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Microseismic Data Analysis of Failure Occurrence in a Deep, Western U.S. Coal Mine: A Case Study

By Richard O. Kneisley

BUREAU OF MINES

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ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	yr	year

MICROSEISMIC DATA ANALYSIS OF FAILURE OCCURRENCE IN A DEEP, WESTERN U.S. COAL MINE: A CASE STUDY

By Richard O. Kneisley[1]

ABSTRACT

Microseismic activity observed in both the laboratory and underground indicates that a quiet period, associated with the closure of existing fractures and strongly influenced by coal seam microstructure, occurs prior to coal bumps. Field studies conclude that coal mine bumps occur against a background of this so-called microseismic calm.

This Bureau of Mines report summarizes microseismic activity associated with face bumps and floor bursts in a deep, western U.S. coal mine. Results conclude that while bumps are often accompanied by panel-wide increases in microseismic activity, bumps are not only preceded by a localized decrease in activity, but occur within these quiet zones. The results of this study concluded that microseismic activity may be applicable to the global detection of potential bump-prone zones, but that future studies are necessary to confirm these findings and to improve the techniques for evaluating stress control effectiveness.

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INTRODUCTION

This report summarizes a Bureau of Mines microseismic study in a deep, western U.S. coal mine, which has historically experienced face bumps and floor bursts in both room-and-pillar and longwall sections. This report is written as part of a Bureau research effort whose objectives are to gain a better understanding of coal mine bumps and to integrate different approaches–experimental, rock mechanics instrumentation, and acoustic emissions–to ultimately provide to the mining industry practical means for detecting and alleviating conditions contributing to coal bumps. Previous studies by the Bureau, academia, and both U.S. and foreign investigators have identified those conditions and mining practices that contribute to or exacerbate coal mine bumps. These studies have suggested both static and dynamic loading mechanisms to explain bumps *(7-8, 12)*.[2] While the actual causes are complex and the results of specific studies differ, it is generally agreed that (1) high-stress concentrations, regardless of cause, are a significant factor, and (2) under bump-prone conditions, the mining method or technique should transfer the high stress away from the active mining front. Experimental and in-mine microseismic studies also indicate that the often observed quiet period prior to a coal bump is due to closure of existing fractures, and is highly dependent upon coal seam microstructure, and that bumps and bursts occur against the background of this so-called microseismic calm *(14-15, 22, 27)*.

This in-mine microseismic study relied heavily upon previous and ongoing Bureau investigations at this mine. The other studies concluded that face bumps and floor bursts were due to high stresses, and a major tailgate floor burst was preceded by anomalously high shield support load *(10)*. This study determined that while overall microseismic activity in the mining panel increased during or prior to observed face and floor bursts, microseismic activity decreased in the failure areas. Since microseismic activity is attributed to fracture-induced energy releases, it is hypothesized that these quiet zones represent localized, nonyielded areas or strong points, which failed violently, releasing stored strain energy when mined into. While not all quiet zones resulted in bumps, all documented face bumps and floor bursts occurred in quiet zones. Results of this study imply that monitoring of acoustic emission activity may provide a means for globally detecting local high-stress zones and, with further refinement, may provide a means for assessing in-mine stress control techniques.

BACKGROUND

BRIEF SUMMARY OF THEORY

The microseismic method, first developed by the Bureau of Mines in the late 1930's *(2-3, 23)*, is based on experimental evidence that rock under load undergoes small-scale displacements, which result in the release of seismic and sometimes acoustical energy.

Laboratory testing of rock indicates increased noise rate with increased stress, the rate increase becoming pronounced as the ultimate stress is approached. Under loading, rock attempts to reach a state of equilibrium through small-scale displacement adjustments. If equilibrium cannot be achieved, these adjustments become more frequent and are characterized by releases of seismic and acoustic energy *(2)*.

While a pattern of increased activity followed by a quiet period immediately prior to bumps underground has been noted by several investigators, this behavior has not been consistently reproduced in the laboratory *(14, 19, 22)*. While some bumps and/or bursts are preceded by rapid increases in the microseismic noise rate; others show no rate increase, and sometimes while rapid rate increases are measured, no bumps and/or bursts occur *(2-3)*.

EXPERIMENTAL STUDIES

Laboratory studies of rock indicate that as the ultimate load is approached, microseismic activity increases. However, tests on highly cleated (fractured) coals show increases in the acoustic emission (AE) rate, which do not coincide with failure *(22)*. McCabe *(22)*proposes that the dominant stress wave frequency is inversely proportional to crack length, and in a fractured coal, as ultimate failure is approached, the cracks coalesce and wave frequency decreases. McCabe further suggests frequency may be a more reliable indicator of potential failure than event rate.

Chugh *(4)* also noted a trend of decreasing frequency with increased stress; however, while microseismic activity increased with load, reduced activity prior to failure was not observed. The authors hypothesize that high-frequency, short-duration signals relate to coal fracturing, while low-frequency, long-duration signals relate to sliding along shear surfaces.

Khair *(15)*, from tests on an Illinois coal, correlated three distinct AE phases to stress-strain characteristics: (1) a high-AE rate associated with a high deformation rate, (2) a decreased AE rate following initial movement with a degree of material compression, and (3) a very high AE rate with increased stress, and corresponding to each local failure.

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

Several investigators have compared pillar loading with the behavior of a soft compression testing machine *(6-7, 19, 25-26)*. Basically, if pillar stiffness exceeds the local mine stiffness, violent pillar failure occurs, and if pillar stiffness is less than the local mine stiffness, gradual failure occurs. The local mine stiffness depends upon the physical properties of the strata, local and regional geology, and the geometry of the mine workings *(7, 19)*. Babcock *(1)* concluded from tests of 11 different coals that stress can produce bumps in many coals if the constraint necessary for pillar survival is suddenly lost. Under confinement large amounts of stored energy can be suddenly released, but with yielding, negligible amounts of strain energy are released.

Stress control at the study site has been simulated using computer modeling. Haramy *(11)* reports on analyses of eight different face destressing patterns, ranging from small, isolated portions through full-face. In general, partial face destressing induces stress transfers onto the nondestressed portions of the face. Dangerous high-stress conditions could result from partial destressing, and the authors recommend complete face destressing to minimize stress levels near the face *(11)*.

MINE STUDIES

Underground studies have been performed in an increasing number of coal mines to locate potential areas of instability and high stress, and to evaluate stress control techniques *(20)*. The following summaries, while hardly comprehensive and in some instances somewhat contradictory, are useful in illustrating applications of AE-microseismic activity.

Large-scale microseismic research in Polish coal mines began in 1963; these investigations have contributed to reducing bumps in the Upper Silesian Coalfield from over 300/yr to only about 20/yr *(27-28)*. The Polish studies indicate a period of increased microseismic activity followed by a period of decreased activity prior to coal bumps, and that the bumps occurred on the background of this so-called microseismic calm.

Microseismic studies in the United States have investigated both room-and-pillar and longwall mining. Leighton *(18)*, from an investigation of room-and-pillar mining, monitored dramatic increases in microseismic activity as mining approached a fault. As a result of this study *(18)* a better mine layout and extraction sequence were established to minimize bumping *(16, 18)*. Analysis of data from the Olga No. 2 Mine near Caretta, WV indicated an increase up to one order of magnitude in microseismic activity prior to a massive bump that damaged approximately 100 pillars *(5)*.

Lessley *(19)* utilized microseismic and convergence data to analyze pillar extraction in a southwestern Virginia coal mine. The results of this thesis *(19)*, which also includes a most comprehensive review of coal bump theory and studies, determined that bumps generally occurred in the area of highest static loading, tended to occur when pillars approached a critical size, and occurred in pillars adjacent to areas of high convergence.

Microseismics has also been used to evaluate destress blasting. In France, a delay in energy release, a period of quiet indicating a potential dangerous energy accumulation, is used to identify areas for destressing *(14)*. Will *(29)* determined that high levels of microseismic activity corresponded with large volumes of cuttings from boreholes. Activity was greatest inby the face, but decreased and remained at a low level, indicating successful destress drilling *(14, 29)*. During destress drilling, source locations were concentrated in a small zone near the borehole, indicating the local effectiveness of the drilling *(29)*.

DATA ANALYSIS

Microseismic data analyses, as an initial step, include both the location of the rock noise sources, and the rate at which the noises occur. Other analyses may include energy release rates and energy per event and, at a more advanced level, analyses of the microseismic wave form to determine the failure mechanism(s) and stress conditions within the rock. This report summarizes only the analyses of event location and rate with respect to observed, documented failures along the longwall face and tailgate.

