feet and as weak as the Pocahontas No. 4 (crushing strength, 2,140 p. s. i. in a 3-inch cube) and as strong as the Island Creek (crushing strength, 4,700 p. s. i. in a 3-inch cube) (*8*).
5. Faults have been observed in several areas where bumps have occurred in coal beds. However, their complete absence in other areas where such phenomena have occurred demonstrates that faults do not necessarily contribute to bumps.
6. Bumps in coal mines have been recorded as occurring in beds dipping as much as 35° (*9*). In the United States the greater number of bursts have occurred in beds dipping less than 10 to 12 percent, probably because most of the coal is produced from such beds.

HAZARDS CAUSED BY BUMPS

The hazards to mine personnel resulting from bumps depend upon the extensiveness and violence of the failure. A study of accidents from this source indicates that injuries may be caused as follows: (1) Men may be struck by flying coal and rock from the burst; hurt by the force and shock of the explosion; or injured by being thrown against posts, cars, cribs, and mining machinery. Careful studies of accidents in southern West Virginia indicate that somewhat less than half of the fatal injuries from bumps occur in this manner (*10*). (2) Men may be injured by loose material shaken from the roof or by dislodgment of posts, allowing broken top to fall. Again, studies of these accidents in southern West Virginia indicate that about half of the fatal injuries from bumps were thus caused (*10*). (3) Men may be suffocated by being buried in the broken material produced or by the gas released from the broken coal. (4) A rock burst that liberates flammable gas may result in a gas explosion. Records indicate that twice in eastern Kentucky (*11*), once in southwest Virginia, and once in southern West Virginia gas has been ignited immediately after a bump in a coal mine. (5) A burst usually produces a dust cloud dense enough to cause a dust explosion if a source of ignition is present. In Utah a dust explosion following a bump took seven lives (*12*).

To prevent injury from occurrences such as these, several precautions may be taken in mines subject to bumps: (1) Adequate ventilation may be provided to dilute and remove any combustible gas liberated. In this connection it should be noted that considerable gas may be produced almost instantaneously and that any ventilating system is likely to be temporarily overloaded by the gas produced.[6] (2) Adequate rock dust may be distributed at the face to render incombustible the dust cloud produced. However, much of the coal dust produced will be generated by the bump itself, and therefore the proportion of incombustibles normally maintained in the mine dust would have to be considerably higher than usually required. (3) Immediately after a bump all sources of ignition for explosions should be eliminated. This requirement dictates that electric power should be switched off the area until a careful inspection indicates that it can be safely restored. (4) More care should be exercised in setting timber so that it will not be so easily displaced by the shock and concussion of a bump. (5) More than ordinary attention should be given to taking down or securing loose rock to prevent rock falls. (6) Precautions should be taken to prevent the bump itself. After the bump occurs the causes of accidents listed are likely, in one or more aspects, to be uncontrollable.

CAUSES OF BUMPS

Fundamentally, a bump is the failure of material from overstress. Several factors contribute to the overstress and control the reactions of the coal pillar and roof and floor rock. Among these are: (1) Manner in which the overstress is produced, (2) strength of the coal and rock being stressed, (3) immediate source of the energy that causes the particles produced to be thrown violently from the failing mass, and (4) method of mining. A detailed discussion of each of these follows.

PILLAR-LOADING CONDITIONS IN COAL MINES

When a passageway is driven in a coal bed the vertical load formerly carried by the material removed must be borne by the pillars on the sides of the opening. The action is illustrated in figure 1. Therefore, there is an area along every passageway outby the pillar line in which the load on the pillars is increased. Moreover, this loaded area extends about the circumference of pillars adjacent to old goaves. A similar area of increased load surrounds the pillars adjacent to an active pillar line, which may be considerably larger than the area around pillars adjacent to old goaves. This area of increased load around areas that have been mined out or partly mined out is usually referred to as the abutment area.

[6] In 1908 a bump at Crow's Nest Pass is estimated to have liberated 3,000,000 cubic feet of gas (*13*).

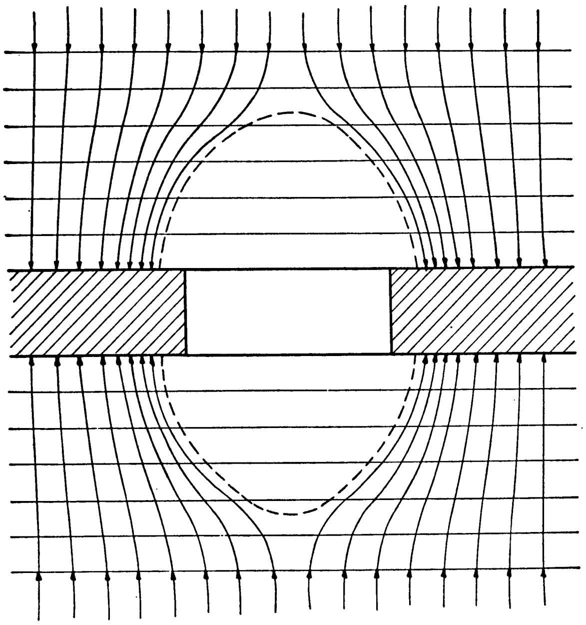


FIGURE 1.—Load Over Passageway Transferred to Supporting Pillars. (Bending, shearing, and horizontal compressive stresses omitted.)

Inasmuch as bumps primarily indicate excessive pressures in coal beds, some information as to the extent of the abutment area is desirable. Table 1 gives this information for an extensive goaf. The data in this table show the distance ahead of pillar lines and longwall faces at which the roof and floor begin to converge. Convergence, however, is caused primarily by an increase in pressure. Therefore, the distance ahead of an extraction line at which the roof and floor began to converge indicates roughly the location at which pressure on the pillar begins to increase. In addition to depth of cover, factors that affect the distance ahead of a pillar line at which the pressure increases probably include the following: (1) Physical characteristics of the coal bed, (2) characteristics of the immediate roof and floor, (3) kind and thickness of the beds composing the overburden, and (4) dimensions of the pillars at or near the pillar line. For similar conditions the distance ahead of the face at which convergence begins in advancing longwall usually is much less than in retreating longwall or in room-and-pillar mining. Considering the data in table 1, the abutment area adjacent to active pillar lines, where the pillars are 60 to 90 feet in least lateral dimensions, can reasonably be expected to be at least 200 to 300 feet wide when the cover is 800 to 2,000 feet deep. The abutment area adjacent to an old goaf may not be so wide because of the readjustments that normally occur with time. The action is illustrated in figures 2 and 3. In a given mine, however, the abutment width is best determined by observation. The actual width of the abutment area may exceed considerably the figures given here.

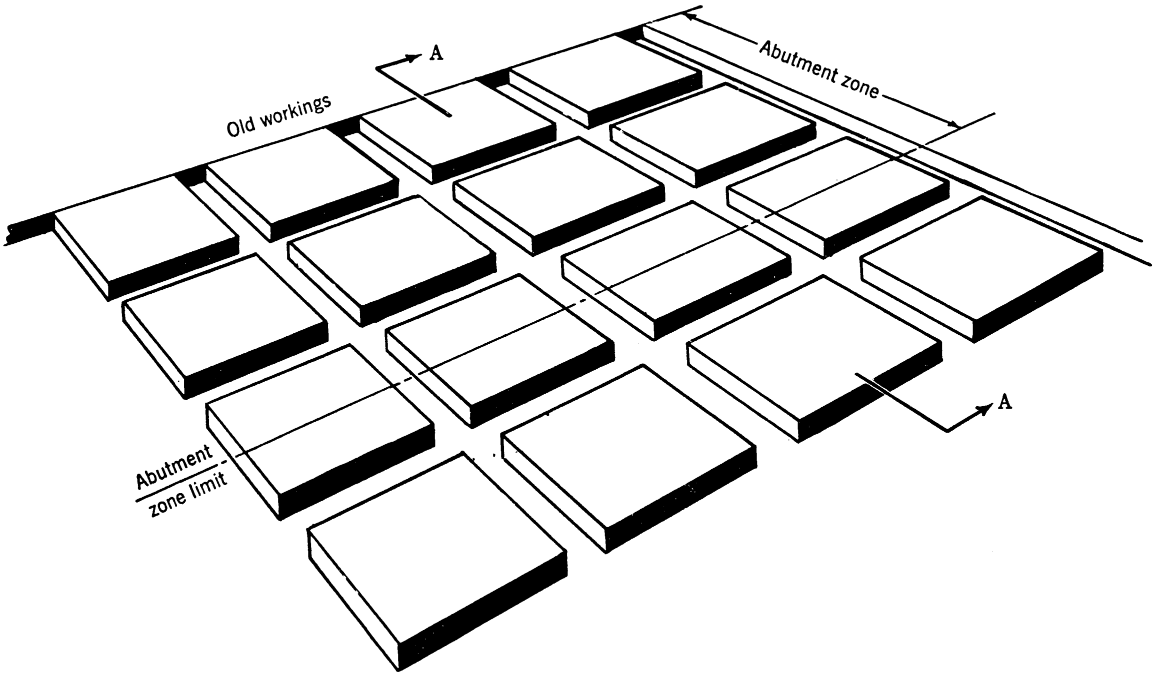
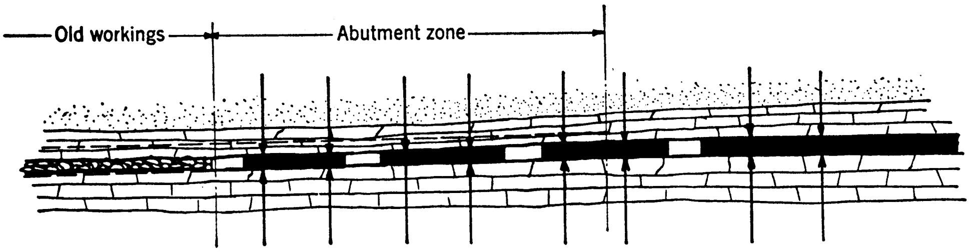


FIGURE 2.—Abutment Zone Paralleling a Mined-Out Area.



SECTION A-A

FIGURE 3.—Load Transferred to Pillars in Abutment Zone. (Sec. *A–A*, fig. 2.)

TABLE 1.—*Distance from face at which convergence caused by coal extraction begins*

Seam	Nature and thickness of immediate roof	Nature of floor	Depth of cover, feet	Bed thickness, feet	Mining method	Distance from face when convergence begins to increase, feet	Nature and thickness of main roof within 50 or 60 feet of coal bed
Pittsburgh [1]	Weak shales.	Soft	290–350	5½	Room-and-pillar	40–140	Sandstone and sandy shale, 49 feet.
Do.[2]	do	do	307–401	6	do	100–170	Principally shales.
Do.[3]	do	do	350	7	do	100–120	Sandstone, 35–65 feet.
Do.[4]	do	do	112–200	7	do	70–205	Soft shale, 32 feet; weak limestone, 34 feet.
No. 2 [5]	Hard shales, 14 to 30 feet.	Hard	2, 800	9	Retreating longwall.	200–450	Arenaceous shale, 14–30 feet; sandstone, 20–68 feet.
Parkgate [6]	Weak clod and coal, 2 to 3½ feet.	do	2, 700	4½	Advancing longwall.	118–152	Sandstone, 44 feet.
Do. [7]	Hard and soft.	Hard and soft.	300–2, 200	4½–6	Longwall and bord-and-pillar.	At least 150.	Sandstone, 30–50 yards.
Harlan [8]	Hard	Hard	1, 200–2, 000	4	Retreating longwall.	At least 80–100.	Sandstone, 70–90 feet.
No. 3 [9]					Longwall	Up to 70	Massive sandstone, 60 feet.
Name not given.[10]	Sandstone	Strong spavin.	2, 100	5. 8	Modified retreating longwall.	Up to 255	Sandstone.

[1] Greenwald, H. P., Maize, E. R., Hartmann, Irvine, and Rice, G. S., Studies of Roof Movement in Coal Mines. 1. Montour 10 Mine of the Pittsburgh Coal Co.: Bureau of Mines Rept. of Investigations 3355, 1937, 41 pp.

[2] Maize, E. R., Thomas, Edward, and Greenwald, H. P., Studies of Roof Movement in Coal Mines. 3. Gibson Mine of the Hillman Coal & Coke Co.: Bureau of Mines Rept. of Investigations 3506, 1940, 9 pp.

[3] Maize, E. R., and Greenwald, H. P., Studies of Roof Movement in Coal Mines. 2. Crucible Mine of Crucible Fuel Co.: Bureau of Mines Rept. of Investigations 3452, 1939, 19 pp.

[4] Holland, Charles T., Pillar Deformation in a Bituminous Coal Mine: Trans. Am. Inst. Min. and Met. Eng., 1938, vol. 130, p. 333–357.

[5] McCall, T. L., Further Notes on Bumps in No. 2 Mine, Springhill, Nova Scotia: Trans. Am. Inst. Min. and Met. Eng., vol. 108, 1934, pp. 41–70.

[6] Phillips, D. W., and Jones, T. J., Strata Movement Ahead of and Behind Longwall Faces: Trans. Inst. Min. Eng., vol. 101, pp. 348–349.

[7] Brass, J., and others, Fifth Progress Report of the Safe Working in Mines Committee. Method of Working and Roof Support in the Parkgate Seam: Trans. Inst. Min. Eng., vol. 86, 1933–34, pp. 231–263.

[8] Bryson, J. F., Further Developments in Preventing Bumps in Harlan County Coal Mines: Am. Inst. Min. and Met. Eng., Contrib. 107, 1937, pp. 3–4.

[9] Winstanley, A., Longwall Roof Control: Trans. Inst. Min. Eng., vol. 81, 1930–31, p. 384.

[10] Hudspeth, H. M., Ground Movements in Advance of Longwall: Iron and Coal Trades Rev., Jan. 6, 1933, pp. 1-3.

STRESS CONDITIONS IN A COAL-MINE PILLAR

The load transferred to a pillar is determined by the area undermined, the weight of the overburden, and the strength of the rocks composing the overburden. The actual stress distribution in the pillar, however, is determined by the physical properties of the material forming the roof and floor and the pillar itself. Figure 4 shows the probable stress distribution in a coal pillar under the following conditions: (1) The least lateral dimension of the pillar is 4 to 6 times the width of the rather narrow passageways that cut it out. (2) The pillar is surrounded by other pillars that are the same size and are composed of coal having uniform physi-

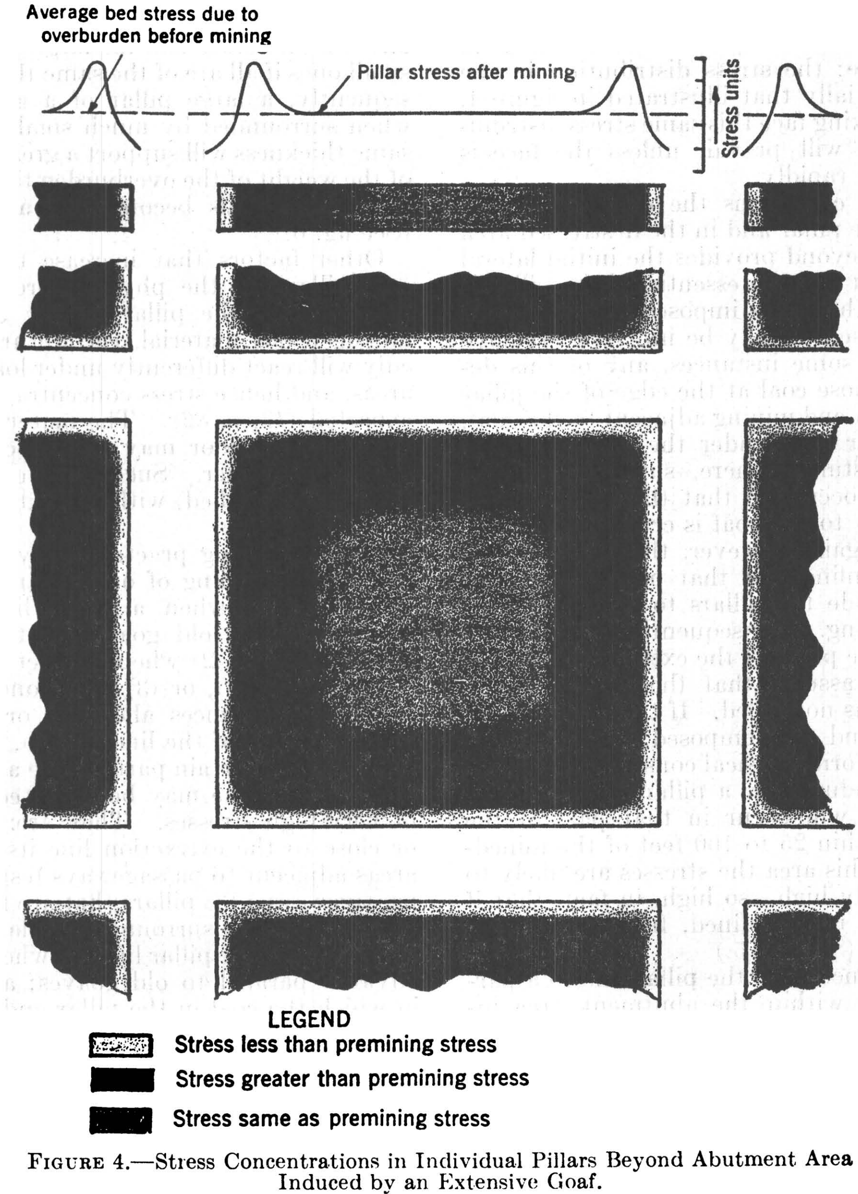


FIGURE 4.—Stress Concentrations in Individual Pillars Beyond Abutment Area Induced by an Extensive Goaf.

cal properties. (3) The pillars are loaded by a thick massive sandstone roof and are supported by a floor that offers great resistance to yielding. The stresses are comparatively low at the edges of the pillar but quickly build up to the maximum a short distance in the pillar. They then gradually drop to a uniform stress, which continues to within a few feet of the opposite side, when the stress conditions described are repeated. For a passageway of given height the intensity of the stress developed and the distance over which the higher stress acts increase with its width (*14, 15, 16*).

