MICROSEISMIC MONITORING OF BUMP-PRONE AREAS

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ABSTRACT

Microseismic techniques have been used in both room and pillar and longwall geometries in coal mines to detect and analyze the rock noise generated by the stress changes accompanying mining of the coal seam. The purpose of these monitoring efforts has been to determine the effectiveness of microseismics as a tool to help determine where and when bumps are likely to occur. Results to date from in-mine field tests indicate that bump areas can be delineated by locating the source of individual rock noises relative to the mine structure and plotting this information on mine maps. Potential failure areas are shown by concentrated rock noise activity. Results also indicate that the rate at which rock noise occurs varies dramatically before failure. Thus, the stability of each area delineated can be estimated by plotting the rate at which rock noise occurs. In some instances, determination of where and when bumps will occur has been possible. Representative case histories are presented.

INTRODUCTION

When a rock mass is subjected to changing stress conditions, such as those caused by mining, small-scale adjustments occur within the rock that release seismic energy. When this energy is in the audible range, it is called rock noise. Those areas where stress changes occur are also the areas of the structure most likely to fail.

Individual rock noises can be detected and analyzed to determine their precise location relative to the mine structure. Over a period of time plots of this data provide a pictorial representation of where stress changes are occurring. This is because rock noise activity tends to concentrate in those areas of the structure most actively ajusting to the changing stresses. Since these areas are the most likely to fail, they can be pinpointed and mapped relative to the structure.

Rock noise rates, or the number of rock noises occurring per unit of time, also tend to vary dramatically before failure. A constant or near constant rock noise rate signifies that the structure is stable, while anomalous rock noise rate behavior is suggestive of structural instability. Thus, the ability to locate the source of individual rock noises provides a means of determining where failure may occur, and rate counting within each area offers a means of assessing when failure may occur. This information, properly treated, can be used to avoid,

control, or warn of impending failure.

The technology of studying rock noise or low-level seismic activity, has been termed microseismics. Successful applications of this technique have provided recent impetus to the effort of developing microseismics into a practical, reliable, and economically feasible tool.

The phenomenon of naturally occurring rock noise was discovered in 1938 by Obert and Duvall (1939) who were measuring seismic velocities in mine pillars. Seismic energy other than what these researchers were generating for research purposes continually registered on their recording equipment.

Further study by these researchers showed that the extraneous seismic energy being recorded was from rock noises that were being generated within the rock in highly stressed areas. Pursuing this interesting phenomenon both in the laboratory and in the field, Obert and Duvall documented the dramatic change in rock noise rate before failure (Obert, 1941). They also established the fact that, in many instances, rock burst failures could be predicted by monitoring and listening to the rock noise activity in rock-burst-prone areas (Obert and Duvall, 1945).

These early efforts clearly showed that microseismics had great potential as a tool for measuring or estimating mine structure stability. Extended testing, however, showed that sometimes rock bursts occurred with no apparent microseismic warning, and that at other times sharp increases in microseismic data were not accompanied by failure.

Also, because precise location of individual rock noises was not possible at that time, one never knew where the failure was going to occur, only that failure near the observation point was likely. The technique clearly offered promise, but was not considered practical then.

In the mid-1960's, the Bureau of Mines undertook a new research effort to improve the microseismic technique. Major improvements were judged possible mainly because new and vastly improved electronic and system components had become available as an offshoot of space program instrument development.

Thus, in 1967, development of a multichannel, broad band, microseismic system began (Blake and Leighton, 1970). Application of this system in rock-burst-prone mines showed it worked well and provided the incentive to develop methods whereby the source location of individual rock noises could be easily and directly calculated (Leighton and Blake, 1970; Leighton and Duvall, 1972; Redfern and Munson, 1982). The improved system and the ability to locate rock noises quickly showed that the microseismic technique offered new and increased potential for providing a useful engineering tool for the mining industry. The following sections briefly describe current microseismic systems and demonstrate by example how they have been successfully applied to the problem of coal mine bumps.

MICROSEISMIC SYSTEMS

Microseismic systems may vary somewhat according to the dictates of application, but all systems include essentially the same fundamental components. A detailed examination of microseismic systems may be found elsewhere (Blake, 1971; Blake et al., 1974; Coughlin, 1982), and only an overview is presented here.