Rock noise rate versus time may be used to make judgments regarding structural stability. The classic, anomalous microseismic pattern is a sudden, high rate followed by an equally dramatic decrease in activity *(2, 17, 21)*. While audible rock noise often warns of imminent danger, there is often a longer period of subaudible noise generated in rock under stress *(2-3)*. The fact that the microseismic noise rate increases as failure approaches, provides the basis for detecting and delineating potential problem areas. The method is not quantitative and requires experience to interpret; however, interpretation is facilitated by the fact that the near-failure noise rate may be 10 to 100 times the background level, or stable noise rate *(3)*.

Analysis of microseismic data also requires the accurate determination of each rock noise, or microseism source location. Several methods may be used to locate noise sources provided that geophone locations, arrival times, and especially in situ seismic velocities are accurately known. As seismic velocity may vary considerably with direction, it is important that seismic surveys be performed to accurately determine source locations and velocities *(3)*. Detailed monitoring, requiring separate, calibrated velocities for each geophone, may be desirable, but correctly selecting the geophone-specific velocity becomes a complex problem, and experience suggests that using average seismic velocities may be sufficient *(2-3)*.

LIMITATIONS

Presently, application of the microseismic technique in coal mines is limited by the accuracy of individual source locations and by the development of automated, real-time analysis instrumentation. The Bureau is presently testing new state-of-the-art digital hardware to record and analyze energy and spectral information in near real-time *(5)*. Source location limitations arise from site geology, material anisotropy, and often limited access that prevents accurate, in situ seismic velocity determinations and complete coverage of the study area. Ideally, the geophone array should be three-dimensional and surround the study area. The array at this study site was not only planar, but the advancing longwall face prevented geophone installation inby the headgate.

STUDY SITE

THE MINE

The mine, located in western Colorado, operates at a depth of nearly 3,000 ft, with other active mine workings located approximately 400 ft above the study panel. The 10-ft-thick coalbed is mined using the advancing longwall mining method. The long axis of the panel parallels the strike, and the 800-ft-long face dips at approximately 12°. Upslope from the panel tailgate are a previously mined longwall panel and old room-and-pillar workings, figure 1 *(10)*.

MINE GEOLOGY

The mine is in the Coal Basin Seam. The immediate roof, approximately 5 ft thick, is composed of siltstone, shale, and sandstone layers and is overlain by a 9-ft-thick competent sandstone layer that does not readily fracture. The floor consists of a variably thick, 4- to 10-ft, strong shale-sandstone layer overlying another 10-ft-thick coal seam. Figure 2 shows a geological column from the panel headgate. Two well-defined faults were mapped across the longwall panels approximately 2,500 ft inby the starting room *(9-10)*.

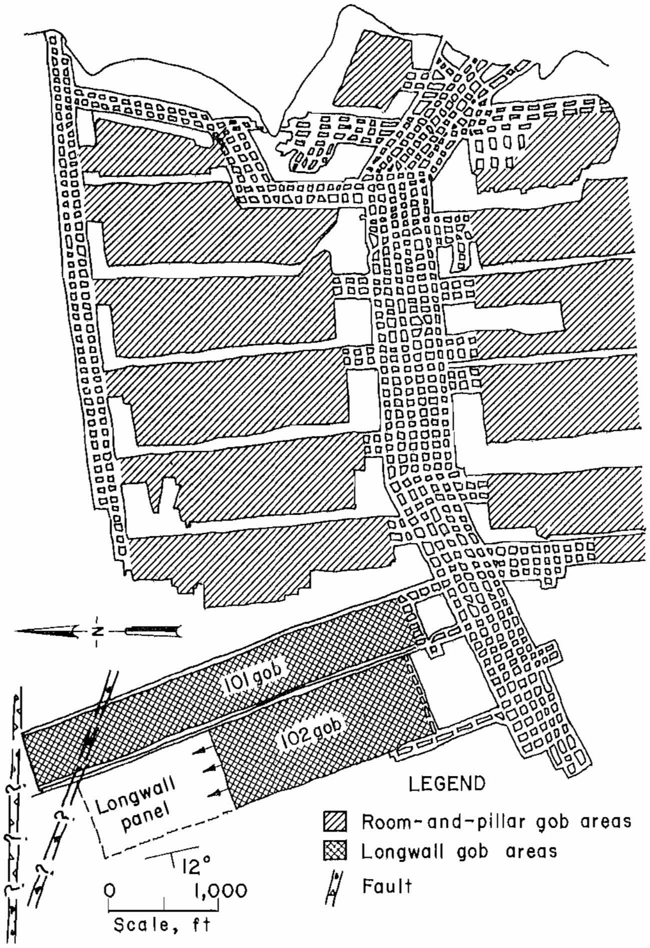

Figure 1.—General mine layout.

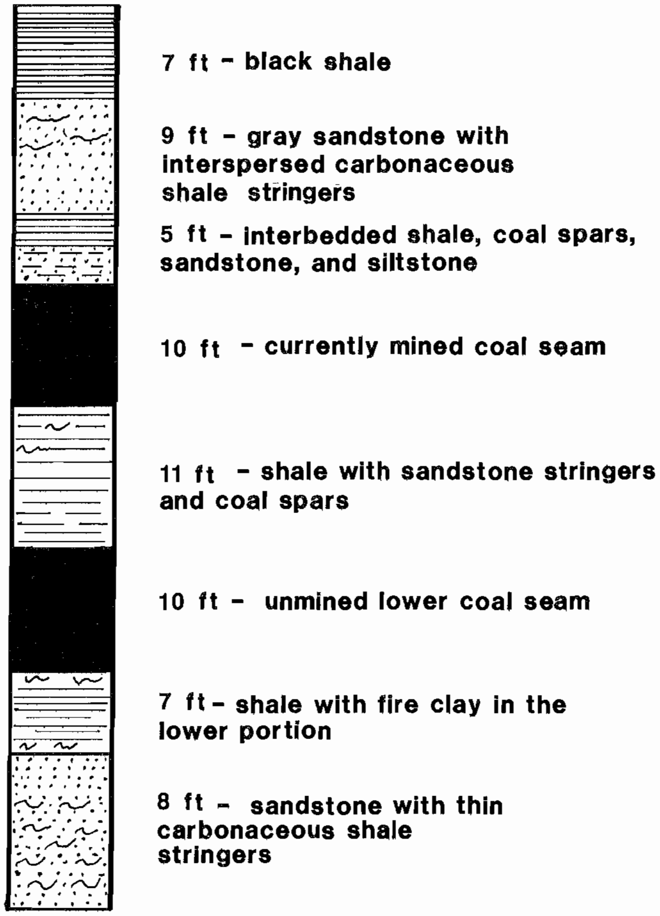

Figure 2.—Study site stratigraphic column.

BUMP AND BURST OCCURRENCES

Because of thick overburden and the existence of strong roof and floor strata, coal bumps and rock bursts have occurred in this mine using both room-and-pillar and longwall mining methods. In 1969, mine management recognized that a change in mining method was necessary. Room-and-pillar mining at this depth had become impractical due to safety and mining costs. Advancing longwall was selected because (1) the self-advancing face would require minimal narrow heading development work, (2) most of the longwall face would be stress relieving because the face could elastically expand, and (3) methane emissions would be less cyclical *(13, 24)*.

Prior to 1983, stress relief by volley firing was practiced to destress the longwall face corners and mining sections at depths exceeding 2,000 ft. Soon after mining began on the longwall panel, face bumps occurred. From January through September 1983, several coal bumps and floor bursts occurred as a result of either mining or destressing (fig. 3).

On April 20, 1983, after 618 ft of advance, a major floor burst occurred. The resulting, instantaneous floor heave extended approximately 1,200 ft along the tailgate and 300 ft along the face. This event disrupted ventilation, stopped production, and damaged the legs on over forty 500-ton-capacity[3] shield supports. Subsequently, mine management instituted a comprehensive program consisting of high-stress area detection via the drill-yield method and relief by volley firing to control face bumps and tailgate floor bursts. The panel advanced 3,900 ft to completion with no reported face bumps; those rock bursts which did occur were in the tailgate and involved floor heave *(10)*.

