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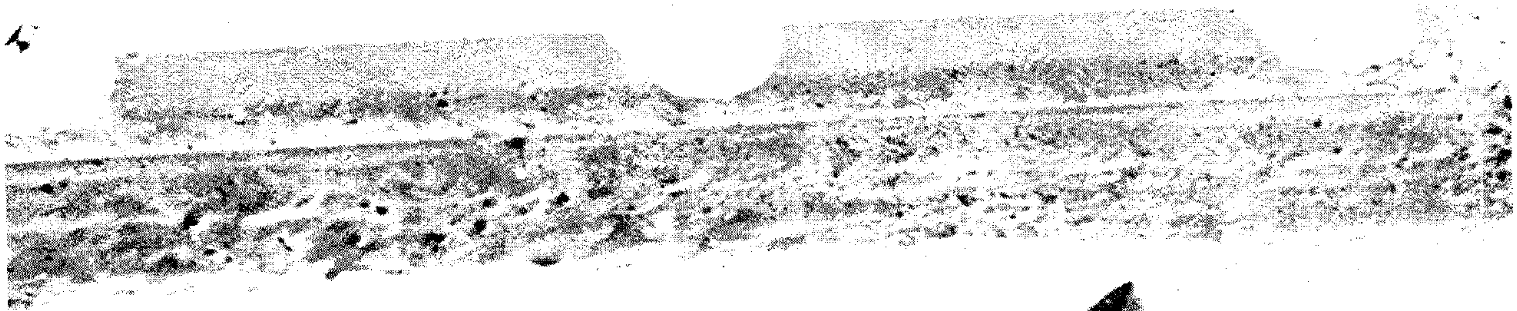
CREATING A SAFER ENVIRONMENT IN U.S. COAL MINES



The Bureau of Mines Methane Control Program, 1964-79

Waiting . . . at the Monongah Mines the day after the explosion of December 6, 1907

COVER: Water spray nozzles, mounted here on a continuous miner cutting head, are directionally alined as part of the Bureau of Mines "spray fan" system for improving faceventilation in coal mines. (See section on Face Ventilation in this report.)

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This report summarizes the principal activities and results of 15 years of research by the Bureau of Mines, U.S. Department of the Interior, on methane control in coal mines. This research has investigated fundamental factors regarding the occurrence and movement of methane in coalbeds, removal of methane prior to mining, and control of methane during mining. The report includes a bibliography listing the more than 150 publications resulting from the Bureau's methane control program as well as numerous other references, a section on methane recovery and use, a look at the upcoming Bureau of Mines research program, and a brief review of methane drainage practices in other coal-producing countries.

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A Bureau of Mines Impact Report

CREATING A SAFER ENVIRONMENT IN U.S. COAL MINES

The Bureau of Mines Methane Control Program, 1964-79

by

Milford L. Skow, Ann G. Kim, and Maurice Deul

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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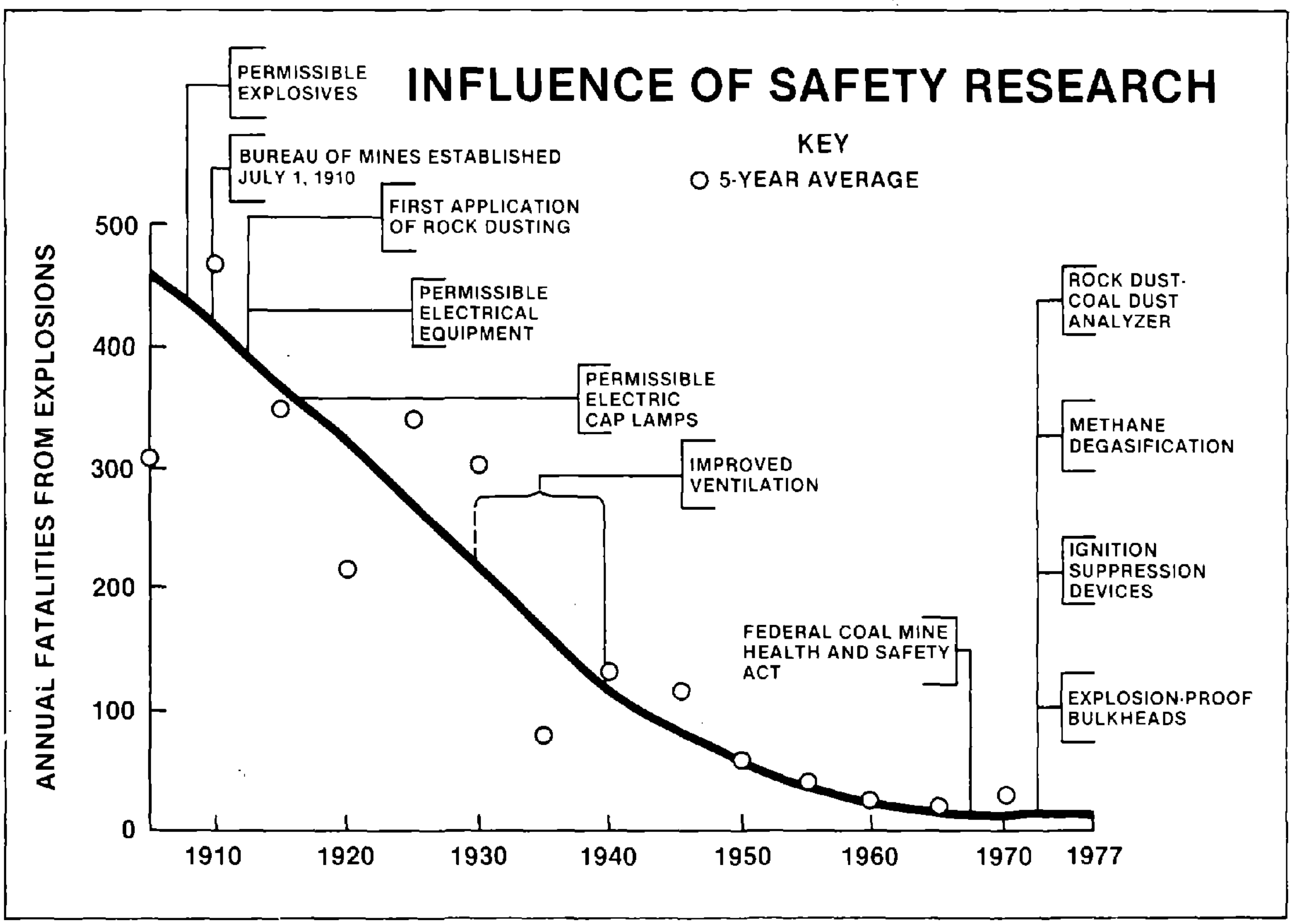

Safety research has played a major role in the steady decline in coal mine explosion fatalities since the Bureau of Mines was formed in 1910. Coal mine disasters like the one at Monongah usually result from ignition of coal dust, methane, or a combination of the two. The ongoing Bureau of Mines Methane Control Program is working to reduce the cost and improve the effectiveness of making coal mines safe from explosions.

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Introduction

This report summarizes the principal activities and results of 15 years of research by the Bureau of Mines, U.S. Department of the Interior, on methane control in coal mines. This research has investigated fundamental factors regarding the occurrence and movement of methane in coalbeds, removal of methane prior to mining, and control of methane during mining. The report includes a bibliography listing the more than 150 publications resulting from the Bureau's methane control program as well as numerous other references, a section on methane recovery and use, a look at the upcoming Bureau of Mines research program, and a brief review of methane drainage practices in other coal-producing countries.

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One hundred twenty-eight men died in the explosion that wrecked these mine cars at the Banner Mine, Littleton, Ala., in 1911. (Photo from Bureau of Mines files.)

The Methane Problem

Methane is a gas that is slightly lighter than air and is colorless, odorless, and nonpoisonous. It occurs in the air of most coal mines because when coal was formed from ancient peat swamps, methane also was formed. Air containing 5 to 15 pct methane and at least 12.1 pct oxygen will explode if ignited.

The common occurrence of methane and its potential explosibility when mixed with air have been directly responsible for numerous mine disasters. However, methane is not the only cause of explosions. Dry coal dust, except anthracite, suspended in air is explosive; however, coal-dust explosions are propagated more readily and more rapidly when methane is present, even in concentrations below the lower explosive limit. Many major mine explosions (those in which five or more people are killed) were attributable solely to an accumulation of methane, and most of those in which dust was a factor were initiated by a localized methane ignition.

The first major U.S. coal mine explosion that has been verified by the Bureau of Mines occurred in Virginia in 1839. Major explosions occurred thereafter at irregular intervals; but between 1876 and 1948, there was at least one major coal mine explosion each year except in 1889.

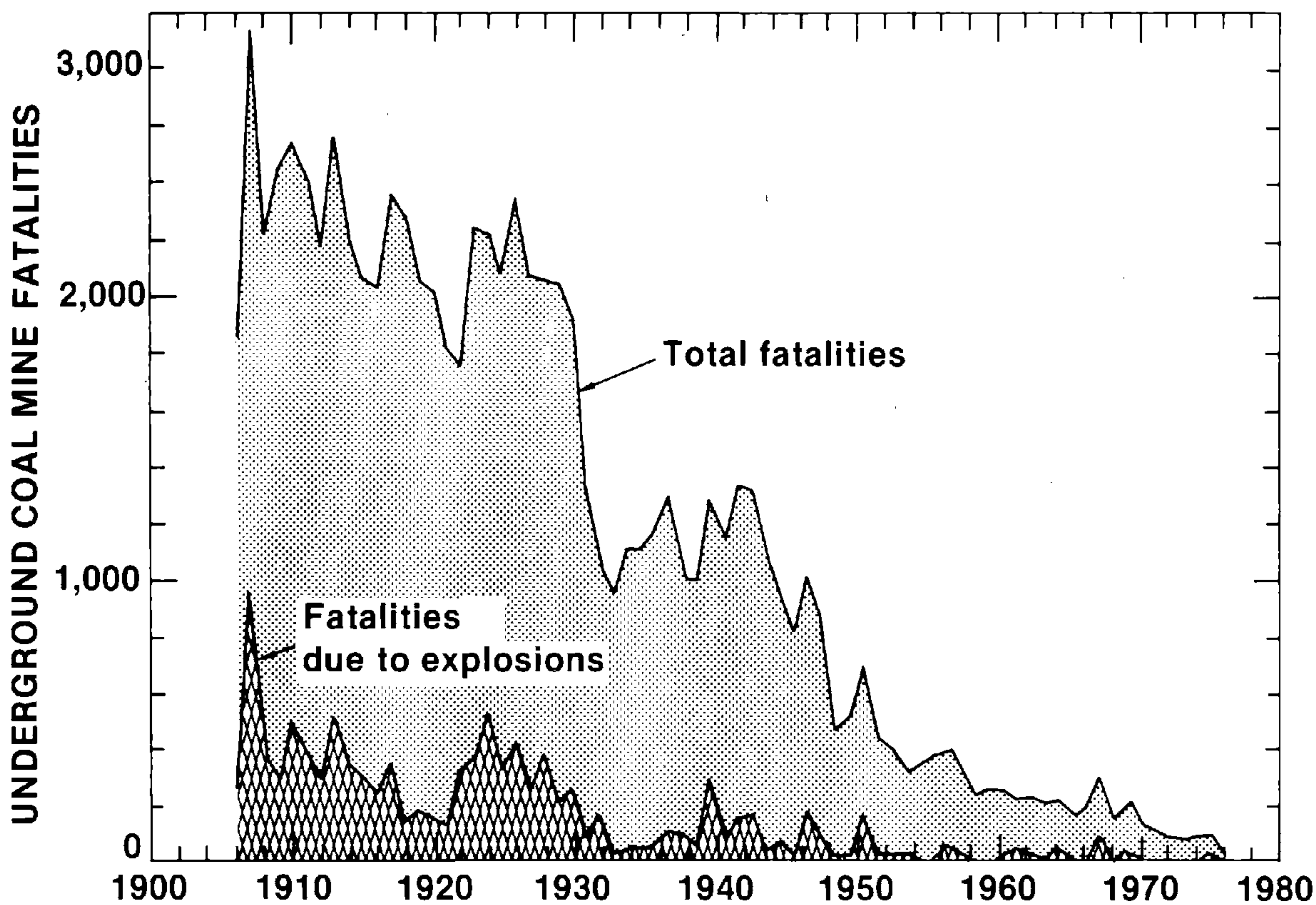
Using jacket to brush out gas, about 1916—once the standard way to improve coal mine ventilation. (Sketch from Bureau of Mines Information Circular 7900, Historical Summary of Coal-Mine Explosions in the United States, by H. B. Humphrey—1957, page 79.)

Since 1906 (the first year for which complete fatality data are available), approximately 10 pct of all underground coal mine fatalities were due to explosions. Since 1950 the number of major explosions in U.S. coal mines has declined, but the danger is still present. After 2 years with no explosion-caused fatalities, 26 men were killed in explosions in 1976, and there were 4 fatalities due to methane ignition in 1977. However, 1978 was again free from fatalities resulting from explosions.