Figure 1 shows a block diagram of a basic multichannel microseismic system. Each channel is comprised of a sensor, a preamplifier, the data transmission cable, and a post-amplifier to condition the signal for final recording. The sensor may be either an accelerometer or a velocity gage, depending on the application.

Each channel is connected to a multichannel high-speed magnetic tape recorder or an automatic monitoring

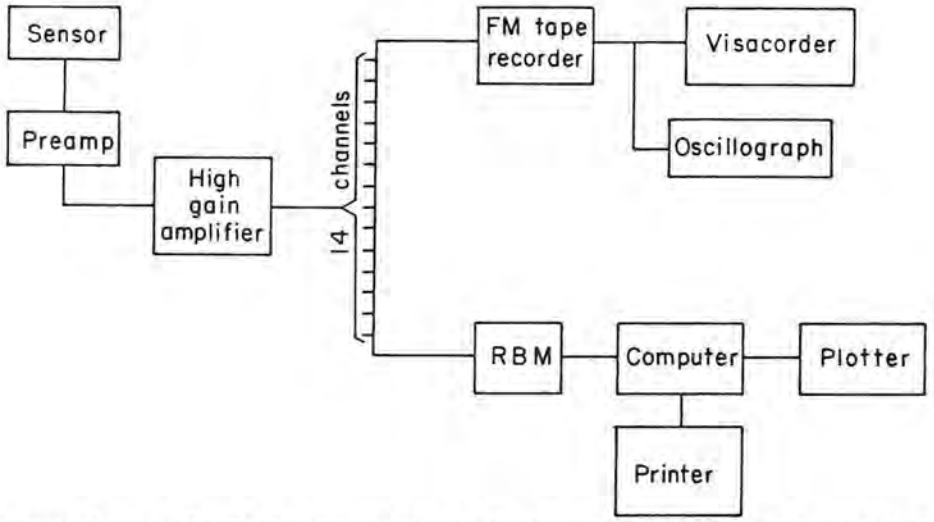

Figure 1. - Block diagram of a basic multichannel microseismic system

system that electronically measures the necessary information from the seismic signals. The data measured by this system are fed into a minicomputer or microprocessor, where they are analyzed to compute the coordinates of the source of each rock noise, which is then plotted on a map of the mine structure.

Microseismic systems are now available commercially, either in package form or by purchasing and assembling individual components. While these systems are not difficult to use, they do require full-time attention and maintenance and are not to be considered a "turn key" operation requiring little or no ongoing commitment of manpower and capital expenditure.

Sensors are sometimes lost during mining and must be replaced, and data transmission lines are often severed or damaged, requiring attention. The data recorded require daily, preferably constant, analysis and interpretation to be of maximum value.

A microseismic system is a tool to be applied to stability problems, and it requires the same dedication in terms of attention and maintenance as do other tools used in the mining routine. Several beneficial applications of these systems have shown this effort to be worthwhile and contributory to a safer and more productive mine.

HOW MICROSEISMICS WORKS

Removal of coal from the seam results in ever-changing load and stress conditions in the coal and in the mine structure support system. As these areas adjust to their new loading environment, small-scale displacement adjustments occur within the rock that release seismic energy, or rock noise, which travels through the structure much as sound travels through air. This energy can be detected by geophones placed throughout the structure, and individual rock noises can be accurately located relative to the structure. This process is simple and straightforward.

Figure 2 shows a rock noise occurring in the barrier pillar of a room and pillar retreat section in a coal mine. The seismic energy released travels outward from the source of the rock noise in all directions at some measurable velocity (not necessarily the same in all directions). It arrives at different geophone locations at different times, as shown in the example seismic record in the lower portion of the figure. Knowing the coordinates of each geophone, the velocity of the seismic energy, and the time that each geophone in the array sensed the arrival of the seismic energy allows one to calculate the coordinates of the rock noise source. Each source is then plotted on the mine structure map, and those areas most

actively adjusting to the new stress regime are delineated by the map areas where rock noise activity is most dense. In this manner, potential failure areas are pinpointed relative to the mine structure.