MICROSEISMIC STUDY

This report summarizes microseismic activity monitored during the first 1,000 ft of mining on an advancing longwall face in the study site. During this period, five face bumps and two large floor bursts occurred. As a result of the first floor burst, an intensive program of full-face destressing and volley firing of the tailgate floor was conducted to enable completion of the mining panel. Field studies of strata movement, pressure change, and support load concluded that the initial floor burst was to some degree due to high loading of the tailgate *(10)*. Face support load, while revealing cyclic behavior (periodic weighting) generally attributed to breaking of the roof, showed that the near-tailgate corner of the panel was highly stressed while the longwall face was advanced to a distance of approximately 145 to 150 ft, prior to the floor burst event.

This analysis summarizes microseismic event count and source locations to investigate the following:

1. General microseismic activity associated with mining,
2. Microseismic activity associated with documented face bumps and floor bursts, and
3. Microseismic activity associated with destressing.

GENERAL MICROSEISMIC ACTIVITY

General microseismic activity was summarized using both the number of locatable events (events per day) and the location of these seismic sources. Source locations were determined using the generated block method (GBLK) that requires geophone coordinates, seismic velocities, and fixing the real time of the data record prior to generating solutions *(3)*.

The study area is divided into blocks which are further subdivided into arbitrarily chosen intervals; this study used a 50-ft interval.

Locatable events are shown in figure 4; the study can be broadly divided into three intervals: (1) February through April, a period marked by headgate area face bumps and the first major floor burst on April 20; (2) May through late August, when intensive face and floor destressing were begun, but no bumps or bursts occurred; and (3) late August through September, a period of gradually increasing microseismic activity, culminating in a second major floor burst in part due to incomplete destressing of the floor. As observed from other in-mine studies, bumps were accompanied or, in some cases, preceded by increased microseismic activity; however, activity increases of equal or greater magnitude were also recorded during May through September, although no failures occurred.

Microseismic source locations for each month of this study are shown in figures 5 and 6; the distances refer to face positions at the first and last of the month, respectively. During February (fig. 5*A*), microseismic sources were generally located at or inby the face and distributed somewhat uniformly along the face, although gaps appeared in the vicinity of the headgate and tailgate. Microseismic activity in the panel is attributed to mining-induced and forward abutment pressure-induced fracturing. Events behind the face, gob events, are hypothesized as being due to fracturing of the roof; as the geophone array was planar and did not include vertical control, gob event locations represent projections onto the horizontal (xy) plane.

March activity (fig. 5*B*) was similar to the previous month; again, face events were uniformly distributed across the face, but the headgate and tailgate remained relatively quiet. Gob events associated with fracturing of the overlying roof strata continued on a wider front and were attributed to enlargement of the undermined roof cavity.

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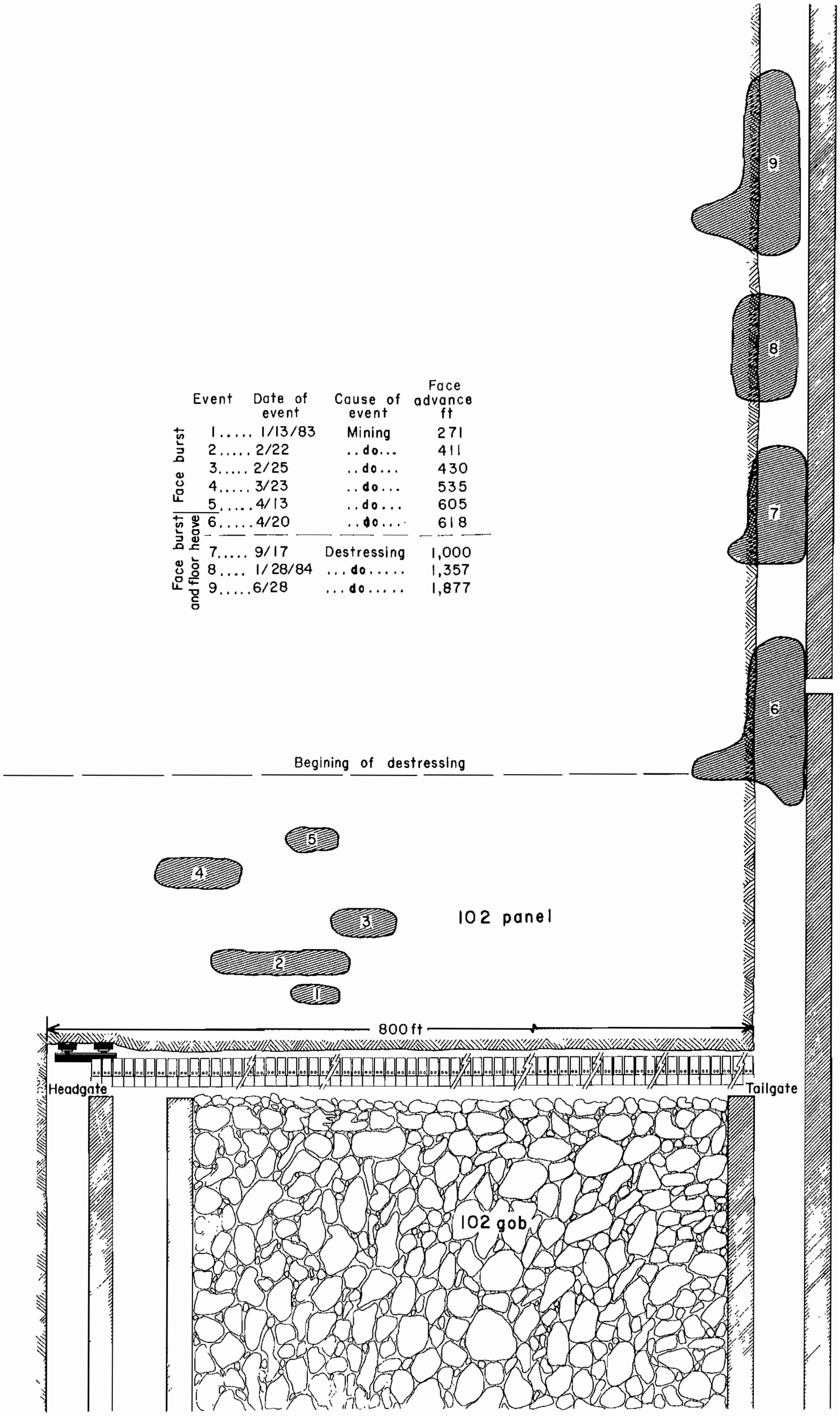
[3] In this report, "ton" indicates 2,000 lbf.



	Event	Date of event	Cause of event	Face advance ft
Face burst	1.....	1/13/83	Mining	271
	2.....	2/22	..do...	411
	3.....	2/25	..do...	430
	4.....	3/23	..do...	535
	5.....	4/13	..do...	605
Face burst and floor heave	6.....	4/20	..do...	618
	7....	9/17	Destressing	1,000
	8....	1/28/84	...do.....	1,357
	9.....	6/28	...do.....	1,877

Figure 3.—Face bumps and floor bursts during study.

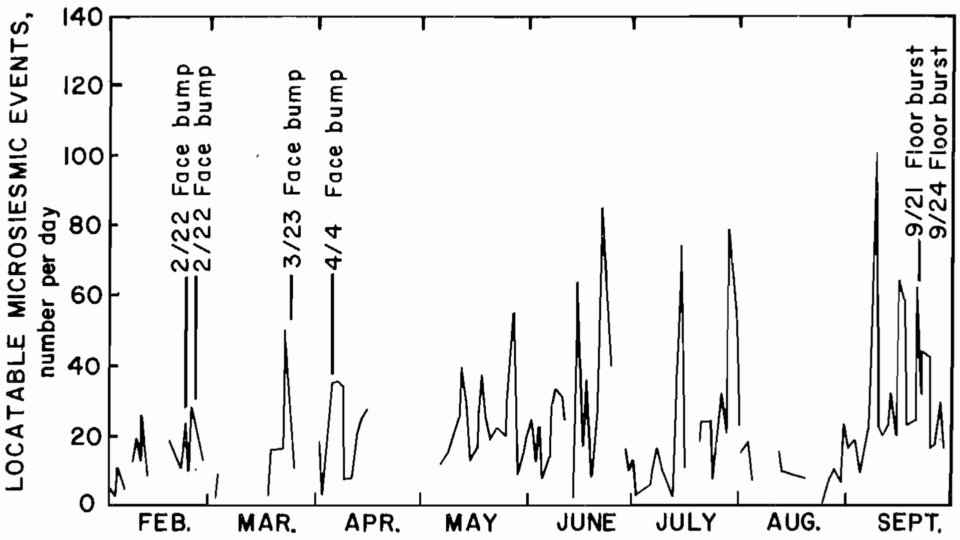


Figure 4.—Locatable microseismic events during study.