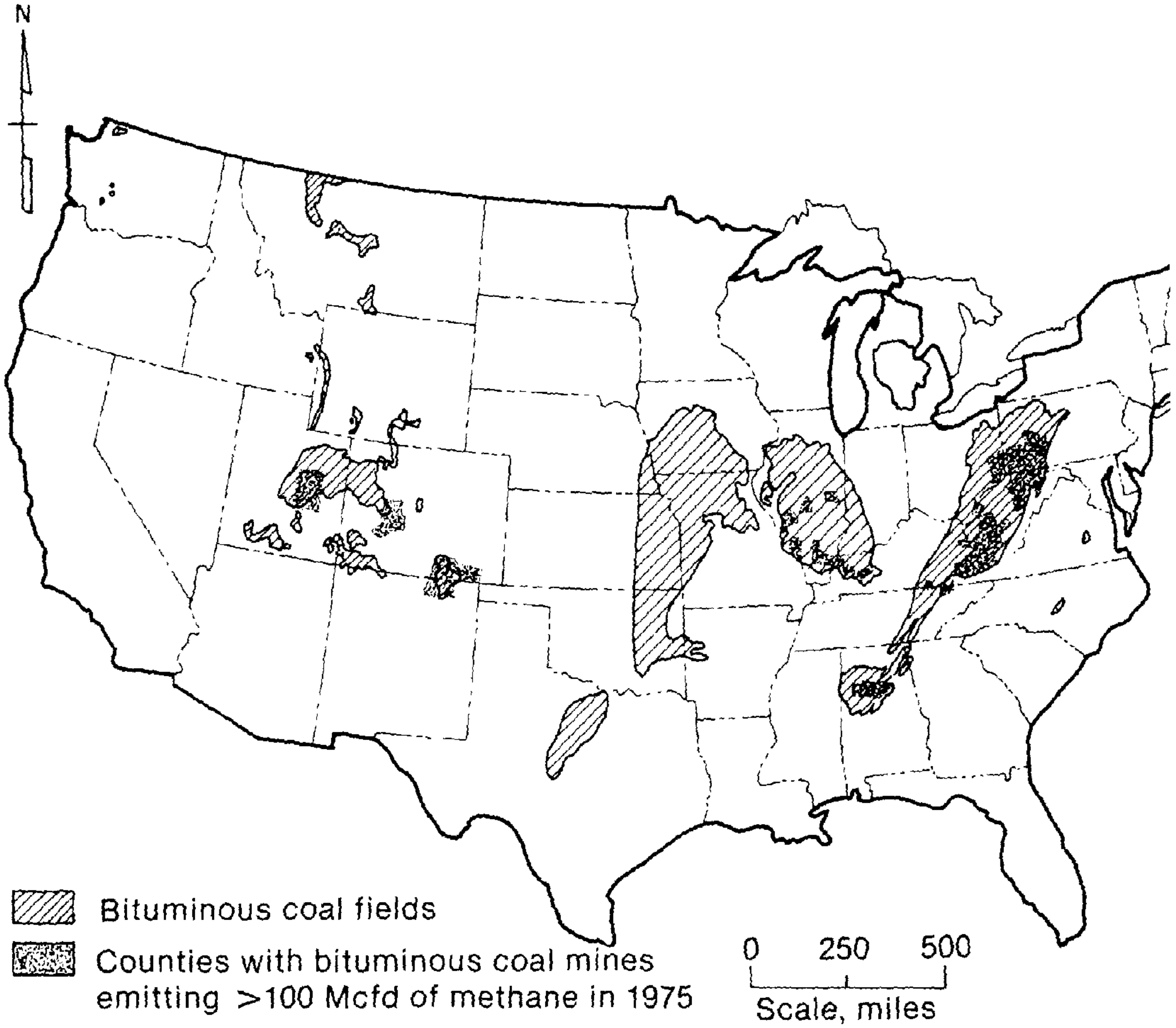
In the early years of coal mining, inadequate ventilation, failure to test for gas (methane), use of open lights, smoking, failure to remove or control dust accumulations, and the improper use of black powder for blasting were the most frequently cited factors in explosions. After 1910, both the number of explosions and the number of fatalities per million tons of coal produced declined. This decline can be attributed to many factors, such as the elimination of open lights, the use of permissible explosives instead of black blasting powder, the development of "explosion-proof electrical equipment," stricter and more accurate tests for methane, the control of dust, and the prevalence of rock dusting. The Bureau of Mines played a major role in developing and instituting these practices.

Coal mine explosions today usually result from inadequate ventilation, often due to failure to control methane. The methane that enters the mine atmosphere can come from adjacent strata as well as from the coalbed itself.

All coalbeds contain methane, the amount of which can vary from 0.01 cubic foot to more than 600 cubic feet per ton. Usually, the amount of methane in coal increases with higher rank and greater depth. The gas is present both adsorbed on the micropore structure of the coal matrix and compressed in the fracture system of the coalbed. Wherever coal is uncovered by erosion or mining, the equilibrium that exists in the coalbed under confining pressure is disturbed, and methane is emitted. Cur-



In 1907, almost 1,000 men died in explosions in coal mines out of nearly 3,000 total deaths; in 1977, only 4 fatalities were due to explosions and ignitions of methane, and total underground mining deaths were under 100.

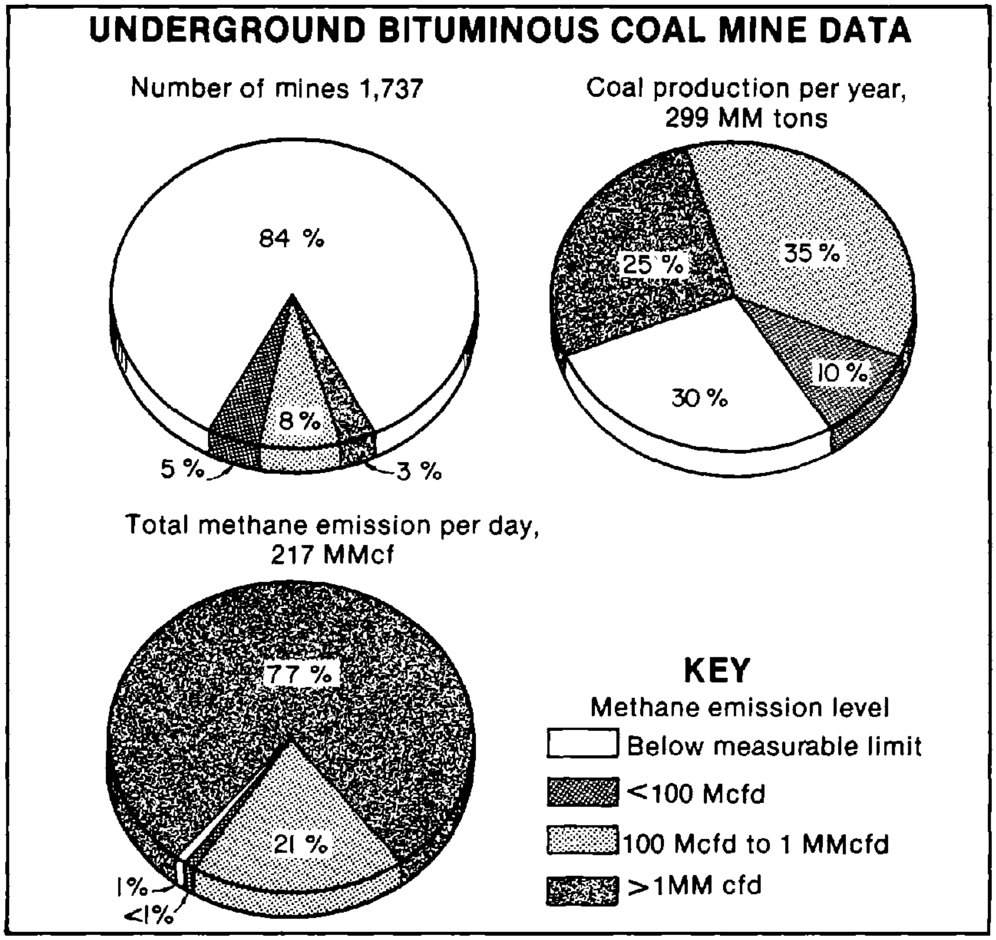


Very gassy coalbeds are found in the Eastern and Midwestern United States. Shaded areas indicate locations of mines with high methane emission rates.

rently, U.S. underground bituminous coal mines daily emit more than 200 million cubic feet (MMcfd) of methane. In 1975, the most recent year the information was tabulated, 136 mines emitted between 0.1 and 1 MMcfd, and 60 mines emitted more than 1 MMcfd of methane. These two categories of mines account for only 11 pct of the total number of underground bituminous coal mines but 60 pct of the total coal production.

The rate of emission underground is dependent upon the pressure gradient between the coalbed and the mine and also upon the permeability of the coalbed. Not all the gas is emitted at the working face where the coal is extracted; as much as 70 to 80 pct of the methane in the mine atmosphere enters from the exposed ribs and adjacent strata. But the emission rate per unit area of coal exposed is many times higher at the face than from the ribs. Thus emission in the face area is frequen determinant of the quantity and rate of fresh a to ventilate the mine.

Ventilation is the only technique used uni underground mines to keep methane at safe l also required by Federal regulations. These r require, in part, that all coal mines be ventilate tinuously operating mechanical fans, that a m 9,000 cubic feet per minute (cfm) of air reac open crosscut, that 3,000 cfm of air reach eac face, that the minimum mean air velocity at th face be 60 feet per minute, that methane con at the face be less than 1 vol-pct, that coal- equipment be automatically deenergized should ane concentration reach 2 vol-pct, and that on sible electrical equipment be used.



Mines with high methane emission rates produce 60 percent of the coal from U.S. underground bituminous coal mines.

To maintain operations within these statutory limits for methane concentration, the general approach has been to increase the quantity of ventilation air as methane emission increases. This requires extremely large quantities of air. Thus, it is not uncommon for a mine to circulate several tons of air per ton of coal mined, and large mines in the Pittsburgh coalbed circulate between 5 and 23 tons of air for each ton of coal extracted. During 1975, an average of 12.1 tons of air was circulated per ton of coal produced by the 60 mines in the United States having individual methane emission rates of more than 1 MMcfd.

At times, even these large quantities of air are not sufficient to dilute and remove the methane adequately. In mechanized working areas, desired rates of coal production often result in methane emission so rapid that there is not enough available ventilating air to keep methane concentration below the danger level. This commonly occurs in newly developing mines or in mines where development headings are being driven into virgin coal. To prevent formation of explosive methane-air mixtures, coal production must be stopped intermittently to enable the ventilation to reestablish and maintain an acceptable methane concentration.

The only alternative to decreasing the rate of coal production so as to maintain statutory methane concentrations is reducing the volume of methane emitted into the mine. To do this requires either removing as much of the methane as possible from the coalbed before mining or controlling the emission of methane underground. Since the rates of uncontrolled methane emission underground depend upon both coal production rate and mining depth, the need for methods other than dilution alone to control methane will increase if production of high-quality coal is to meet the predicted demand.

To supply this increased demand for coal, a large number of new underground coal mines will be needed. As relatively shallow reserves are depleted, new mines will be opened in deeper parts of the coalfields. In theory and in practice, deeper coalbeds contain more methane than most coalbeds currently being worked. Traditional ventilation methods thus may not be able to control methane emission without adversely affecting productivity. Thus, effective methane control technology, including improved conventional methods, innovative techniques, and reliable instruments and equipment for methane control, is essential to safe underground coal mining and to increased U.S. coal production.

The Research Program

In 1964 the Bureau of Mines undertook a program of systematic research on methane drainage. The general objective then, as well as now, was to develop the technology necessary for safe and economic mining of methane-laden coalbeds so as to prevent the mine disasters caused by accidental ignition of methane-air mixtures. The early program was funded at a modest level and was concerned mainly with establishing principles that are dominant in controlling the occurrence and movement of methane in coalbeds.

Initially, the emphasis was on geologic studies to develop correlations between geologic structural conditions and the presence of methane and the mode of its occurrence, and on laboratory and in-mine studies to assess the physical properties of coal and adjacent strata that influence the retention and emission of methane. To conduct these studies, it was necessary to develop equipment, such as accurate permissible recording methanometers, suitable borehole packers, and drilling equipment, and to train personnel to obtain scientifically valid data, often under adverse circumstances. Early in the program, locating suitable sites for field tests was also a problem. Few mine operators were interested in having a research crew in an active part of their mine, no matter what the eventual benefits might be.

As a result of the disaster at the No. 9 mine at Farmington, W. Va., in 1968, funding for the program was increased for 1969. An accelerated program was instituted with expansion of in-mine work to establish relationships between coalbed properties and methane emission and to develop control techniques.

In early 1970, the program was expanded again. Part of the increased funding was allotted from the appropriation for Conservation and Development of Mineral Resources, previously the Bureau's sole source of funds for the methane program. Subsequently, this appropriation was not used to support the research on methane control. The remainder came from the appropriation authorized for research by the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91–173). The program has continued since then as an integral part of the Coal Mine Health and Safety Research Program. The significantly increased expenditures for the 2 years beginning in July 1970 were for development and acquisition of necessary tools and instruments, expansion of in-mine testing, experimental degasification borehole patterns in eight different coalbeds, and a small-diameter shaft for methane drainage tests. At this time also, the program was broadened in scope to consider all methods of controlling methane, whereas formerly it was concerned only with methane drainage.

No single method of methane control can be universally applicable, since methane may be emitted in different ways depending on the nature of the coalbed and surrounding strata, the geologic conditions, and the methods of mining. Therefore, the approach is to define the problems through collection and analysis of fundamental data and to develop a number of control techniques and drainage methods from which mine operators can choose to suit their particular operations. Thus the research and development program includes work in the following three problem areas:

Fundamental Factors

These studies are concerned with determining how the geology and physical properties of coalbeds being mined now, and of those likely to be mined in the future, affect methane emission and with compiling and analyzing gas emission data from new and existing coal mines as these develop and as new mining methods are introduced. Understanding these factors is necessary to be able to predict the methane in a block of coal, the pressure under which it occurs, and factors governing its movement, and thus to design effective systems for methane control and ventilation.