Under heavy cover the coal on the ribs at the passageway may fail and form a loose mass resting against the pillars. This loose coal then starts the confining pressure that permits the coal farther in the pillar to resist the load without failure; the stress distribution in the pillar is essentially that illustrated in figure 4. Even at a working face this same stress distribution probably will prevail unless the face is advanced very rapidly.

Under such conditions the crushed coal at the sides of the pillar and in the destressed area immediately beyond provides the initial lateral constraint that may be essential if the pillar is to withstand the stress imposed. If the pillar is highly stressed, it may be unwise to remove much and, in some instances, any of this destressed and loose coal at the edge of the pillar except by open-end mining adjacent to the goaf.

At the pillar line, under the roof and floor conditions postulated here, sufficient convergence usually occurs so that the coal immediately adjacent to the goaf is crushed or partly destressed. Again, however, this crushed coal affords the confinement that permits the coal a few feet inside the pillars to resist the load without crushing. Consequently, a short distance inside the pillar at the extraction line it is reasonable to assume that the coal is highly stressed but has not failed. If the pillars are of uniform size and are composed of coal having essentially uniform physical constants, the maximum stress induced by a pillar line or an old goaf normally will occur in that part of the pillar lying within 25 to 100 feet of the mined-out area. In this area the stresses are likely to be exceptionally high—so high, in fact, that if the coal were not confined, failure probably would occur. (See fig. 5.)

As the distance from the pillar line to a particular locality within the abutment area increases, the stress in that locality normally decreases until at a considerable distance from the pillar line it is the same as that due to the static weight of the overlying rocks. Beyond that point for a short distance the stress in the pillars may become somewhat less than the average to be expected from the weight of the overlying rocks.

Other conditions, though not so generally recognized, can set up high-pressure areas. One condition often encountered in coal mines is that of a large pillar surrounded by a number of smaller ones. It can be demonstrated, for example, that the compression of a pillar under load is a function of the restraint imposed on the pillar, the compression decreasing with increasing restraint. The restraint in turn probably is related to the thickness of the pillar as compared to its width, increasing as the width of the pillar increases (*17, pp. 75–79*). The average amount of compression for a given stress is therefore less for large pillars than for small ones if all are of the same thickness. Consequently, a large pillar of a given thickness when surrounded by much smaller ones of the same thickness will support a greater proportion of the weight of the overburden than the smaller pillars and thus becomes an abutment area. (See fig. 6.)

Other factors that increase the stress in a coal pillar are the physical properties of the coal forming the pillar. Since coal is not a homogeneous material, certain areas undoubtedly will react differently under load than other areas, and hence stress concentrations are to be expected (*17, p. 82*). The material composing the roof and floor may be expected to act in the same manner. Such areas cannot, in general, be identified without extensive testing (*17, pp. 92–93*).

Certain mining practices may act to superimpose the loading of one abutment upon another, as (1) when a pillar line is worked adjacent to an old goaf or between two old goaves (fig. 7), (2) when two active pillar lines converge (fig. 8), or (3) when one section of a pillar line advances ahead of or falls behind the remainder of the line (fig. 9).

Therefore, certain parts of the abutment area near a pillar line may be expected to be areas of very high stresses. They are: (1) Areas at or close to the extraction line itself; (2) pillar areas adjacent to passageways (especially, wide passageways); (3) pillars that are larger (longer and wider) than surrounding pillars; (4) points formed on active pillar lines or where pillar lines advance parallel to old goaves; and (5) areas in which the coal in the pillar and the top and bottom rocks have appreciably different physical properties to the rocks in adjacent areas. Figure 10 shows the pillar-stress conditions to be expected close to the extraction line.

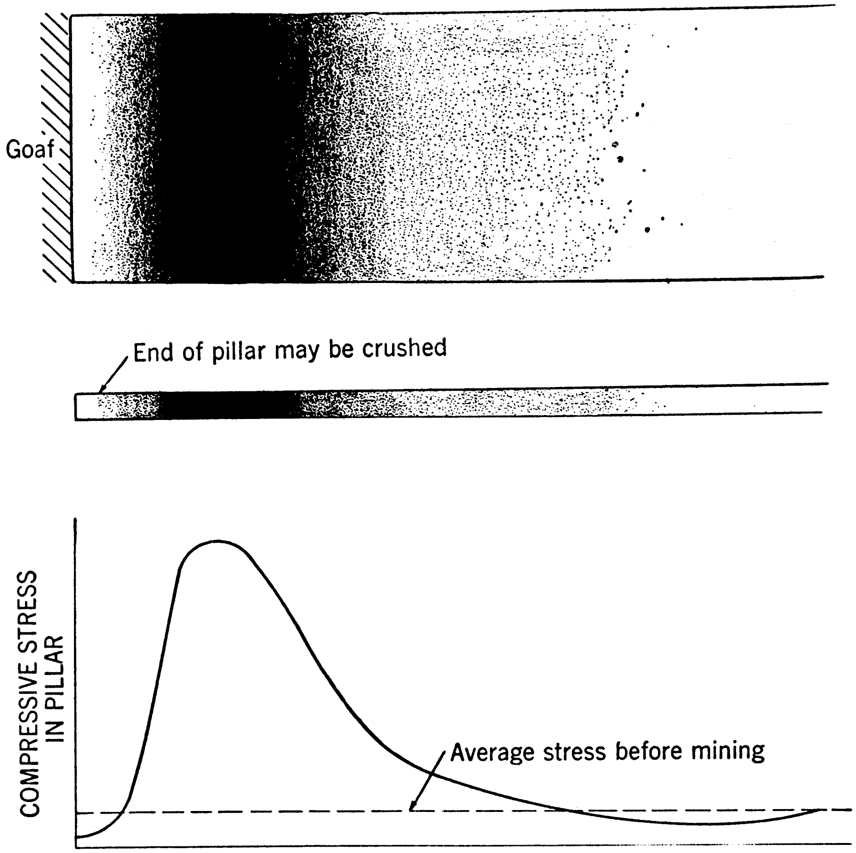


FIGURE 5.—Stress Concentrations in Pillars Paralleling Extensive Mined-Out Areas Under Strong Roof and on Strong Floor.

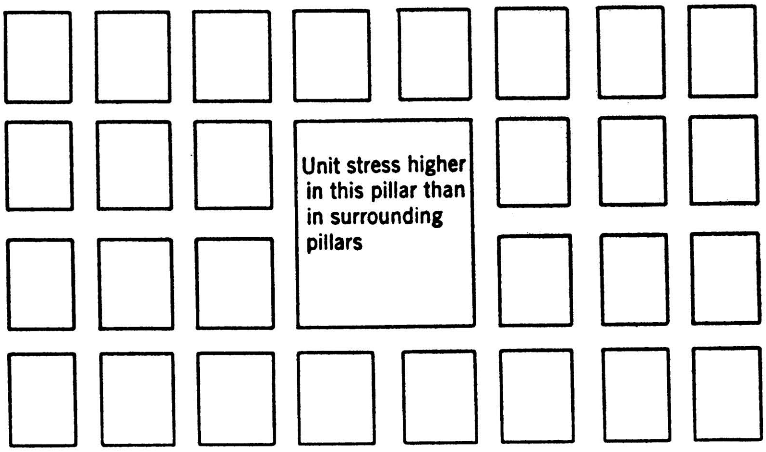


FIGURE 6.—Conditions Under Which a Large Pillar May Be Overloaded When Surrounded by a Number of Smaller Pillars.

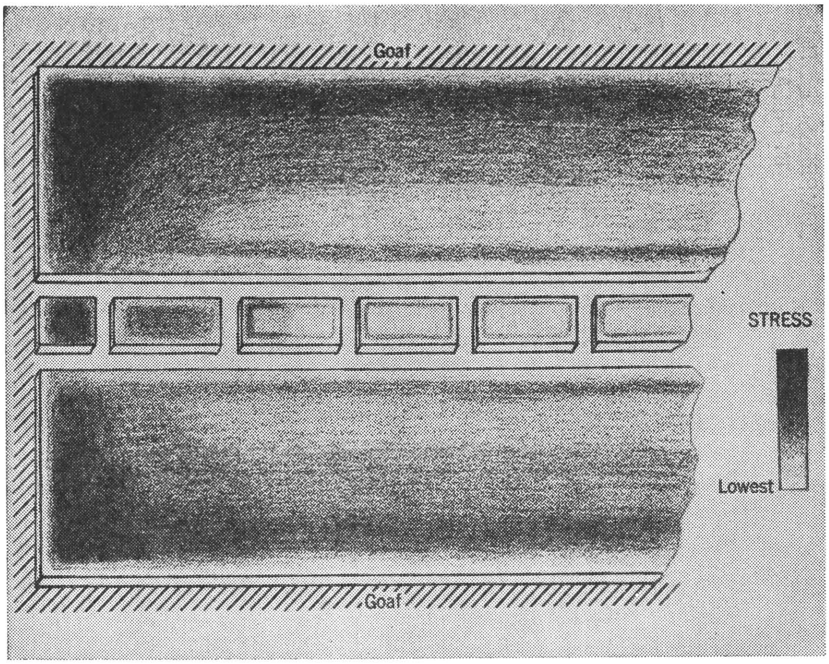


FIGURE 7.—Stress Conditions When an Active Pillar Line Abuts on an Old Goaf or Goaves.

The intensity of stress is indicated by the shading.

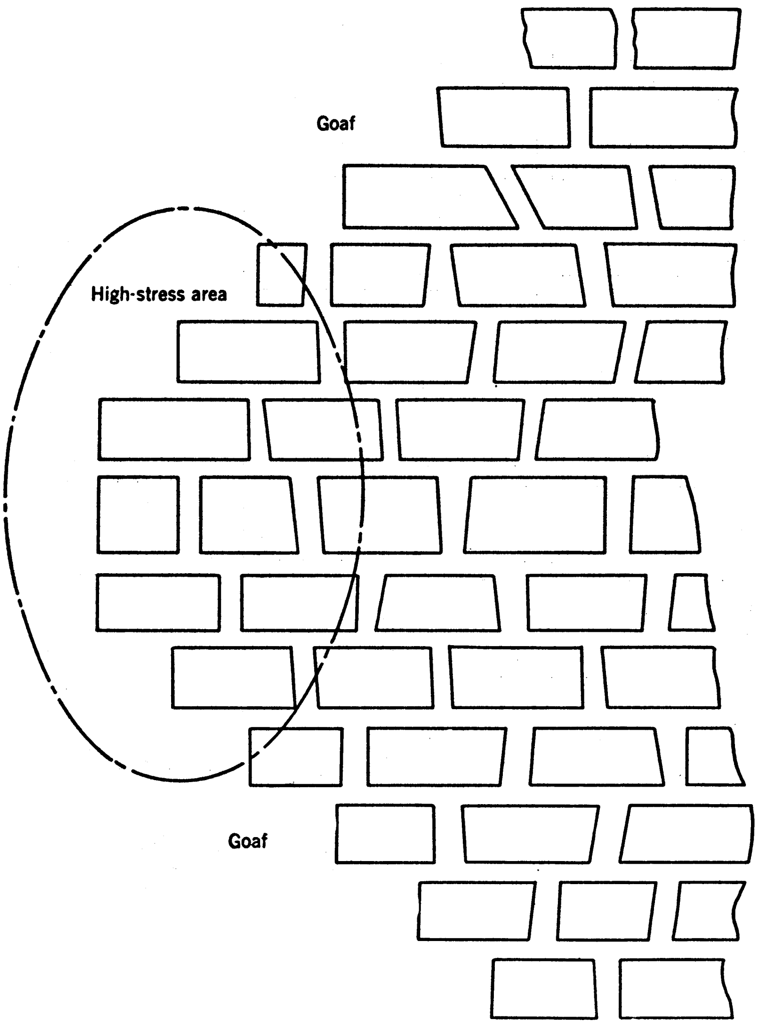


FIGURE 8.—High-Stress Area Caused by Convergence of Two Active Pillar Lines.

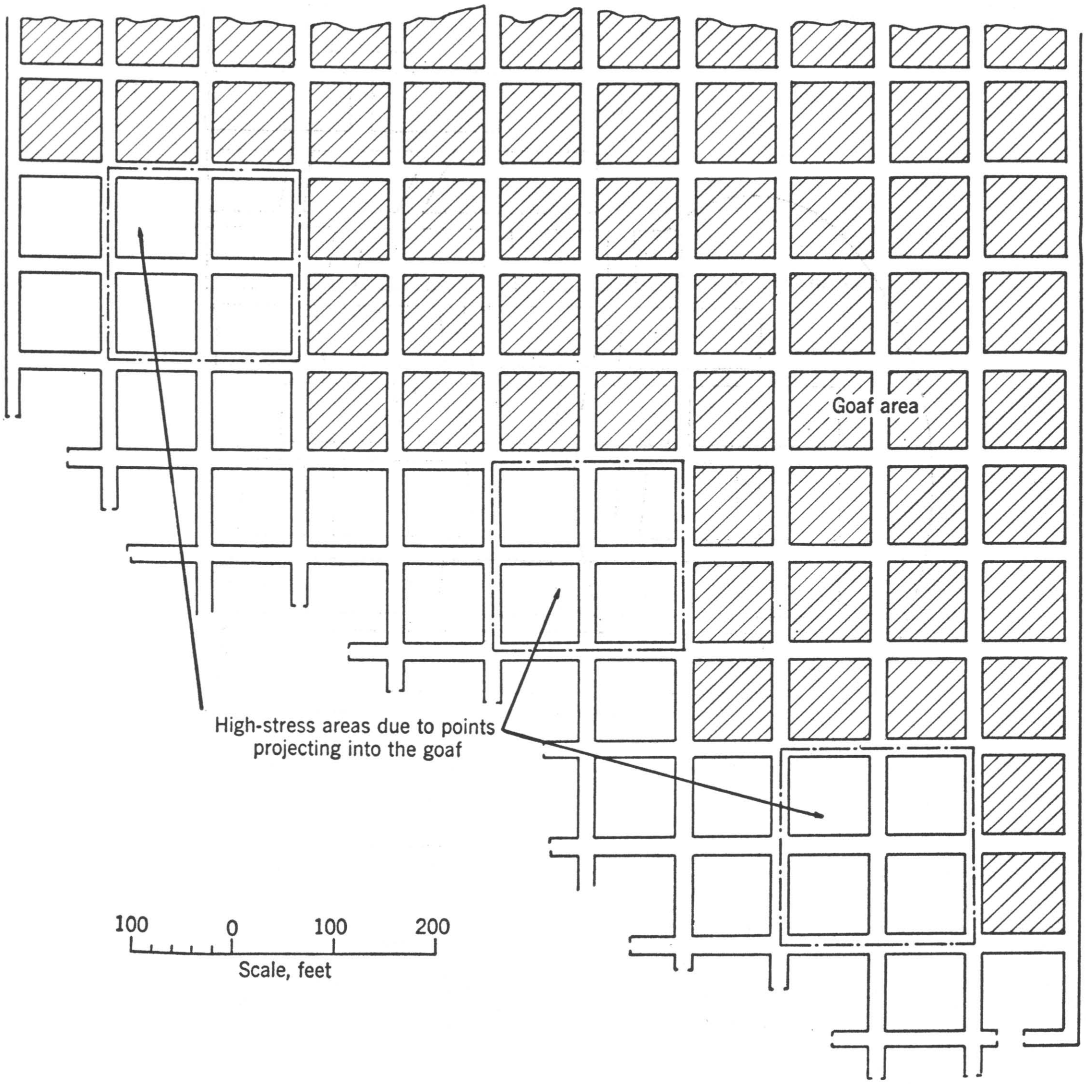


FIGURE 9.—High-Stress Areas Caused by Pillar Lines Being Out of Step.