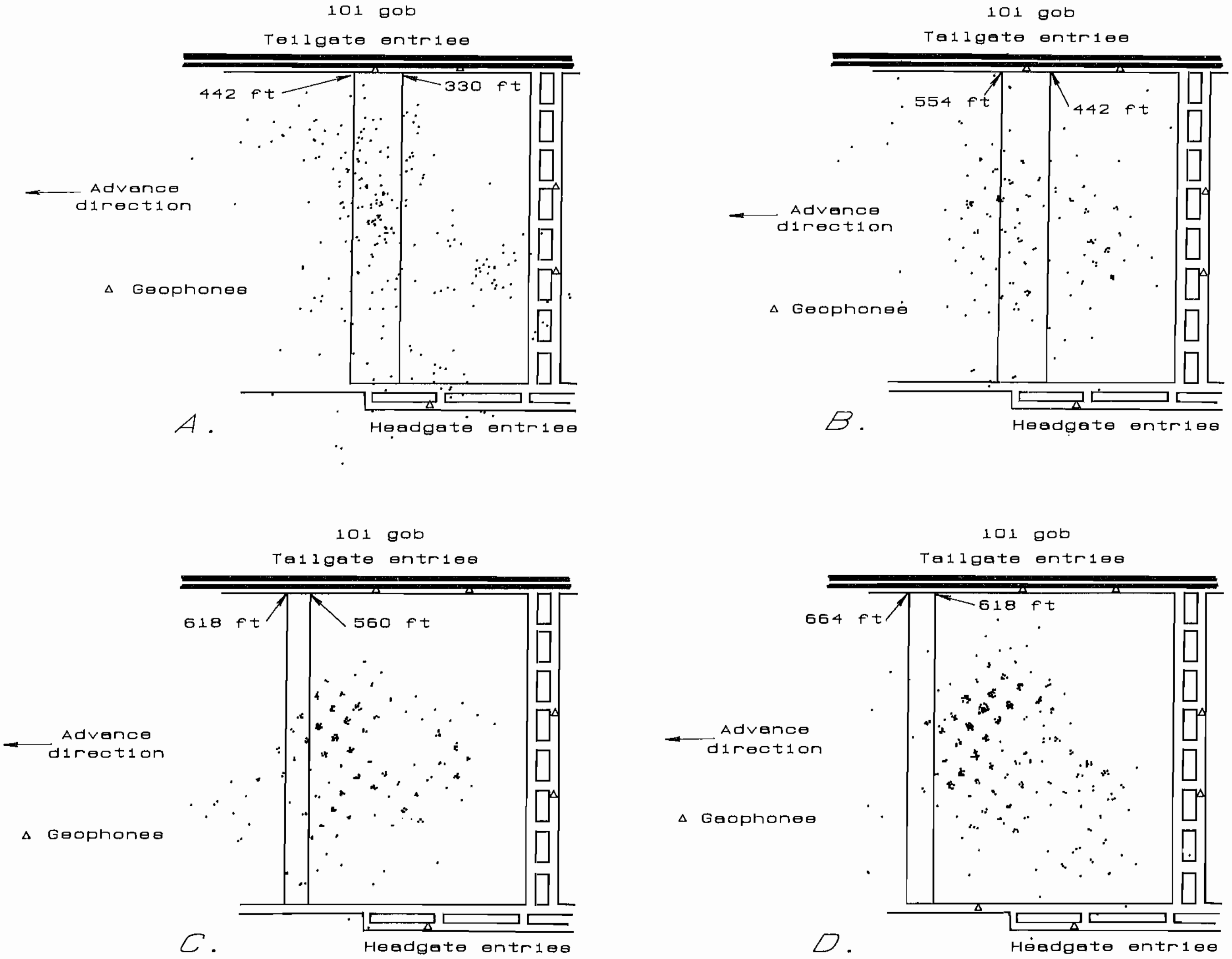


Figure 5.—Microseismic source locations, February through May.

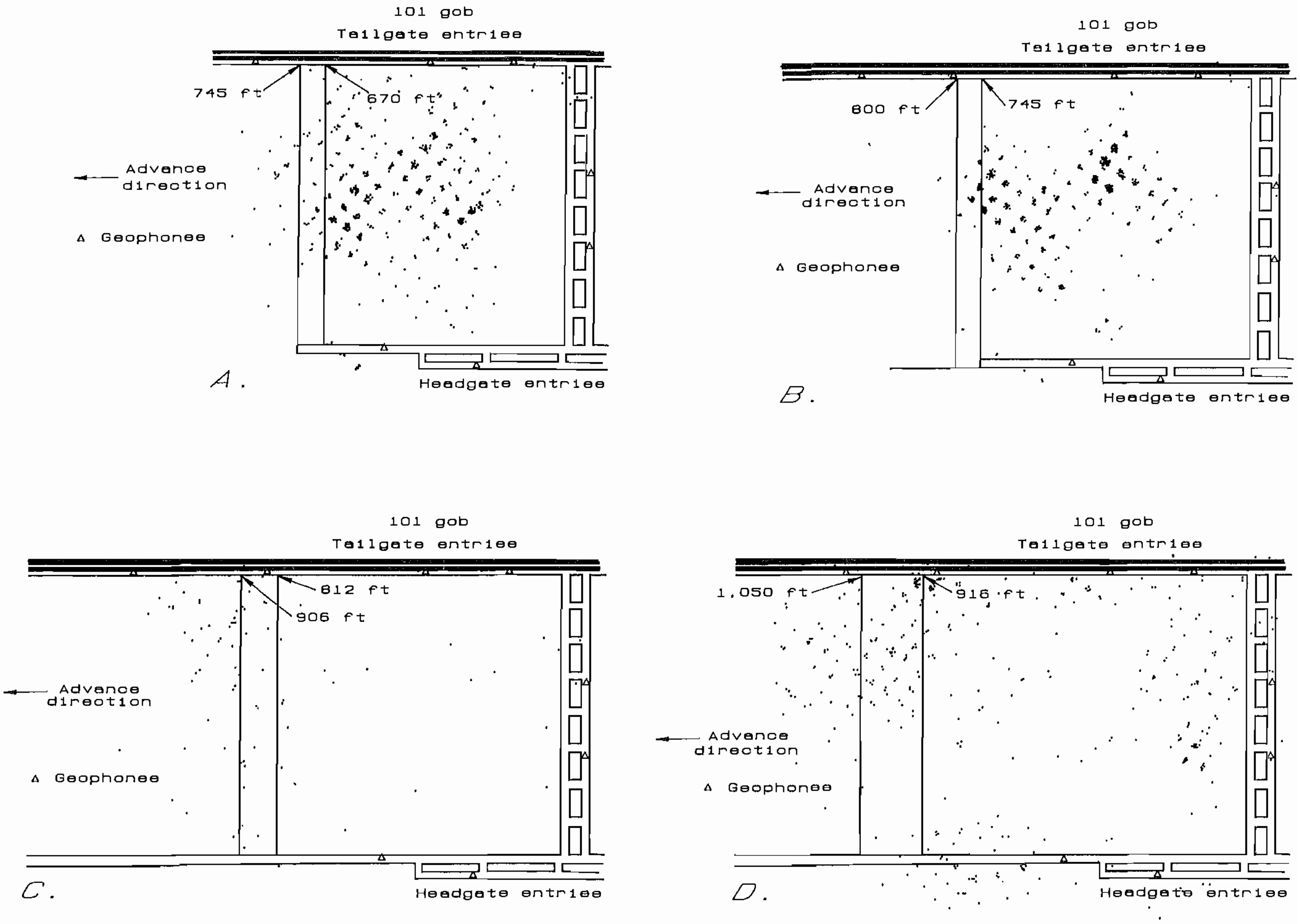


Figure 6.—Microseismic source locations, June through September.