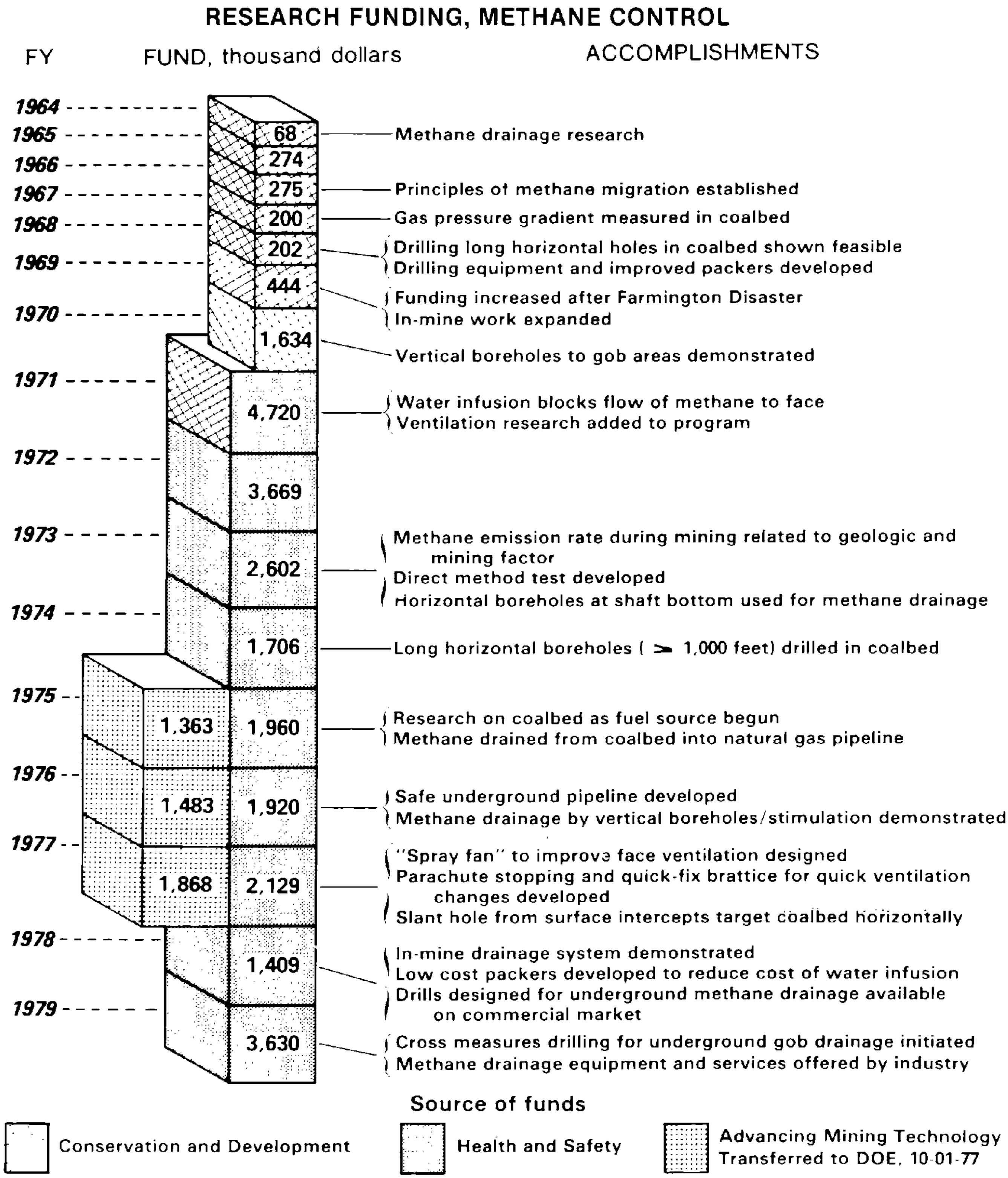
Control in Advance of Mining

These studies are concerned largely with removing methane from virgin coal. Several drainage techniques are currently in various stages of development; namely, vertical boreholes from the surface, horizontal boreholes from the bottom of a shaft, and directional boreholes from the surface.

Control During Mining

These studies include drainage from ahead of the face through horizontal holes, water infusion to divert methane from the face, novel methods of improving face ventilation, and more effective removal of gas from gob areas in active mines.

From July 1, 1974, until it was transferred to the U.S. Department of Energy (DOE) on October 1, 1977, the Bureau's Advancing Coal Mining Technology Program furnished supplementary funding for the research program on methane control. The objective of this segment of the program was to demonstrate the feasibility of recovering commercial quantities of methane from virgin coalbeds and from underground gob areas in order to



Research funding for methane control and ventilation has produced many significant accomplishments.

increase the coal production potential and overall productivity from U.S. coal deposits. To achieve maximum progress toward this objective, the research and development was focused on the following five activities:

1. Establishing optimum well density for coalbed degasification through vertical boreholes by tests and demonstrations conducted under cost-sharing/cost-reimbursable contracts.

2. Further developing directional drilling for degasification of coalbeds.

3. Drilling and testing to determine the degasification potential of coalbeds not widely mined.

4. Improving the data base for candidate coalbeds for gas production.

5. Evaluating the potential of gob gas resources as a supplemental energy source.

The intended concern of the activities was with one or more of the following goals:

1. Production and recovery of gas as an energy source with the operation completely independent of and unrelated to any mining.

2. Stimulation of early production from presently unmined coalbeds by economically producing sufficient gas to drastically reduce the explosion hazard when mining is undertaken.

3. Demonstration of gob gas utilization.

The transfer of funds for these activities to DOE was responsible for only part of the large drop in expenditures for the program in 1978. The rest of the decrease was not planned but rather reflects the difficulties and complexities in obtaining suitable agreements for demonstration projects. In objectives and implementation, the continuing Bureau of Mines methane program is clearly distinguishable from the activities that were transferred to DOE. Any research on methane drainage in connection with a mining operation, either currently existing or having definite plans to start, is inseparable from the primary objective of safety. Drainage of methane from coalbeds when mining is existent or contemplated will not only reduce the hazards of the mining operation but also result in economic benefits, such as reduced downtime of mining machines, reduced capital expenditures and operating costs for ventilation, and production of a salable gas.

Technician displays equipment used for sensing methane in a coal mine. Telemetry line from methane sensor can be used for emergency communications, and methane concentration is determined by the recording methanometer.

The Results

The emphasis of the Bureau's current methane control program is on demonstrating the effectiveness of developed technology for methane control and ventilation in underground mining and further improving techniques now available. Research on methane control and ventilation is now being conducted on improving drilling technology, developing continuous in-hole surveying techniques, improving bore-hole stimulation methods, improving drainage rates from low-permeability coalbeds, obtaining more data on the gas content of coalbeds, quantifying the effect of methane drainage on productivity and ventilation costs, using tracer gas to pinpoint ventilation problems, improving face ventilation, developing effective but inexpensive temporary stoppings, and increasing the effectiveness of packers for water infusion while decreasing the cost.

The basic methods of draining methane from coalbeds have been demonstrated. However, demonstrations of developed methods must be repeated to show their adaptability under various conditions, to compare conditions before and after degasification, to determine the cost-benefit relationship, and to provide mine management with a source of practical experience for use in solving their problems with methane emission.

In the 15 years since the methane control program began, the Bureau of Mines has overcome many obstacles and developed effective solutions to methane control problems. For instance, new mine development may be slowed due to excessively high methane emission from virgin coal. In this case, techniques to *drain methane from coal in advance of mining* (through shafts or through vertical boreholes) can allow mine development to proceed more rapidly. A section of an established mine may be gassier than normal, and *in-mine drainage* can be used to keep methane emission at safe levels. *Water infusion* can be used to direct the flow of methane away from active mining. The efficiency of the ventilation system can be improved by using a *spray fan* to enhance air movement at the face. Measuring leakage by the *brattice window method* can show where air leakage occurs, and *parachute-type stoppings* can be used to make temporary or emergency changes in the ventilation system. These techniques can be used alone or in a combination to solve methane problems. With the control methods developed to date, gassy coalbeds can be mined safely and economically.

Significant technical accomplishments of the methane control program are discussed briefly below, grouped according to the three elements, or problem areas, of the program. More detailed information can be found in the more than 150 technical publications and patents that have also been products of this research.

Fundamental Factors

Developing solutions to methane control problems in mining required obtaining basic data on coal geology, on factors affecting gas flow in coal, and on the actual scope and extent of methane emission in coal mines. Federally collected and analyzed data have shown that total methane emission from U.S. coal mines is more than 200 MMcfd. In 1975, emissions were over 1 MMcfd in 60 mines, with 1 mine emitting more than 10 MMcfd. In most coal-producing States, methane emission from coal mines is increasing.

Continuous monitoring of the methane concentration in mine air can be used to determine the relation of methane emission to mining parameters such as production rate, depth of overburden, and length of virgin rib. For this

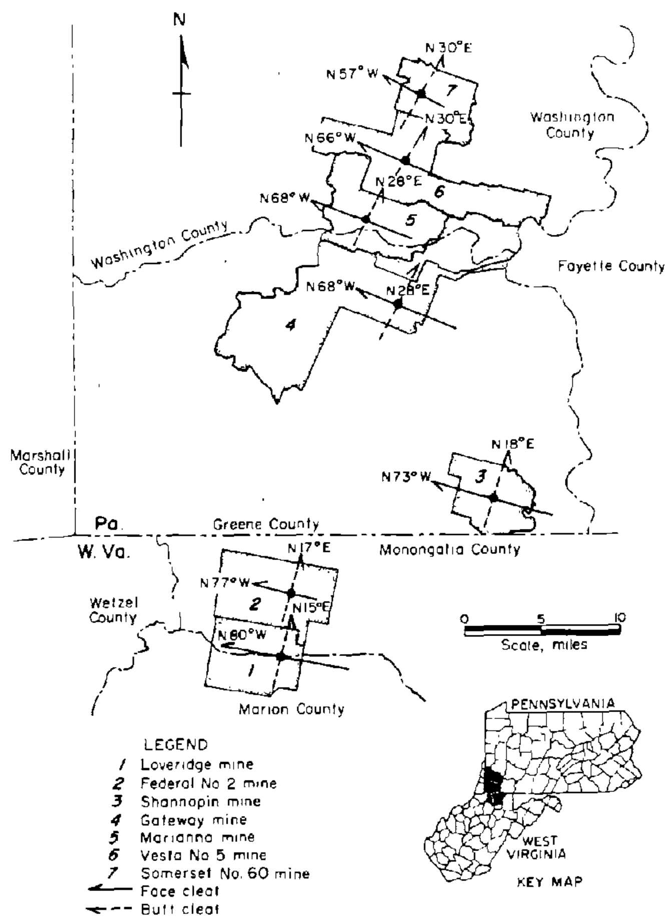
A surface exposure of a coalbed shows the orthogonal

purpose a continuous recording system, containing methane sensor assemblies, power supply, and a receiver assembly, was developed and tested. The sytem allows up to 16,000 feet between sensor and receiver assemblies. As used to determine sources of methane emission in underground coal mines, it includes multiple methane sensors and continuous remote monitoring. It can activate alarms and control fail-safe devices at a preset methane level. The system has been installed in several large coal mines (Federal No. 2, Marianna No. 58, and Sunnyside No. 1). The methane sensor used in this system is simple, accurate, and rugged enough to operate in the hostile environment of an exhaust fan cone. This sensor was combined with suitable electronics and a recorder to provide a means of monitoring the methane content of the air at an exhaust fan. This instrument, which is inexpensive, accurate, and reliable, can operate unattended for a month and is easily maintained.

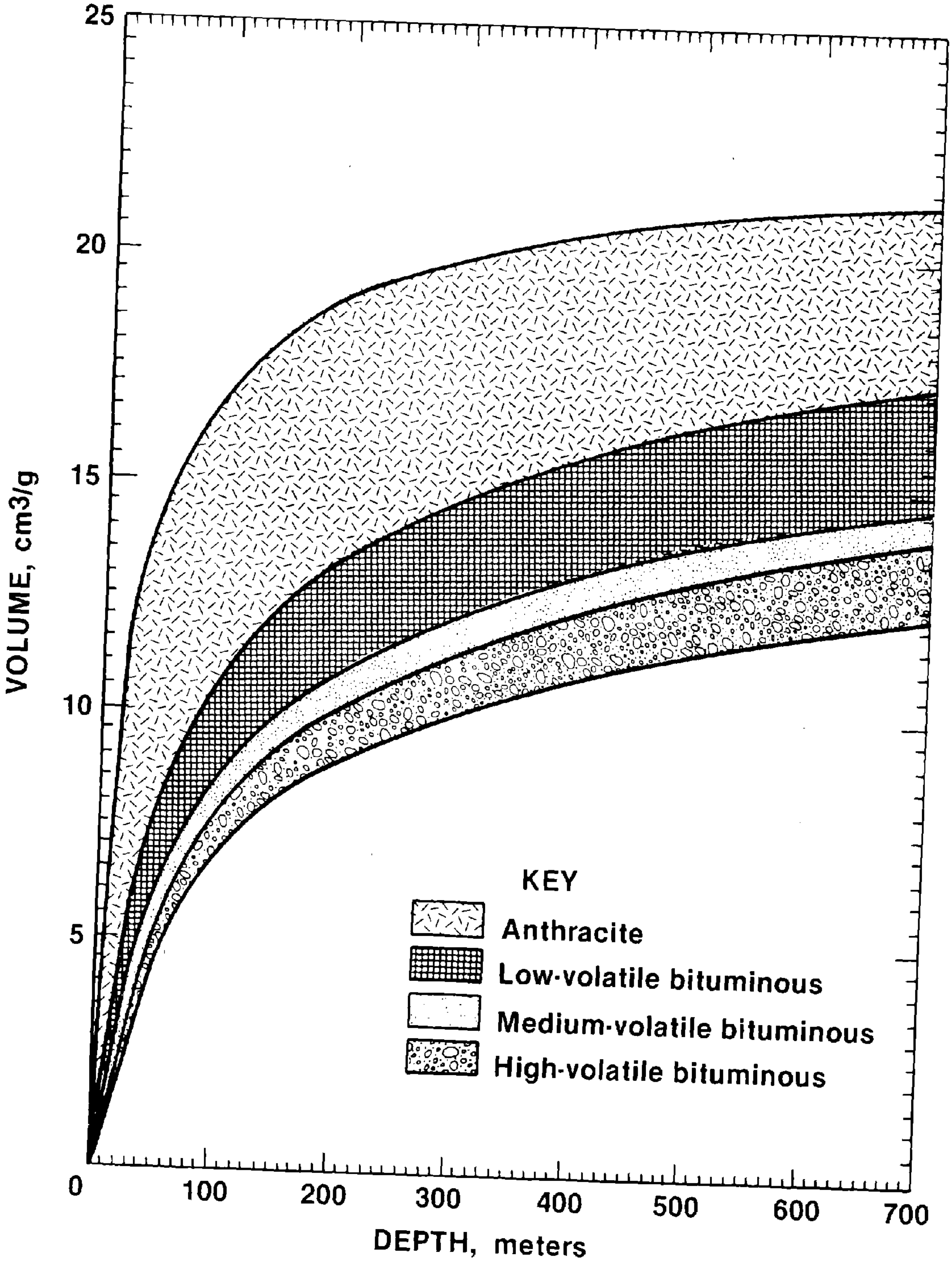
To define areas in which methane control problems can be anticipated, the Bureau of Mines conducted geologic studies on coalbeds in Alabama, Colorado, Oklahoma, Pennsylvania, Utah, Virginia, and West Virginia that will be mined extensively in the near future. The resulting data have been used to delineate areas of high methane concentration in the Mary Lee coalbed in Alabama, the Hartshorne coalbed in Oklahoma, the Pittsburgh and Freeport coalbeds in Pennsylvania, and the Pittsburgh and Beckley coalbeds in West Virginia. Maps showing coal cleat orientations are helping various coal mining companies plan mine ventilation systems more effectively and assess the feasibility of methane drainage ahead of mining.