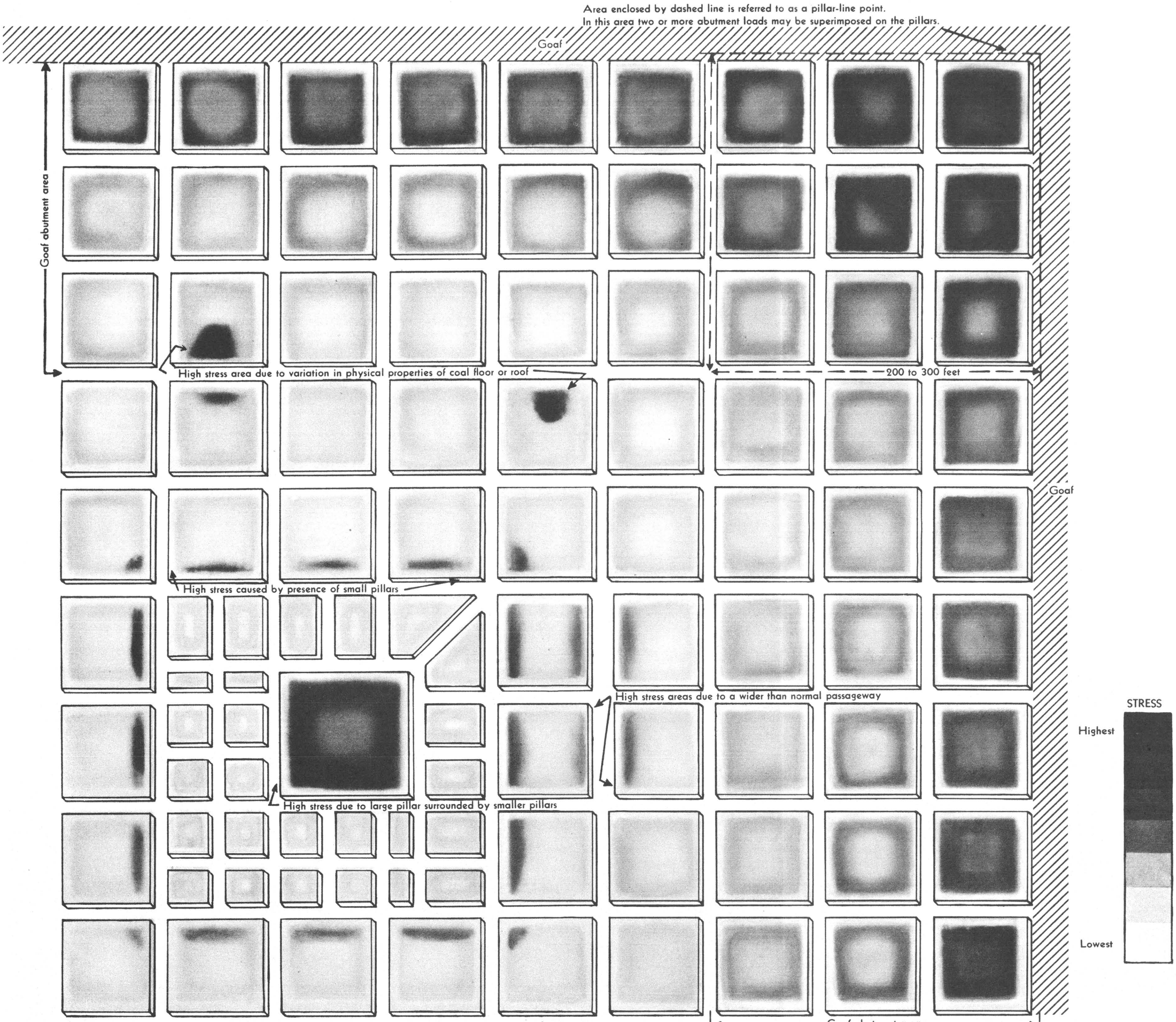


FIGURE 10.—Probable Stress Conditions on a Pillar-Line Point in a Coal Mine. The area enclosed within the dashed line is the point.

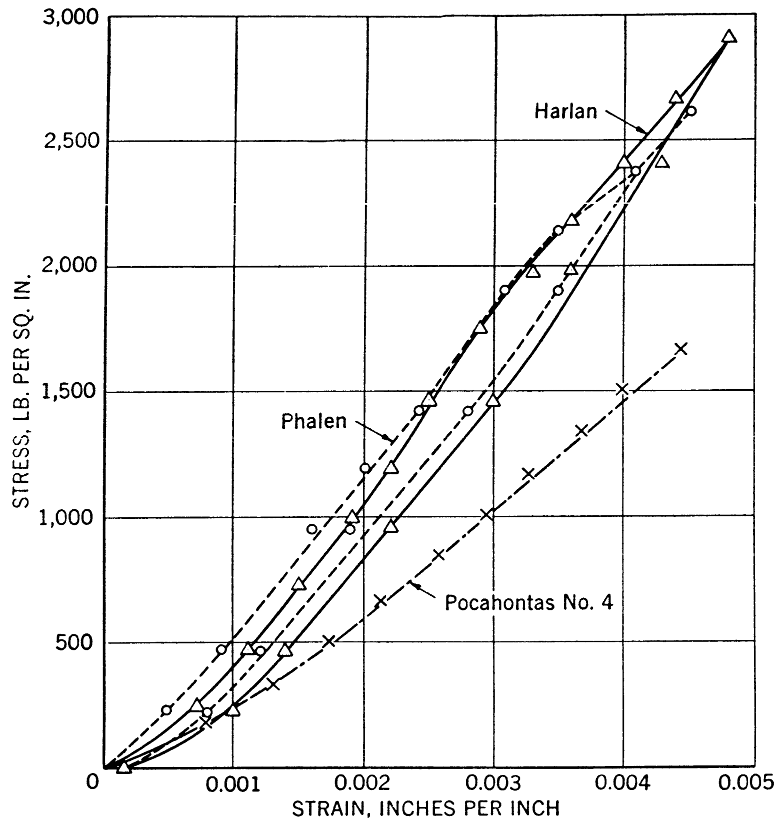


FIGURE 11.—Typical Stress-Strain Curves for Coal.

Very severe bumps have occurred in the Harlan, Phalen, and Pocahontas No. 4 coal beds.

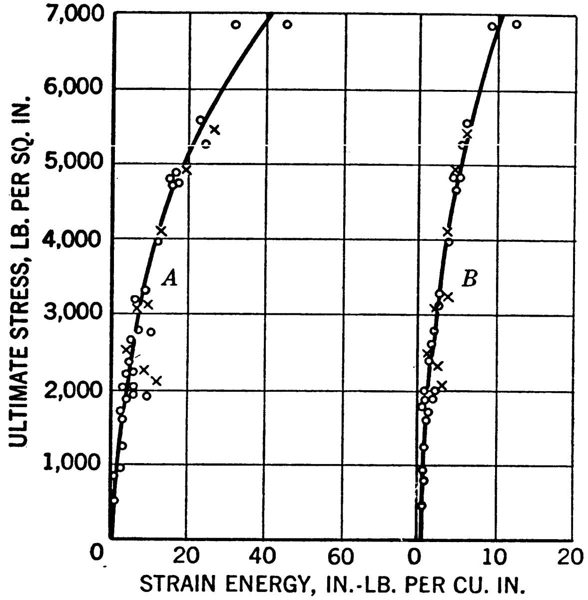


FIGURE 12.—Strain Energy Stored by Coal.

A, Energy estimated to be stored when the coal is stressed to its ultimate strength; *B*, energy stored when the coal is stressed to one-half its ultimate strength; circles represent coals from mines in which bumps have not occurred; crosses represent coals from mines in which bumps have occurred. Each point is the average of determinations made on 2 to 4 specimens when no constraint exists. Strain-energy values for stresses less than 1,000 pounds per square inch were calculated from Greenwald's experiments on small mine pillars.

STRAIN ENERGY AS RELATED TO BUMPS

Coal placed under stress deforms, and the principal deformation is in the direction in which the stress acts. When the stress is released the deformation is reduced considerably. The action is illustrated by the stress-strain curves of figure 11. A material of this kind stores mechanical strain energy when under stress. The amount of energy stored, when the material *is not confined,* depends upon the strength the material develops before failure and upon its elastic modulus. The curves of figure 12 show the probable amount of energy that coal can store at various ultimate strengths (*17, p. 85*). Experiments indicate that much

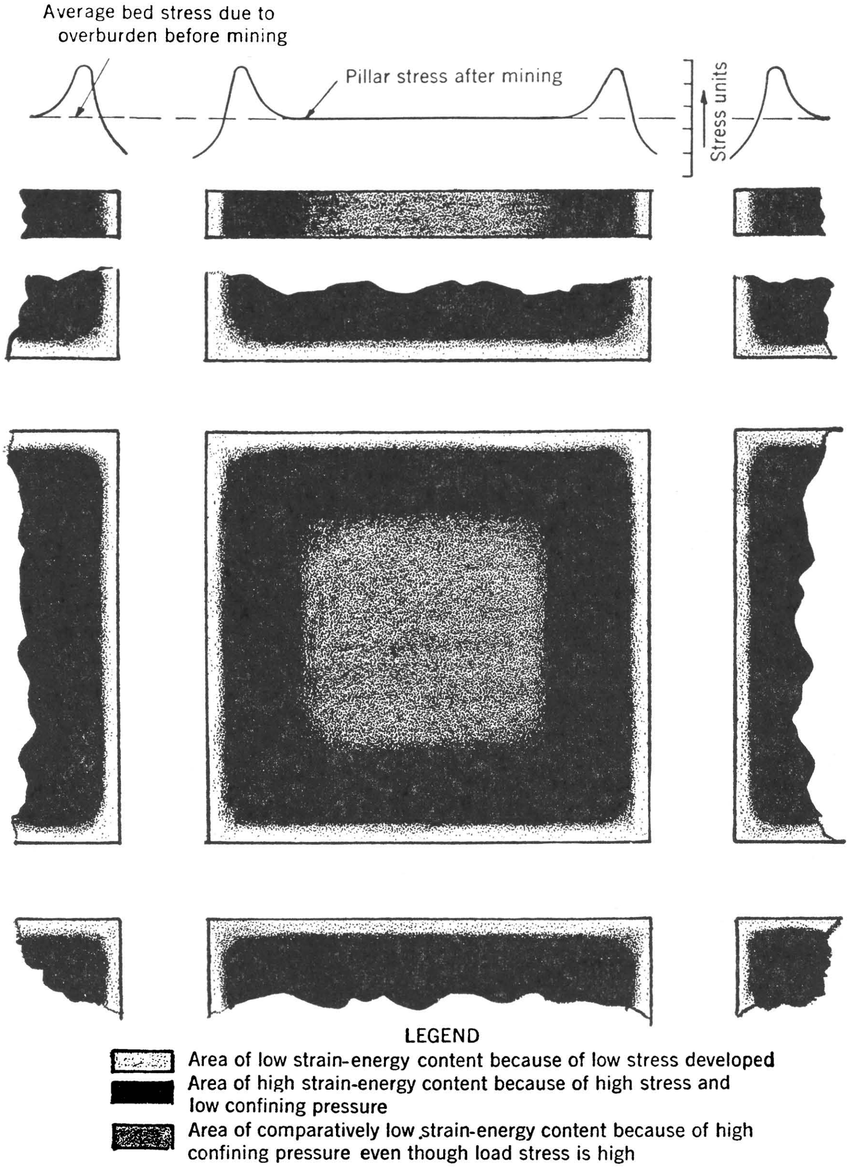


FIGURE 13.—Strain-Energy Conditions in Coal-Mine Pillars That Parallel Narrow Passageways.

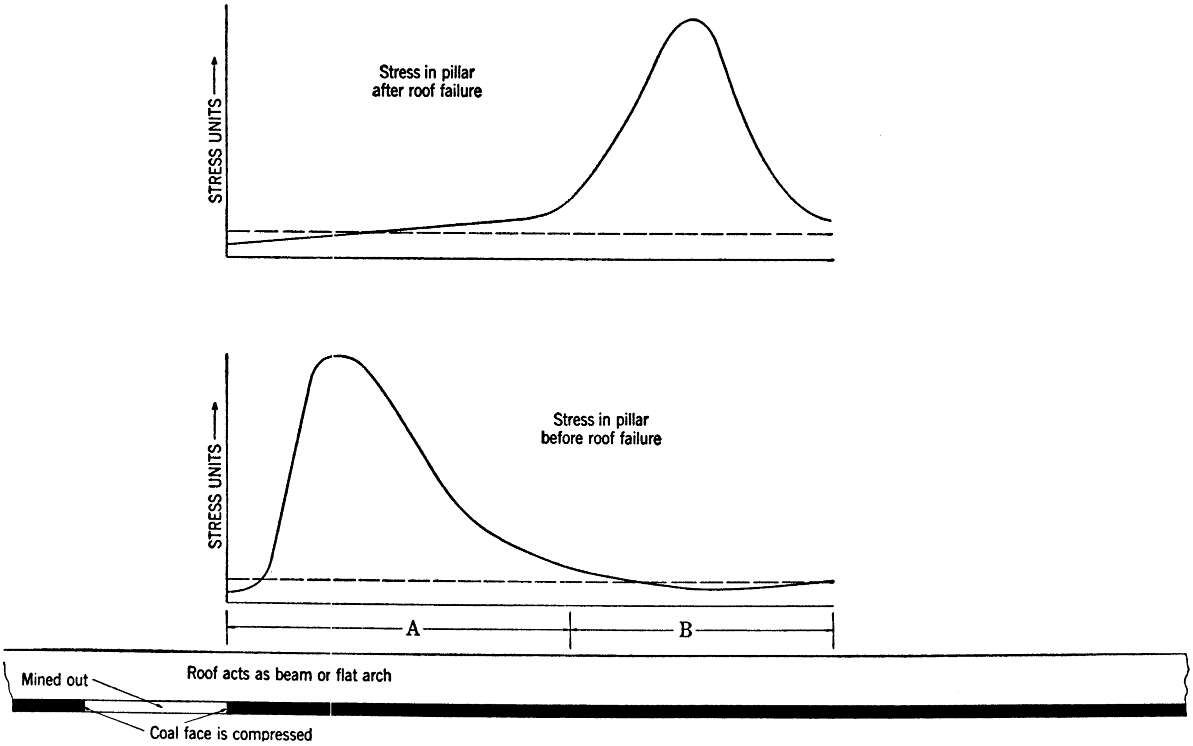


FIGURE 14.—Impact Stresses in Coal Beds Due to Energy Released in Roof and Floor Rocks by Failure of Beam or Flat Arch.

Note that the stress is proportional to the vertical height of the stress-strain diagrams. A shock bump might occur in area *B* at the instant of beam or arch failure. A pressure bump might occur in area *A* before rupture of the beam or arch.

of this energy can be and is released when the coal specimen fails. Other materials such as sandstone and shale can also store energy when stressed, and if stressed to failure they, too, can release the strain energy; but, in general, at the same stress they do not store and release as much energy per unit volume as coal.

Coal in a large pillar, however, is under constraint, so that the amount of energy stored is influenced by properties in addition to its ultimate strength and elastic modulus (*14, p. 61*). As a result of the effect of these factors, coal at the outer edge of the pillar stores comparatively little energy. As the distance in the pillar from its free side increases, however, the amount of energy stored per unit volume increases quite rapidly until the maximum is reached; then, as lateral constraint is developed, it drops rapidly in the inner parts of the pillar. Figure 13 illustrates strain-energy conditions in coal-mine pillars.

As the pillar is mined the area of coal storing large quantities of strain energy tends to move back from the mined area at approximately the same rate as the extraction line advances. There is always the probability, however, that a deep cut may reach the high-energy coal as well as the area highly stressed and produce a violent failure.

The rocks in the roof and floor of the mine, which form beams or plates that span or partly span the mined-out area, can also store strain energy. For a given rock stratum the amount of energy stored depends primarily upon the actual length of the span and whether the stratum spans the mined area as a beam or plate fixed at both ends or as a cantilever beam or plate. For a given type of beam and for a given stratum the amount of energy stored varies as the fifth power of the length of the span, although cantilever beams store about 36 times as much energy as a similar beam fixed at each end if the span length of both beams is the same (*14 pp. 58 and 59*). This energy may be released by failure of the beam or plate or by failure of its abutment and cause bumps some distance from the extraction line. (See fig. 14.) Failure of a flat arch span would produce essentially the same action, but this probably is a rather infrequent cause of bumps. Nevertheless, it is important under heavy cover to avoid long roof spans or, if this is impossible, to take measures to prevent their abrupt failure.

MINING CONDITIONS AND PRACTICES WHERE BUMPS HAVE OCCURRED

In this study 117 bumps, which occurred in coal mines, have been investigated and analyzed. The results of this investigation and analysis are given in tables 2 and 3.

As may be noted, all of these bumps occurred during pillar-recovery operations or adjacent to an area where pillars were being or had been extracted. Moreover, 67.6 percent occurred on points formed by the intersection of pillar lines or where an old goaf joined an active pillar line. Figures 15 to 22 illustrate bumps on pillar-line points. A pillar-line point is that area lying within 200 to 300 feet of converging pillar lines. (See fig. 10.) In such an area the coal pillars are subjected to the load caused by two or more abutment areas acting together. Under such conditions mine pillars doubtless are subjected to tremendous loads. Of the 117 bumps studied, only 12.1 percent definitely were not associated with pillar-line points, and 5.1 percent probably were not so influenced. Figures 23 to 26 show bumps that did not occur on pillar-line points.

