

# MICROSEISMIC MONITORING IN COAL

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## ABSTRACT

The U.S. Bureau of Mines has actively conducted microseismic research in coal mines for many years. The purpose of this research is to provide the mining industry with reliable techniques to warn of imminent coal mine bumps and outbursts so that miners may evacuate dangerous areas prior to ground failure. In this paper, the Bureau's research program in microseismic monitoring is discussed, including recent achievements of microseismic techniques applied to recognizing impending catastrophic ground failure in coal mines and the development of an automatic digital microseismic monitoring system. Event source location accuracy in coal is examined providing recommendations for future research to improve source locations.

## INTRODUCTION

A coal mine bump is a sudden and sometimes catastrophic ground failure within the mine structure. This type of rapid failure is capable of causing multiple injuries or fatalities in addition to damaging a working section in a mine. An outburst is a sudden release of energy accompanied by a large volume of gas, usually methane, and coal dust. In addition to the potential for worker injury from flying rock, outbursts can leave an explosive mixture of methane, air, and coal dust. For example, on April 15, 1981, 15 miners died as a result of an explosion after an outburst in Dutch Creek #1 Mine near Redstone, Colorado (Elam et al. 1981).

Literally, a microseism is a "small earthquake." The word is derived from the Greek words "micros," meaning small, and "seismos," meaning earthquake. As detected in a mine, a microseism is sometimes an audible, sometimes subaudible, noise resulting from vibrations introduced into the mine structure by rock fracturing or slipping. There is no strict

magnitude definition of a microseism. On the lower end of the scale, a practical limit is the sensitivity of the actual detection system installed; on the upper end, most all coal mine related bumps can be included because they are considered small by earthquake standards. However, some large mining induced earthquakes have been reported with Richter magnitudes greater than 5 (Mendecki et al. 1988).

Microseisms in coal mines are detected by securely attaching an array of velocity gages to the rock surrounding the area of interest, usually near the face. Since these transducers are "listening" for rock vibrations, they are generically called "geophones." When a rock noise, or microseism, is detected by several geophones, the origin of the noise can be calculated from the relative arrival times of the signal at the different geophones.

Vibrations travel through the mine at the speed of sound in rock, which usually varies along the path of the sound wave. As an example, if a geophone is 30 m farther from a

microseismic source than the closest geophone, the signal will arrive at the more distant geophone 10 ms later than at the closest geophone, assuming a 3000 m/s sound velocity. These time differences are used to calculate source locations that best fit the data.

Microseismic research was initiated in the late 1930's by Leonard Obert of the U.S. Bureau of Mines. It was an outgrowth of exploratory investigations to devise a method for determining the pressures on rock columns and arches in mines. One approach suggested to solve this problem was based on the possibility that as pressures develop on rocks there may be microscopic readjustment that would produce sound vibrations capable of detection if sufficiently amplified (Obert 1939). The initial field testing of microseismics, initially called "subaudible noises," was reported by Obert in 1941. Over the last 5 decades, instrumentation, recording capability, and understanding of microseismic techniques have advanced significantly.

Since sources of microseismic activity are caused by rock fracturing or slippage along planes of weakness within the rock mass, locating and plotting sources of microseismic activity can point to areas of a mine adjusting to changing stresses induced by mining. Microseismic techniques have been used to delineate potential areas of ground failure. If a dangerous area can be identified days in advance of a failure, then there may be sufficient time to modify mining plans to prevent the failure. If a failure cannot be prevented, then microseismics may be used to provide warning so that miners may move to safety before the failure.

The Denver Research Center of the U.S. Bureau of Mines had a microseismic monitoring project at the Dutch Creek Mine, near Redstone, Colorado (e.g. Leighton 1984). The mining method employed at the Dutch

Creek Mine is advancing longwall, extracting a 3 m thick coal seam, dipping at 13° under nearly 900 m of overburden. A second coal mine is 120 m above the workings. Microseismic activity has been monitored at the Sunnyside Mine, Sunnyside, Utah (a retreating longwall under 400-750 m of overburden). Through a contract with the Colorado School of Mines, the Bureau monitored a mountain bump-prone area of the Olga Mine, Caretta, West Virginia (a retreating room-and-pillar mine, Descour and Miller 1988).

This paper outlines current microseismic systems available for coal mines, presents an example of monitored activity prior to a failure, and indicates areas of research necessary to fulfill the promises of microseismics.

## INSTRUMENTATION

To successfully predict bumps, the ability to monitor and locate microseismic activity must be at least 3-4 orders of magnitude lower than that which needs to be predicted. Thus, to predict a catastrophic failure of Richter magnitude 2, microseismic activity whose magnitudes are as low as -2 must be successfully monitored and located. There are two reasons for looking at small events. First, Bureau experience has shown that major failures are usually preceded by an increase in the number and intensity of background microseismic events. Second, extrapolating a series of large events to predict a future large event is not very meaningful to the mining industry. Prediction must be based on observations of smaller events. The Bureau has, therefore, concentrated its microseismic research efforts on monitoring individual areas of mining with a local geophone network. A local network is designed to monitor a relatively small section of a mine, a section 100-200 m in extent. In a mine with several working sections, complete coverage requires several