These geologic studies also established that most coalbeds have a directional permeability, due to sets of interconnected vertical fracture planes within the coal. In coal termed blocky, a set of prominent fractures, or face cleats, are spaced 1 to 6 inches apart. A secondary set

… of the face cleats and butt cleats.



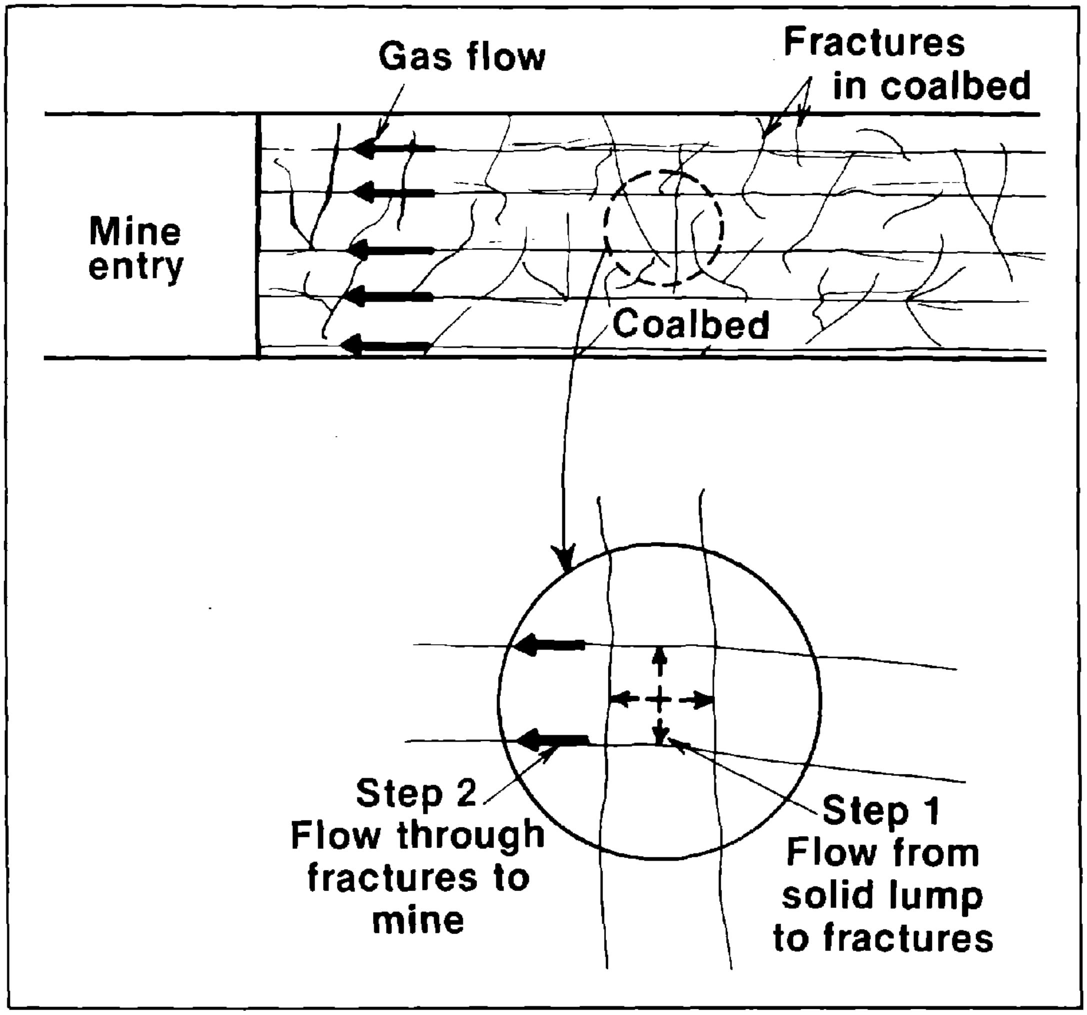
Coal cleat orientation in seven mines in the Pittsburgh coalbed shows cleat rotation.



Adsorption isotherms for coal show that deeper, higher rank coalbeds are gassier.

of fractures, the butt cleats, occur at right angles to the face cleats. In coals that are called friable, the fracture spacing is less than 1 inch, and both sets of cleats are equally prominent. In blocky coal, methane emission rates are higher along the face cleats. Rib stability and roof conditions are also related to cleat orientation.

Where actual measurement in mines is not feasible, methods developed by the Bureau are used to predict cleat orientation. Surface and photolinear methods have been used to determine cleat orientation for 32 coalbeds in Pennsylvania, West Virginia, Virginia, Alabama, Oklahoma, Colorado, and Utah.

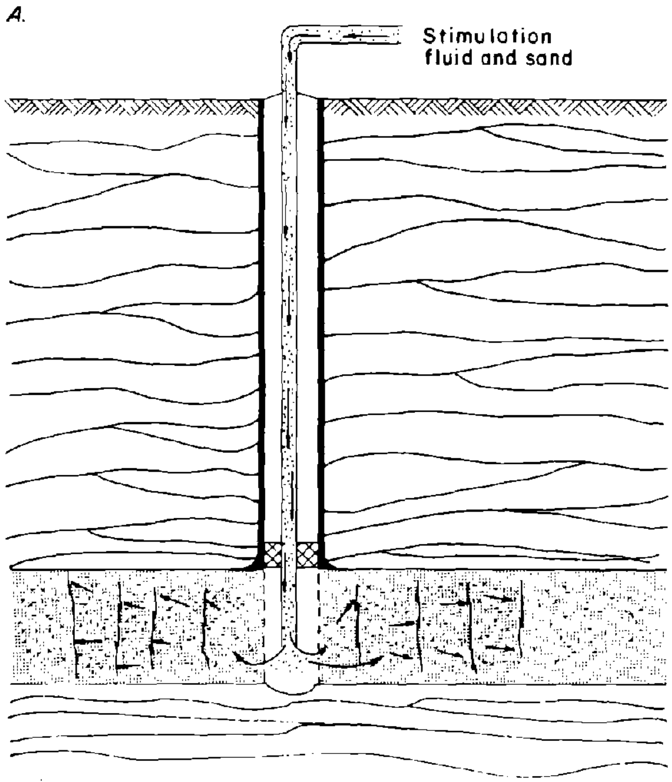


Methane flows through coal in two steps; first from the solid coal into fractures, then along fractures into the mine.

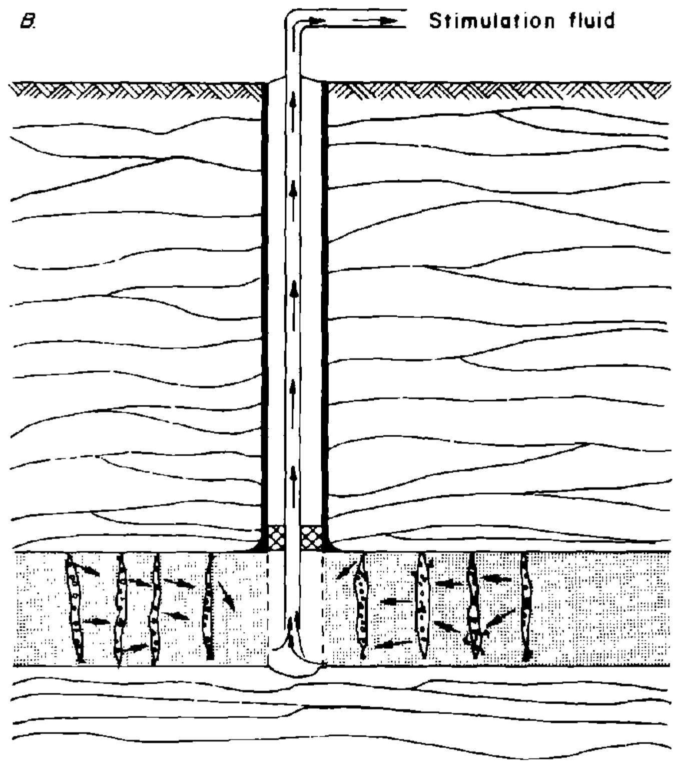
Factors affecting the retention and migration of methane in coalbeds were studied to provide a basis for the more rational design of coalbed degasification systems. The following information resulting from the studies has been useful in designing more effective systems for draining methane from coal and essential in explaining apparently anomalous field results. The physical structure of coal, with both very small pores and larger cracks and fractures, affects the methane emission rate. Methane flows from the pores by diffusion; flow through the cracks is laminar. In this two-step process, the relationship between diffusion coefficient and fracture permeability, which varies for different coals, determines the methane emission rate. Methane emission was found to be retarded by the water normally found in coalbeds. As the coalbed is dewatered, methane emission rates increase. Laboratory studies of methane adsorption on coal indicated that coals that are higher in rank are capable of holding larger quantities of methane. Also, at higher pressures, coals can contain more methane. Since both rank of coal and pressure increase with depth, deeper coals can be expected to be substantially gassier than shallow coals. Adsorption data have been used to obtain a rough estimate of how much gas a coal contains.

The equipment for a direct determination of the methane content of a coal core is easy to set up in the field and is relatively inexpensive.

The actual gas content of coalbeds depends on factors in addition to rank and depth. In order to determine the actual gas content of a coal, a direct method was developed that uses simple and inexpensive equipment and a coal core taken during exploratory drilling. Because of its simplicity and low cost, this method is being used by at least nine major coal companies to evaluate their coal properties and by two consulting firms to provide gas determination services. The U.S. Geological Survey, six State geological surveys, and one university are also using the direct method. The Bureau has received requests for assistance in determining the gas content of coalbeds from 35 companies in 11 coal-producing States and from other countries. Determining how basic factors affect methane flow rate was a first step in the successful development and application of methane control techniques. However, problems from methane emission may also be related to other factors, such as the mine's age, size, productivity, quality of maintenance, and ventilating system design. To be effective, a methane control technique must be geared to the problem, and the Bureau has developed several such techniques. Some of these are to be applied before mining begins, the others while mining is in progress.



Vertical boreholes to drain methane. A, stimulation fluid and sand are pumped into the coalbed;



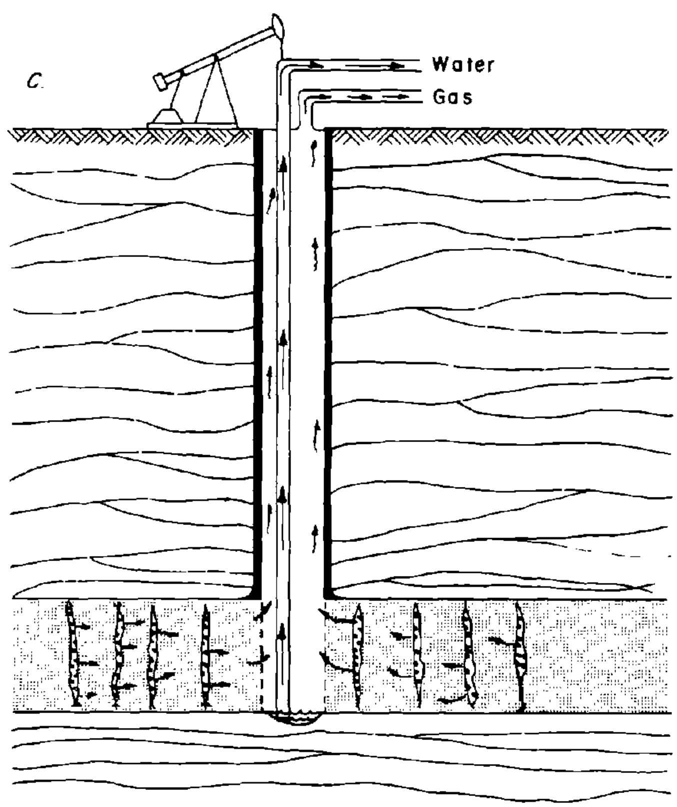
B, stimulation fluid is removed, and sand props open the widened fractures;

Methane Control in Advance of Mining

A relatively simple yet effective method of reducing the methane load on a mine's ventilation system is to drain the methane from a large block of coal before mining begins in this part of the coalbed. Several techniques are currently in various stages of development; namely, vertical boreholes from the surface, horizontal boreholes from the bottom of a shaft, and directional holes from the surface.

Drainage Through Vertical Boreholes

Methane may be recovered from coal in advance of mining by drilling small-diameter (less than 10-inch) vertical boreholes from the surface to the coalbed. Casing is set and cemented in the borehole. When water in the coalbed is pumped off, methane flows out of the coal. Because of coal's low permeability, vertical boreholes in coalbeds, like natural gas wells, normally produce gas at very low rates. Hydraulic stimulation, a standard technique for increasing these rates in oil and gas production, has been adapted for use in coalbeds. By this method, naturally occurring fractures in the coalbed are enlarged and extended beyond the borehole by hydraulic pressure and injection of gelled, sand-bearing water through perforations in the well casing. When the water is removed, the sand remains to prop open the fractures and thus increase the effective drainage surface of coal.



C, gas and water flow from the coalbed.