April events (fig. 5C) were limited to the first 2 weeks; the monitoring system was shut down 1 week prior to the major floor bursts, and monitoring did not resume until early May. The major floor burst, occurring on April 20 after 618 ft of advance, was apparently centered about 80 to 100 ft inby the tailgate. Instantaneous floor heave, up to within 1 ft of the previously 9- to 10-ft high roof, extended approximately 1,200 ft along the tailgate entries and up to 300 ft along the face *(10)*. These limited April data indicate that microseismic activity ahead of the face was concentrated over the center of the longwall panel and continued over the gob. The tailgate, which experienced the major floor burst after 618 ft of advance, however, showed little or no activity prior to the burst. However, Haramy *(10)*, not only measured anomalously high loading of the tailgate shield supports beginning at the face position of about 145 ft before the burst, but also concluded that high stress, possibly due to cantilevering of the main roof, contributed to the floor burst.

Figures 5D and 6A through 6C illustrate microseismic source locations during a period of high-event frequency, but no documented occurrences of face bumps and/or floor bursts. Significant microseismic activity apparently occurred over the previously mined 101 panel gob. These events, which could not be accurately located due to a lack of vertical control and because they were outside the geophone array, are not shown in the source location figures. Following the April 20 floor burst, a program of full-face stress detection and relief and volley firing of the tailgate floor inby the face was initiated. Face destressing was apparently effective as no further face bumps were documented *(10)*. May through August data reveal continued expansion of fracturing over the gob roof and initiation of fracturing over the previously mined 101 panel gob. Although the face was volley fired, little activity associated with blasting-induced fracturing of the coal seam was monitored. The grid-like source locations, especially noticeable for the gob events, are due to panel orientation with the mine coordinate system and to the 50-ft point interval specified for the GBLK source location program. August also reveals a rotation of microseismic activity away from the panel center and gob onto the panel tailgate and adjacent, previously mined 101 panel gob. However, compared with the previous months, the mine was relatively quiet.

September (fig. 6*D*) was the most active month; during this period seismic events increased dramatically over the 101 panel gob and inby the face on the tailgate half of the active panel. A smaller zone of increased activity also occurred behind the headgate and on the adjacent solid coal. Increased activity in and/or above the gob areas was attributed to fracturing of the main roof and to development in the upper mine, approximately 400 ft above.

Summarizing overall panel activity, microseismic sources appear to be related to mining-induced and forward abutment-induced fracturing of the coal seam and to fracturing and/or caving of the roof over the gob; increased activity over the previously mined 101 panel gob and active panel gob are attributed to breaking of the main roof and, to a lesser degree, to development in the overlying seam. No definite trends are apparent regarding face-area activity related to destress blasting. Prior to the large floor burst, after 618 ft of advance, microseismic activity across the face abated and in the tailgate failure area was negligible even though face support loading was anomalously high.

MICROSEISMIC ACTIVITY AND FACE BUMPS AND/OR FLOOR BURSTS

Previous studies, laboratory and especially underground, indicate that coal exhibits a quiet period preceding a bump. Marcak *(21)* has proposed two models that explain the behavior of coal under load. The catastrophic model accounts for most laboratory and in situ tests, which are preceded by increased AE activity. This model, however, assumes rock mass homogeneity and isotropy which in situ only occur locally, and therefore, only local failures are explained by this model. The cascading-coalescing model considers geologic conditions that may limit crack propagation. Decreased microseismic activity, often observed underground, is apparently related to coal seam microstructure. Within individual lithological units stress redistributions occur once cracks reach their maximum possible length. This redistribution tends to close smaller cracks, and future rock mass response is influenced only by the larger cracks. This process enlarges the rock mass volume where cracks can develop and alters rock mass properties. When crack density exceeds some critical value, stress redistribution occurs, and the process is repeated until equilibrium is achieved or a coal bump occurs *(21)*.

Trombik *(27)* observed that bumps in Polish coal mines occur on the background of this so-called microseismic calm. During this study it was observed that while documented face bumps and floor bursts could be associated with increased microseismic activity, periods of equal or even greater activity were monitored when no documented events occurred. Figure 4 shows that microseismic activity during a period of no documented failures, May through August, equalled or exceeded activity associated with floor bursts and face bumps. As event rate did not appear to exclusively be associated with failures and as previous

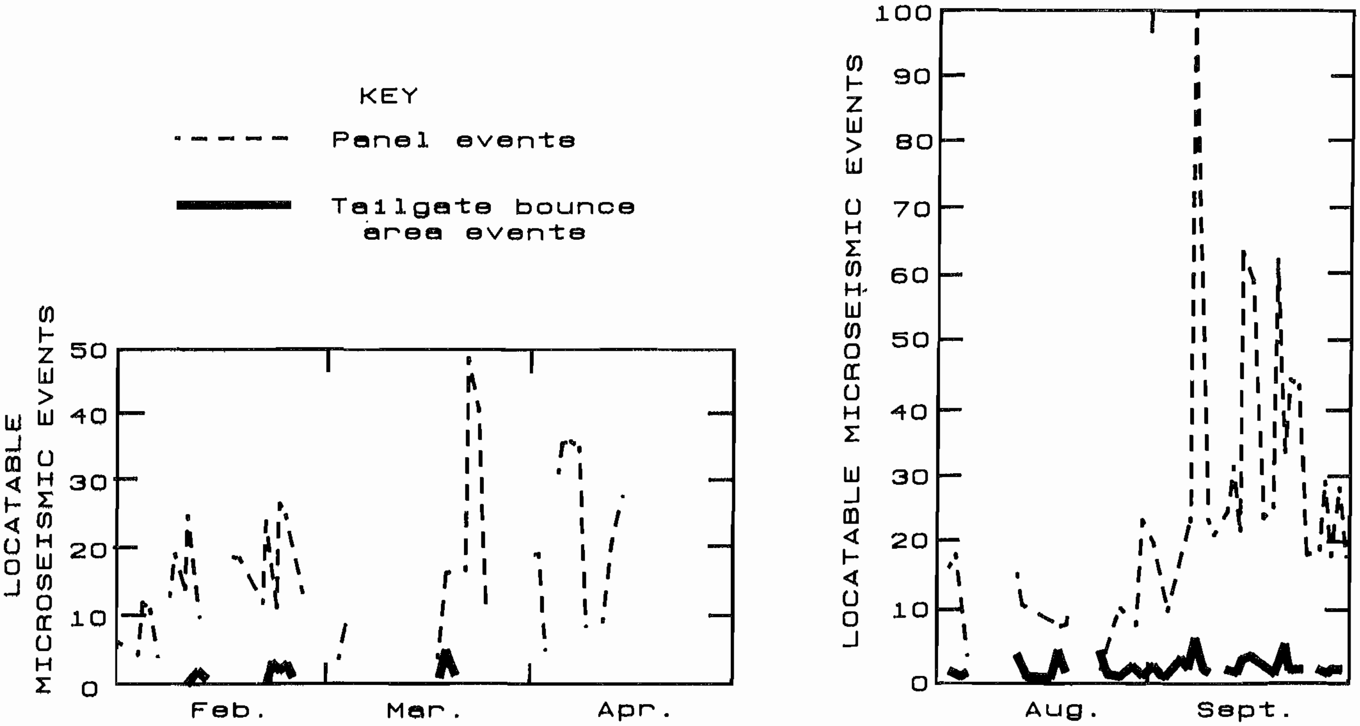


Figure 7.—Panel and failure area microseismic events.

