Regional Bumps: Case studies from the 1958 Bump Symposium

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I. Abstract

A variety of dynamic failure cases with regional impact were described at a bump symposium held in 1958. These types of events, while rare, are of particular interest because their ability to impact a large area has disaster potential. These cases can be grouped into two broad classes of events by mechanism. These are (1) slip along steeply dipping faults and (2) fracturing of strong strata above, or below, the coal seam. Both failure modes produce dynamic or “shock” loads on the perimeter (roof, rib, floor) of mine openings. Special consideration should be given to these failure modes in planning of deep coal mines since their occurrence is not within the professional experience of many contemporary workers, and their potential is not evaluated by many of the analysis tools commonly used to evaluate hazards in coal mine plans.

II. Introduction

Local pillar bumps and outbursts of coal are a concern in many coal mines, and have received considerable attention from industry and regulators. Sudden, dynamic failures with regional impact have been much less common. This is important, since the bump cases reviewed in this paper show that a bump with regional impact is not simply a large version of a local bump – it may well be caused by a different mechanism.

Given the rarity of regional scale bumps, a long view is needed to capture case histories and insights into these phenomena. The historical literature is marked by periods of relatively intense interest in such events, often in response to particularly damaging or disastrous occurrences. This literature gives a variety of names to these events, including bounces, district bumps and shock bumps, that often imply a particular mechanism, at least with respect to a particular mine or district. The general term “regional scale bump” is used in this review to avoid implicit links to these mechanisms.

A Bump Symposium held at the 1958 Annual Meeting of AIME marks one historical era of heightened interest in regional scale bumps. The introduction to this symposium defines the term “mountain bump” as the “sudden rupture of one or more coal pillars under excessive stress” and goes on to say that these “bursts occur with varying degrees of violence and sometimes include adjacent strata, especially the bottom rock.” The problem is characterized as “extremely complex” and preventative measures, to be successful, must be “based on a thorough study of conditions in the individual mine.” This characterization remains appropriate, although the discussion predates modern longwall mining. However, longwall mining was a topic of considerable discussion in 1958, primarily as a means to control bumps through caving. Thomas (1958) credits the late George S. Rice, former chief mining engineer of the U.S. Bureau of Mines, with being an early advocate for “open-ended” longwall mining which had been “most successful in combating the bump hazard in mining coal under deep cover, especially in Great Britain.”

The Symposium Proceedings, published in two successive issues of Mining Engineering, are preceded by a summary titled “Progress in Control.” This title is consistent with the optimistic tone of many of the published papers, including one titled “Coal Mine Bumps Can Be Eliminated.” Confidence within the Bureau of Mines, in particular, had been sufficiently high that there was a ten-year pause in bump research dating from Rice’s retirement until 1951, when three bumps involving fatal injuries occurred. This over-confidence was further underscored by the 1958 Springhill bump disaster, which claimed 75 miners.

The waxing and waning of interest in bumps, particularly regional bumps with disaster potential, is likely a result of their rarity. This rarity means that few mining professionals can apply personal experience to evaluation of their potential in practice. As such, there is a real danger of ignoring these types of events, analogous to the ever-present temptation to build on that 100-year flood plain.

As in 1951, and 1958, we are reminded that bumps of regional scale, while uncommon, have not ceased. This paper looks at historical descriptions of bumps with regional scale, in the hope that by investigating dynamic failure modes with potential to create the next disaster, that disaster might be averted. Such a pursuit is central to the mission of the National Institute for Occupation Safety and Health (NIOSH) – and of great concern to our partners in industry, labor and academia. This paper presents the beginning of an effort to address this issue – stated as:

“How do we evaluate and manage the disaster potential of various modes of regional scale dynamic failure in deep coal mines?”

The 1958 Symposium papers describe a variety of regional scale bumps that can be sorted into two broad classes of events that were caused by (1) slip along faults in the overburden and (2) fracturing of strong strata above, or below, the coal seam. Both failure modes produce dynamic loading of mine opening perimeters. In the first case, dynamic loading is typically described as widespread shaking, particularly along a fault trace. In the second, loading is described as an impact generated by sudden failure of hard strata. Treatment of these two modes by the 1958 symposium is reviewed here.

III.Fault-Slip Bump Cases

The first set of regional bump cases were selected from events reported by Peperakis (1958) as related to the Sunnyside fault zone. Two types of bumps are described, localized bumps at the face that occurred during mining in close proximity to the fault, apparently as stress concentrations were encountered, and widespread shaking of main accessways by slip within the fault zone. This review focuses on the later. These bumps typically occurred a great distance from active pillar workings and were associated with faulted structures.