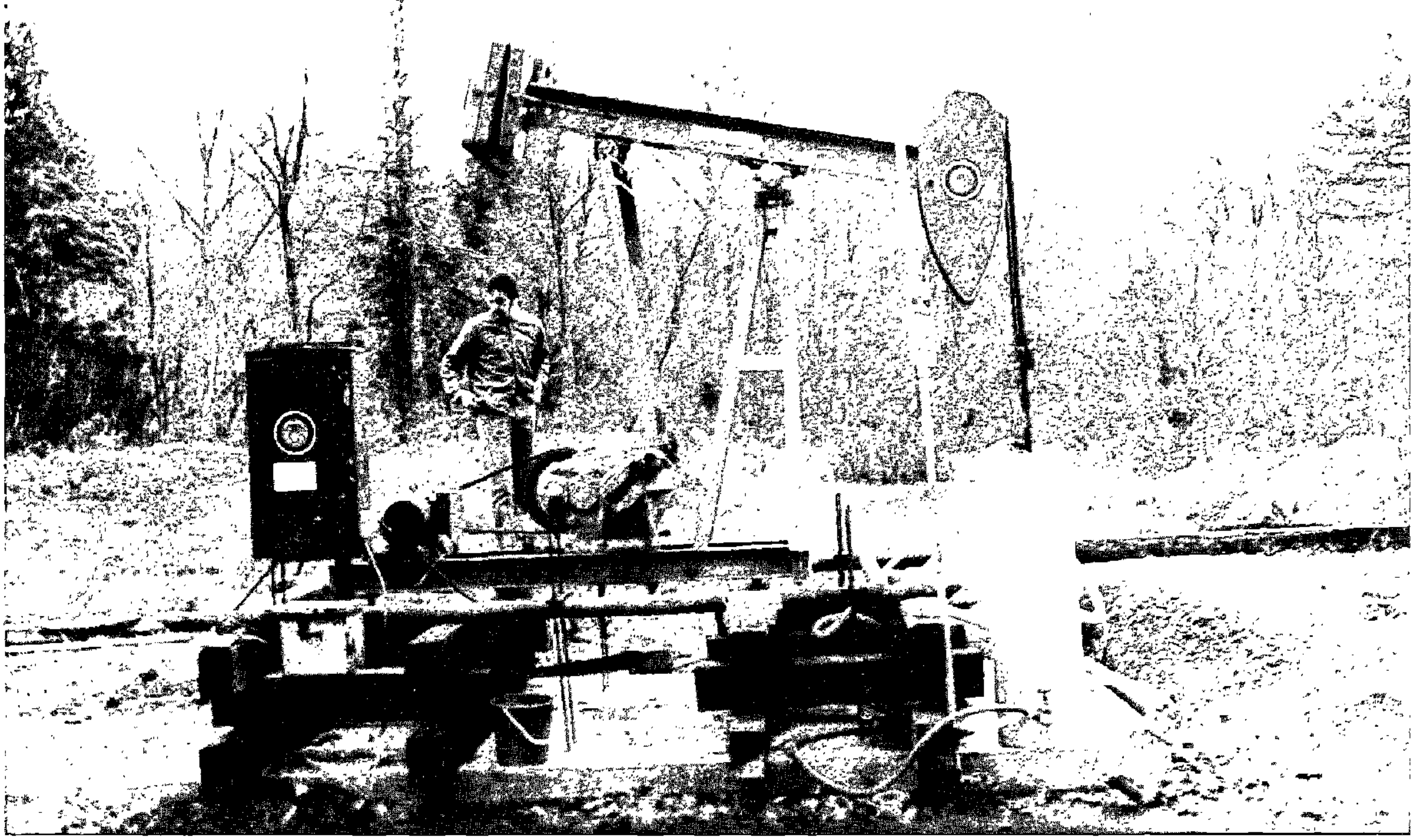
Small-diameter vertical boreholes have drained methane from coalbeds with varying degrees of success. Best results have been obtained in coalbeds that are deep, blocky, and moderately gassy. Even in deep, gassy coalbeds with good permeability, errors in well completion and/or stimulation will result in low production rates. Sustaining high flow rates requires that these boreholes be serviced and maintained like gas wells. To date, the Bureau of Mines has data on 39 wells in 5 coalbeds at 8 sites. Hydraulic or foam stimulation has been used to increase the gas production from 23 of the 39 wells. Prestimulation gas production rates have ranged from 0.5 to 10 Mcfd. After stimulation, production rates of over 100 Mcfd have been obtained from some boreholes in the Pittsburgh and Mary Lee coalbeds. Up to July 1979, 500 MMcfd of methane had been drained from the Pittsburgh and Mary Lee coalbeds through vertical holes which the Bureau of Mines had drilled or stimulated. In boreholes stimulated under Bureau contracts and subsequently mined through, no damage to roof or floor was observed.

Drainage Through Shafts

In another method, the Bureau of Mines has demonstrated that large quantities of methane can be drained through long horizontal holes drilled into virgin coal from the bottom of an air shaft, 3 to 5 years before the shaft is needed for ventilation. This advance drainage decreases gas pressure within the coalbed and reduces the methane load on the ventilation system during mining.

In the first test of the method, seven horizontal drainage holes, with an aggregate length of 4,325 feet, were drilled into the Pittsburgh coalbed from the bottom of a small-diameter shaft at the Federal No. 2 mine. After being drilled, the holes were closed with a Bureau-designed mechanical packer and connected to a gas collector-water separation system from which the gas was piped to the surface. Gas drainage from the horizontal holes began in September 1972. The average gas flow rate since the start is more than 450 Mcfd, including a period of over 8 months when methane emission was drasticallly reduced because the shaft was flooded. With the influence of mining advancing toward the shaft now noticeably reducing the volume of methane being discharged, the average flow rate in June 1979 was about 250 Mcfd.

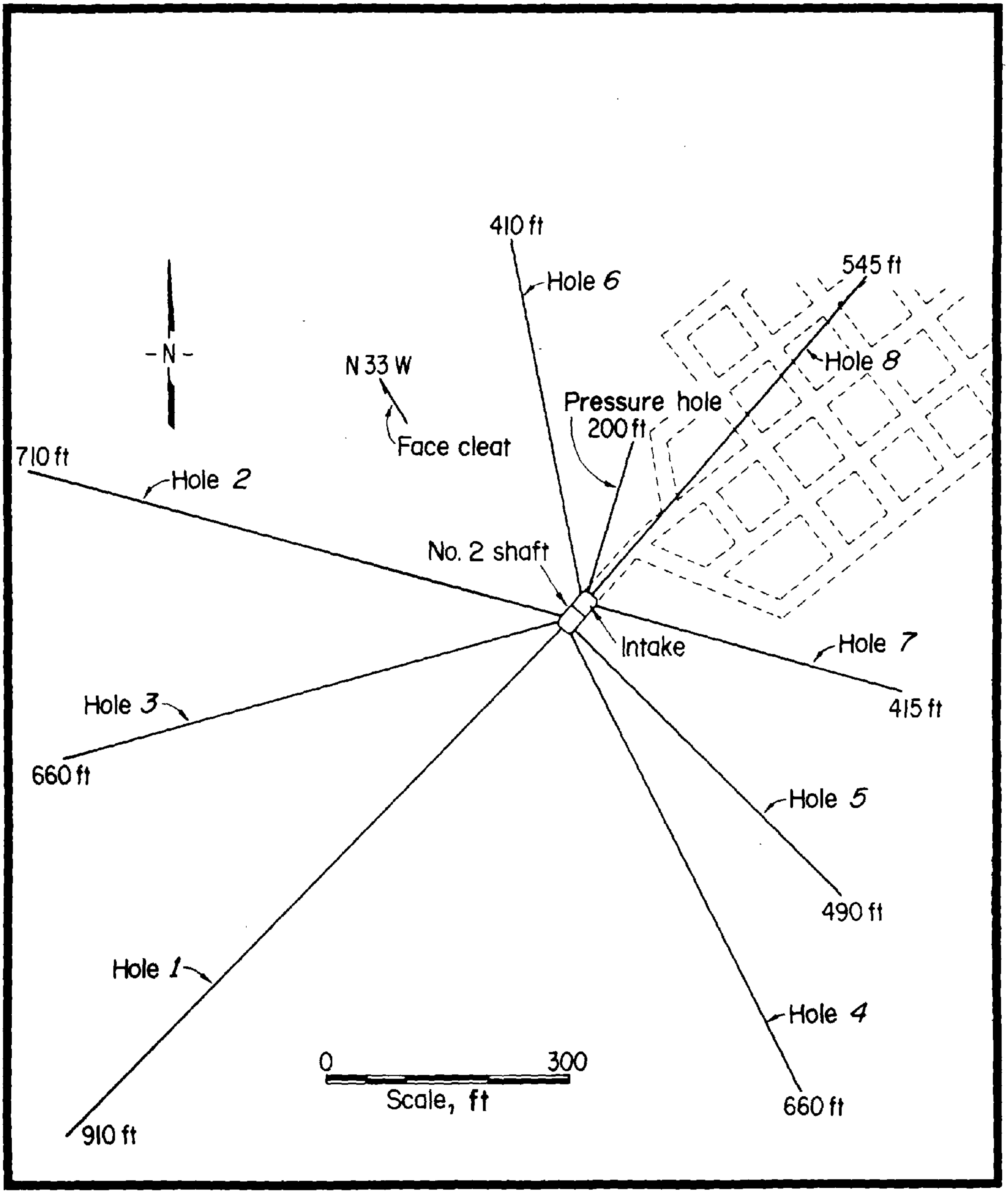
In less than 7 years, more than 1.1 Bcf of gas has been drained from the Pittsburgh coalbed at this installation. The average composition of the gas is 90 pct methane



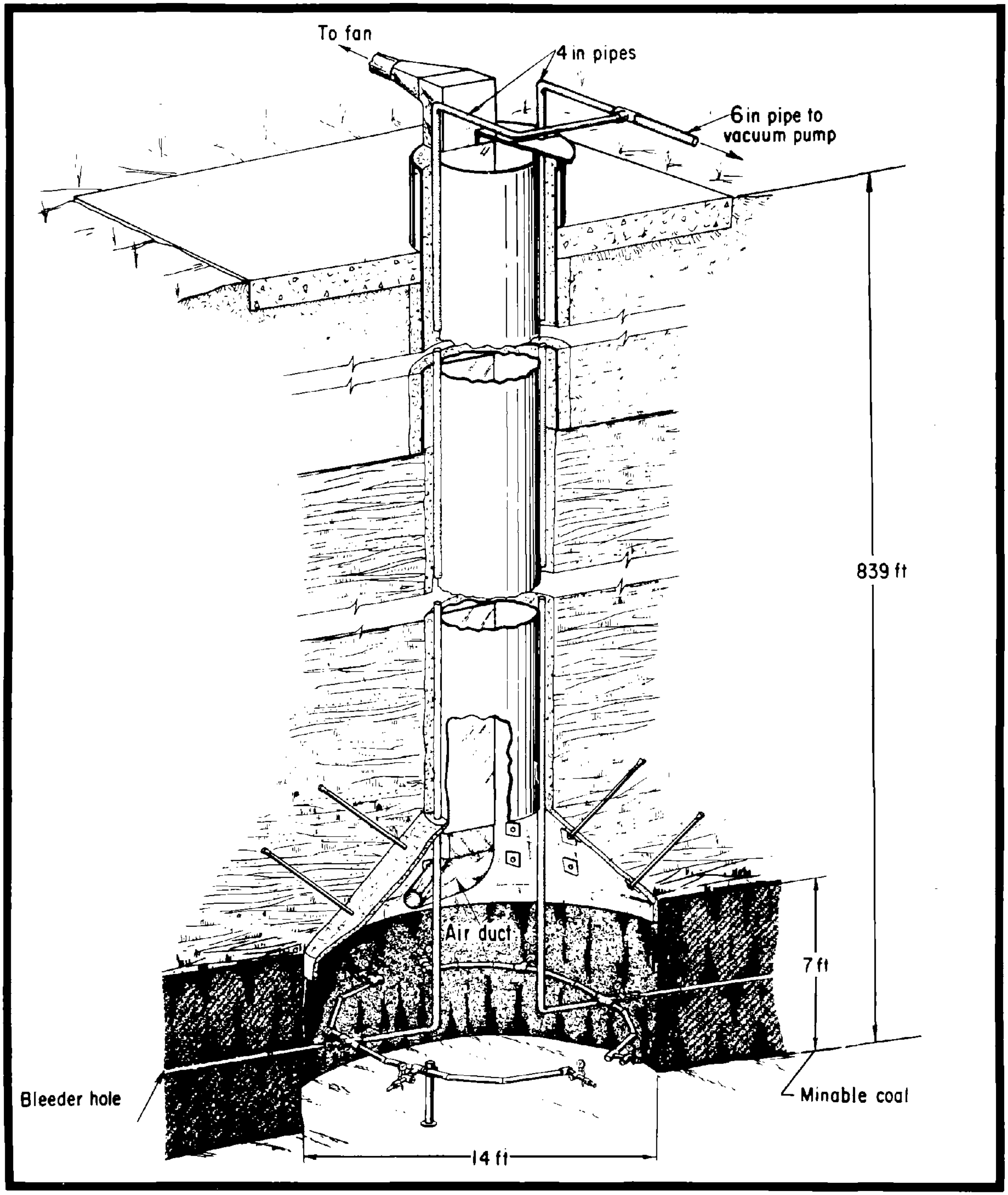
A sucker rod pump is used to remove water from the coalbed. The gas and water flow to the separator tank in the foreground. The water is drained to the pond in the background, and the gas is vented through a stack (not shown).

Methane drainage through shafts. Surface installation at Multipurpose Borehole.

Methane drainage through shafts. Methane is carried to the surface through 4-inch hoses behind the 4-foot-diameter casing, while smaller pipes remove water. Bucket in center is used to transport workers and equipment between the surface and the bottom of the shaft.