TABLE 2.—*Location of bumps*

	Number	Percent
Pillar-line point	79	67.6
Probably pillar-line point	14	12.0
Probably not pillar-line point	6	5.1
Definitely not pillar-line point	15	12.8
Insufficient information to classify	3	2.5
Total	117	100.0

The mining operation most frequently associated with a bump was slabbing a pillar toward a goaf. This action is illustrated in figures 17, 27, and 28. All these operations involve driving a working place into or through an abutment area. Other such mining operations are (1) development in an abutment area and (2) splitting a pillar by driving from the outby end. Table 3 shows that 46.2 percent of the bumps investigated occurred while one or more of the operations mentioned, including slabbing a pillar, were in progress. These operations other than pillar slabbing are illustrated in figures 29, 30, and 31.

Pillars usually are slabbed because a roof fall has obstructed the passageway driven in development work. As removal of the fallen rock often is costly, an adjacent pillar is slabbed or split. In an abutment area where high stresses prevail either procedure is hazardous. Of the two practices, slabbing the pillar has generally proved the less hazardous. If driving a slab place is attempted, the place should be kept as narrow as possible—just wide enough to provide the necessary track or conveyor room. Digging in and hammering on the solid coal face and sides should be prohibited. If the face of the slab is cut by machine, the kerf should be started on the loose end of the face. Since bumps often occur while a cut is being made, the machine crew should stay as far away from the machine as possible, operating it at the "nips" if feasible.

Recovery of a pillar by cutting slabs across the back end of it and advancing toward the goaf (fig. 17) should not be attempted. Not only does this practice greatly increase the danger of bursts but also often leaves large pillar remnants that may increase abutment-area pressures.

Open-end operations (figs. 15, 20, and 23) were associated with 19.7 percent of the bumps studied. The proportion of bursts occurring while mining in this manner is considerably larger than would ordinarily be expected. However, a large part of the coal mined where bumps occur is obtained by open-end methods; this fact probably accounts in part at least for this large proportion of bumps in open-end pillar-recovery operations. No definite figures can be assembled to support the belief, yet the incidence of bumps per unit of coal mined appears to be much less in open-end methods than in other mining operations that conduce to bumps. Table 3 shows that 60.8 percent of the bursts that occurred in open-end pillar-extraction operations were in the area defined as a pillar-line point.

The principal advantage of open-end pillar recovery is that mining is done in that part of the pillar which is either crushed or partly destressed (fig. 5). If the lift being taken is so wide that it reaches beyond this region, then the place is being worked in coal that definitely tends to bump. The extent of the destressed or crushed zone depends upon a number of factors, such as physical properties of the coal, physical properties of the roof and floor, thickness of the coal, and possibly others. One important factor in relation to a given coal bed is the width of the

TABLE 3.—*Bumps occurring during various mining operations in coal mines*

Mining operation in progress	Number of bumps	Percent of total	Bumps that occurred on pillar-line points	
			Number	Percent of total (col. 4÷col. 2)
1	2	3	4	5
Open-end pillar extraction	23	19. 7	14	60. 8
Slabbing pillars in abutment areas	31	26. 5	23	74. 2
Developing in abutment areas	14	12. 0	8	57. 0
Splitting pillars in abutment areas	9	7. 7	7	77. 8
Mining pillar; bump not at face	2	1. 7	1	50. 0
Pillar back from extraction line not being mined	11	9. 4	6	54. 5
District bumps	6	5. 1	6	100. 0
Recovering pillars by pillar-and-stall method	5	4. 3	3	60. 0
Recovering pillars surrounded by goaf and small pillars or partly mined pillars	3	2. 5	3	100. 0
Miscellaneous	4	3. 4	2	50. 0
Insufficient information to classify	9	7. 7	6	66. 7
Total	117	100. 0	79	----------

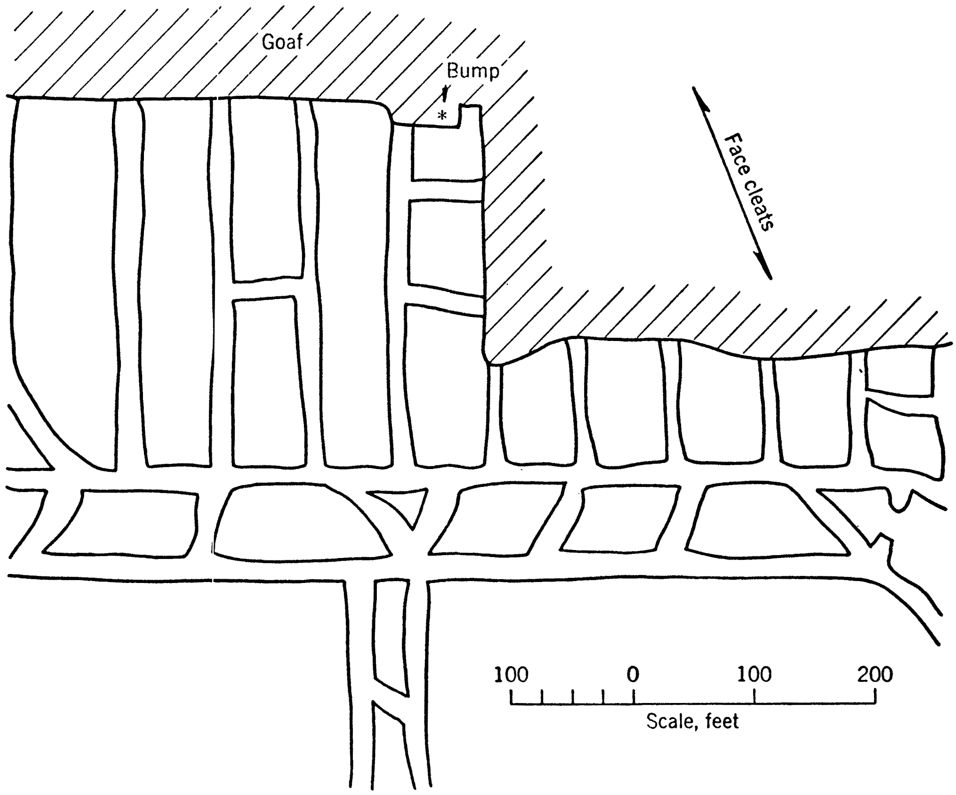


FIGURE 15.—Bump on a Pillar-Line Point Where the Lift Was Being Worked From the Open End.

Cover, 1,550 feet; coal thickness, 58 inches; roof and floor, strong.

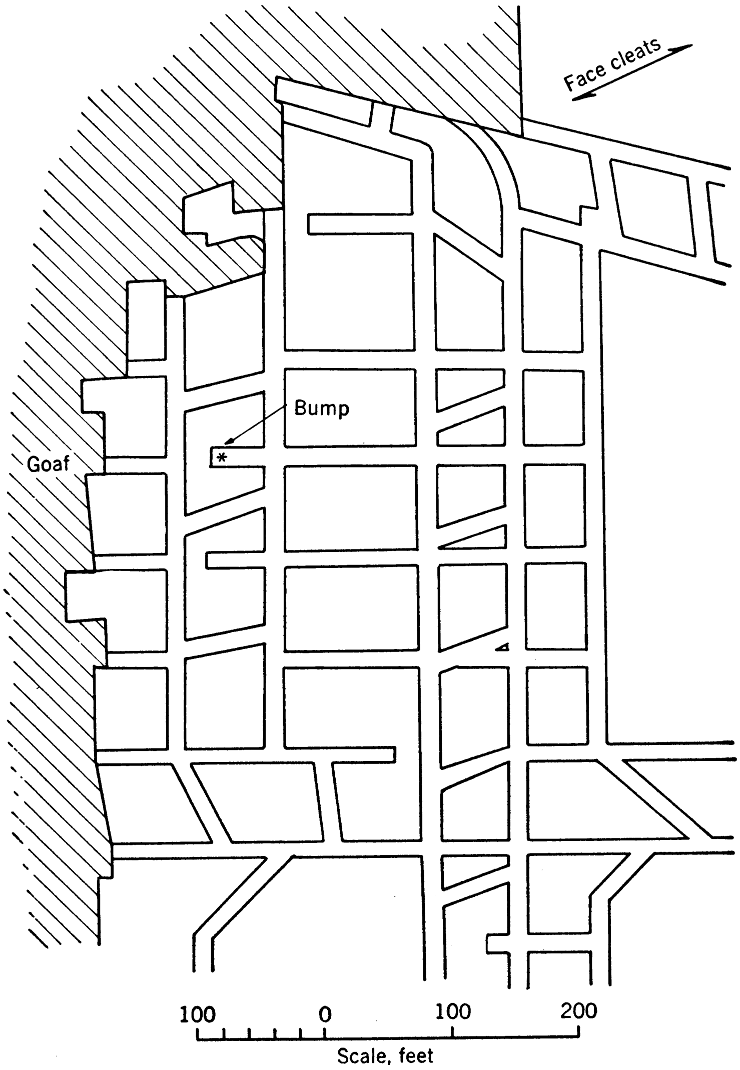


FIGURE 16.—Bump on a Pillar-Line Point Where a Place Was Being Driven Through the Abutment Area Toward the Extraction Line.

Cover, 1,225 feet; coal thickness, 69 inches, with 10 inches of middle slate; roof and floor, strong.

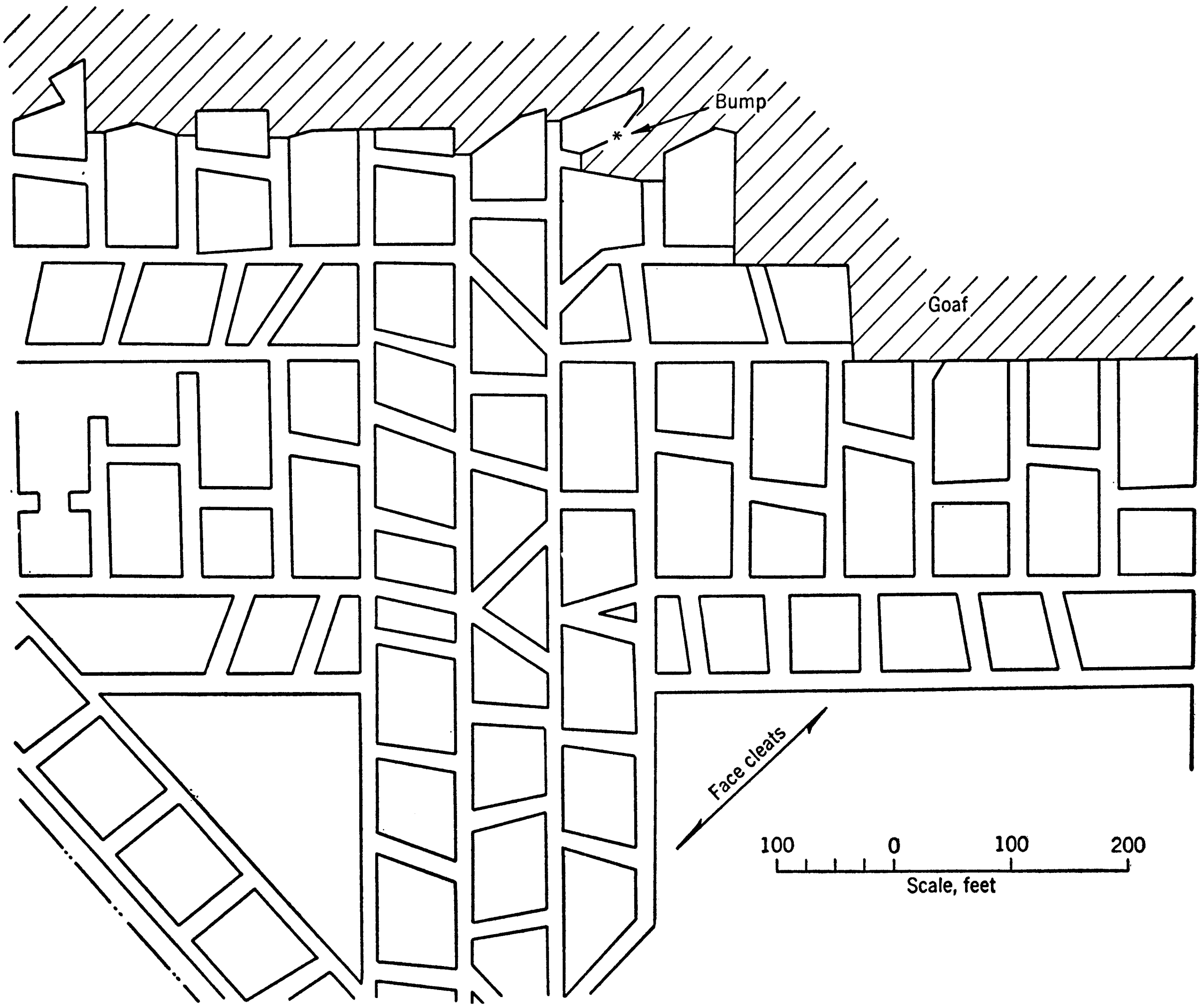


FIGURE 17.—Bump on a Pillar-Line Point Where a Pillar Was Being Slabbed Across the Back and in an Area of High Abutment Stress.

Cover 1,400 feet; coal thickness, 44 inches; roof and floor, strong.

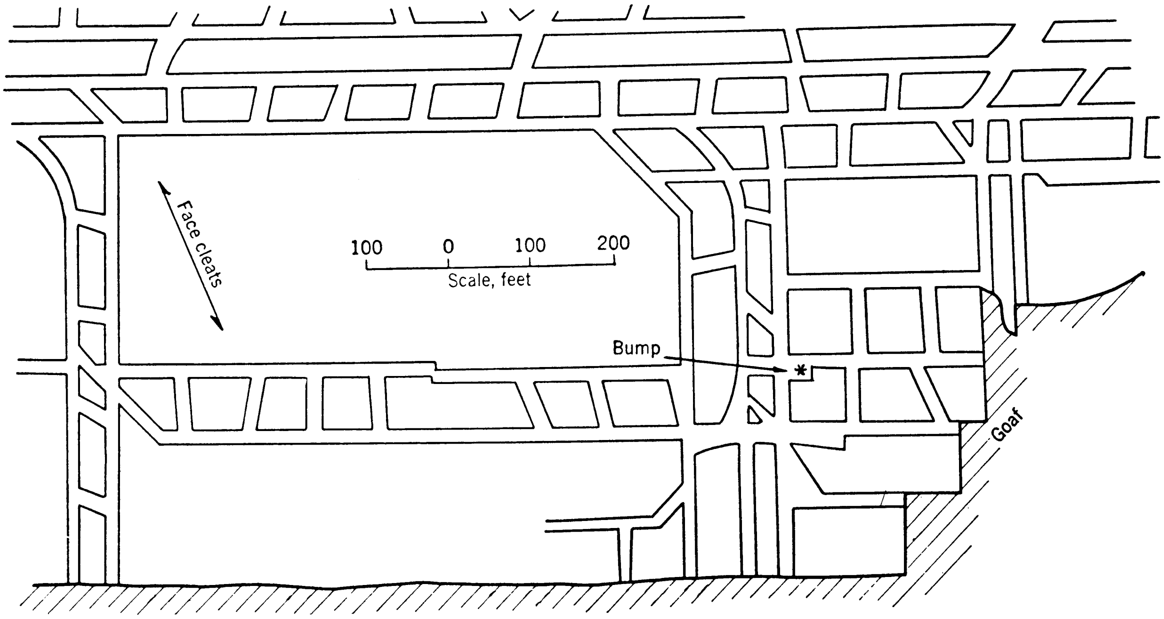


FIGURE 18.—Typical Bump on a Pillar-Line Point; a Slab Was Being Taken Across the Back End of a Pillar in an Area of High Abutment Stress.

Cover, 1,850 feet; coal thickness, 70 inches; roof and floor, strong.

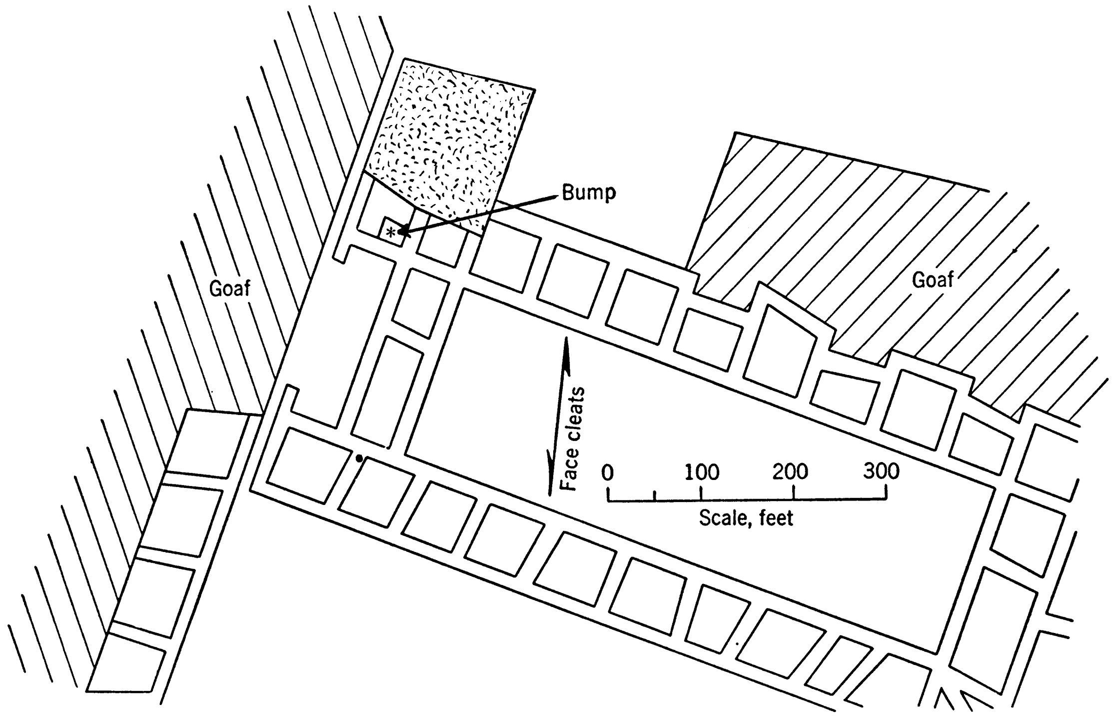


FIGURE 19.—Bump on a Pillar-Line Point Where a Pillar Was Being Slabbed and the Slab Driven Through an Area of High Abutment Stress Toward the Extraction Line.