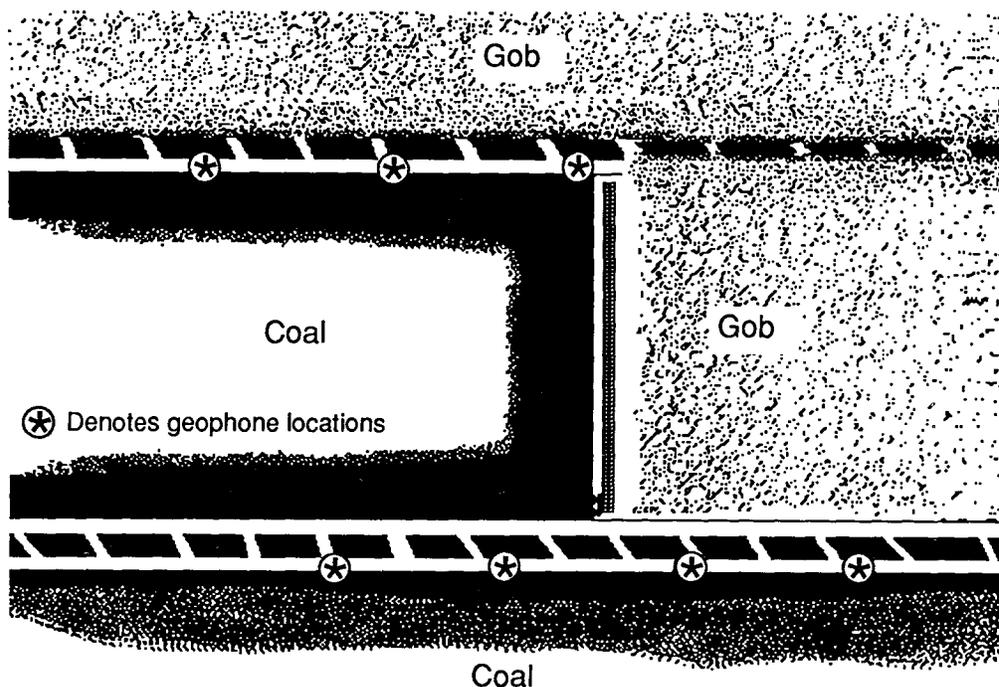


Figure 1. Plan view of a typical geophone layout for a longwall coal mine. Geophone spacing is about half the width of the longwall panel.

local systems which can be tied together such that data can be shared to make a mine-wide system.

A typical array at a longwall coal mine is two dimensional, consisting of at least seven geophones, Figure 1. A two dimensional array means that all geophones are located on a single plane, the plane of the coal seam. Through experience, it has been found that geophone spacing along the gate roads should be approximately half the width of the longwall face. More geophones closer together in the gate roads would slightly improve location accuracy, but at a considerable increase in cable cost. Actual geophone locations are subject to roof conditions and proximity to noisy equipment, such as pumps and transformers.

A three dimensional array has geophones placed significantly off the plane of the seam. The advantage of a three dimensional array is that accurate source locations can be determined in three dimensions. A two dimensional array allows good

resolution of source locations on the plane but does not allow accurate resolution off the plane. For example, an array of geophones placed around a horizontal coal seam does not allow for distinguishing whether the event took place in the floor, coal, or roof. In order to determine this information, additional geophones have to be mounted in the roof and floor.

#### MICROSEISMIC MONITORING

The basis of microseismic monitoring is the detection of signals and the location of their sources. Plots of event locations are superimposed on a mine map for given periods of time, (e.g. Kneisley 1989). Events in a given area are counted to produce rate plots. For example, the number of microseismic events per day may be plotted against the days of the month. An anomalous increase in the daily event rate may presage a bump. Sometimes contours are sketched to show areas of event concentration (Blake et al. 1974 and Leighton et al. 1974). However, mining progress must be considered because there is

usually more microseismic activity during coal extraction than during non-mining cycles. Data presentation and interpretation, an area of microseismics requiring more research, are the keys to predicting bumps.

Microseismic activity in coal mines has indicated something anomalous happening prior to several major bumps (Kneisley 1989 and Descour and Miller 1986). For example, at the Olga Mine, Caretta, W.V., an anomalous increase in microseismic activity was observed by the on-site observer prior to a massive series of bumps that occurred on Monday, June 3, 1985, destroying approximately 100 coal blocks. This increase in activity occurred even though mining was limited to pulling fenders which did not normally induce much microseismic activity. The buildup in microseismic activity began during late May. Unfortunately, after the tape ran out on Saturday, June 1, 1985, no more data were available until Monday after the tape was changed (Descour and Miller 1986).

The Bureau's microseismic monitoring system for coal mines has been based on a commercial analog tape recording unit that records up to 14 channels of data on a 7200 ft. (~2200 m) reel of magnetic tape, at 15/16 in/s (~24 mm/s), giving a total available recording time of 25+ hours. After data have been recorded on analog tape, the tape is played back on a second tape deck while new data are being recorded on the first. Under the best of circumstances, when the on-site investigator can immediately begin data analysis, it is still yesterday's data being analyzed. The 25 hour limitation of the tape deck has also proven to be a short-coming of the analog system. Without changing tapes every day, data are lost.