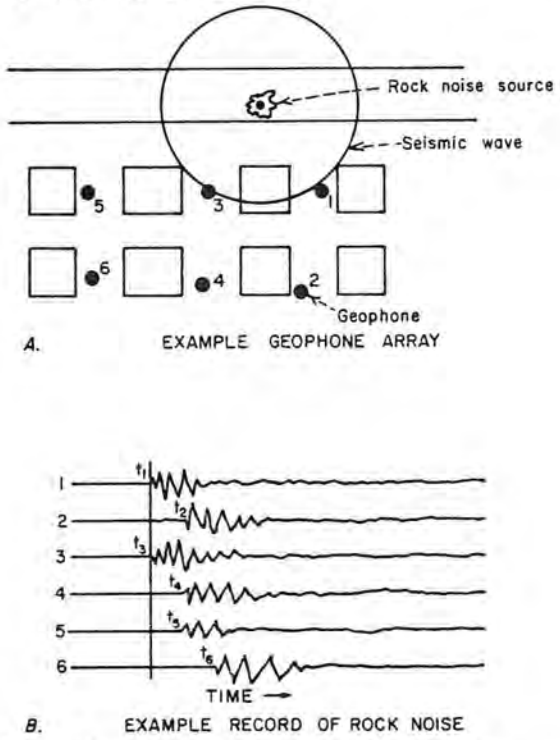

Figure 2. - Example of a geophone array and time-of-arrival record.

An example of this type of plot is Figure 3 which shows a rock noise concentration in the barrier pillar of a room and pillar retreat section. This concentration occurred over a period of about 10 days and clearly delineated the location of the eventual bump. The rock noise density has been contoured in this instance, i.e., the inner contour represents the higher incidence of rock noise, with decreasing activity along the outer contours. This example shows the importance of being able to locate the source of rock noises and demonstrates the technique's ability to accurately pinpoint problem areas.

Another feature of rock noise activity is that the rate at which it occurs tends to fluctuate dramatically in a failure area before the failure occurs. In many instances this warns of the impending failure. Figure 4 shows the rock noise rate, or number of rock noises recorded per unit of time, for the location data displayed in Figure 3. Note the dramatic increase in the rock noise rate before the bump.

These two data analysis procedures in combination represent the way in which microseismic techniques are used in current practice, in conjunction with multichannel microseismic systems. Microseismic data have provided sufficient information to withdraw or bar men from the working area, thus saving lives and preventing injury.

Using these techniques over longer periods of time also has allowed control measures to be used whereby failures have been avoided or triggered while men were not in the area. Successful applications such as these show the potential of microseismic methods as an aid in dealing with the bump problem. Some complete case histories are now presented.

CASE HISTORIES

The Bureau of Mines has maintained a coal mine bump study and monitoring project at Mid Continent Resource's Dutch Creek #1 Mine in western Colorado for several years. During this time, a research-grade microseismic system has been used to record complete bump histories in room and pillar mining configurations and in longwall geometries. Analysis of these data has shown the effectiveness and potential of using microseismic techniques in bump prone areas, and a complete case history from each type of mining configuration is presented below.

Room and Pillar History

The room and pillar system monitored was being retreated in an area under about 1500 feet of cover. Mining height was 8 feet, pillars were on 100 foot centers, and the total mining front was about 900 feet in length. Figure 3 shows this mining system and the spacing at which geophones were installed to provide coverage for microseismic monitoring.