Peperakis describes terrain above the Sunnyside Mine as “exceedingly rough.” Overburden depth increases quickly, reaching 2000 ft of overburden within 2700 ft of the outcrop. Much of the overburden consists of massive sandstone but the immediate roof is described as "generally very poor." Seismic shaking of the immediate roof and ribs by large fault slip events accounts for a large portion of the damage. The floor is a strong massive sandstone bed 20 to 50 ft thick. Faulting is described as "very extensive" with maximum displacements of 33 to 90 ft.

The Sunnyside fault lies along a roughly 3.5 mile southeast trend, subparallel to the strike of bedding with displacement reported to be 30 ft (Clark, 1928). Osterwald et al (1993) report on more recent mapping of the northwest-trending Sunnyside fault zone (figure 1). They describe the fault zone as follows:

> "… a belt of fractures about 1930 m (1.2 miles) wide in the southern part of the [Sunnyside] district, but it narrows to a single break in the northern part of the district. It dips almost vertically, and the stratigraphic separation across the zone is commonly about 9 m (30 ft). The southwest side is downthrown."

Peperakis (1958) reported the occurrence of "extremely violent bumps near the intersection of the main slopes of No. 1 mine with the main Sunnyside fault" and concluded that "most of the really severe bumps that have struck the workings in recent years have taken place close to the main Sunnyside fault." Many of these bumps produced widespread shaking of the mine (and surface, in many cases), suggestive of fault slip movement. Recurring damage to slopes (main accessways) well outby the mining front was an added source of concern. Many of these bumps were described in detail at the symposium. A selection are summarized here.

The first occurred in December of 1944 with the mine almost entirely on development (i.e. little or no pillar mining). A major seismic event "initiated working of a 350-ft section of roof that caved over the ensuing 45 minutes." Other slopes were described as "badly shaken" but did not cave. A similar event eight years later, in November of 1952, was felt through most of the mine and on the surface, causing extensive rib sloughage in the slopes, in some cases extending to the portal.

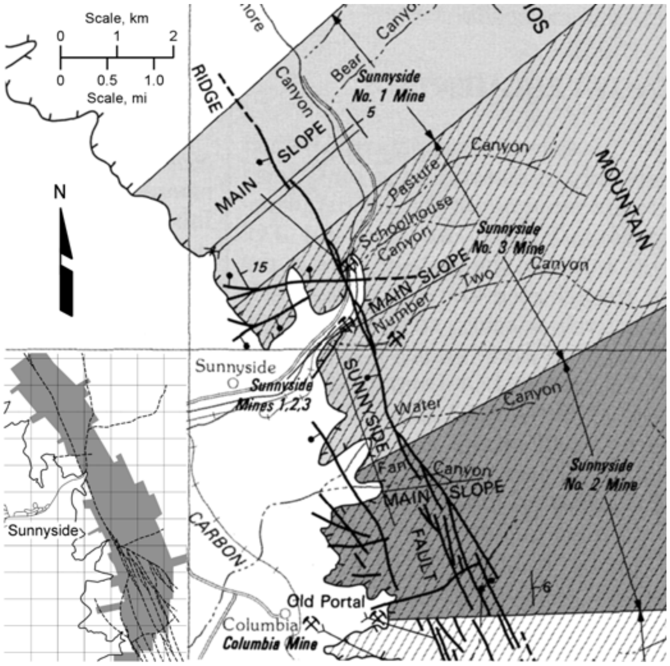

Figure 1 The main Sunnyside fault zone in the Sunnyside 1,2 and 3 Mines (after Osterwald, 1993). Inset is a map of mining to 1958. Shaded area is 4 sq. miles of worked out or first mined coal seam (after Peperakis, 1958).

The 1944 and 1952 bumps were followed by a succession of four similar major events in 1957. The first two, on January 24th and 27th, caused considerable damage to the main slopes, including heaving of 1300 ft of track entry, caving of roof along 550 ft of main slope entries and an additional 500 ft of main slope where heavily bolted roof "settled on the bolts." In addition, top coal was shattered along 2000 linear feet of entries and widespread entry roof "breakage" was reported.