An automatic microseismic monitoring system has been available for hard rock mining for several years (Coughlin 1982). The Bureau has attempted to transfer the knowledge gained from automatic rock burst

monitoring directly to coal with marginal success. Sources of strong microseismic events whose signals had sharp first breaks have been accurately located, automatically. The rest of the locatable events were not accurately located. The principle of operation of a rock burst monitor (RBM) is the determination of arrival times by detecting the times when the microseismic signal arriving at each geophone crosses a preset threshold. These relative arrival times are then sent to a computer for calculating sources. The signal wave forms are not recorded and there is no possibility of reconstructing signals to check arrival times. The only cross check of data comes from the attempt to calculate source locations that best fit the measured arrival times. If a reasonable source location cannot be calculated from the arrival time data, nothing further can be done. After the source location that best fits the measured arrival times has been found, relative arrival times at each geophone of a microseismic signal emanating from this source can be calculated. The reasonableness of a source location is determined by comparing arrival times calculated for the "best fit" source to the measured arrival times. If the comparison is good, the solution and data are assumed good. Otherwise, the raw data are considered suspect. Out of the comparison of measured vs. calculated arrival times, an estimate of the uncertainty of the solution is calculated and displayed.

Automatic systems in coal mines have failed because signal frequencies observed in coal mines are much lower and signal amplitude relative to noise is much lower than in hard rock, Figure 2. The major differences in signals observed, hardrock vs. coal, are due to several conditions: 1) hard rock is a better transmitting medium than coal and sedimentary materials typically found above and below coal beds; 2) since a coal seam is one of many layers, the resonant frequencies and absorptive characteristics of the

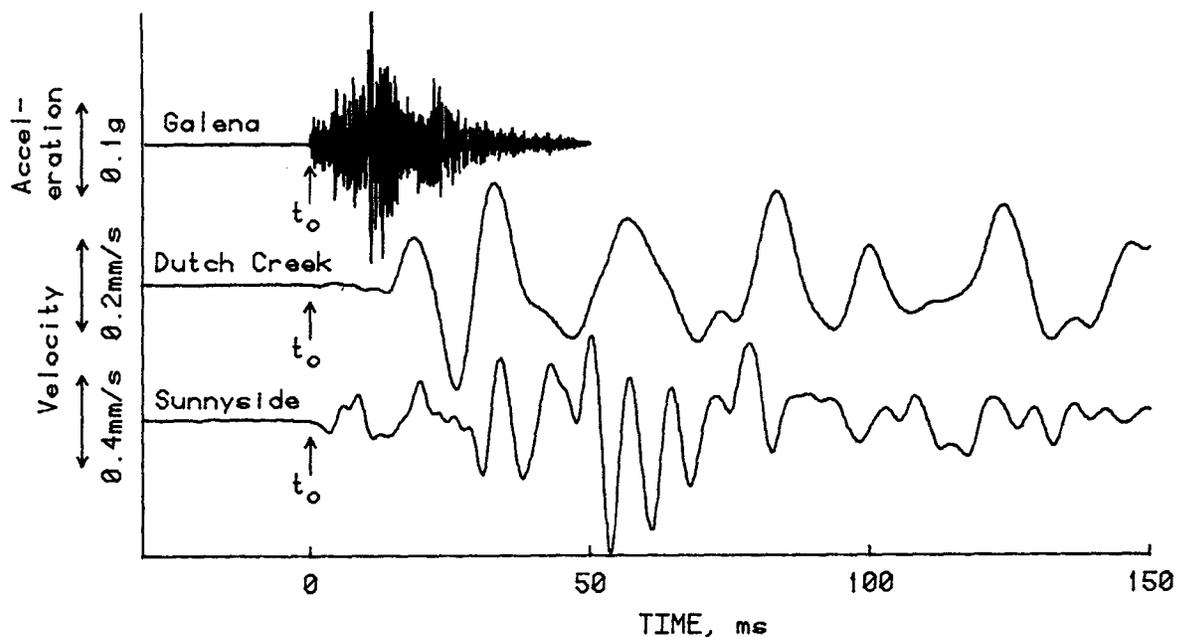


Figure 2. Comparison of typical microseismic signals from a hard rock mine (Galena Mine) and two coal mines. Microseismic signals from hard rock mines have much higher frequency content and are much shorter in duration than signals from coal mines.

layers probably dominate observed signal frequencies and amplitudes; 3) mine entries and working areas are generally much larger in coal mines than in hard rock mines resulting in lower resonant frequencies; 4) in coal mines, geophones are farther apart and generally farther from signal sources allowing greater attenuation of higher frequencies; and 5) a typical microseismic event detected in a coal mine is larger than a typical event detected in a hard rock mine.

The order of magnitude differences in signal frequency and duration between coal and hard rock (Figure 2) have contributed to the success and failure of automatic monitoring systems in each type of mine. Because signal frequencies and amplitudes are low in coal mines, automatic first break picking has not been sufficiently accurate. When using a simple threshold picking routine, the first breaks of the closest geophones may be picked accurately while the first break picks on more distant geophones may

miss the first cycle and catch the 2nd or 3rd cycle or even miss the P-wave altogether and pick a point on the shear wave.

The location error resulting from missing the first or second cycle is worse in coal than in hard rock because the frequencies are much lower. When the first cycle of a 2 kHz signal is missed in hard rock because its amplitude is too low, the resulting error in time (0.5 ms) caused by picking the second peak corresponds to a distance error of less than 3 m (sound velocity ~5600 m/s). When the first cycle of a 50 Hz signal in coal is missed, the time error of 20 ms corresponds to a distance error of 60 m (sound velocity ~3000 m/s) resulting in an unacceptably poor location. Final location errors are usually less than those just cited because of the error averaging characteristics of location routines. However, when the first cycle of a microseismic signal is detected from some geophones and the second cycle from other geophones, the calculated source location can be

meaningless in coal, but still usable in hard rock. When an automatic system is able to detect the first break of corresponding cycles in the signals received from each geophone in a coal mine, it does very well in calculating accurate source locations.