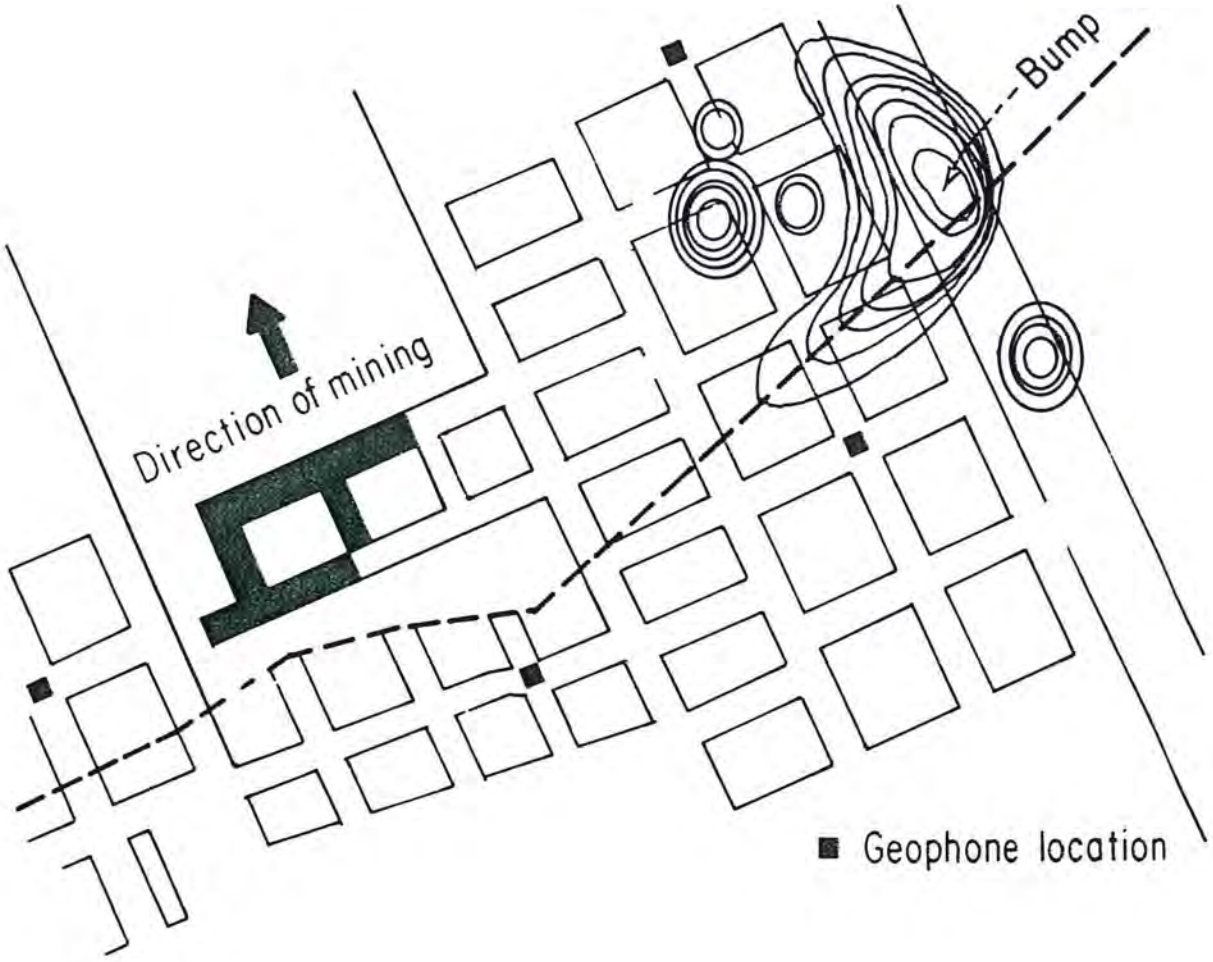

Figure 3. - Rock noise concentration prior to a bump

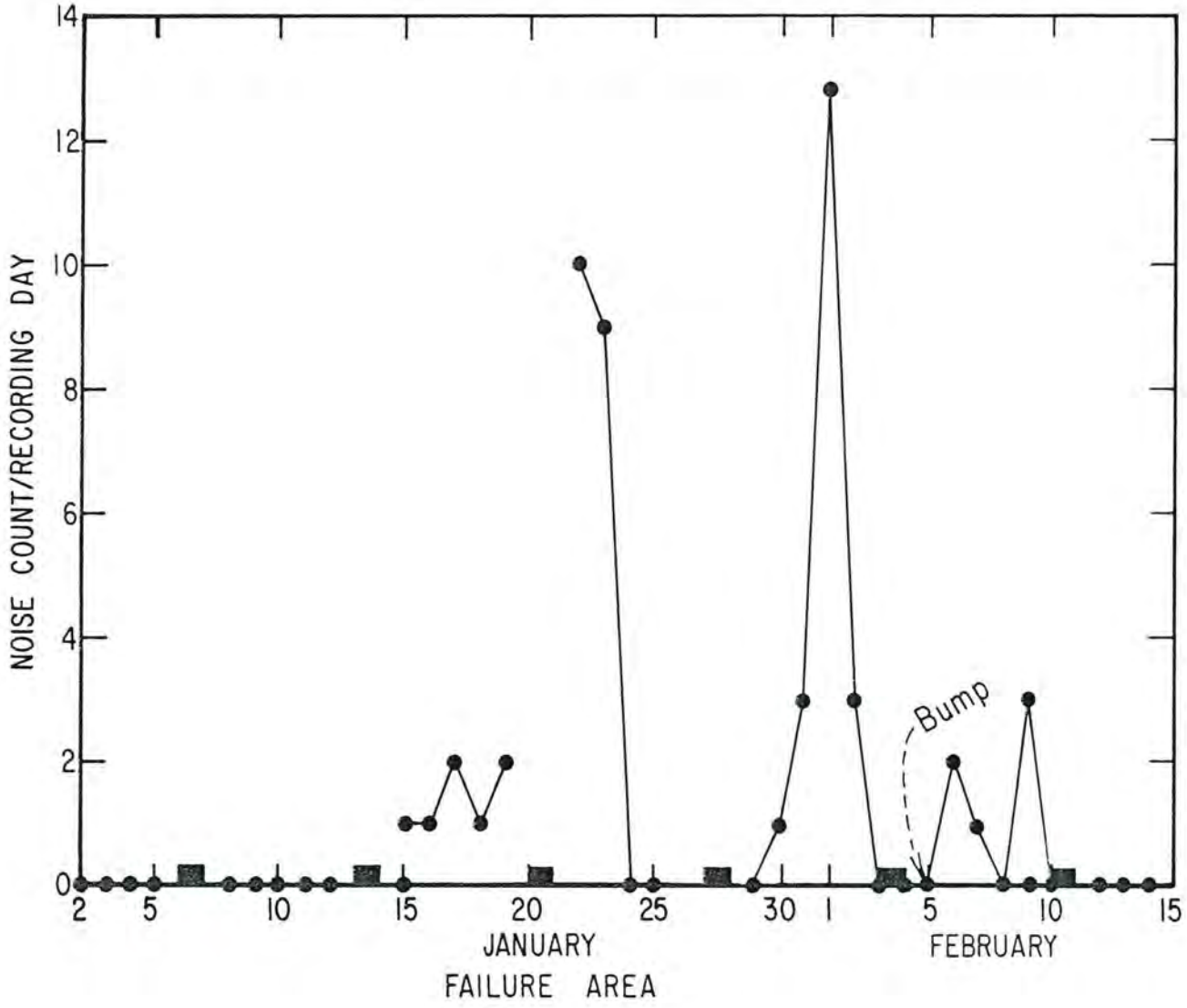

Figure 4. - Rock noise rate before a bump

Figure 5 shows representative plots of the development, growth, and eventual failure of a bump area in the center block of the retreat system. This data set is shown using a rock noise location method known as cumulative plotting. The logic for cumulative plotting is to accumulate all data starting from a particular date, the starting date being chosen when an anomalous area of activity away from the area of active mining becomes evident. This history is representative of several bumps whose growth began about 150 feet in front of the new mining, near the center of the main block. Also, the rock noise location data are contoured to visually accentuate the center of the high-stress area. Thus, the inner contour represents the area of highest rock noise activity, and the outer lines represent decreasing activity. Finally, all rock noise generated by or associated with the continuous miner has been removed from these plots, simply by keeping track of where the miner was and ignoring data from its location. This turns out to greatly simplify the resulting plots and is an acceptable practice because the miner moves around within the mining area fairly quickly, but the failure area data do not move at all.

Chronologically, Figure 5 offers the following indications of where and when the eventual bump occurred:

1) A distinct concentration of rock noise was observable on April 3, and this concentration precisely located the eventual failure location. This concentration occurred 27 days before failure.