Cover, 1,700 feet; coal thickness, 52 inches; roof and floor, strong.

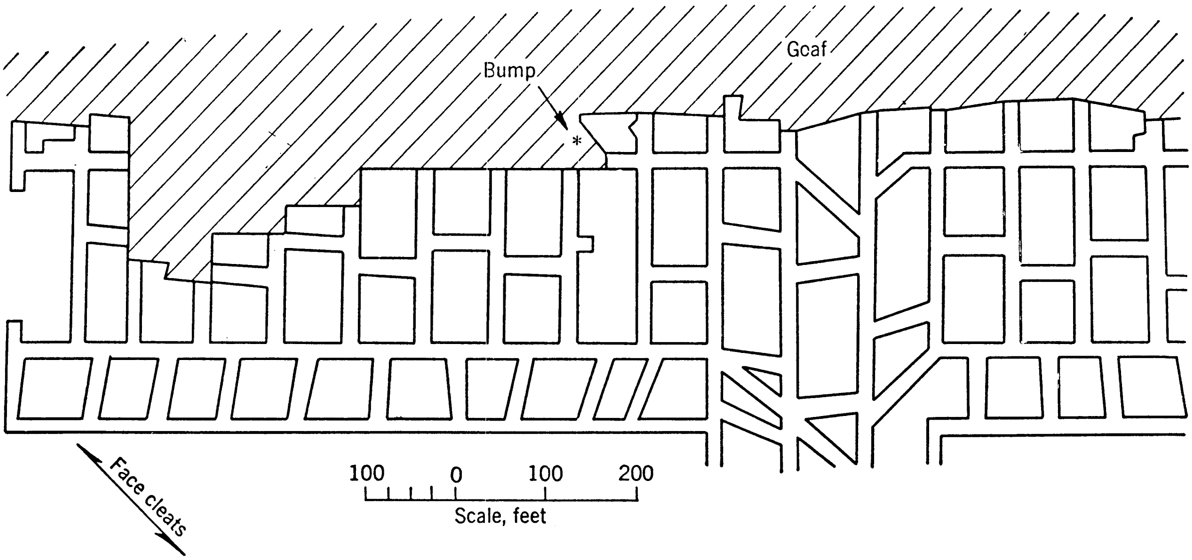


FIGURE 20.—Bump on a Pillar-Line Point; a Slanting Open-End Place Was Being Worked. Cover, 1,700 feet; coal thickness, 52 inches; roof and floor, strong.

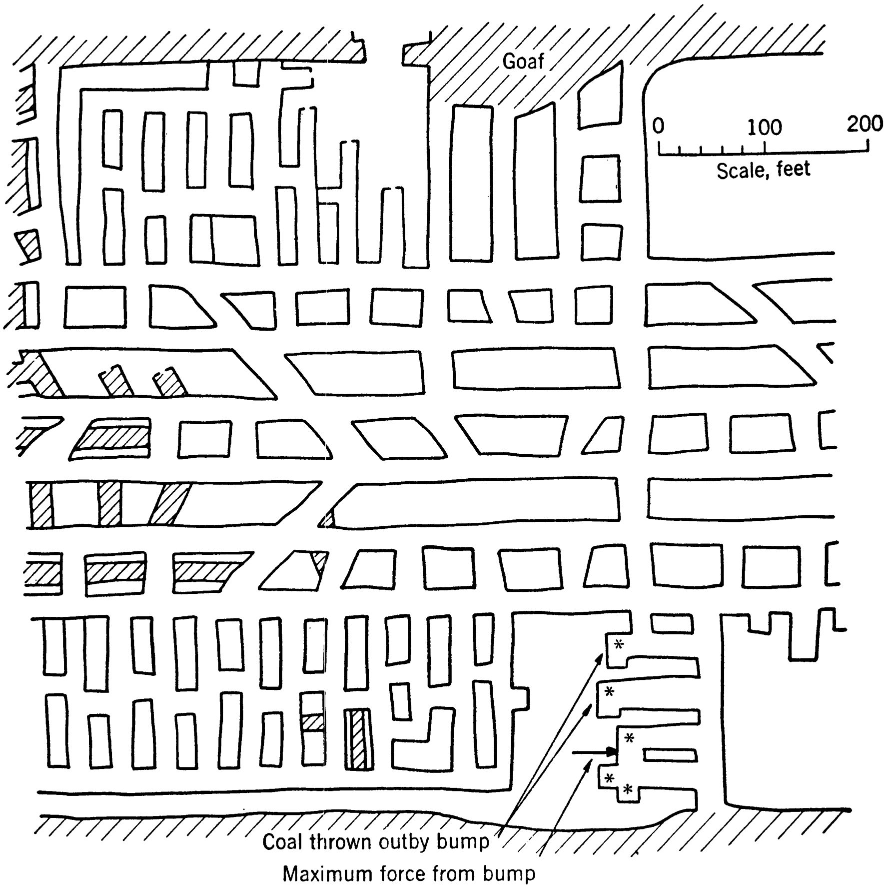


FIGURE 21.—Bump in an Extraction Area; a Large Pillar Was Being "Honeycombed" in an Abutment Area.

The abutment load in this instance was caused by a mined area on 1 side and small pillars on 2 other sides. The working places probably had reached the area of highest stress when the bump occurred. The coal was about 42 inches thick.

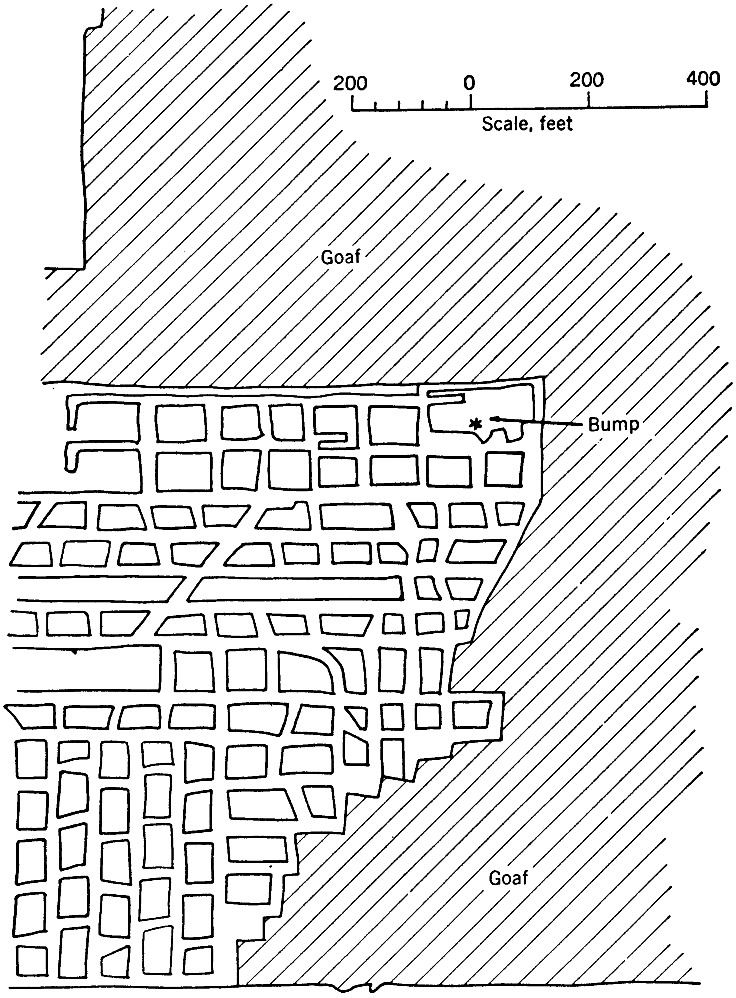


FIGURE 22.—Typical Bump in an Extraction Area on a Pillar-Line Point.

The point was caused by an extracted area on two sides and small pillars on the remaining sides. The large pillar is certain to have been an abutment area of very high stress. Cover, more than 1,000 feet; coal thickness, approximately 6 feet; roof and floor, strong.

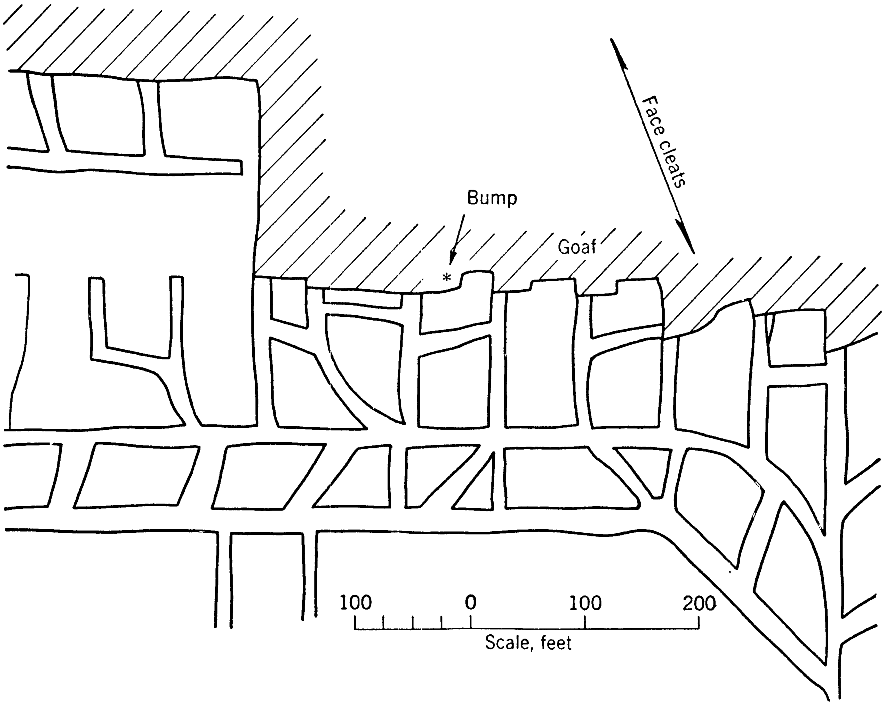


FIGURE 23.—Bump on a Pillar Line in a Notch About Where One Would Expect the Maximum Stress From a Roof Bridge.

Cover, 1,650 feet; coal thickness, 56 inches; roof and floor, strong.

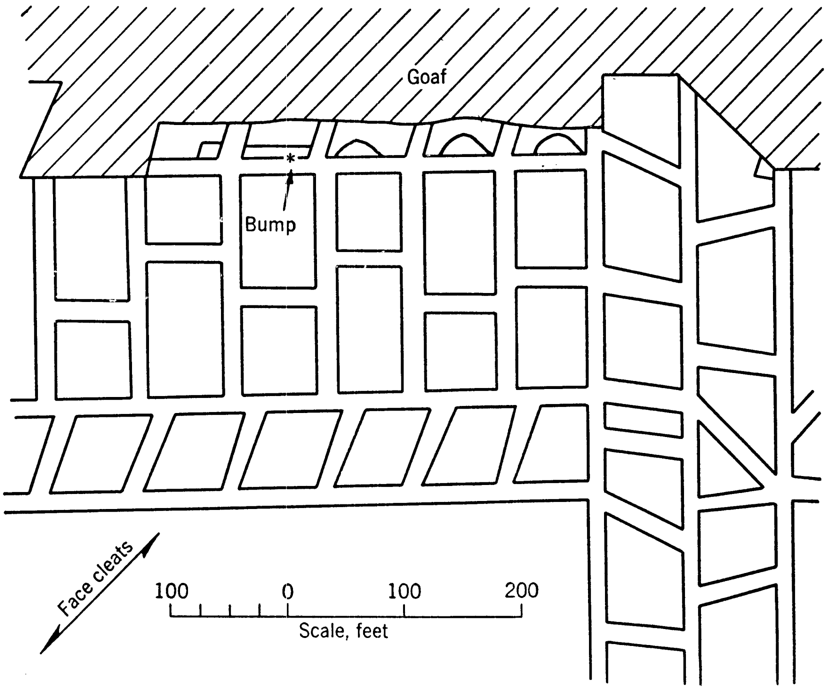


FIGURE 24.—Bump on a Pillar Line in Which the Back Ends of the Pillars Were Being Slabbed, Resulting in a Wide Passageway.

The increased abutment stress caused by widening the passageway was superimposed upon the abutment stresses from the goaf. Cover, 1,350 feet; coal thickness, 53 inches; roof and floor, strong.

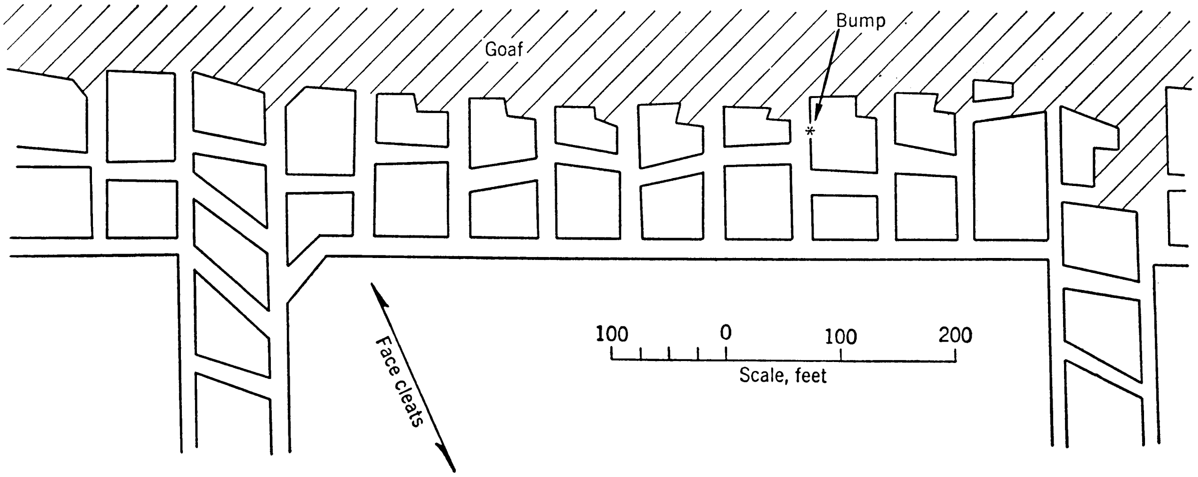


FIGURE 25.—Bump on a Pillar Line in Which the Pillars Were Being Worked by the Open-End Method; the Bump Did Not Occur on the Extraction Line.

Cover, 1,600 feet; coal thickness, 60 inches; roof and floor, strong.

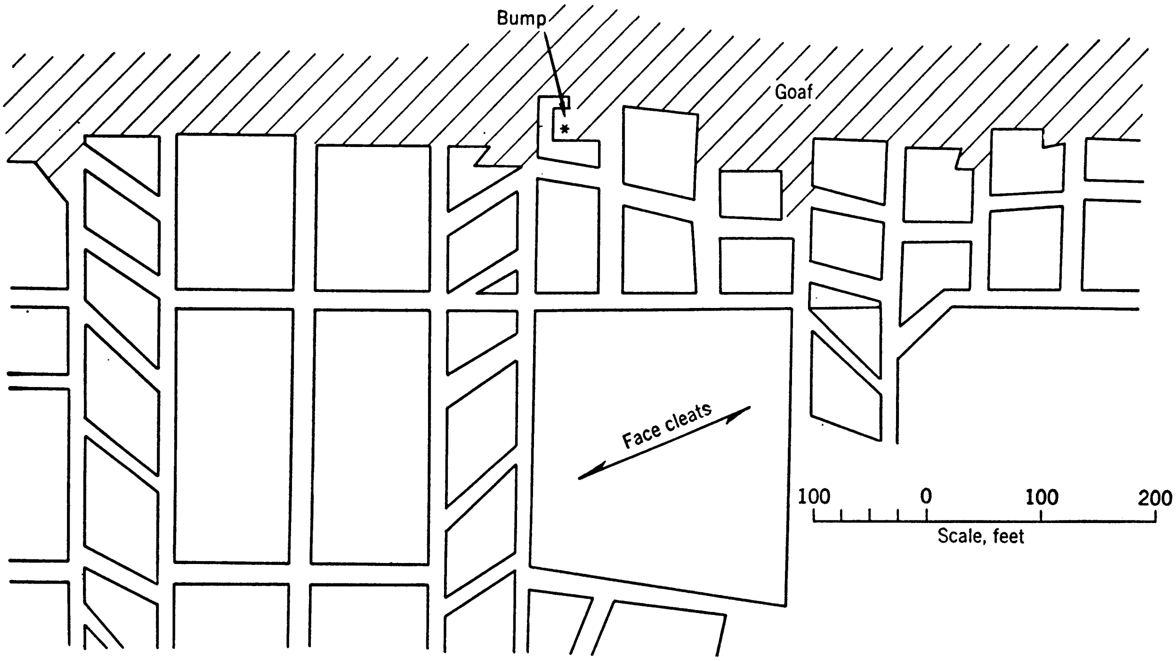


FIGURE 26.—Bump on a Pillar Line in Which the Pillars Were Being Extracted by a Method Similar to Pillar-and-Stall.