The approach to minimizing the problem of first break picking errors has been to judiciously adjust signal amplification and detection threshold so that the threshold is barely above the noise level of the ambient signal. Any signal above the noise level is then detected and picked. This approach has been effective in hard rock mines, but not in coal. Figures 3 and 4, showing two microseismic signals recorded about two hours apart at Sunnyside Mine, illustrate the problem. Figure 3A shows a signal recorded while the shear was not operating; Figure 3B keeps the same time scale but is expanded vertically by a factor of twelve to show details of the signal near its first breaks. In this example, the relative differences between hand picked arrival times and threshold picked arrival times ranges up to 9 ms (geophone 1). The difference in calculated source locations was 14 m. Using hand picked arrival times, the source was calculated to have been in the coal ahead of the face; using threshold picks, the source was calculated to have been in the gob. With errors of this magnitude, conclusions drawn from microseismic data might be suspect.

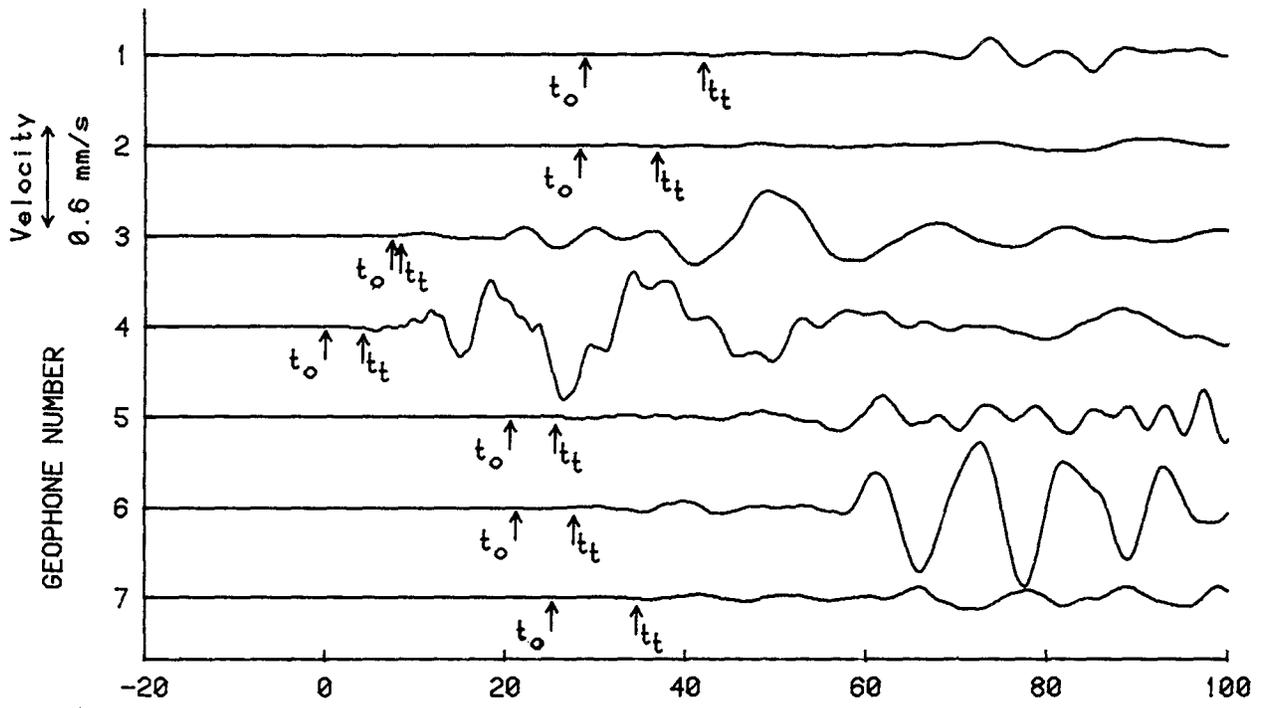
Based on Figure 3, one might conclude that location accuracy might be improved by tightening the threshold. The dilemma is illustrated in Figure 4 which shows a microseismic signal recorded while the longwall shear was operating. Any reduced threshold would be continuously surpassed by the noise, as is the case with geophone 6. Thus microseismic source location would be impossible while the shear was operating. With the threshold set as indicated in Figure 4, the difference between locations calculated using

hand picked arrival times vs. threshold picked arrival times (ignoring geophone 6) is about 10 m, but the calculated uncertainty in location is double that estimated when the shear was not operating. In comparing Figures 3 and 4, it is apparent that there is no correct threshold adjustment level for coal. Because of this, simple automatic detection devices have had only limited success in automatically locating sources of microseismic activity in coal. The automatic system used at the Olga Mine did prove useful in indicating the amount of microseismic activity and the times of event occurrences; it was only location accuracy that could not be trusted.