2) No other concentrations were noted in the mining area during this period, which indicated that the rest of the structure was stable and behaved normally during mining.

3) When new mining approached the failure area on April 10, the area did not fail, as might have been expected. However, as can be seen in the noise rate plots, this stress concentration simply did not become unstable.

4) When mining again approached the failure area on April 30, a bump occurred. This time, however, the rock noise rate in the area clearly indicated that failure was likely, by a 4-fold increase in activity, followed by a sharp decrease. This behavior is often observed in successful applications of microseismic techniques.

Thus Figure 5 shows that bump areas can be detected and located prior to failure, and that the eventual failure area can be discerned far enough in advance to take action to control or trigger the bump. Also, the noise rate plot demonstrates that bump area behavior can be assessed in terms of both its apparent stability and instability, as evidenced by the noise rate characteristics around the dates of April 10 and April 25. In this example then, both where and when the bump would occur could have been predicted with enough accuracy to have been useful in a production environment.

Longwall History

More recently, Mid Continent has gone to longwall mining methods in the deepest part of their mine. They are presently operating an 800 foot long face, 10 feet in height, under a cover of up to 3000 feet, using an advancing headgate and a retreating tailgate. The tailgate end of the face has had a tendency to bump periodically, and the company has instituted an intensive program of ground control using the latest technologies. Past experience had shown that microseismics could be used in longwall mining geometries, and as part of our ongoing effort to understand bumps and to improve microseismic monitoring techniques, a geophone array was placed in this new area. The following data were taken during a bump sequence that occurred prior to application of current control efforts in this longwall.