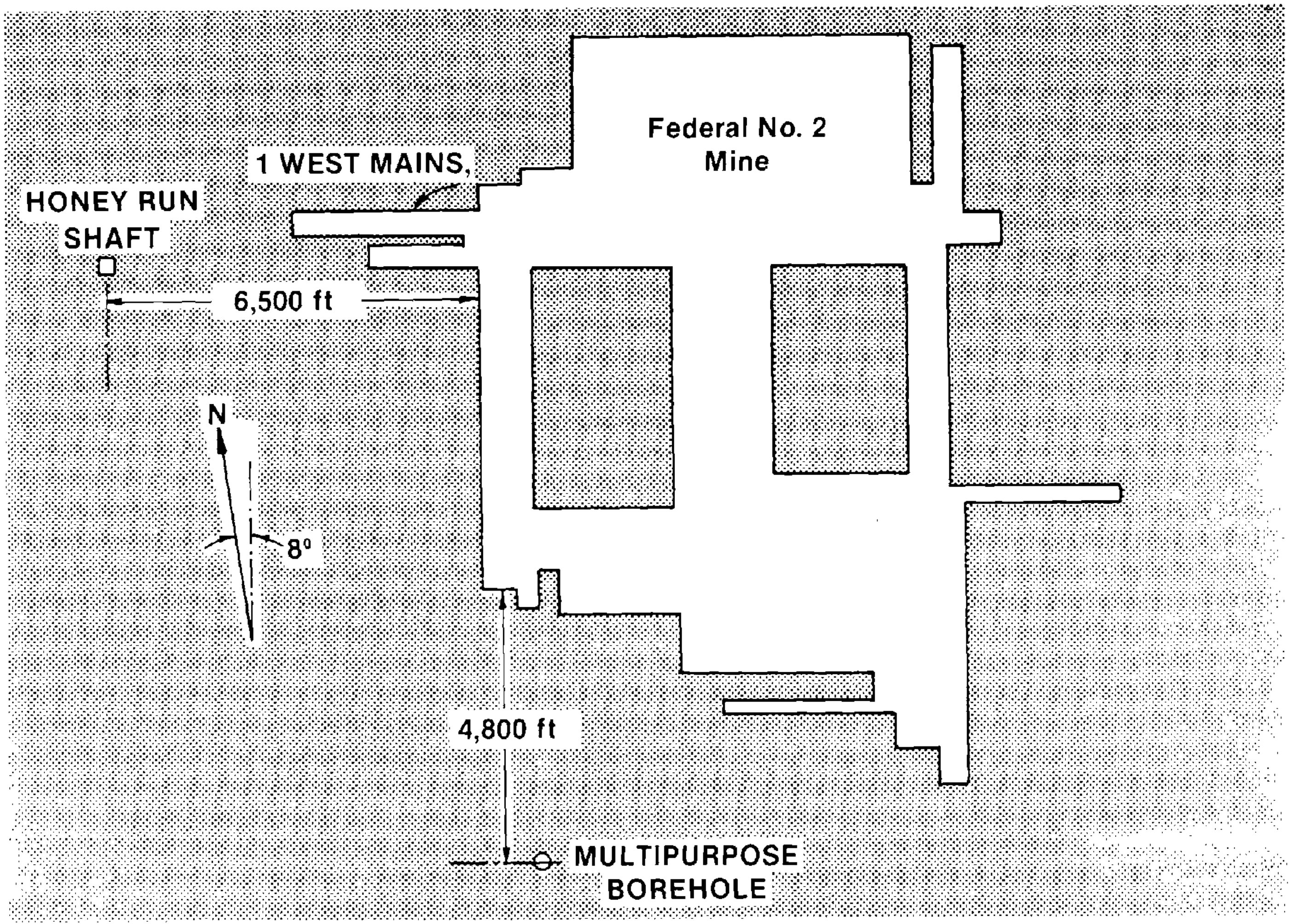
Methane drainage through shafts. Layout of horizontal boreholes and projected mine development at start of drainage project at Multipurpose Borehole.



Methane drainage through shafts. Schematic of Multipurpose Borehole.

Methane drainage through shafts. A venturi-type flowmeter is used to measure the methane emission rate from one of the horizontal boreholes.

Methane drainage through shafts. Methane from a horizontal borehole flows through a 25-gallon separator tank. The 3-inch pipe carries the methane to a central collector tank.



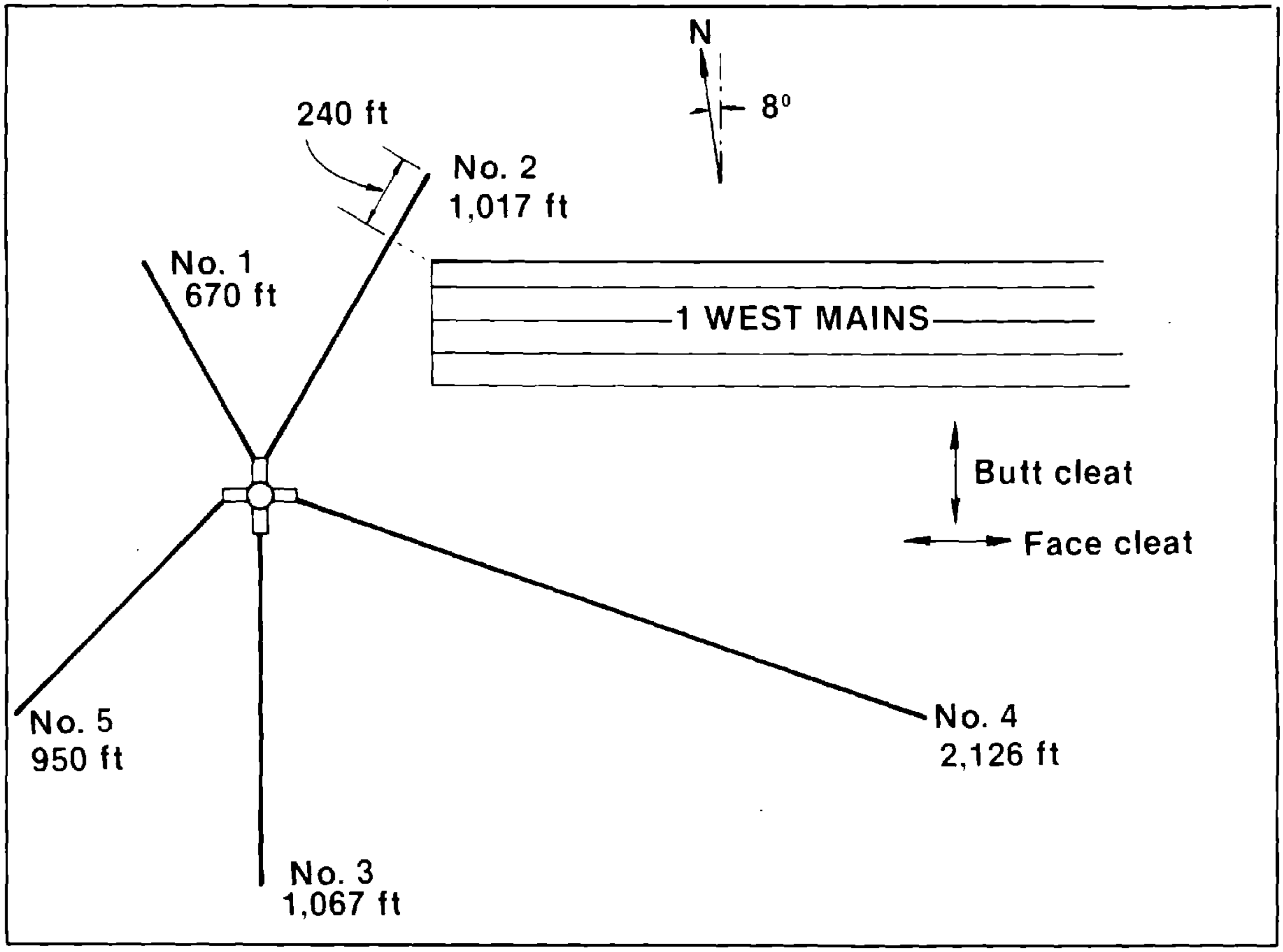
Methane drainage through shafts. Almost 2 Bcf of methane has been drained from the Pittsburgh coalbed through the Multipurpose Borehole and the Honey Run Shaft, both located on the Federal No. 2 Mine property.

and 10 pct CO_2. The heating value of the gas averages 880 Btu per cubic foot. Beginning in January 1974, the gas from the coalbed was compressed and sold for direct addition to a natural gas pipeline. Since then more than 500 MMcf of gas from this installation has been sold.

As a result of the success of this project to drain methane through shafts, an 18-foot-diameter air shaft on the same mine property was made available for another test of the method. Here, five degasification holes, with an aggregate length of 5,830 feet, were drilled from the bottom of the shaft. When the fifth hole was connected to the receiver system, the total flow rate through all five holes initially reached almost 1 MMcfd. About 400 MMcf of methane had been drained from the coalbed by that time, and in the 3.7 years between the connection of the first hole and the plugging of all the holes preparatory to their interception by mining, a total of almost 900 MMcf of methane had been removed. Of this total, 121 MMcf was sold and added to the gas supply for Wadestown, W. Va.

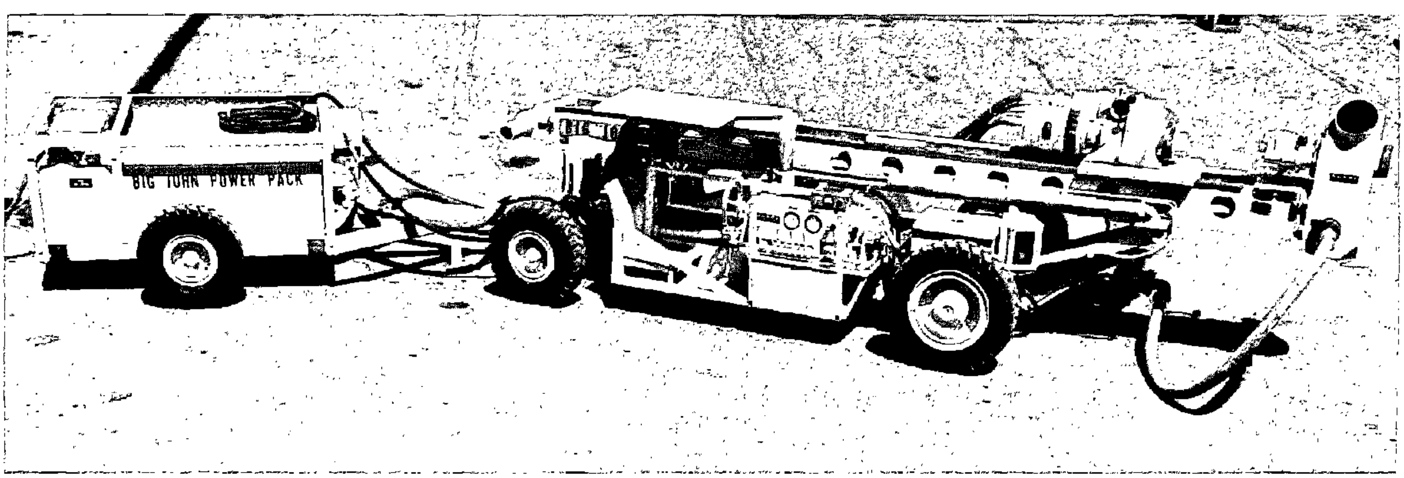
The effect of methane drainage through this shaft on mining became apparent when the active face was more than half a mile from the shaft. Normally, as headings are driven into virgin coal, methane emission at the face increases. In the headings driven toward this shaft, methane emission declined by as much as 70 pct. Methane emission along the rib also declined, and the declines continued as long as the shaft was used for methane drainage.

The rate at which methane can be removed from the coalbed through horizontal holes depends on the length of the drainage hole. Drilling long horizontal holes in coalbeds requires maintaining a drill bit on the proper trajectory within a relatively small target zone. Since coal is a soft and brittle material, the natural tendency of the drill bit is to drop; it also can be deflected by harder inclusions in the coalbed. To overcome these problems, procedures and equipment were developed for closely

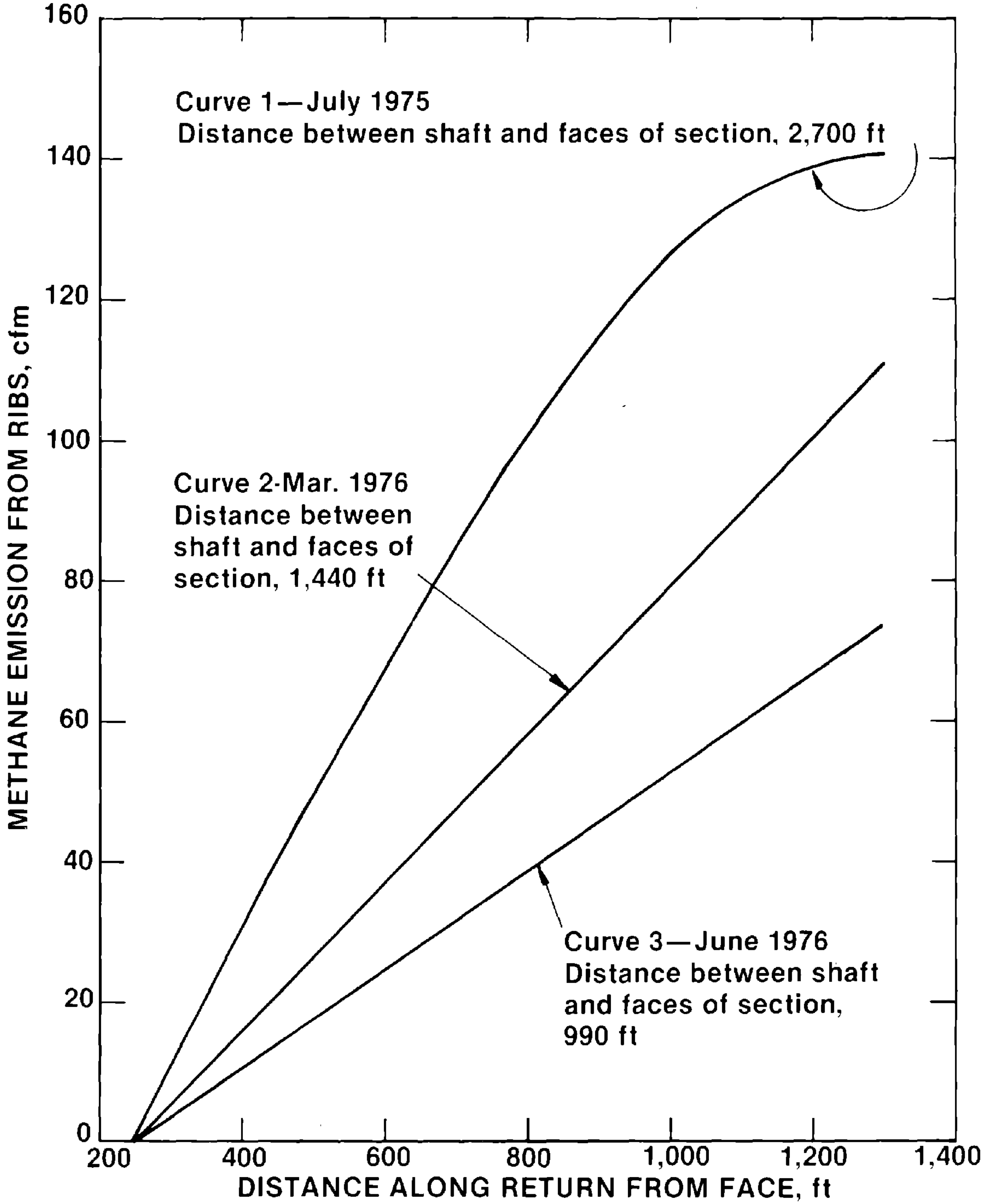


Layout of horizontal boreholes and projected mine development at start of drainage project at Honey Run Shaft.