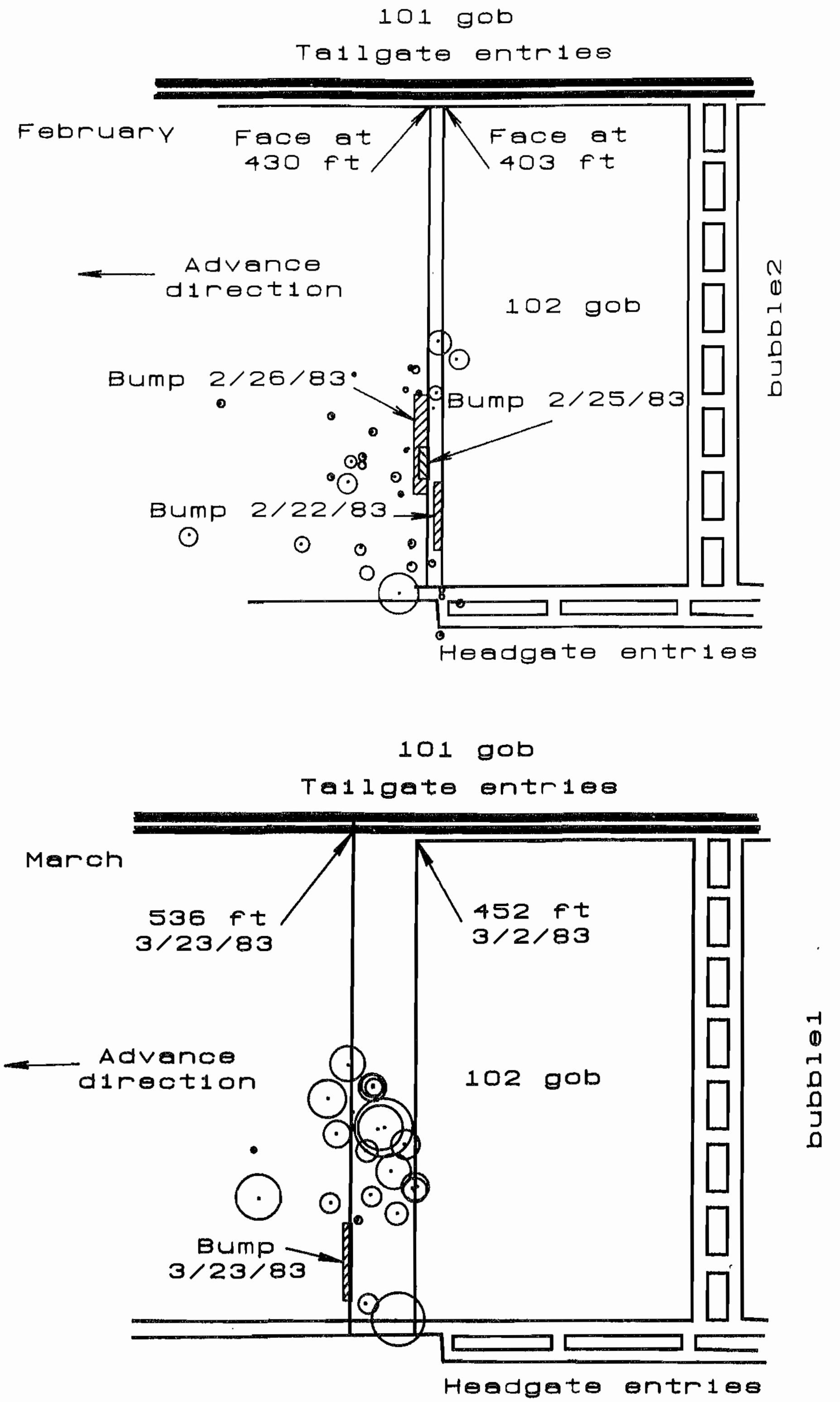


Figure 8.—Microseismic source and face bump locations, February through March.

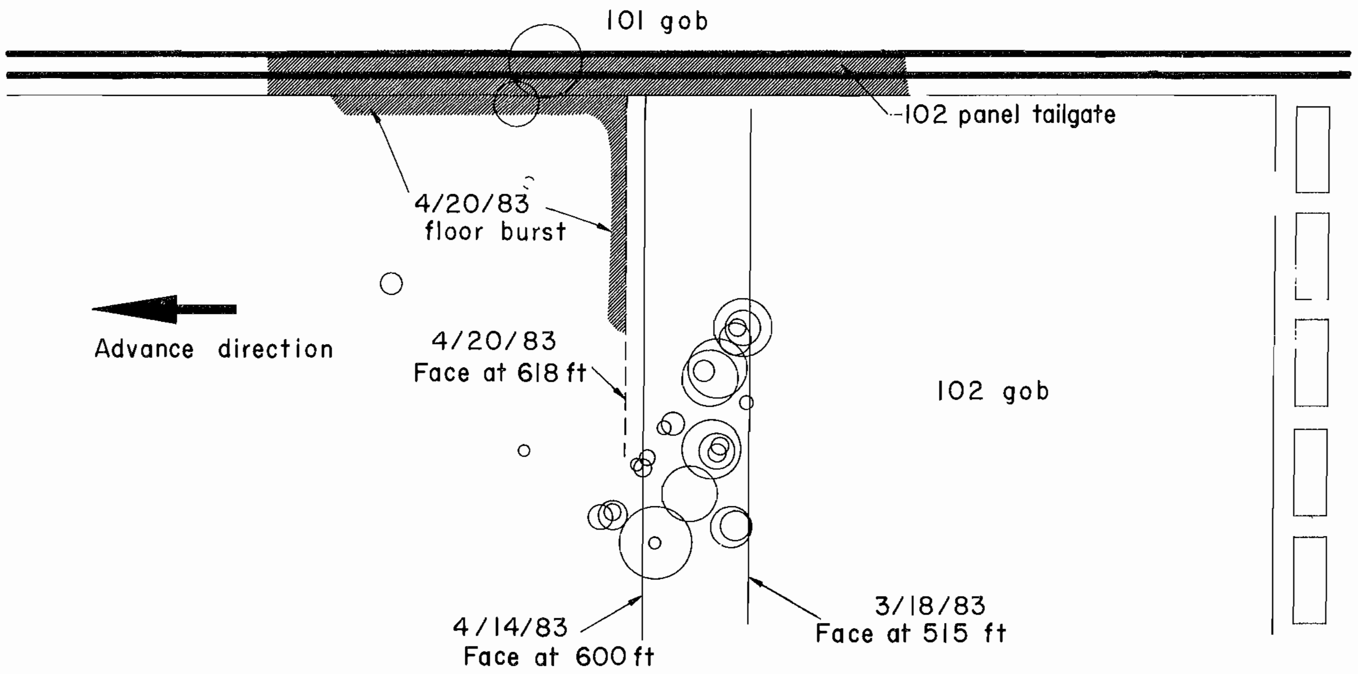


Figure 9.—Microseismic source and floor burst locations, April.

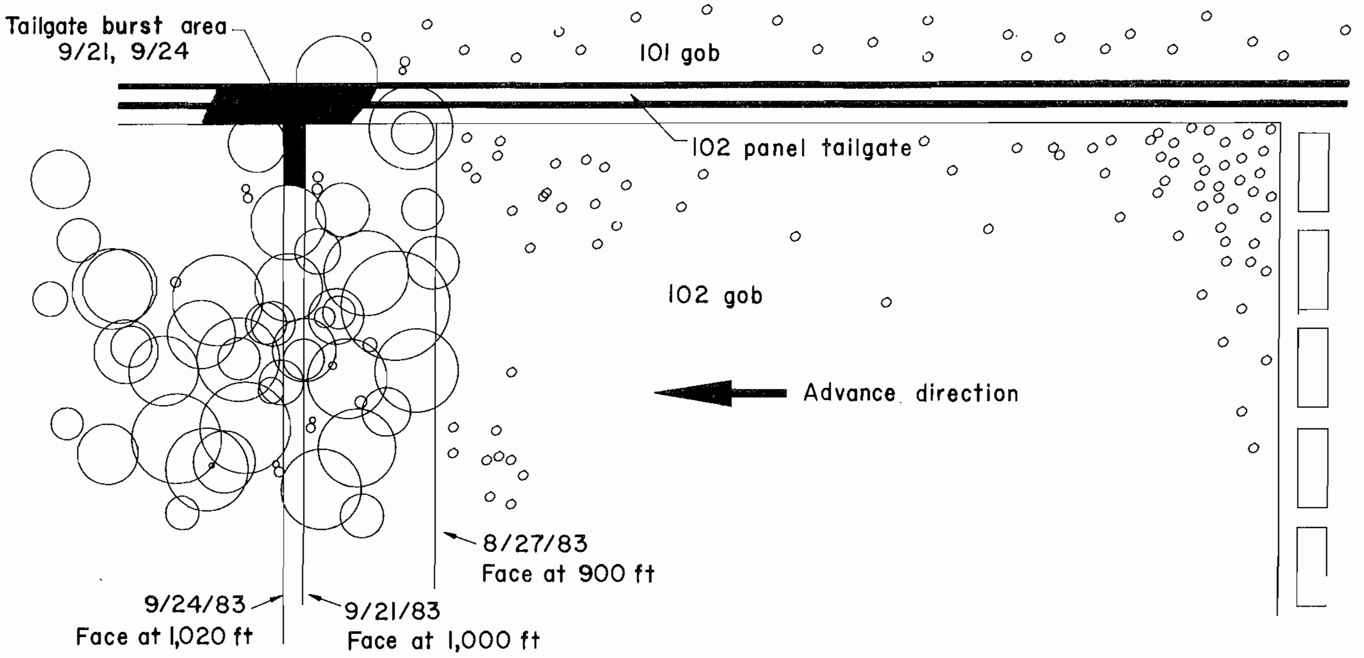


Figure 10.—Microseismic source and floor burst locations, September.