Cover, 1,000 feet; coal thickness, 36 inches.

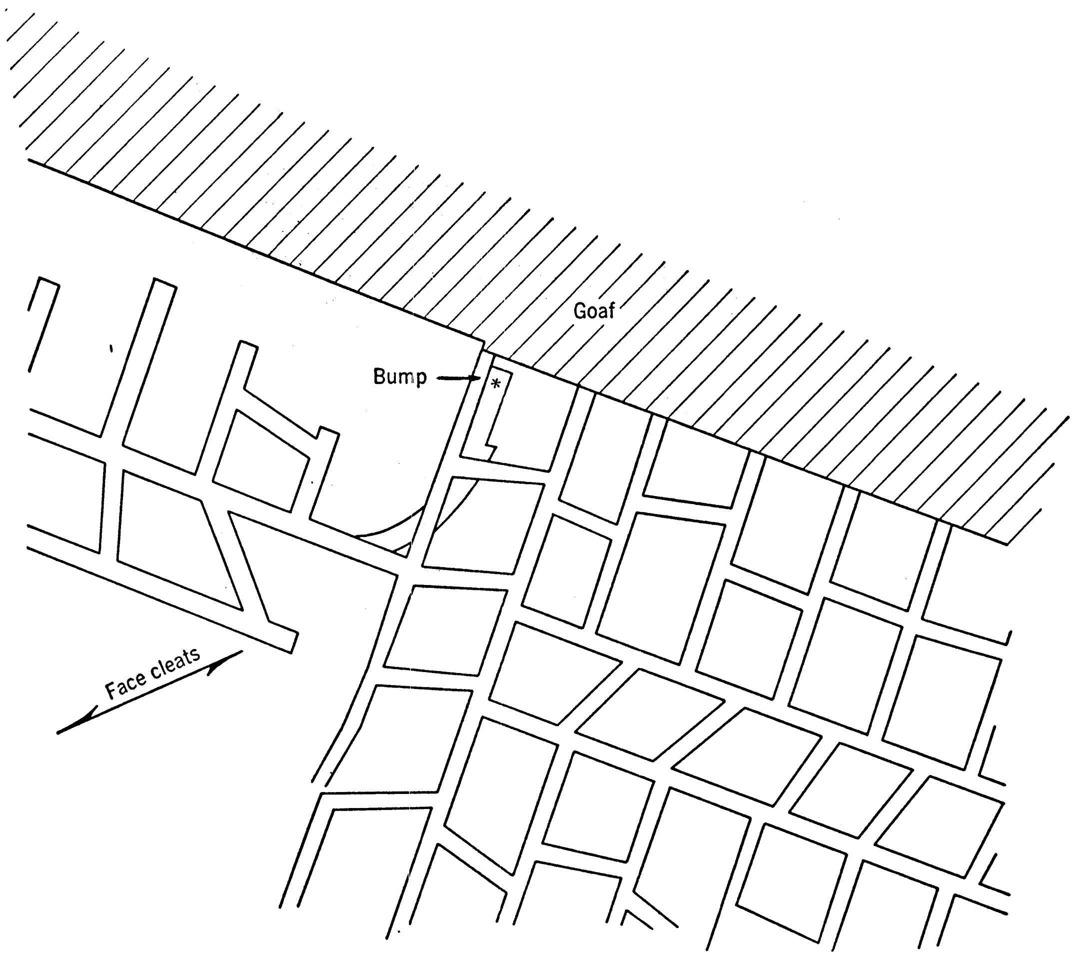


FIGURE 27.—Bump on a Pillar Line in Which a Pillar Was Being Slabbed and the Slab Driven Through an Area of High Abutment Stress Toward the Extraction Line.

Cover, 1,250 feet; coal thickness, 59 inches. Scale: 1 inch=154 feet.

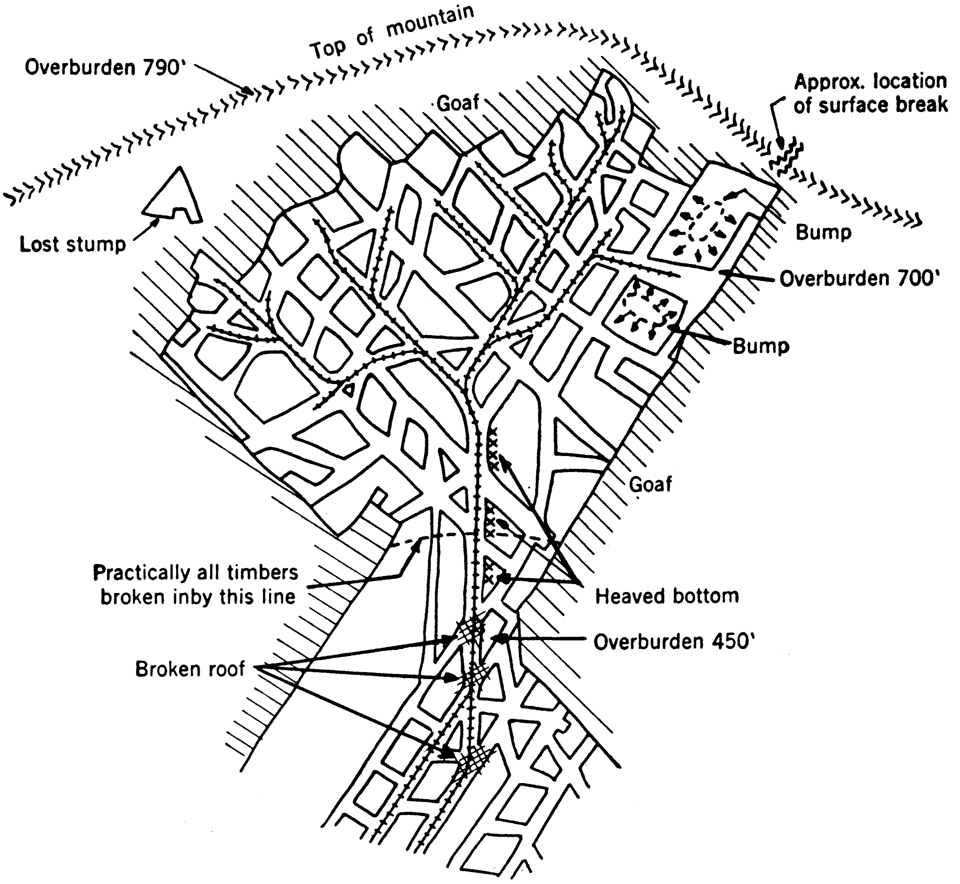


FIGURE 28.—Pillars That Burst on a Pillar-Line Extraction Point; a Slab Started at the Back End of the Pillar Was Being Advanced Parallel to an Old Goaf, Which Had Been Standing for Many Years, Toward a New Extraction Line.

The pillars that bumped were substantially larger than the neighboring pillars. Cover, 700 feet; coal thickness, approximately 7 feet; roof and floor, strong. Scale: 1 inch= 267 feet.

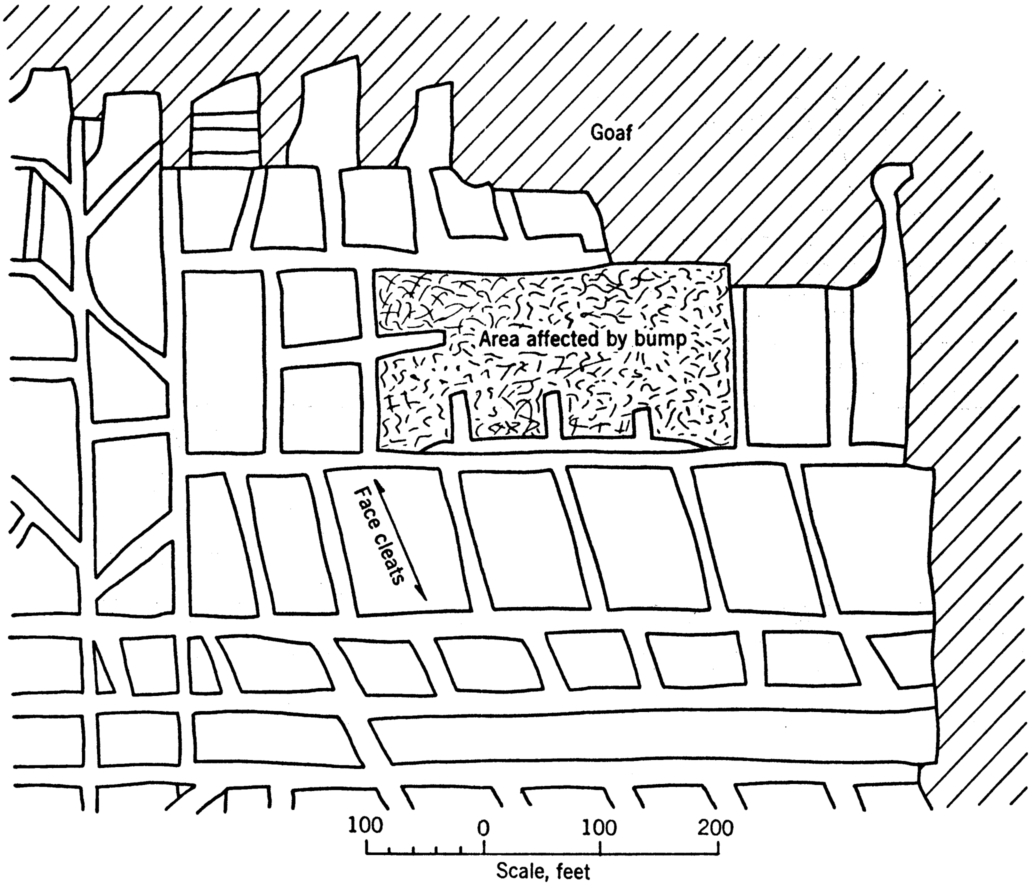


FIGURE 29.—Bump on a Pillar-Line Point Where Development Work Was Being Done in a Highly Stressed Abutment Area; 4 Working Places Were Destroyed by 1 Bump.

Cover, 1,500 feet; coal thickness, 60 inches; roof and floor, strong.

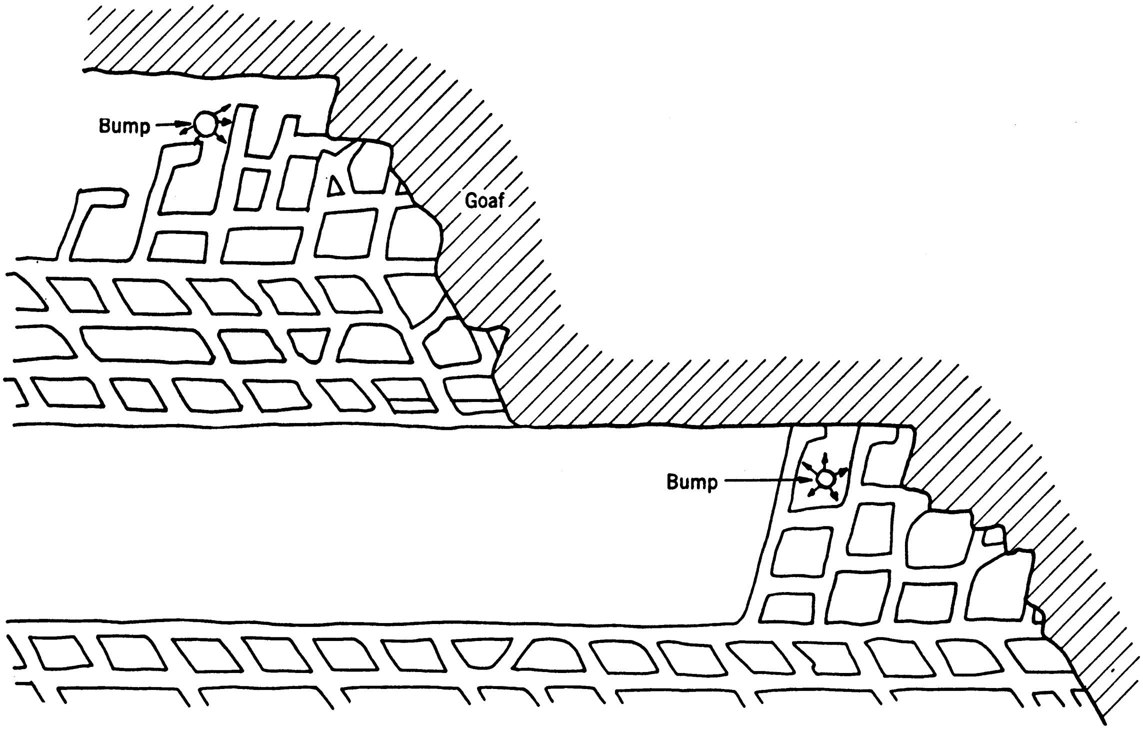


FIGURE 30.—Bumps That Occurred in an Area Stressed by an Old Goaf as Well as by the Approach of an Active Pillar Line.

Cover, 1,200 feet; coal thickness, about 7½ feet. Scale: 1 inch = 242 feet.
Note that both bumps occurred on points.

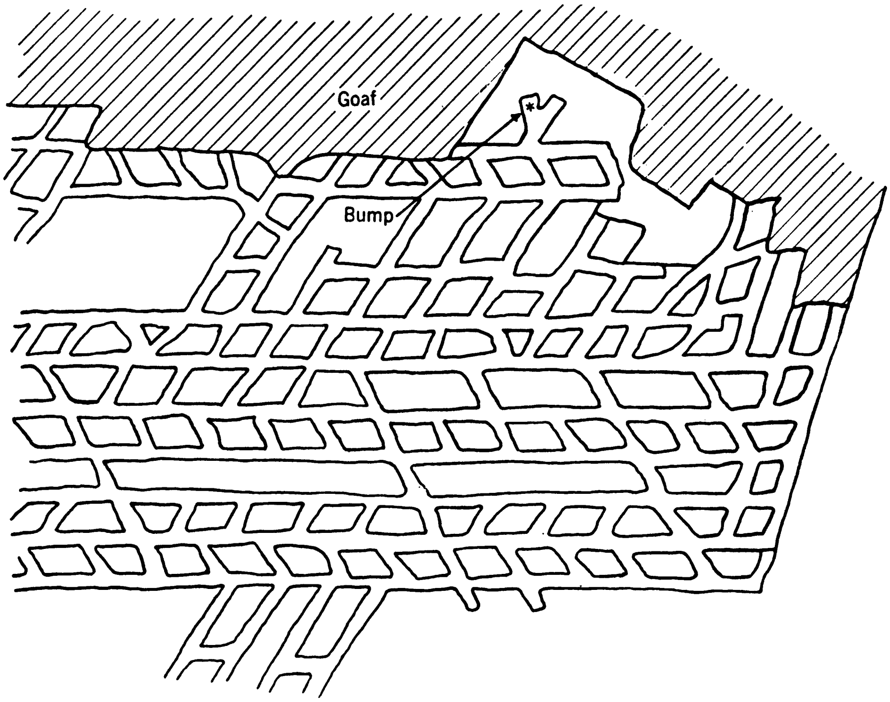


FIGURE 31.—Bump That Occurred When a Large Pillar-Line Point Was Being Split, a Typical Result of Splitting Pillars in Highly Stressed Areas.

Cover, about 1,100 feet; coal thickness, about 7 feet; roof and floor, strong.
Scale: 1 inch = 222 feet.

open-end lift as compared to the coal thickness. Inasmuch as thick beds can compress a greater distance without crushing and will fail at a lower stress than thin beds, it is suggested that this ratio be less for thick beds than for thin beds. Experience in beds approximately 5 feet thick suggests that if this ratio—width of lift to coal-bed thickness—is kept at 2.5 or 3 bumps will be comparatively rare. For a bed thickness of 3½ to 4 feet the ratio might be increased to 3 or 3.5. For beds thicker than 6 feet it probably should be decreased to 2 or less if the bed is thicker than 9 feet. Perhaps, a lift width of 12 to 14 feet would be reasonably satisfactory for all bed thicknesses.

Certain practices in open-end pillar recovery are believed to decrease the probability of a bump occurring, while others are thought to increase that probability. These are illustrated in figure 32.