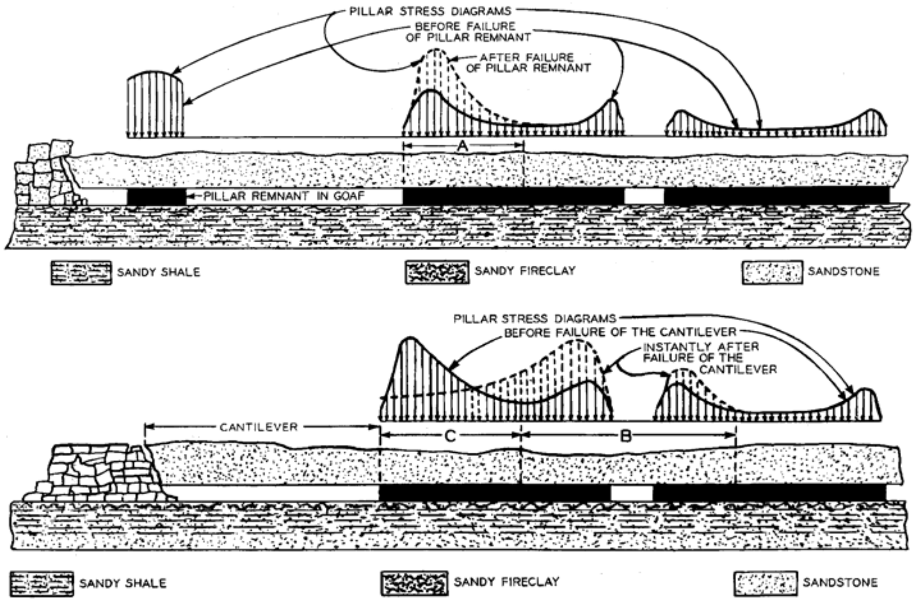

Figure 2 Sketches by Holland (1958) illustrating two variations of his proposed bump mechanism (not to scale). Top, failure of a pillar remnant suddenly transmits stress to the mining front. Bottom, failure of a strata lever that has reduced stress on the coal seam at B fails, suddenly increasing stress at B while reducing stress on coal at the mining front.

A similar pair of events occurred in December of 1957. The first induced bursting of 220 feet of “main slope pillar,” filling the manway with rock and badly shaking the main slope. Heavy support, including roof bolts, 12x12 inch crossbars and cribs, was credited with preventing damage. The second was a violent bump that was recorded by men “working at four points along three different fault planes” with a lateral extent of 7000 ft.

Peperakis identified strong or well-reinforced roof as the key to prevention of damage and accidents in “all areas subject to bumps” at the Sunnyside Mine. Support suggestions included roof bolts in combination with cribs, crossbars on cribs, and 16-in diameter props, augmented by the “steel yieldable arch type of support” in slope areas and haulageways. This emphasis on roof support is a particular, local conclusion aimed at preventing damage from seismic shaking of the “generally very poor” roof rock at the mine.

IV. Strata-Failure Bump Cases

The second set of regional bump cases was selected from events reported by Holland (1958) and Campbell (1958) as related to failure of strong strata above and/or below the coal seam. This group of regional scale dynamic failures is characterized by widespread damage outby the retreat line – with or without damage on the line. The location of damage behind the mining front while, in some cases, the mining front remains unaffected, has been attributed to strong strata acting as a lever sitting on a fulcrum which is the mining front. Failure of the lever then causes impact loading of the coal seam behind the mining front.

Herd (1930) provides an early version of this explanation in the context of the Springhill Mine as follows (pp. 178-179):

“This sandstone, being very strong and compact, has not the ability to fall or shear until a very considerable area has been excavated, during which time it is hanging back in the waste supported on a fulcrum at the coal face, resulting in an upward stress in this band and those above, reaching far over the solid coal. When this band finally breaks somewhere back in the waste, or possibly only slips very slightly on a fracture, the cantilever effect ceases, the rocks in upward strain over the coal are subject to a sudden reversal of stress and the coal ahead of the face is struck a sudden and hammerlike blow… This may explain damage up to 1350 ft. ahead of the wall faces…"

Holland (1958) also described (and illustrated, in figure 2) how failure of hard strata might cause impact loading of large areas behind the pillar line (or working face in a longwall method). He describes impact loading as follows:

"… impact loading, which comes about because stratified mine roof spans an opening by acting as a series of beam or plates. Such structures impose high stress in support areas and perhaps relieve stress in areas behind the support. Then, as illustrated in figure 2, the failure of such a beam or plate or a failure of its support (such as a pillar or pillar remnant) can cause a high impact load on the pillar adjacent to the failed support, or, if the roof beam actually fails, on an area behind the pillar. Action such as this may cause a rock burst at the pillar line or at a place considerably removed from a pillar line."