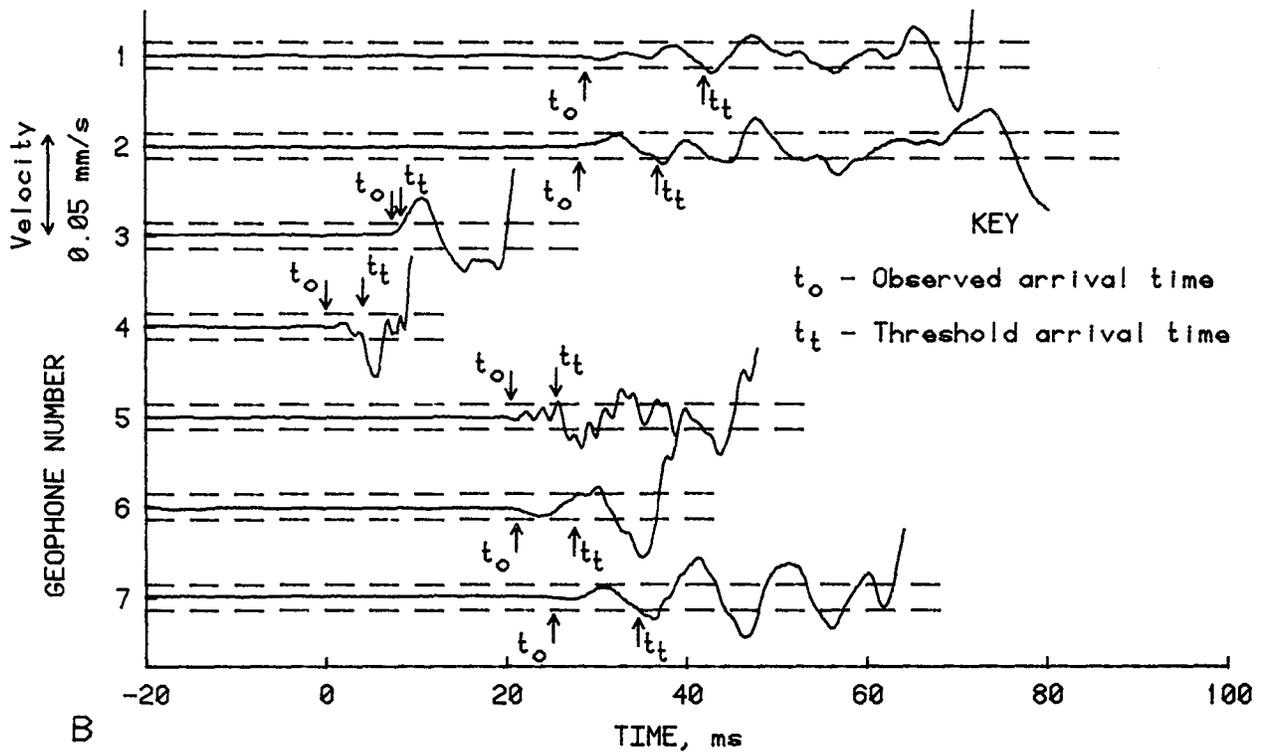
#### AUTOMATIC MICROSEISMIC MONITORING SYSTEM (AMMS)

Analog and digital recording of microseismic data have advantages and disadvantages. The advantage of an analog tape recording system is that all data are recorded on the tape and can be played back at any time. No signals are missed as long as the tape is running. Disadvantages of a tape system include: the tape must be changed before it runs out (data gathered at coal mines has had gaps over weekends and vacations because man power was not available to change tapes), data storage on magnetic tape is expensive (over \$100 per reel which lasts one day), retrieving data is expensive (the linagraph print paper used with the visicorder usually costs over \$50 per day), time consuming (one person would have trouble retrieving and analyzing more than 25 events every day), data analysis takes place a day late, at best, and finally, analog tape noise (hiss) is added to the signal, which lowers the signal to noise ratio, making accurate first break picking more difficult.

The current rock burst monitor (RBM) used at the Galena Mine has several advantages over a tape system. Data reduction is fast (less than a second between signal occurrence and completion of source location