Longwall mining has been advocated as a means of preventing bumps in coal mines. While extensive mining has been done under heavy cover by this method without bumps, yet serious bumps have occurred under certain conditions with its use. Some of these are illustrated in figures 33, 34, and 36. As may be noted, the coal had been mined on two or more sides of the area where the bumps occurred, and the pillars left were so small that the abutment load from more than one undermined section of overburden overlapped in the areas being mined. In figure 36 the bump occurred in the floor; in all the others the bumps were in the coal.

Figure 35 shows the typical conditions that conduce to bumps in retreating longwall. Here, the pillar being mined forms a gigantic point where abutment loads of two undermined areas can overlap.

Figure 37 shows the conditions that existed where both bord-and-pillar and longwall mining methods were used in adjoining areas. This bump was particularly violent. Again, it will be noted that the pillars in which the bump occurred supported the abutment loads imposed by mined areas nearly surrounding the pillars (*18*).

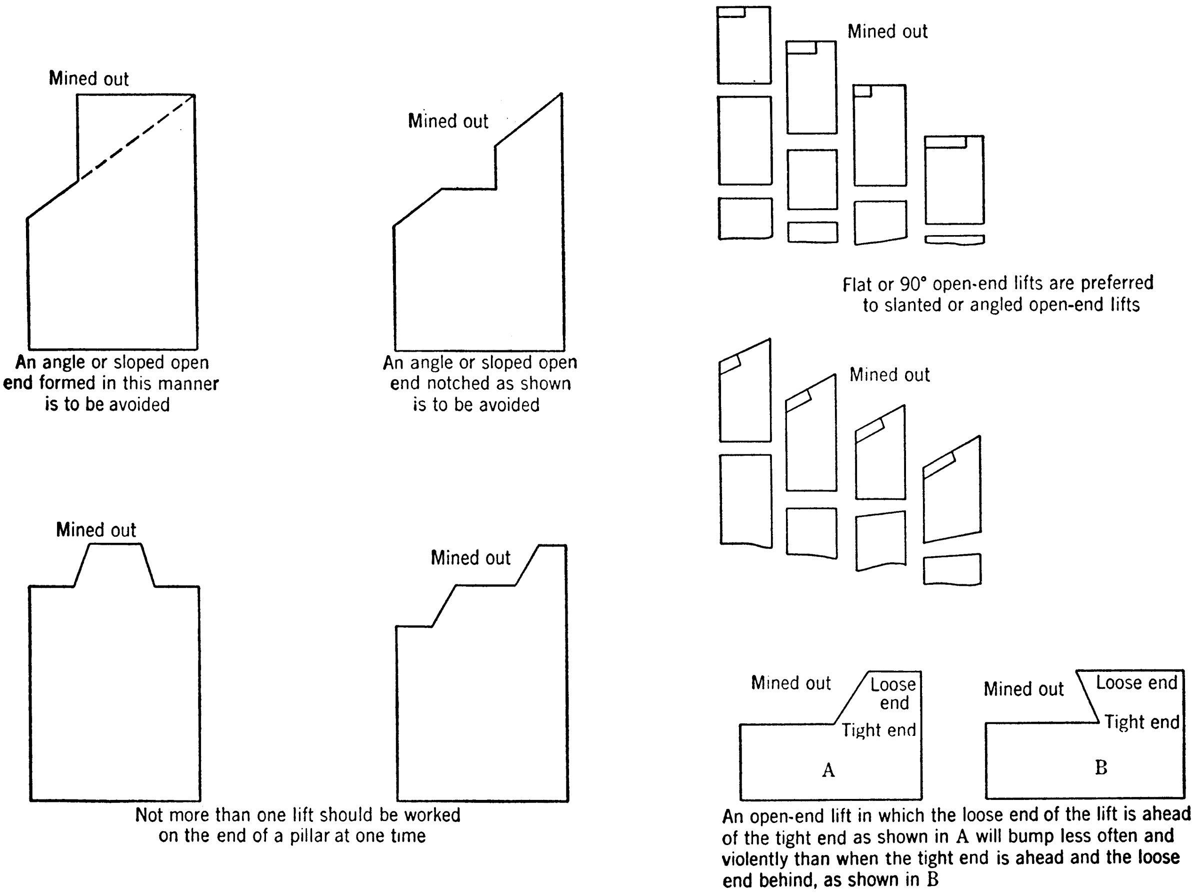


FIGURE 32.—Open-End Pillar-Extraction Practices That Should Be Carefully Considered in Areas Where Rock Bursts Are Likely to Occur.

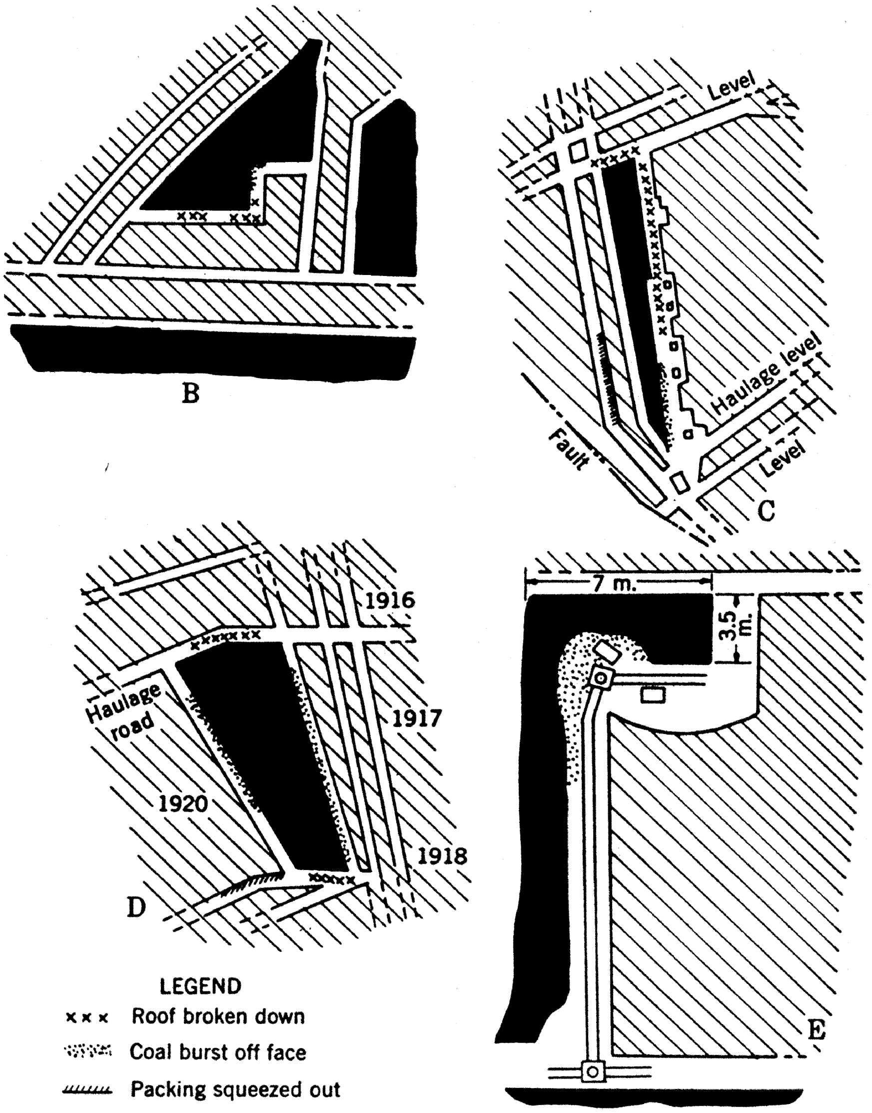


FIGURE 33.—Mining Practices That Have Caused Bumps in Longwall Mining of Coal; the Bumps Occurred in Remnants That Were Stressed by Abutment Loads From Mined Areas on Two or More Sides. (After Phillips (*14*).)

Length of face in *D* was 240 feet and in *C*, 360 feet. The diagonal length of the pillar that bumped in *B* was 520 feet.

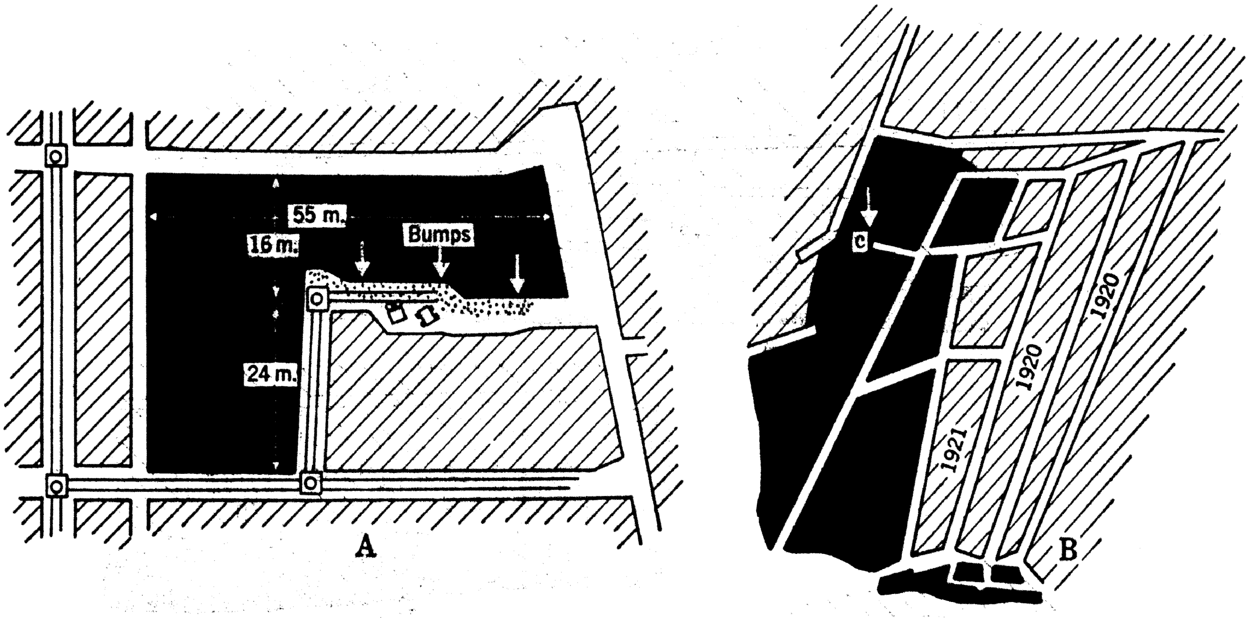


FIGURE 34.—Mining Practices That Have Caused Bumps in Longwall Mining; the Bumps Occurred Where the Pillar Remnant Formed a Highly Stressed Abutment Area on Which Loads Were Imposed From All Sides. In *B* the Bump Occurred at *C*. The Roadway at *C* Was 35 Meters Long. (After Phillips (*14*).)

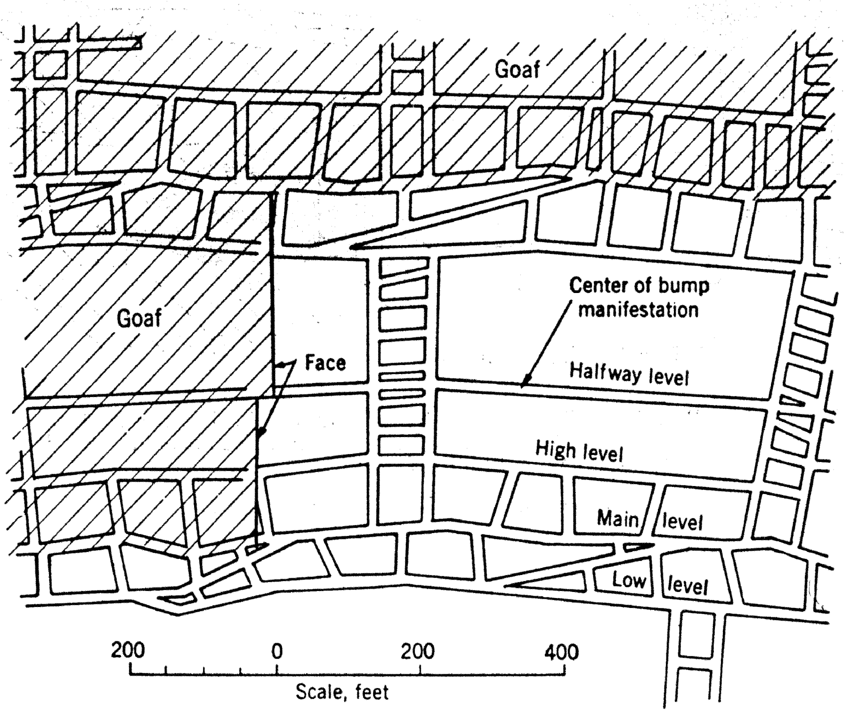


FIGURE 35.—Conditions Under Which Bumps Have Occurred at Springhill, Nova Scotia.

The system of mining was changed from room-and-pillar to retreating longwall in the hope of preventing bumps. In certain parts of the mine bumps have continued to occur. Note that the coal being mined forms a gigantic point. Cover, 2,500 to 2,800 feet; roof and floor, strong. (After McCall.)

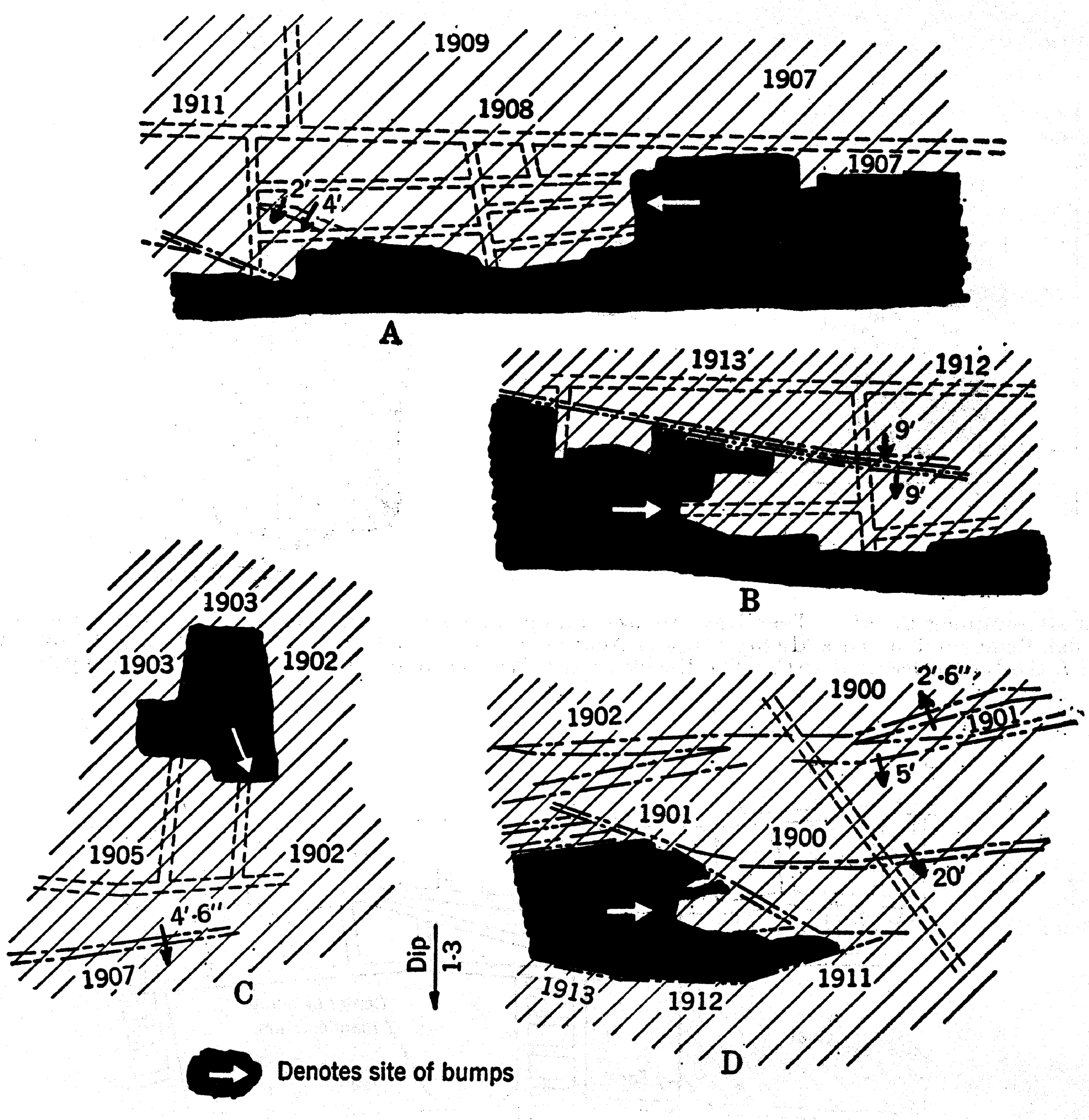


FIGURE 36.—Mining Practices That Have Caused Bumps in Longwall Mining; the Bumps Occurred in Areas Where the Coal Being Mined Was in an Abutment Area Stressed by Two or More Mined-Out Areas. (After Phillips (*14*).)

Approximate scale: 1 inch=250 feet.