Holland also cautions that "this mechanism has not been comprehensively analyzed" – a caveat that still applies. Indeed, no convincing analysis of this mechanism is known to the authors, despite the availability of sophisticated numerical modeling tools. Nonetheless, this concept continues to be the "state-of-the-art" description of this type of bump in contemporary works (e.g. Peng, 2008).

Holland presents a number of bump cases from which he deduced this mechanism, including a large event that caused extensive damage behind the pillar line while leaving the pillar line undamaged (figure 3).

Campbell (1958) provides a number of similar bump cases from the Springhill Mine. The first of these occurred Dec. 6, 1924 (figure 4). Damage, marked by crosshatched zones and letters, occurred primarily in levels developed on strike, and was described as "rails were thrown up against the roof by the eject coal and pavement [floor] strata." This case differs a bit from Holland's example in that that pillars were not fully developed before retreat. Also, the damage is reported as originating from failure in the floor, rather than the roof.

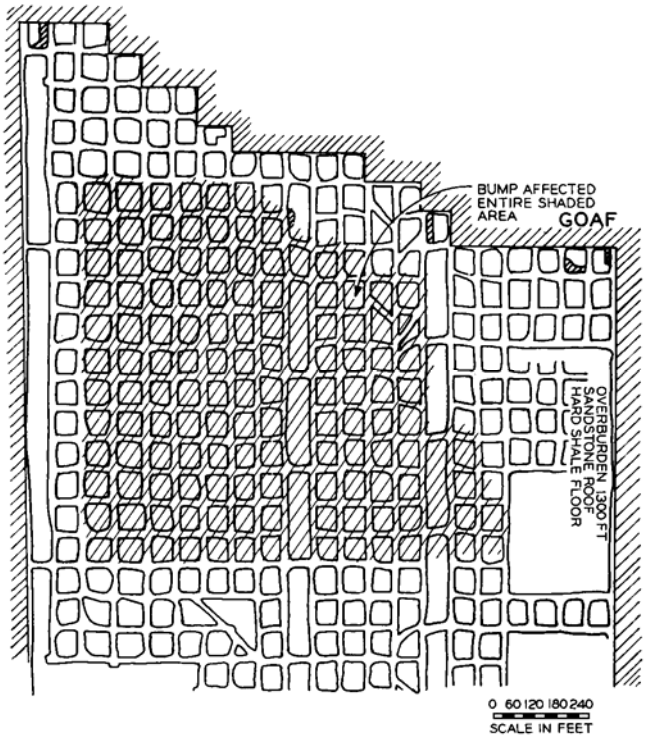

Figure 3 A very large district bump described by Holland (1958) spared the pillar line but produced several thousand tons of debris in areas behind in this un-named mine. Shading on pillars adjacent to the gob in this drawing show active mining. Orientation was not given.

Holland began with the assumption that the strong, brittle stratum that drives failure forms the immediate roof. However, the proposed mechanism is equally plausible for a key bridging stratum located in the floor, at least until the gob develops sufficiently to confine the floor.

Longwall mining was introduced at Springhill in August of 1926 with starting of the 220 ft wide 5700 and 5900 East longwalls (Herd 1930), in an attempt to control bump hazards. Longwalls were developed on dip with levels (gateroads) developed on strike for access to the wall. On Oct. 12, 1928, an event damaged a level for a length of 1350 ft, starting a little more than 150 ft from the wall, which was not affected. As was the case in 1924, damage was characterized by "ejected coal and pavement [floor]," suggesting the basic district-bump mechanism had not changed with the change in mining method. In general, Campbell (1958) found that "the most dangerous zone was on the levels for a distance of several hundred feet from the face."