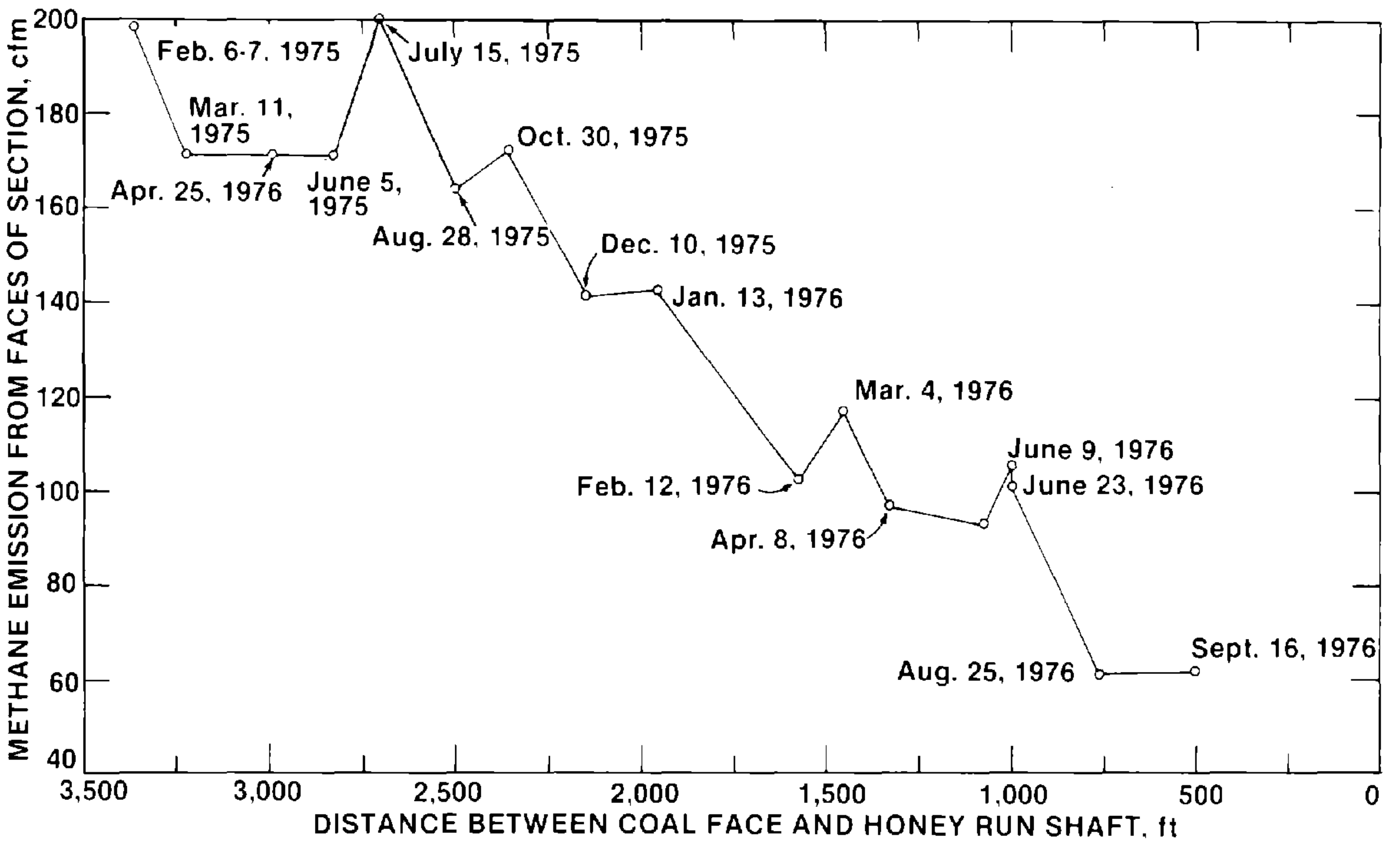
controlling the thrust, torque, and rotational speed of the drill bit. A self-propelled version of the Bureau-designed drill, known as the "Big John" underground methane gas exploration drill, is commercially available.



This self-contained, self-propelled drill is one type used to drill horizontal holes into the coalbed.



Methane emission from the ribs was lowered by horizontal boreholes draining methane through the Honey Run Shaft.



Methane emission from the face declined as mining approached the Honey Run Shaft.

In order to control methane emission while drilling horizontal holes into coalbeds, the Bureau developed a stuffing box. Drill cuttings and water drop to the bottom of the box, and gas is drawn off the top. When drilling is completed, the stuffing box is removed, and the hole is connected to a 4-inch pipeline.

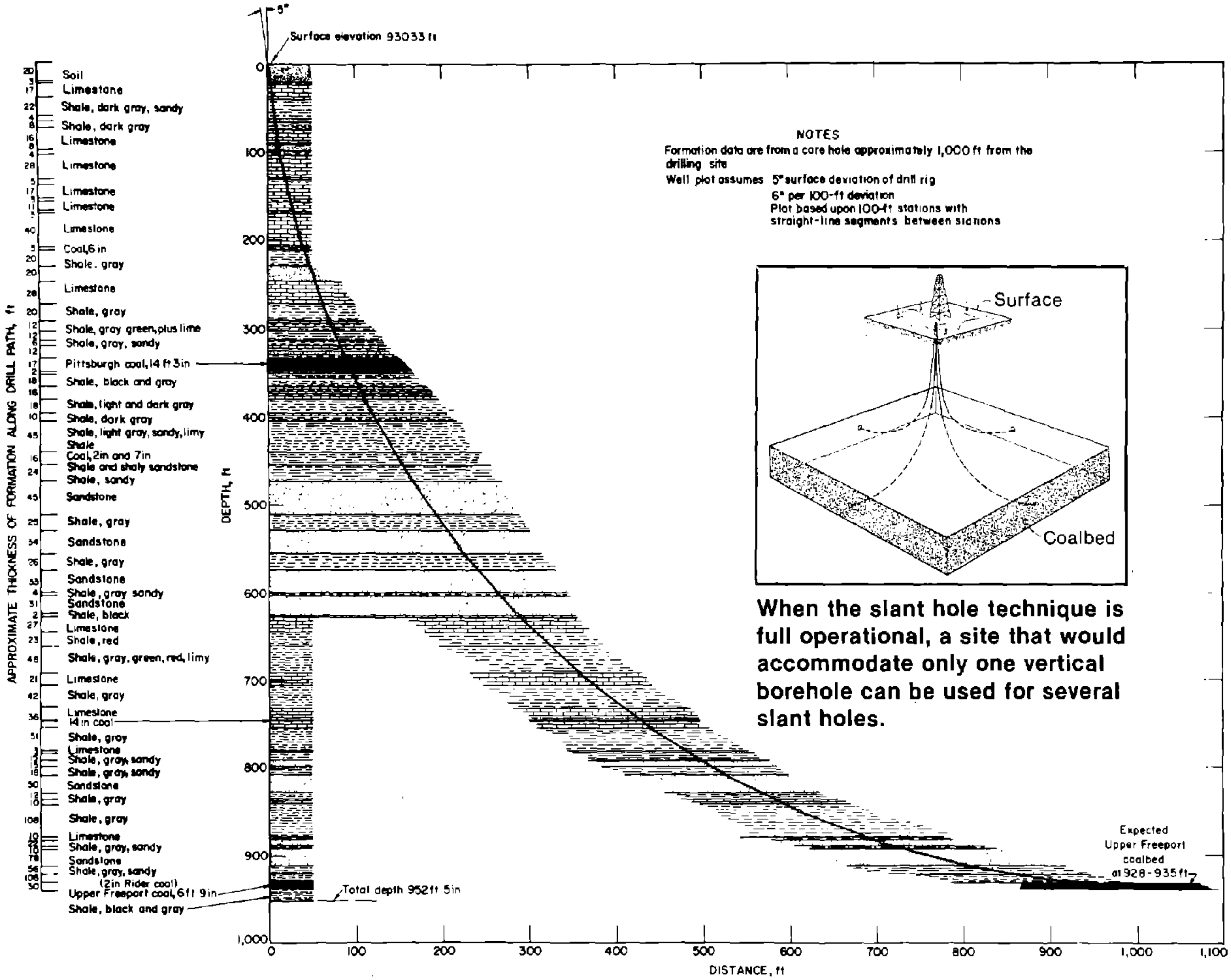
When horizontal drainage holes are in the path of mining, they must be plugged before being cut into. Grouting of such holes is required to insure that no "pipe-type" flow will flood the mine workings with methane when the holes are intersected. A simple plugging technique was developed, which fills the hole completely with a cement-fly ash-water mixture. When the horizontal drainage holes at the air-shaft project described above were plugged in this way and mined through, no methane problems or other safety hazards occurred.

Drainage Through Directional Slant Holes

Another technique for draining methane from virgin coal is the directional slant hole, currently being developed by the Bureau of Mines. This method combines features of horizontal drainage holes and vertical boreholes from the surface. A small-diameter borehole is drilled from the surface and intentionally deflected to penetrate the coalbed parallel to the bedding plane, thereby maximizing intersection of the natural vertical fracture system of the coalbed.

Two tests have successfully demonstrated the feasibility of drilling a directional hole to a predetermined target and continuing parallel to the bedding plane of the coalbed. In the first test, a 3-inch borehole was drilled from the surface to the Pittsburgh coalbed 780 feet below the surface. After traversing about 1,300 feet along an arcuate drill path, the hole penetrated the coalbed and continued into the coalbed for 417 feet, when drilling was discontinued. The borehole for the second test of the technique was drilled to the Upper Freeport coalbed, which is about 930 feet deep at the drill site. The borehole penetrated the coalbed along a slanted trajectory and continued horizontally for 390 feet. Erratic coal thickness caused the test to be discontinued.

Both tests showed that problems in bit control and downhole surveying must be solved before slant holes can be drilled routinely. Moreover, the problem of dewatering a slant hole must be solved before this technique can be used effectively to drain gas from coalbeds. All boreholes produce water, which must be removed to maintain gas production. Currently available downhole pumps are designed to operate in a vertical position and malfunction when operated horizontally.



When the slant hole technique is full operational, a site that would accommodate only one vertical borehole can be used for several slant holes.

A directional slant hole is drilled from the surface at an angle to intercept the target coalbed horizontally.

Methane Control During Mining

Methane must be controlled during mining so that its concentration does not exceed the statutory limits for various places in the mine. Techniques are being developed not only to assist the conventional method of diluting the methane with ventilating air but also to improve it. Included are in-mine drainage, water infusion, novel methods of face ventilation, and more effective control of gas in gob areas of active mines.

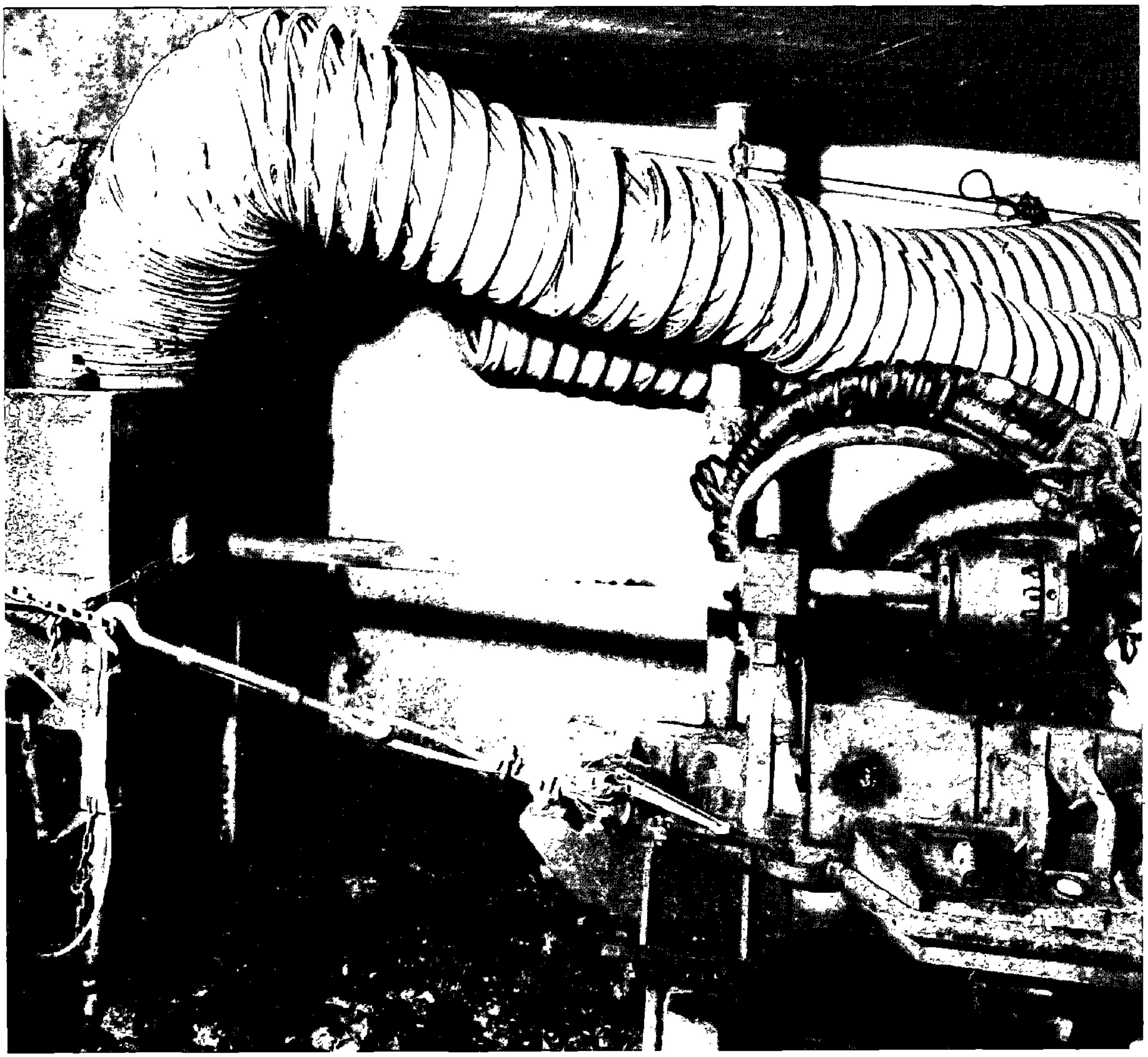
In-Mine Drainage

When methane has not been drained from coal before mining starts, horizontal holes drilled from outside entries are very effective in removing methane from the coal just ahead of the mine face. Methane that normally flows toward the faces of an advancing section can be diverted through these drainage holes drilled ahead of the face. This lowers the gas pressure just ahead of the face and reduces methane concentrations at the face, where most ignitions occur.