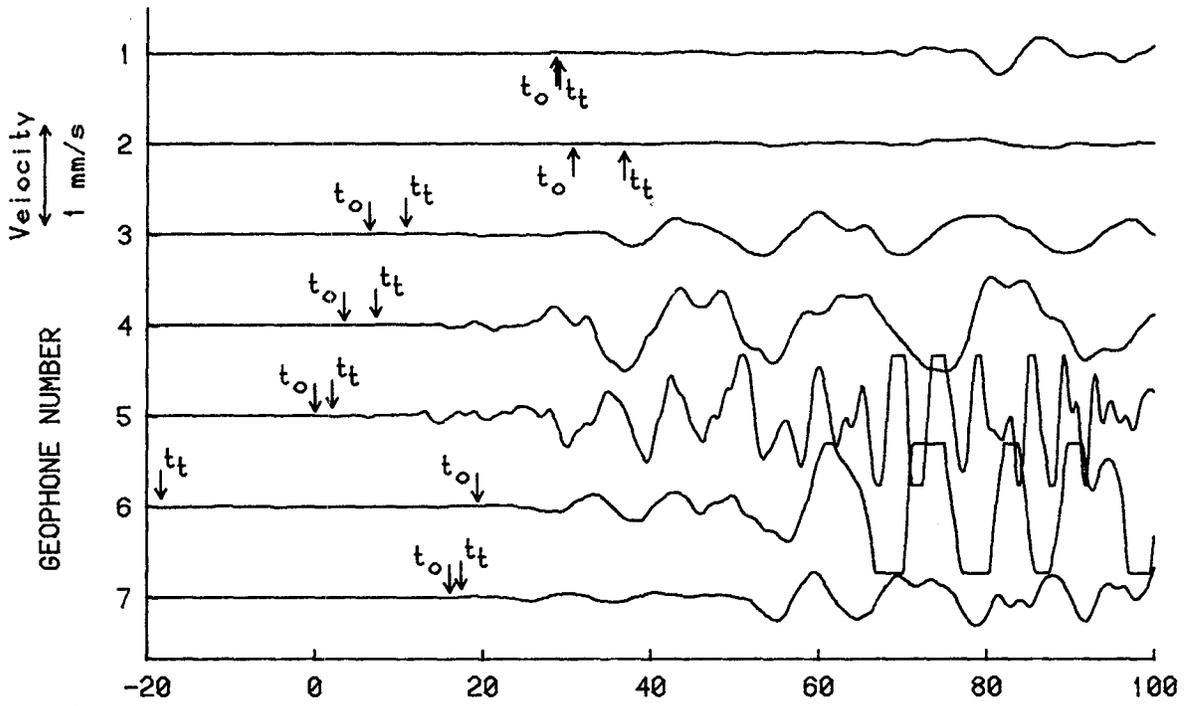


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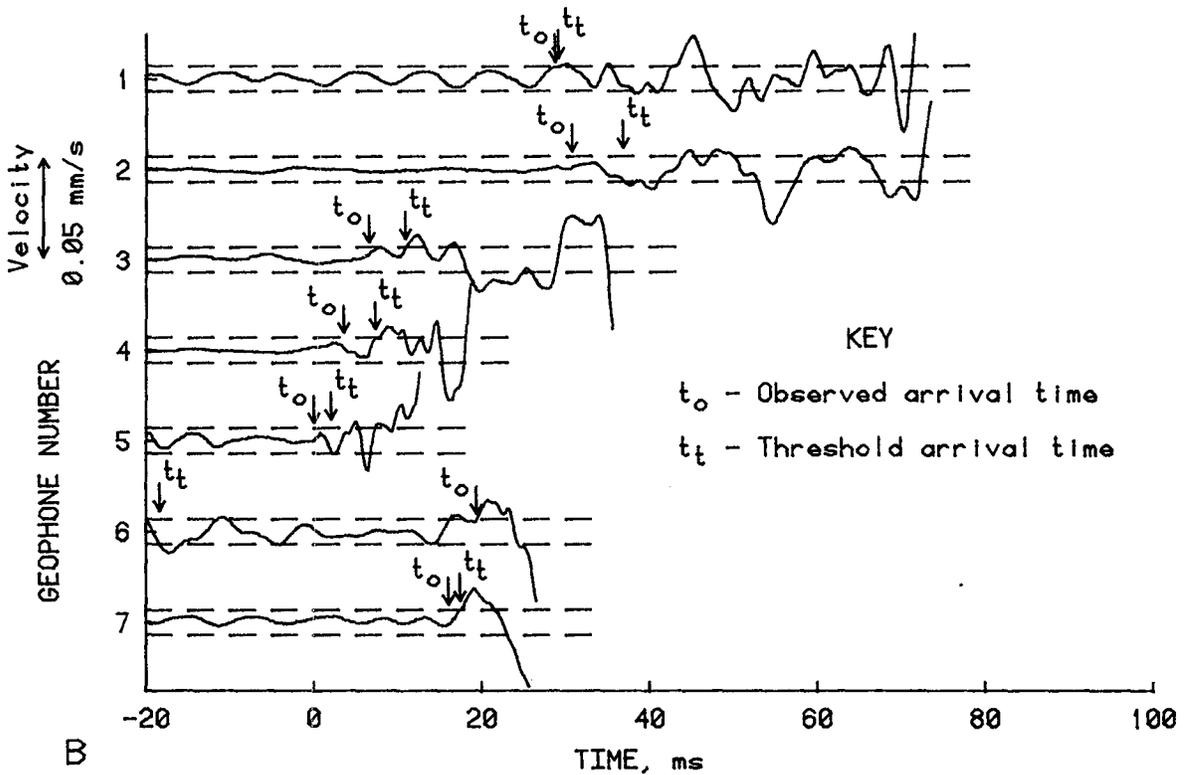


B

Figure 3. Vibrations from a background microseismic event at Sunnyside Mine while the shear was not operating. Dashed lines indicate possible rock burst monitor thresholds.



A



B

Figure 4. Microseism recorded at Sunnyside Mine two hours later than the signal shown in Figure 3. The longwall shear was operating which caused increased background noise clearly visible in the 20X vertically expanded figure, part B.

calculation) and automatic. Data storage is cheap; an average week of data can be stored on 1 or 2 floppy disks. The system can run unattended and is fairly simple to use. With current hard disk storage capacity, the system can run over a long weekend without losing data. The primary disadvantage of the RBM is that only arrival times and an approximate energy are retained, and this information cannot be double checked. All other signal characteristics are lost.

A full digital system will record the complete microseismic signal from each geophone for automatic and immediate analysis, retaining the advantages of both the analog and RBM systems. By eliminating periods of no data and judicious elimination of meaningless data, storage of digitized signals can be kept reasonable.

Since standard RBM systems have had only limited success in coal mines, the analog tape system, with all its disadvantages, has been the standard for microseismic monitoring in coal mines. The necessity of having an automatic and continuous microseismic monitoring system in coal has been apparent for some time. Development of an AMMS for coal is currently a high priority. There are two goals of an automatic system. First, the source location and signal characteristics of a microseism should be automatically and accurately calculated and displayed within seconds of an event's occurrence. Second, the system must be able to run for extended periods of time, unattended. In order to accomplish these goals, the Bureau has been investigating full digital data acquisition systems, in which the computer receives, from each geophone, a complete voltage vs. time history. The computer can then look at each time history to determine relative arrival times of a signal at each geophone. If the algorithm for determining relative arrival times is good enough, accurate source locations will follow. Developing such an algorithm will require

extensive field trials on real microseismic signals.