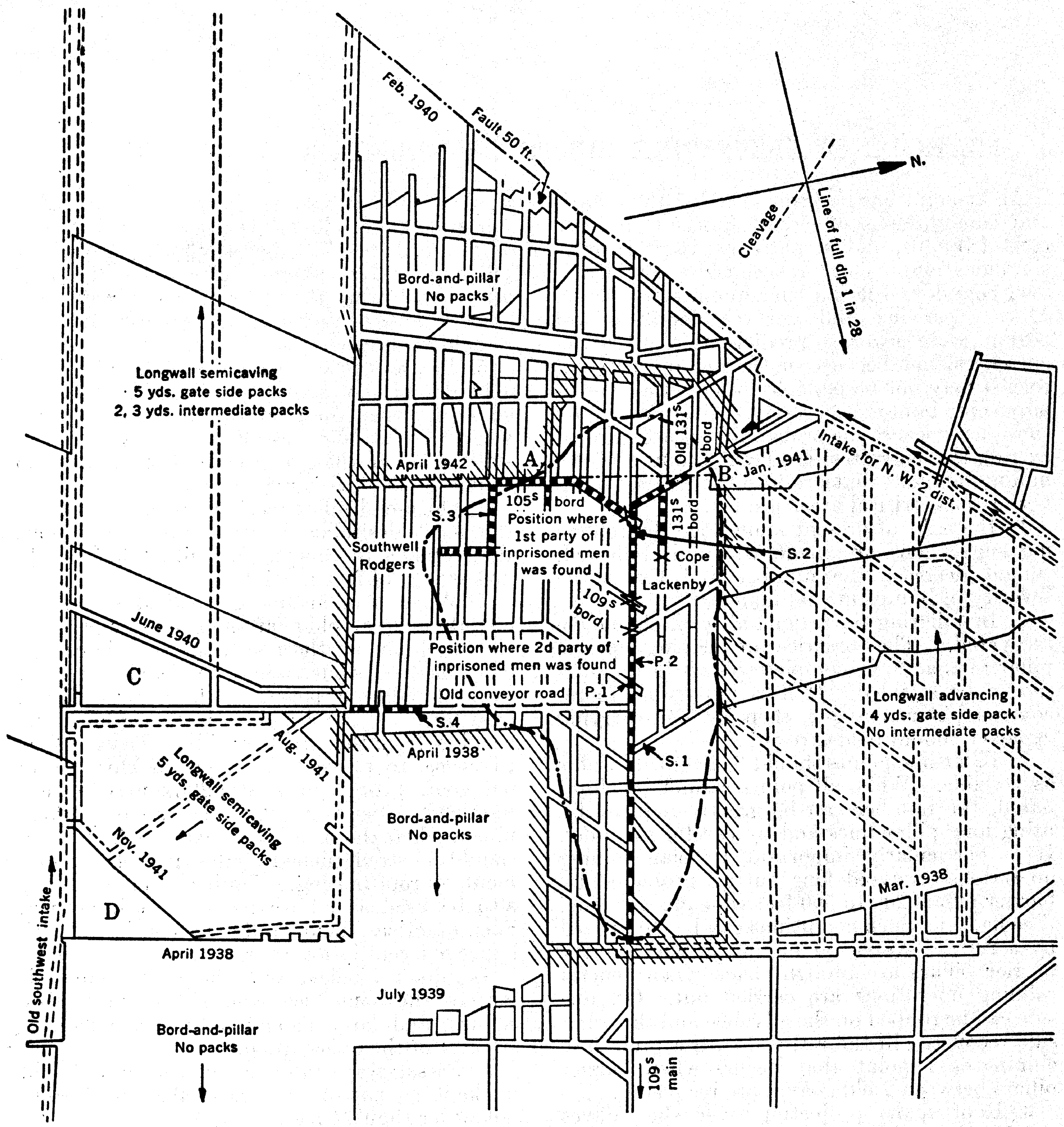


FIGURE 37.—Bumps in Bord-and-Pillar Work; the Bumps Occurred in an Abutment Area on Which Loads Were Imposed From Mined Areas on Three Sides. The Principal Effects of the Bumps Were Confined Within the Area Enclosed by the Dashed Line. (After Humphrys (*18*).)

Approximate scale: 1 inch=365 feet.

METHODS OF PREVENTING BUMPS OR MINIMIZING THEIR EFFECTS

An attempt has been made to list the factors and combinations of circumstances that have caused bumps, and perhaps the result is oversimplification. Their relationship actually is very complex, especially in a quantitative sense. More experience and research doubtless will permit more accurate predictions of these occurrences, but because of the heterogeneity of rock it may not be possible to measure or evaluate some bumps accurately. Therefore, only those areas where the probability of a bump occurring is the greatest are pointed out, and the mining methods that produce the greatest number of these critical areas are listed.

In the light of present knowledge the following suggestions are made which, if followed, should decrease the number and lessen the severity of bumps in coal mines.

1. In pillaring operations all coal should be recovered. The practice of leaving sprags, pillar remnants, or complete pillars in the goaf should be avoided. If it is impossible to recover a pillar remnant, then its load-carrying capacity should be destroyed.

2. Pillar-line points should be avoided insofar as possible. While all points cannot be eliminated, the number can be greatly reduced by using long pillar lines and by careful planning. It is particularly important to plan mining operations to avoid long entries protected by barrier pillars 200 to 500 feet wide on each side. (See fig. 7.) Such conditions can be eliminated by a retreat system of mining in which entry barrier pillars are brought back when general robbing operations are carried out. Or, one side can be robbed on the advance and the other side recovered in the retreat; such a procedure eliminates 1 point that occurs when barrier pillars between 2 old goaves are recovered.

3. Roof spans projecting over the goaves should be kept as short as possible or else provided with such support that the roof beds do not fracture. The length of roof spans can be reduced by orienting the direction of the pillar line so that it parallels the direction in which the roof rocks break most readily. Long pillar lines also help to reduce long spans between unmined areas and the pillars on the extraction line.

4. Development work should not be done in abutment areas. Under conditions that conduce to bumps, development work, blocking out pillars, etc., should be so planned that such work is not less than 3 or 4 pillars ahead of the pillar line. Development places should not be advanced toward the pillar line in an abutment zone because of the probability of encountering a high-stress area.

5. Pillars on or near the extraction line should not be split; nor should they be slabbed, other than on the goaf side, except when absolutely necessary. If they must be slabbed other than on the goaf side, the slab should be kept as narrow as possible.

6. Open-end pillar recovery is believed to be the most desirable practice under conditions that conduce to bumps. The lifts taken should not exceed 14 feet in width.

7. When a pillar line is worked so that 1 end abuts on an old goaf and excessive pressure causes bumps on the point, the trouble can be controlled to some extent by leaving 1 or 2 rows of pillars adjacent to the goaf unmined. (See fig. 38.) If the pillar lines are long, the coal lost from this practice will not be excessive. Likewise, to prevent development close to an old goaf, 1 or 2 rows of pillars may be left unmined. (See fig. 39.) To recover these pillars when the next lift is extracted, the roof should be strengthened at the time of development by roof bolting. Timbers and cribs may also be used as additional support if needed. Such practices, incidentally, are consistent with approved ventilation practices.

8. Pillars blocked out should be approximately the same size and shape, preferably square, and large enough to insure adequate support of the overburden.

9. Passageways in development work should be kept as narrow as practicable, preferably not wider than 14 feet.

10. Most bumps are the result of improper mining methods and practices. Doubtless, some are caused by the physical condition of the coal and adjacent rocks. Therefore, in areas where rolls, change in dip, change in coal thickness, and change in texture or hardness of the coal occur, particular attention should be given to selection of mining practices and methods that will give the miner as much protection as possible.

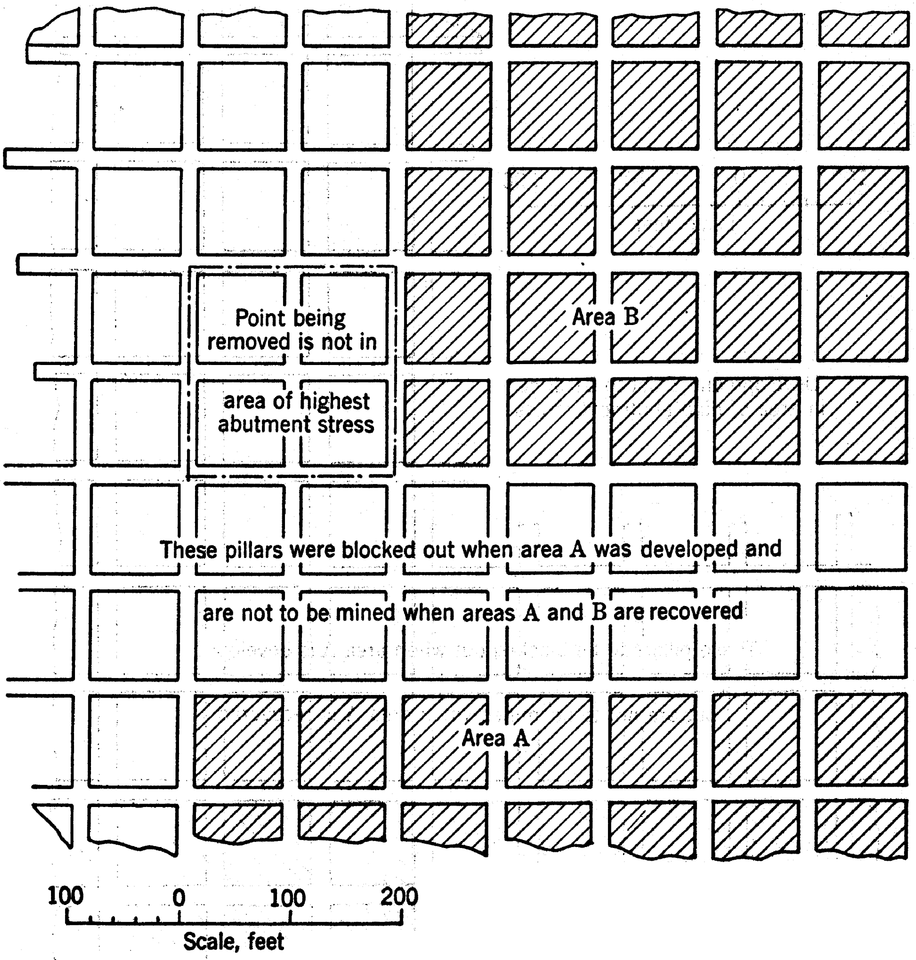


FIGURE 38.—Suggested Method of Keeping Area Being Mined Away From Area Subjected to Highest Abutment Stress.

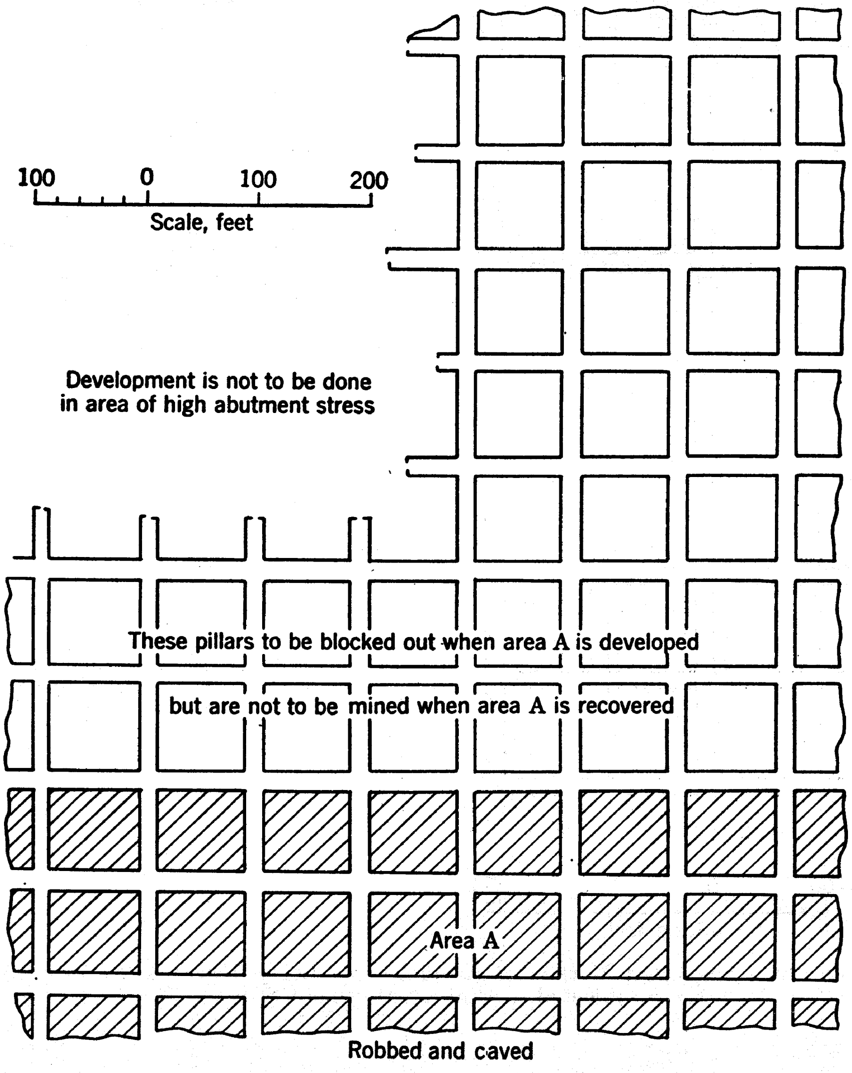


FIGURE 39.—Development in High-Stress Areas Adjoining Old Goaves Can Be Avoided by Leaving 1 or 2 Rows of Pillars Blocked Out and Unmined When the First Section Developed (*A*) Is Recovered.

BIBLIOGRAPHY

1. Rice, George S. Bumps in Coal Mines of the Cumberland Field, Kentucky and Virginia: Causes and Remedy. Bureau of Mines Rept. of Investigations 3267, 1934, 36 pp.
2. ———. Bumps in Coal Mines. Trans. Am. Inst. Min. and Met. Eng., vol. 119, 1936, pp. 11–39.
3. Herd, Walter. Bumps in No. 2 Mine, Springhill, Nova Scotia. Trans. Am. Inst. Min. and Met. Eng., vol. 88, 1930, pp. 151–206.
4. Jones, D. J., Wilden, N. W., and Maurice, John F. Bumps in the Coal Field of Harlan County, Ky. Kentucky Dept. Mines and Minerals, Geol. Div., Bull. 1, ser. 8, Dec. 1, 1934, 26 pp.
5. Holland, Charles T. Coal-Mine Bumps. Min. Cong. Jour., June 1942, pp. 26–30; July 1942, pp. 34–37.
6. South Staffordshire and Warwickshire Institute of Mining Engineers, Safe Working in Mines Committee. The Occurrence of Bumps in the Thick Coal Seam of South Staffordshire. Trans. Inst. Min. Eng., vol. 75, 1927–28, pp. 116–147.
7. ———. First Progress Report on the Problem of Bumps in the South Staffordshire Thick Coal Seams. Trans. Inst. Min. Eng., vol. 105, 1945–46, pp. 458–499.
8. Lawall, Charles E., and Holland, Charles T. Some Physical Characteristics of West Virginia Coals. West Virginia Eng. Exp. Sta. Bull. 13, ser. 37, 1937, p. 27.
9. Evans, G. W. Discussion on Bumps in No. 2 Mine, Springhill, Nova Soctia. Trans. Am. Inst. Min. and Met. Eng., vol. 88, 1930, p. 194.
10. Holland, Charles T. Some Aspects of Violent Failures of Coal-Mine Pillars and Adjacent Strata. Proc. West Virginia Coal Min. Inst., 1943, p. 54.
11. Bryson, J. F. Method of Eliminating Coal Bumps or Minimizing Their Effects. Trans. Am. Inst. Min. and Met. Eng., vol. 119, 1936, p. 40.
12. Odendahl, W. B. Final Report on Explosion at Kenilworth Mine, Independence Coal & Coke Co., Kenilworth, Carbon County, Utah. Bureau of Mines, Mar. 14, 1945. (Manuscript rept.)
13. Caufield, B. Discussion on Instantaneous Outbursts of Carbon Dioxide. Trans. Am. Inst. Min. and Met. Eng., vol. 94, 1931, p. 104.
14. Phillips, D. W. Rock Bursts or Bumps in Coal Mines. Trans. Inst. Min. Eng., vol. 104, 1944–45, pp. 55–84.
15. Duvall, W. L. Stress Analysis Applied to Underground Mining Problems. I. Stress Analysis Applied to Single Openings. Bureau of Mines Rept. of Investigations 4192, 1948, 18 pp.
16. ———. Stress Analysis Applied to Underground Mining Problems. II. Stress Analysis Applied to Multiple Openings and Pillars. Bureau of Mines Rept. of Investigations 4387, 1948, 11 pp.
17. Holland, Charles T. Properties of Coal and Associated Rocks as Related to Bumps in Coal Mines. Trans. Am. Inst. Min. and Met. Eng., vol. 149, 1942, pp. 75–91.
18. Humphrys, H. J. Report on Causes of and Circumstances Attending the Upheaval of Floor Which Occurred on 24th April, 1942, at the Barnsborough Main Colliery, South Yorkshire. H. M. Stationery Office, C 6414, London, England.