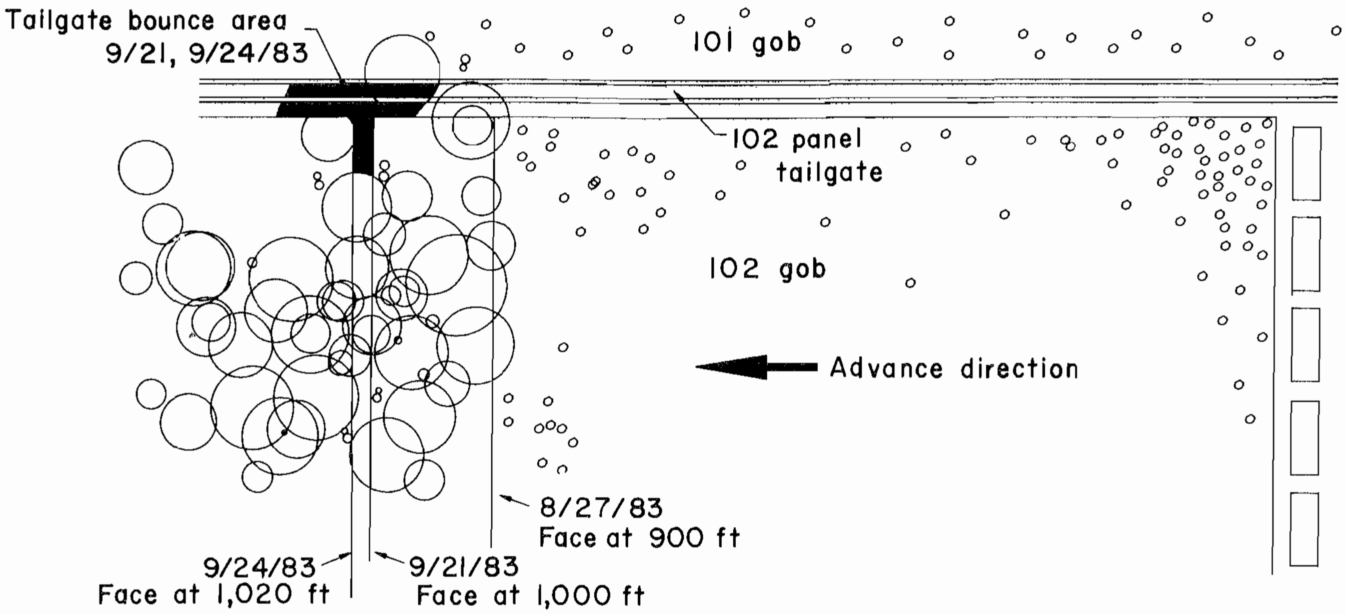


Figure 11.—Panel 102 tailgate and burst area events, August through September.

investigations noted quiet periods prior to bumps, this study concentrated not only on event rate, but possibly more important, on source location.

The analysis was based on the following assumptions. (1) Microseismic activity results from fracturing, hence energy release. (2) Observed quiet periods represent continued loading of the mine structure and energy storage. Mining practice under bump-prone conditions suggests that high-stress zones be avoided and that mining be concentrated in destressed areas. A working hypothesis was formulated that bumps not only occur against a background of a microseismic calm; bumps occur *within* these calms and result from mining into local, nonfailed zones that fail violently with immediate release of stored strain energy.

Both total and failure area event frequencies (figs. 7, 11) and microseismic source location plots (figs. 8-10) illustrate the fact that while overall AE activity may increase immediately prior to or during a bump, the actual bump area either quieted down or never indicated microseismic activity. The circles (figs. 8-10) represent the GBLK-generated microseismic source location error.

Face bumps occurring during February and March are shown in figure 8. From the event frequency plot (fig. 7) it is evident that while panel-wide microseismic activity occurred, the failed areas were essentially quiet. The microseismic source location plots (fig. 8) clearly indicate that microseismic activity, attributed to a combination of mining- and destressing-induced fracturing, occurred around the face bumps, but did *not* occur at these localized failure locations. Active areas adjacent to the face bumps are attributed to fracturing and energy releases that further load the nonfailed portions of the coal face. These localized areas, loaded by a combination of forward abutment stress, lateral stress from the previously mined panel, and transfer from the adjacent fractured zones at the face, violently released stored strain energy (bumped) when mined into. Haramy *(11)*, from computer simulation of various face destressing patterns, showed that incomplete destressing of the face may increase the bump potential and create local, highly stressed zones at the mining front.

The most violent events were floor bursts, two of which occurred after 618 ft and 1,000 ft of advance, respectively, are shown in figures 9 and 10. As observed with the face bumps, while overall microseismic activity increased, the failure areas remained quiet. Analysis by Haramy *(11)* concluded from face support loading and forward abutment pressure measurements that the April 20 floor burst resulted from anomalously high loading of the tailgate area. Although the tailgate was highly stressed (shields *F* and *G*), microseismic activity was negligible (fig. 12). Additional analysis of face support resistance with observed face bumps and floor bursts proved inconclusive. No definite trends were noted regarding microseismic activity and face support load. Gaps in the AE record and insufficient detail regarding time of events from the face support pressure charts precluded a more detailed analysis.

The second tailgate floor burst occurred after approximately 1,000 ft of advance and occurred in a quiet zone (fig. 10). Unlike the earlier floor burst, this event may have been triggered by incomplete destress blasting of the floor. Analysis of this event by Leighton *(16)* documented

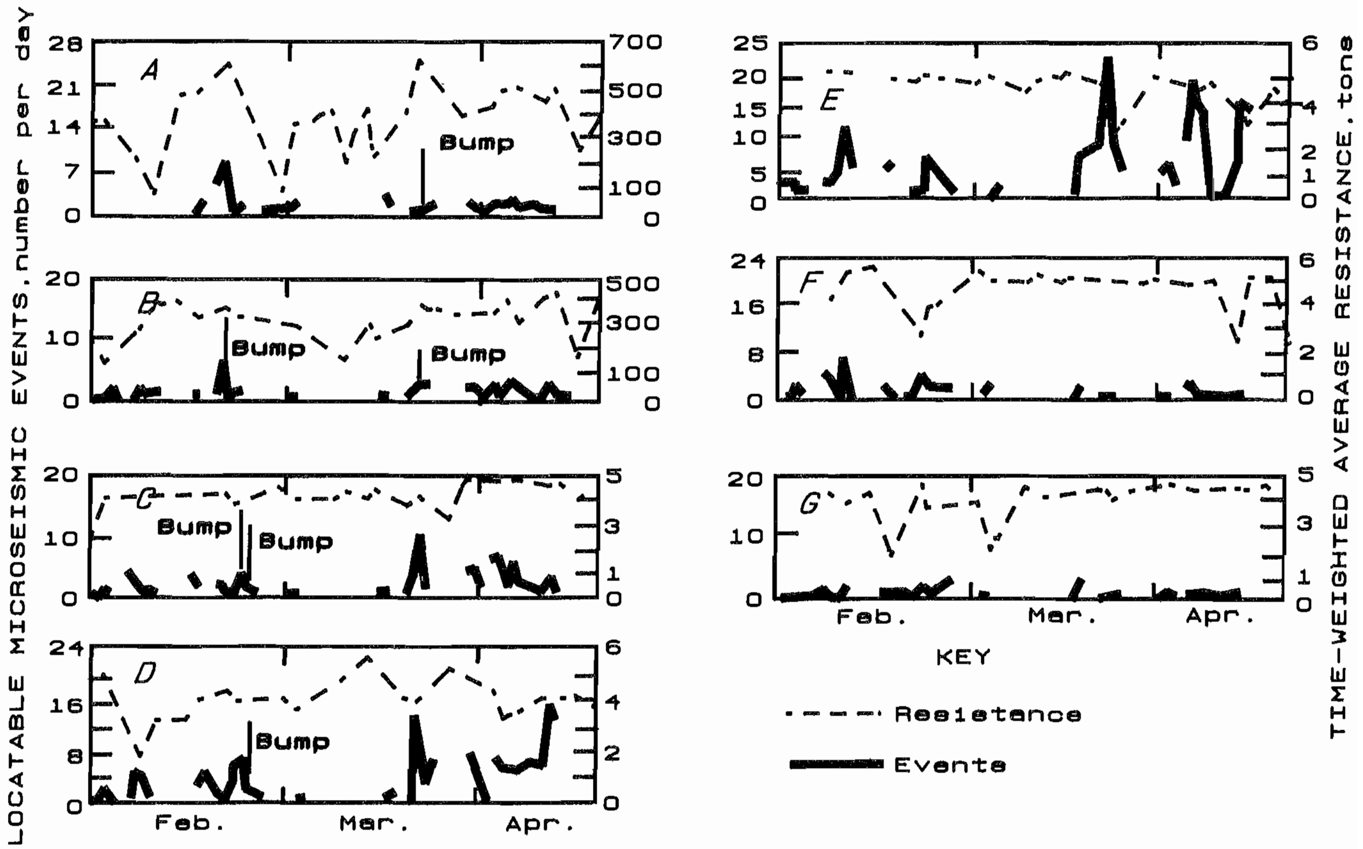


Figure 12.—Mean support load density versus microseismic activity.