To further the objective of automating microseismic monitoring in coal, two commercial computer data acquisition systems were purchased for testing and evaluation. The MASSCOMP System 5450 (now Concurrent Computer Corporation - reference to a specific trade name is made for identification only and does not imply endorsement by the Bureau of Mines) was chosen for further development because it has more computer power and is about half the cost of the other. It is capable of simultaneously digitizing signals from 16 geophones at sampling rates of 20,000 samples/s, 12 bit analog to digital conversion resolution. The data can be automatically recorded, stored, analyzed, and displayed in a multitasking mode of operation. This unit was field tested during the summer of 1988 at the Galena Mine and will be placed in operation at a coal mine during 1989. This type of system is expected to become the standard for coal mine microseismic monitoring, relegating the analog system to the roll of back-up to be used mainly during anticipated high activity periods, such as distress volley firing.

#### LOCATION OF RECORDING ROOM

There are three general locations for a central recording room: in the mine, on the surface at the mine site, and remote from the mine. The Bureau has engaged in microseismic research using underground enclosures and surface trailers for the central recording room, the work station of the on-site investigator.

In a coal mine, the recording equipment must be in fresh air; the geophone array must be permissible. In any mine, the recording equipment must be far enough away from active mining to minimize the chance of equipment damage from ground motion caused by a large bump.

The advantages of an underground recording room are routed in its

close proximity to the area of mining being monitored. First, cable runs are shorter and less expensive to install. Second, it is quicker to find and repair a geophone or cable problem in a short cable run than a long cable run. Third, the time involved in getting to a problem, repairing it, and getting back to the recording room can be excessive when mine entrance and exit are dictated by man trip timing as compared to the on-site investigator already being underground for the shift. Fourth, a better rapport with the miners is established by being underground. Fifth, it is easier for the observer to keep track of the mining sequence and progress when underground every day. Sixth, the data are readily available to the underground boss.

There are two advantages of a central recording room on the surface. Access to equipment is not hindered by temporary mine closures and some people consider it safer, for both equipment and personnel, outside a mine than inside.

The only reasons for having the central recording area remote from the mine site are when several mines are being monitored at one location and/or no qualified engineer or scientist is willing to work at the mine site. The more remote the observer is from the microseismic activity, the less complete his knowledge will be of what is really going on in the mine and the less likely the project will succeed. Modern telecommunications are marvelous for transmitting data, but no replacement for on-site observation and contact with the mining situation. In research, the post analysis of data can be done anywhere, anytime, but data analysis loses its immediacy as the observer gets farther away from the mine.

#### LOCATION ACCURACY

The location accuracy of events from within a geophone array, after obtaining arrival times from real data obtained from geophones placed in a mine, is about 10% of the

geophone spacing. In a longwall mine with a 200 m face and geophone spacing of about 100 m, the expected uncertainty in microseismic source locations is about 10 m, for strong events with easily discernable arrival times. Location accuracy for weak events and those from outside an array is worse. Even with accurate arrival times, there are many potential errors that creep into source location calculations. Many articles have been written on the subject of location algorithms for earthquakes, microearthquakes, and microseismic events. Prugger and Gendzwill (1988) give a bibliography of many of the papers written on the subject. A series of assumptions is usually made to solve for source locations in a reasonable time with known information. Usually, it is assumed that the acoustic wave travels from a point source to the geophone in a straight line, at an average velocity. For lack of better information, the velocity is usually assumed to be the same from the source to each geophone. Sometimes the velocity is given and sometimes it is calculated by the algorithm to give a best fit.

Solutions can be refined using results from a velocity survey. In practice, this is seldom done after the initial survey because the extra effort is time consuming and the new information usually does not improve accuracy enough to make the effort worthwhile. The assumption of straight line travel of the signal from source to geophone is very optimistic. The fastest travel path from source to geophone is most likely not a straight line, especially in a coal mine where the fastest path will usually be through a sandstone layer above or below the coal seam.

Various schemes to calculate location errors based upon errors in the assumed velocity and measured arrival times have been used to optimize geophone arrays. These exercises provide valuable insight for laying out geophone arrays (within the constraint of mine layout) and

evaluating calculated source locations from real data (Redfern and Munson 1982). Location accuracy will improve to better than 10% of geophone spacing as detection of first arrivals improves, as the layout of geophone arrays improves, and as location algorithms and velocity models improve.

## DISCUSSION

Control of unstable ground in mining is a world wide problem. As mining goes deeper to obtain natural resources, problems with ground control will probably get worse. Microseismic monitoring needs to be a partner with other rock mechanics techniques to aid mining difficult-to-retrieve resources.

Techniques of microseismic monitoring have advanced significantly over the past few decades. Microseismic monitoring works well as long as the observer is aware of both the strengths and pitfalls of current microseismic monitoring techniques. The strength of microseismic monitoring is its ability to locate sources of microseismic activity. Data interpretation has advanced to allow the prediction of major events under some circumstances. Accurate predictions of rock bursts have been made in hard rock mines, but prediction of catastrophic bursts is not totally reliable, at this time. Predictions could have been made in coal mines had the data been available for automatic and immediate analysis. The accuracy and reliability of predictions will improve as the understanding of rock fracture improves and the ability to obtain a complete and accurate history of microseismic activity in a mine improves.