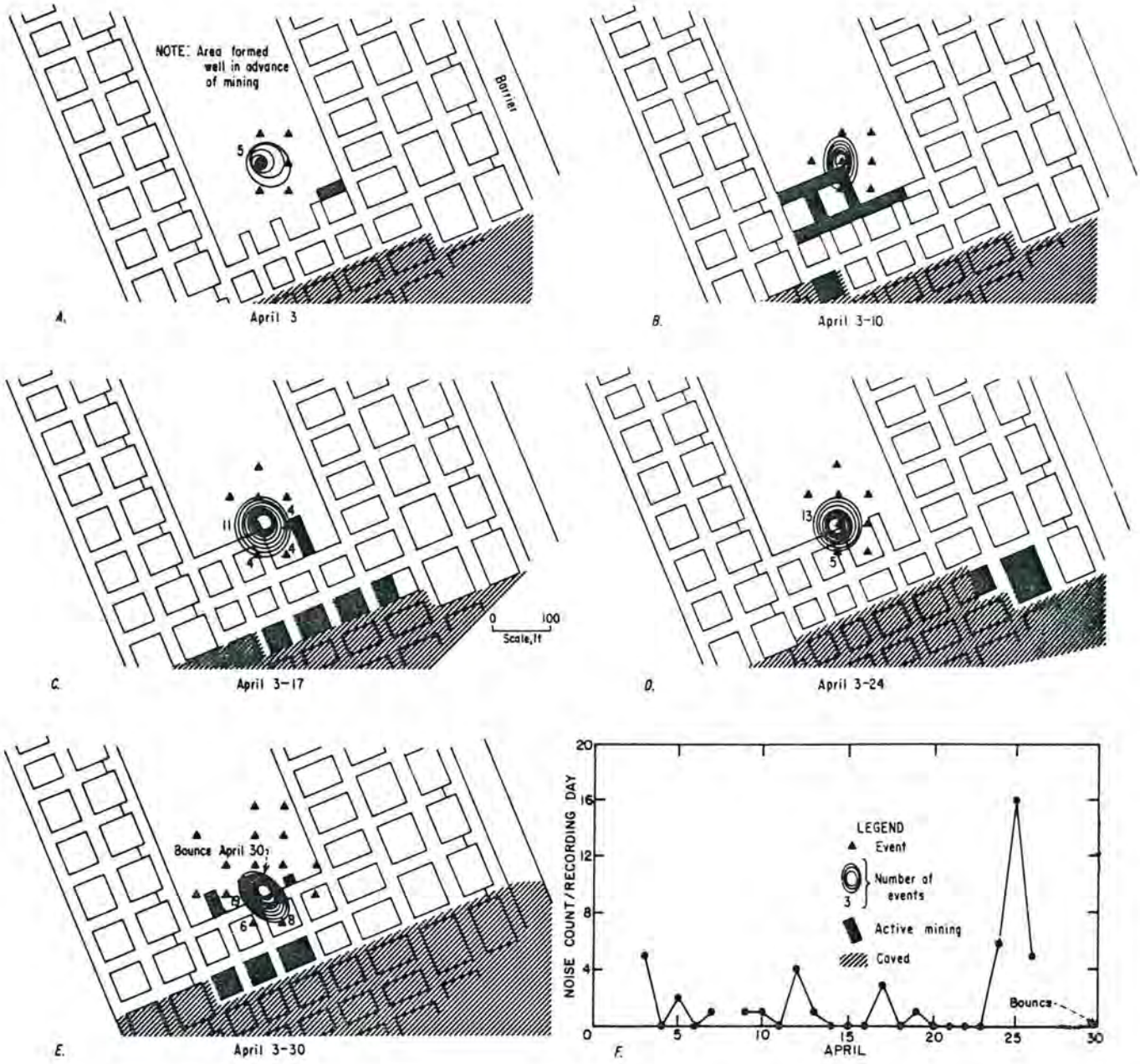

Figure 5. - Rock noise location and rate plots before a bump in a room and pillar section

Figure 6 shows the mining geometry, the location of the geophones in the microseismic array, and the rock noise location and rate plots covering the period 4 weeks before the bump sequence and 1 week after. These data are plotted differently than those in Figure 5, in that rather than being plotted cumulatively from the beginning of the data set, they are plotted cumulatively by individual week. Thus, stress changes are observable on a weekly basis.

Chronologically, Figure 6 offers the following indications of where and when the eventual bumps occurred:

1) Week 1 - rock noise activity through out the longwall area was minimal, and only inconsequential rock noise concentrations were observable. This reflects the condition of the longwall 4 weeks before the failures.

2) Week 2 - rock noise activity increased slightly, showing a somewhat increased concentration at the face-tailgate juncture and in the gob area several hundred feet above the seam.

3) Week 3 - rock noise activity showed a definite increase, both in the number of concentrations and in the rock noise rate. There was now activity in the headgate, where previously there had been none.

4) Week 4, the week of the bumps - rock noise activity showed a marked increase in the number of concentrations and in the rock noise rate. The concentrations are somewhat larger, more intense, and appear to encircle the working area. Both areas along the face near the tailgate bumped, as did an area behind the start line. In general, these bumps coincide with the noise rate peaks. The largest bump, which was triggered by destressing methods, occurred on September 26, when the noise count had dramatically decreased to zero just before the failure.

5) Week 5 - the large bump had apparently destressed the area, as there were rock noise concentrations along the face, the headgate, or in the gob. There was activity in the tailgate, where some floor heave occurred.

The primary conclusions concerning these longwall data are that, as best we can determine, the bump areas that failed could have been delineated prior to bumping, but over a much shorter time period than was experienced in the monitoring of room and pillar systems. Most importantly, the decision by the company to destress the area using control methods was made in part due to the rock noise rate data, which were behaving anomalously. That the decision to destress was timely was borne out by the triggering of the large bump when no men were present in the area. Thus, in this case, microseismics provided an ability to assess the stability of several areas of a complete longwall and also provided timely information to aid in the determination that control measures should be applied.