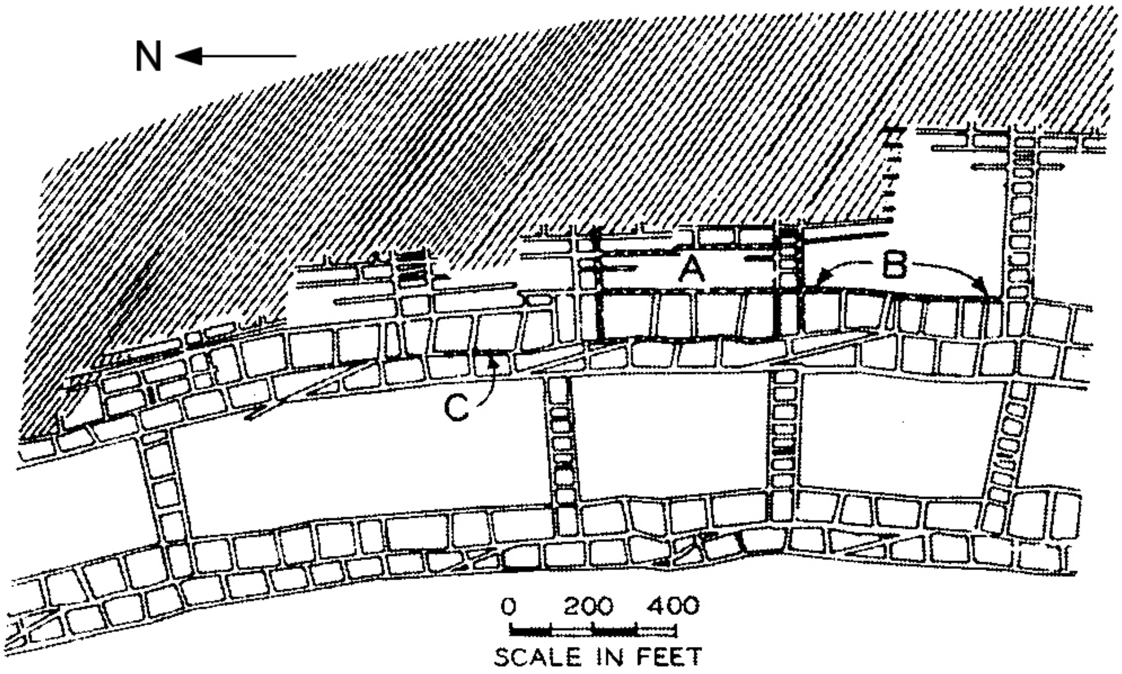

Figure 4 Location of damage from a large bump at Springhill Mine, Dec. 6, 1924. Damage to levels is marked by crosshatched zones and letters. After Campbell (1958).

V. Discussion and Conclusions

This paper presents historical cases of large bumps with regional impacts on coal mines that fall into two classes by mechanism. These are (1) slip along faults in the overburden and (2) fracturing of strong strata above, or below, the coal seam. While these general mechanisms have been identified, detailed understanding is lacking. Both failure modes produce dynamic loading of mine opening perimeters (roof, rib, floor) and both impact areas outby the retreat line. The character of dynamic loading, however, differs significantly.

In the first case, the low frequency seismic shaking over large areas is typical of mining induced seismic slip of a pre-existing fault. Peak particle velocities in such cases are relatively low and can be handled by many support systems, even those dating from 1958, as is evident in recommendations put forward by Peperakis.

In the second case, the relatively severe but more focused impact loading is typical of seismic rupture of hard, brittle rock. The high frequency component of dynamic loading creates high peak particle velocities that challenge support not specifically designed for such loading. Even the best support is often reduced to controlling rather than preventing damage. Application of the recommendations put forward by Peperakis in this case would be relatively futile.

Other regional scale failures have been addressed by companion papers, including a review of sudden floor heave events in deep western coal mines (Maleki et al, 2009), and a review of large scale collapse of overburden over evaporite mines, many of which involve overburden remarkably similar to that over some deep coal mines (Whyatt and Varley, 2008). The possibility of other mechanisms is being investigated.

All of these mechanisms need to be considered when examining potential bump hazards in deep coal mines, particularly those mining within hard strata. While uncommon, these mechanisms are well represented in the historical record. The next step is to apply modern geomechanics tools, particularly numerical methods, to gain a better understanding of these mechanisms, factors that influence the likelihood of occurrence, and their control. This step is being undertaken by an ongoing NIOSH research project with the assistance of collaborators in industry and academia.

While more needs to be done to fully understand these mechanisms and incorporate this understanding into the design of mines, it is clear that the more we can understand the causes and effects of these mechanisms, the better we can anticipate, provide protection from, and reduce the chances of, their occurrence.

The focus on mechanism is a characteristic of modern rock mechanics. In part, this is a reflection of advances in our ability to compute, but it is also a realization that all rational ground support criteria depend on failure mechanism. This applies to empirical as well as analytic methods.