As computer technology has advanced, the price of digital data acquisition has decreased. As research aspects of microseismic monitoring are completed and requirements for a production system are determined, the price of microseismic monitoring

systems will continue to fall. Bureau research suggests that, after further development, a complete microseismic monitoring system based on a desk top computer can be put together for \$10,000 plus cable cost. Signal transmission cable or fiber optic cable running from the geophones to an underground instrumentation room may add another \$10,000.

The ultimate goal of microseismic monitoring is not to predict catastrophic ground failures, but to aid in preventing them from happening. The Bureau's goal is to anticipate catastrophic failures in time to modify mining procedures to prevent failure. Until catastrophic failures can be reliably anticipated long enough in advance and until methods for controlling ground failure are developed and understood, the immediate goal is to predict all imminent catastrophic failures in time to allow miners to leave the mine safely.

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## SURVEILLANCE MICROSEISMIQUE DU CHARBON

Glen A. Rowell

Depuis de nombreuses années, le Centre de Recherches de Denver (DRC), Bureau des Mines Américain, mène d'actives recherches microsismiques dans les mines de charbon. Le but de ces recherches est de fournir à l'industrie minière des techniques fiables d'alerte de secousses et de dégagements imminents dans les mines de charbon, de manière à permettre aux mineurs d'évacuer les zones dangereuses avant l'effondrement du sol. Notre rapport présente la situation et les progrès du programme de recherches du DRC; il fournit de récents résultats des techniques microsismiques permettant de détecter l'imminence d'effondrements catastrophiques du sol dans les mines de charbon; il décrit le développement d'un système automatique de surveillance microsismique numérique de 16 pistes, d'une résolution de 12 bits, à l'intérieur d'un appareil disponible dans le commerce. Il étudie l'exactitude de la détection de la source de l'évènement et fournit des recommandations de futures recherches sur l'amélioration de la surveillance microsismique.

## MICROSEISMISCHE ÜBERWACHUNG VON KOHLE.

Glen A. Rowell

Das Denver Research Center (DRC), U. S. Bureau of Mines, unternimmt schon seit Jahren microseismische Untersuchungen in Kohlegruben. Zweck dieser Forschung ist Entwicklung einer zuverlässigen Methode zur Warnung gegen drohende Gebirgsschläge und Gasausbrüche, damit das Gefahrengebiet rechtzeitig evakuiert werden kann. Der Vortrag befaßt sich mit dem Stand und Fortschritt des DRC Forschungsprogramms, einschließlich der neuesten Erkenntnisse in der microseismischen Technik zur frühzeitigen Erkennung von bevorstehenden katastrophalen Gebirgsschlägen in Gruben. Es wird außerdem die Entwicklung eines automatischen digitalen microseismischen Aufzeichnungssystems mit 16 Kanälen und 12 bit Wiedergabeschärfe vorgestellt, das in Gestalt eines im Handel erhältlichen Gerätes vorliegt. Die Genauigkeit, mit der Auslöser des Gebirgsschlages lokalisiert werden können, wird untersucht. Weitere Forschungsvorschläge zur Verbesserung der microseismischen Überwachung in der Zukunft werden vorgelegt.

## МИКРОСЕЙСМИЧЕСКИЕ НАБЛЮДЕНИЯ НА УГОЛЬНЫХ МЕСТОРОЖДЕНИЯХ

Глен А. Роуэлл

Денверский исследовательский центр Горного бюро США уже много лет осуществляет интенсивные микросейсмические исследования на угольных месторождениях. Целью этих исследований является обеспечение горной промышленности надежными методами предупреждения угрожающих угольных отслоений и выбросов, чтобы шахтеры смогли очистить опасные отсеки до обвала. В докладе обсуждается состояние исследовательской программы на сегодняшний день и достигнутый прогресс, включая новейшие микросейсмические методы, с помощью которых было своевременно распознано приближение катастрофических обвалов в угольных шахтах. Большое значение придается разработке 16-ти канальной, с разрешающей способностью в 12 бит, автоматической цифровой системы слежения, которая может быть использована с уже продающейся аппаратурой. Рассматривается точность локализации источника выброса угля. Предлагаются рекомендации для будущих исследований по улучшению микросейсмических наблюдений.

## 煤矿中微地震监测法

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美国矿务局丹佛研究中心 (DRC) 几年来一直积极地从事煤矿微地震探测法的研究。此项研究工作的宗旨是给煤炭工业界提供一个可靠的技术来报警即将发生的煤矿石突出和塌方事件, 从而矿工们能在地面崩塌之前撤离危险地段。本文将阐述丹佛研究中心 (DRC) 的研究现状和进展, 其中包括新近取得的预告煤矿内即将发生的灾难性塌方的微地震探测技术; 本文还提到了一个 16 频道, 12 位解析度的微地震自动数字监测仪的研制, 此仪器组装在一个单元里并可从市面上购得。震源在煤矿里位置的准确度也在这里提到。本文并提供了微地震监测今后的研究和改进方向。



U.S. BUREAU OF MINES  
OPEN FILE REPORT  
**OFR 27-89**

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**第23届采矿安全研究学院国际会议**

**Washington, DC  
September 11-15, 1989**

**Organized by the U.S. Department of the Interior, Bureau of Mines**