CONCLUSIONS

The case histories shown here demonstrate that when properly applied, microseismic techniques can be used to delineate bump areas before they fail and can provide information valuable for giving warning of failure or for making the decision that control measures should be applied to make the working area stable and safe. In our experience, all situations are not so clear as these examples, and continued research is necessary to improve both data recording and data analysis techniques. Different situations may require different methods of application to assure success, but there is substantial evidence that microseismics can provide a unique and workable method for combatting the problem of coal mine bumps. The Bureau intends to continue this research effort to obtain the complete technology required to protect our miners from coal mine bumps in the

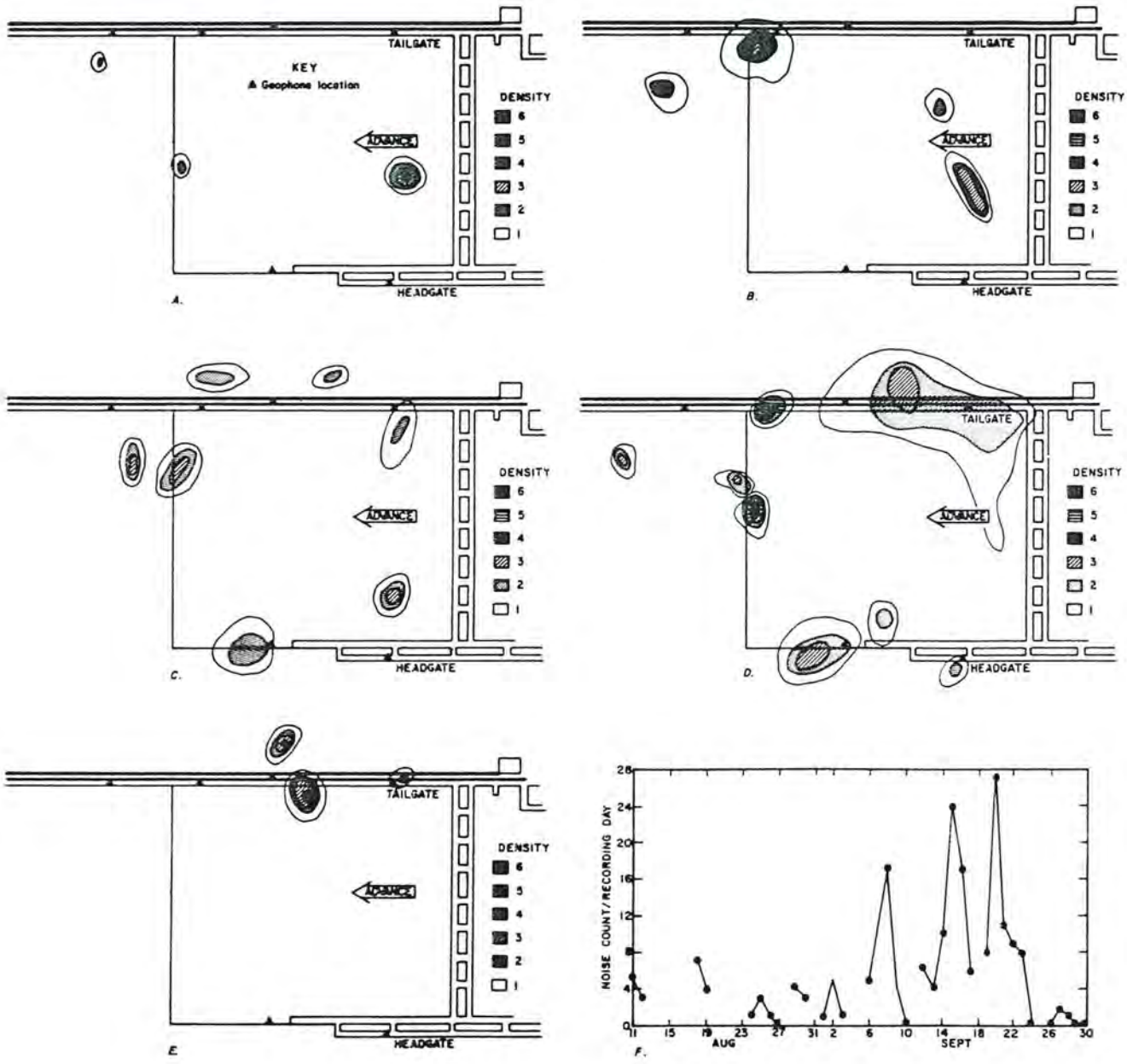

Figure 6. - Rock noise location and rate plots before a bump in a longwall section

future, thus providing a safer and more productive working environment.

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