The empirical approach is well-tested and useful. It is not, however, independent of mechanism. Rather, it collects successes and failures for common conditions with the implicit assumption that the failure mechanism (or mechanisms) is consistent. Any departure from common conditions and failure mechanism(s) may invalidate the empirical rule.

Bieniawski (1989, p. 66) addresses this issue by describing the data base underlying empirical rock mass classification systems he reviews and states “The data base used for the development of a rock mass classification system may indicate the range of its applicability.” Peng (2008, p. 249), in discussing empirical pillar design formulas: “the reliability and applicability of the formula selected depends on the quality of, and range of mining and geological conditions covered by, case histories used in the calibration.”

Control mechanisms are, necessarily, also closely linked to failure mechanism. This link may be implicit if the control mechanism has been developed by trial and error, or if it is specified by an empirical criteria, but the danger of extrapolation holds nonetheless. Put plainly, application of the wrong control mechanism to a given failure mechanism may increase, rather than decrease, the hazard to miners.

These cases show that rare but potentially disastrous bumps are caused by mechanisms different from local pillar bumps and outbursts, and can originate outside the coal seam. In other words, regional scale bumps are not simply large versions of local pillar bumps and outbursts. Protecting against these regional scale events, then, requires explicit consideration of other mechanisms. Thus, at the fiftieth anniversary of the 1958 Bump Symposium, it is appropriate to review these rare but potentially disastrous types of bumps.

VI. Postscript

The threat posed by regional scale bumps was, sadly, underscored shortly after the 1958 symposium by a truly catastrophic bump in October of that year at the Springhill Mine. Campbell (1958) set the stage for this event in the conclusion to his paper as follows:

> "To date some 500 bumps have been recorded in No. 2 mine. Many miners have been injured, and too often lives have been lost. It has been fortunate that in most cases bumps have occurred when men were absent from the affected areas."

He also notes "three retreating longwalls – the 13,000, 13,400 and 13,800 walls – are in operation today." These walls were operating in hard strata under up to 4,350 ft of overburden.

Fortune ran out for the No. 2 mine on October 23rd of 1958, when a disastrous bump hit levels accessing all three walls, and portions of the faces, killing 75 miners. Notley (1984) described the damage as follows:

> "The final bump occurred at 8:06 p.m. and affected all three longwall faces. The pavement of the four levels leading to the faces was heaved for up to 400 feet from the face and coal bursting from the ribs completely filled the level for distances ranging from 90 feet on the 13,400 level to 434 feet on the 12,600 level. On the longwall faces the floor had heaved, smashing many of the timber packs, and in some places raising the conveyor pans to the roof. Coal burst from the face completely filled most of the face area."

Survivors were rescued from pockets along the face at the levels, after arduous excavation of heavily damaged levels (figure 5). This bump was later examined in a Ph.D. thesis summarized by Notley (1984), but the mechanism, including any similarity to those proposed for earlier events by Herd (1930) and Holland (1958) was not explored.

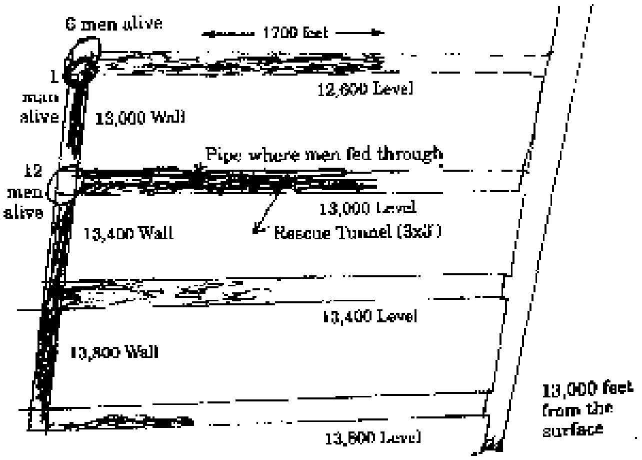

Figure 5 Plan view of damage (shaded regions) caused by the 1958 Springhill bump which claimed 75 lives. Survivors were rescued from relatively undamaged pockets at intersections between the longwall and the upper two levels. Gob was located above and to the left of the walls shown. The sketch was made by Dr. Arnold Burden (2008), a Physician assisting in the rescue, is not to scale. North is to the left in this sketch.

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