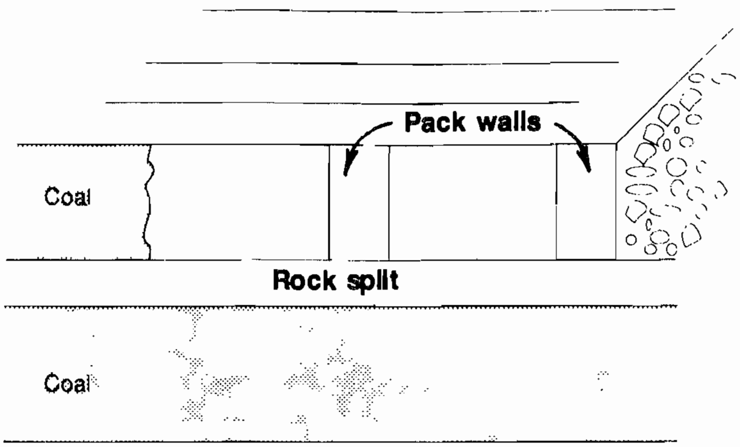
the clustering of microseismic activity around the failure area prior to the floor burst, and that the failure occurred soon after the noise count dramatically decreased to zero.

For all documented face bumps and floor bursts at this mine, although panel-wide microseismic activity increased, those areas that failed were quiet prior to failure. While not every quiet zone bumped, no documented bumps or bursts occurred in an area delineated by AE activity. Based on the previous given assumption that zones of activity delineate fracturing and stress relief, the quiet zones which failed are concluded to be localized strong points, which through either noneffective destressing or local geological conditions, stored strain energy that was violently released when mined into.

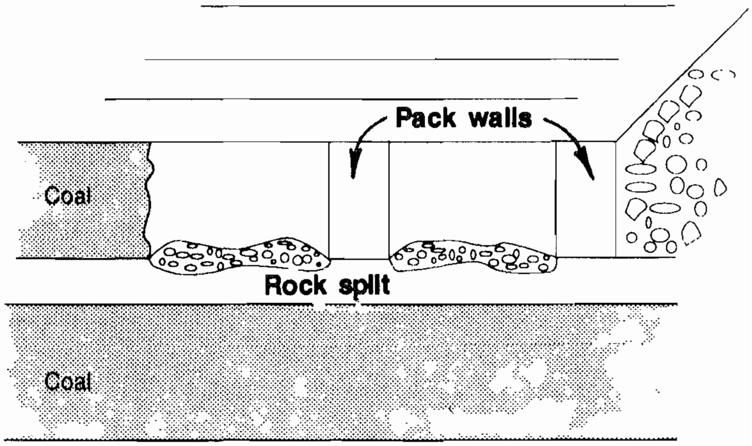
MICROSEISMIC ACTIVITY AND DESTRESSING

Microseismic activity associated with destress blasting of the face and tailgate floor was inconsistent. Although face destressing began after the April 20 event and continued through completion of the panel, no uniform pattern of blast-induced microseismic activity across the face was evident. The only in situ verification of the effectiveness of the face destressing program was that no further face bumps occurred. Future studies including both geophones and accelerometers will attempt to better correlate the drill-yield detection method and destress blasting with AE data.

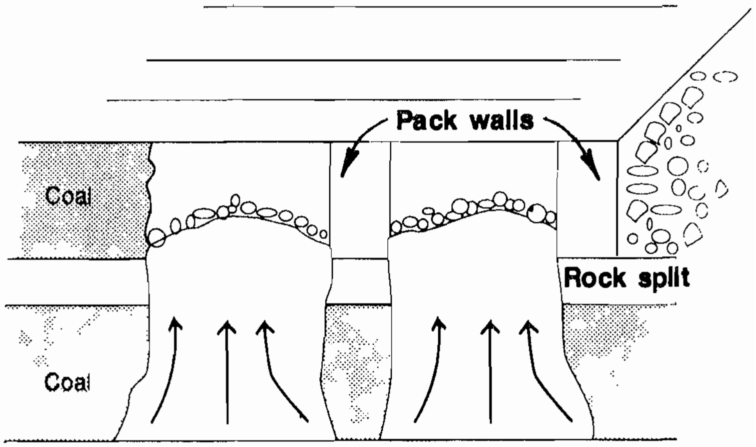
The only indication of a clear relationship between destressing and microseismic activity involved the possibly destressing-induced floor burst occurring after approximately 1,020 ft of advance. During August and September (fig. 11) increasing microseismic activity from the 102 panel tailgate convinced mine management that reshooting the floor rock was necessary. While tailgate activity increased, the located microseismic sources clustered around, but did not occur within the eventual bounce area (figs. 10-11). Prior to reshooting the floor, microseismic activity within the bounce area decreased to nearly zero, and when the floor was reshot, the rock split was broken, releasing stored energy as the underlying coal seam and floor rock heaved (fig. 13).



Before shooting floor



After shooting first time; rock split not fully broken



After reshooting floor; rock band broken, releasing energy as floor heaves

Figure 13.—Destressing-induced floor burst scenario, September.

IMPLICATIONS FOR STRESS DETECTION AND STRESS CONTROL EFFECTIVENESS

This study suggests that AE techniques may provide means for global detection of potential bump-prone areas. Present methods of stress detection, pressure cells, convergence, and drill-yield provide only localized information or require daily drilling to detect highly stressed zones. If other field studies corroborate the findings of this investigation that bumps and/or bursts only occur within zones of stored strain energy, delineated by quiet zones, other localized stress-detection techniques could be deemphasized, and the quiet zones destressed.

Assessment of stress control effectiveness may require the testing of accelerometers and ultrasonic instrumentation. AE data from this study discerned no clear trends concerning face destressing effectiveness, but was able to identify that the rock split was highly stressed and provided input to mine management so that destressing occurred when no personnel were present in the area *(16)*.

RECOMMENDATIONS FOR FUTURE STUDY

Ongoing and future studies should concentrate on validating the finding that potential bump areas can be delineated by a localized lack of AE activity and/or determining if various stress control techniques can be evaluated using a global AE network. All presently used stress control techniques–destress blasting, large-hole drilling, yield-pillar concepts, mining sequence, and mining itself–use fracturing or softening of the structure to transfer the mining-induced (abutment) pressure away from the active mining face and onto outby pillars or onto the longwall panel. If AE techniques can be proven effective in (1) detecting potential bump-prone areas, and (2) delineating the extent of stress control-induced fracturing, a practical, global use for microseismic-AE techniques in bump-prone coal mines will be established.

SUMMARY AND CONCLUSIONS

Results of this study of microseismic activity associated with documented face bumps and floor bursts in a deep, western U.S. coal mine indicate that potential bump-prone areas may be identifiable. Recent experimental and in-mine studies suggest that decreased acoustic emission (AE) activity due to closure of existing fractures and related to the microstructure of the coal seam precede coal bumps. In-mine studies reveal that coal bumps occur against a so-called "microseismic calm," a period of decreased acoustic activity. This study observed that not only do coal bumps and/or rock bursts occur during this localized calm, they occur within them and may be delineated by zones of little or no activity. While not all calm or quiet areas resulted in bumps or bursts, *all* documented bumps and bursts occurred within these zones. Based on this study and recognizing the fact that more reliable instrumentation, which uses improved source location algorithms and incorporates more rapid, real-time analysis of noise-generated wave forms, needs development, AE monitoring may provide a basis for globally detecting potential bump-prone areas and for assessing the effectiveness of specific stress control methods for coal mine bump mitigation.

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