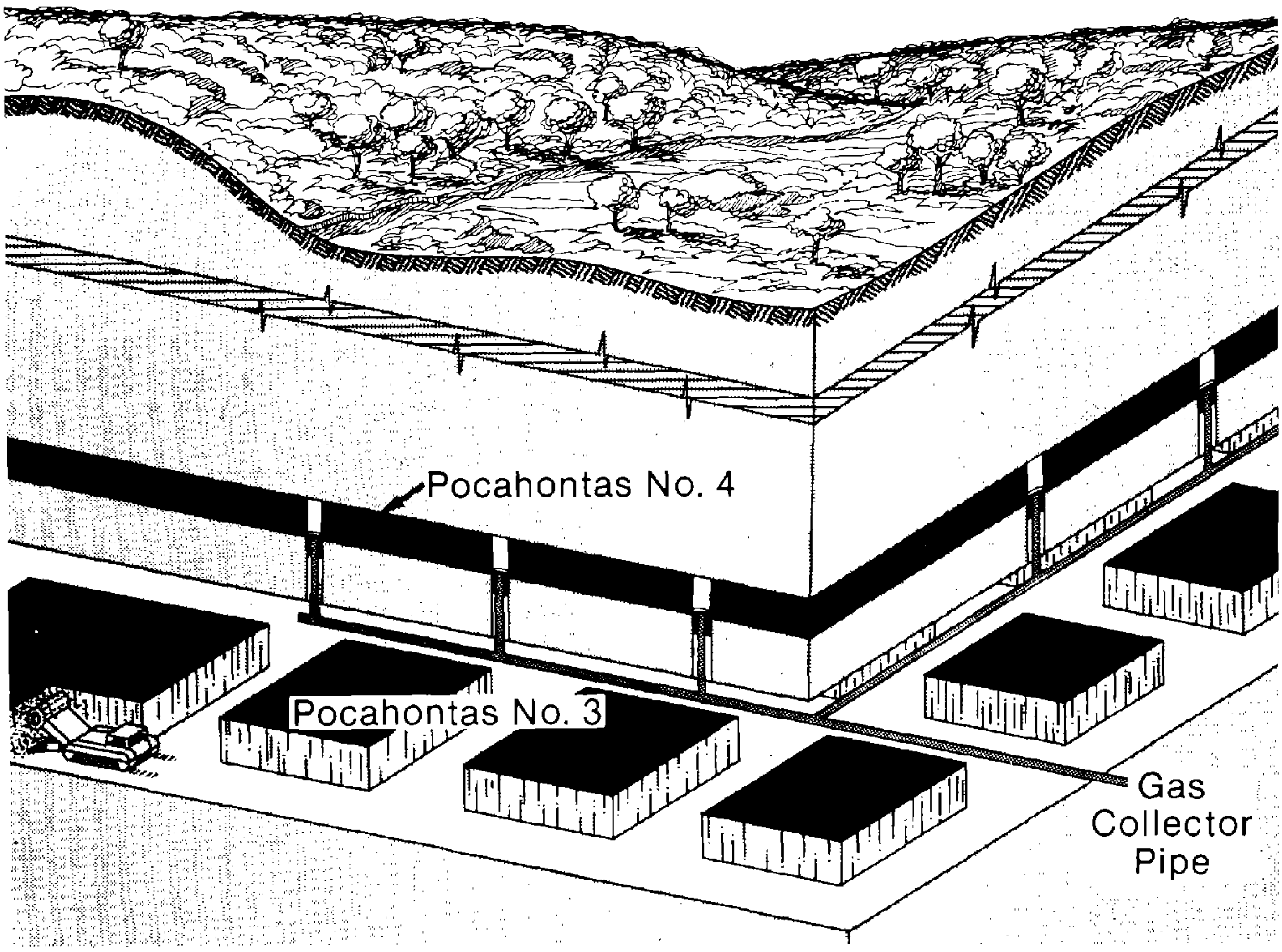
In early trials of this technique, methane from the horizontal holes was vented into the returns. This, however, requires extremely large volumes of ventilating air to prevent the formation of explosive methane-air mixtures. An alternative is to pipe the methane from the mine to the surface in an inherently safe pipeline. Such a pipeline was designed for the Bureau through a contract and includes a ceiling-hung pipeline, electronic methane sensors, a pneumatic control line, and automatic shut-in valves. If the methane concentration near the pipeline exceeds a preset value, an electronic methane sensor activates an alarm and the shut-in valves. Rupture of the pneumatic control line by roof fall, pipeline collapse, or human error also activates the shut-in valves. On the surface the methane can be flared, used by the mine, or sold.

Four horizontal drainage holes have been drilled into the Pittsburgh coalbed in Bethlehem Mines Corp.'s Marianna Mine. The aggregate length of the holes is almost 5,800 feet, with the longest hole extending 2,500 feet. After an initial maximum rate of 580 Mcfd, the methane drainage rate has stabilized at about 285 Mcfd. By June 1979 almost 65 MMcf of methane had been removed from the coalbed. In Kaiser Steel Co.'s Sunnyside Mine in Utah, two 450-foot holes were used to degasify a section that had previously been too gassy to mine. The drainage rate for the two holes was initially almost 200 Mcfd and averaged about 100 Mcfd for the 16-month period before the section was advanced beyond the ends of the holes. A total of 60 MMcf of methane was removed from the coalbed, and methane emission at the face was reduced by 40 pct.

A variation of this technique was used to eliminate a potentially hazardous situation in the Virginia Pocahontas Coal Co.'s No. 5 Mine in the Pocahontas No. 3 coalbed. Methane emission from the overlying Pocahontas No. 4 coalbed was causing excessively high methane levels in



The drill enters the coalbed through a stuffing box, designed to handle water and methane emission during drilling.



In-mine drainage techniques have been used to drain methane from overlying coalbeds.

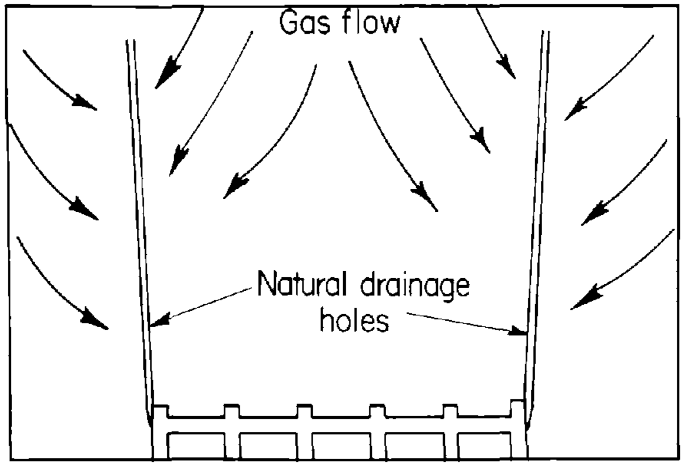
the mine. At the company's request the Bureau drilled drainage holes from the mine into the overlying coalbed. The drainage holes were connected to a pipeline that carried the gas to the surface. During a 35-day period, approximately 7 MMcf of methane was drained from the Pocahontas No. 4 coalbed. Methane levels in the mine dropped 33 pct, allowing the normal mining cycle to resume.

These tests demonstrated that horizontal drainage holes can be used in a mine in which the coal has a relatively good permeability. The Pittsburgh, Sunnyside, Beckley, Mary Lee, and Hartshorne are typical of coalbeds in which in-mine drainage can effectively lower the methane load on the ventilation system. Using this method to lower methane emission levels at the working face decreases the hazard of ignitions and explosions; it also reduces the amount of downtime due to high methane emission rates and thus allows more productive use of mining equipment.

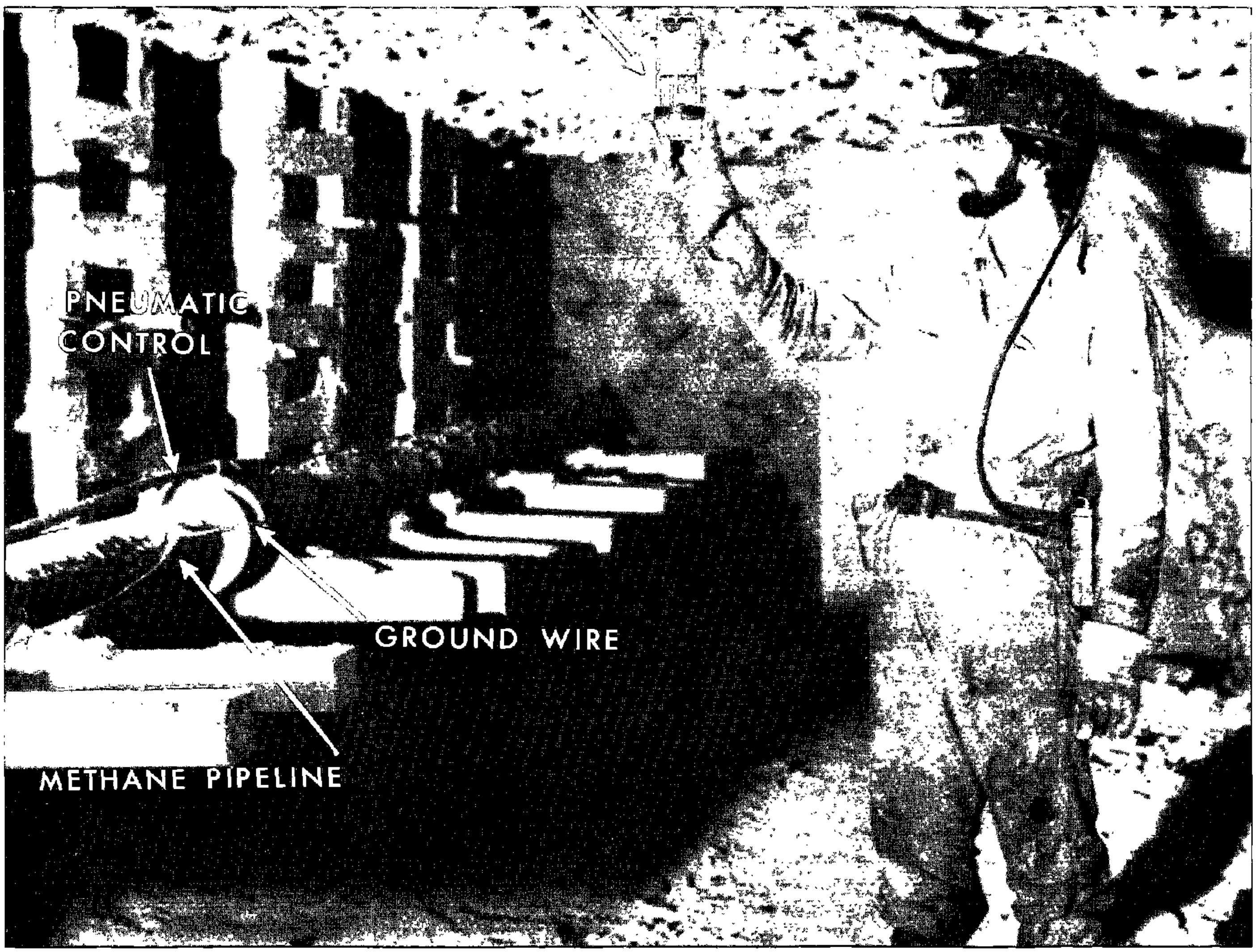
Water Infusion

The infusion of water into a coalbed can be used to block the migration of methane toward the face during developmental mining. The successful application of this technique depends upon the fracture permeability and cleat orientation of the coalbed. Blocky coalbeds, such as the Pittsburgh and Beckley, are characterized by a fracture spacing of 1 to 6 inches and can be infused successfully at pressures as low as 300 to 400 pounds per square inch. Friable coalbeds like the Freeport, Kittanning, and Pocahontas No. 3 have a fracture spacing of about one-fourth of an inch and require infusion pressures 3 to 4 times greater. Water is forced into the fracture system through horizontal holes drilled into the coalbed. After the hole is sealed, water enters the coalbed through a small segment (10 to 15 feet) at the rear of the hole.

A typical section advancing into virgin coal may be about 500 feet wide. To reduce methane flows through the section faces, a continuous waterbank must be emplaced to form a barrier across the width of the section. This prevents methane from flowing toward the faces and routes it around the water-infused zone, allowing it to enter the mine opening through the ribs outby the face areas of the section. Since most ignitions occur in the face area, diverting methane to the returns reduces the possibility of an explosion.



Horizontal boreholes drilled in an active mine are used to drain methane away from the working face.



A flame safety lamp is used to check methane levels near an underground methane pipeline. If the pneumatic control line on top of the pipe is ruptured, the horizontal boreholes are automatically shut in. The ground wire prevents electrostatic buildup along the 4-inch steel pipe.

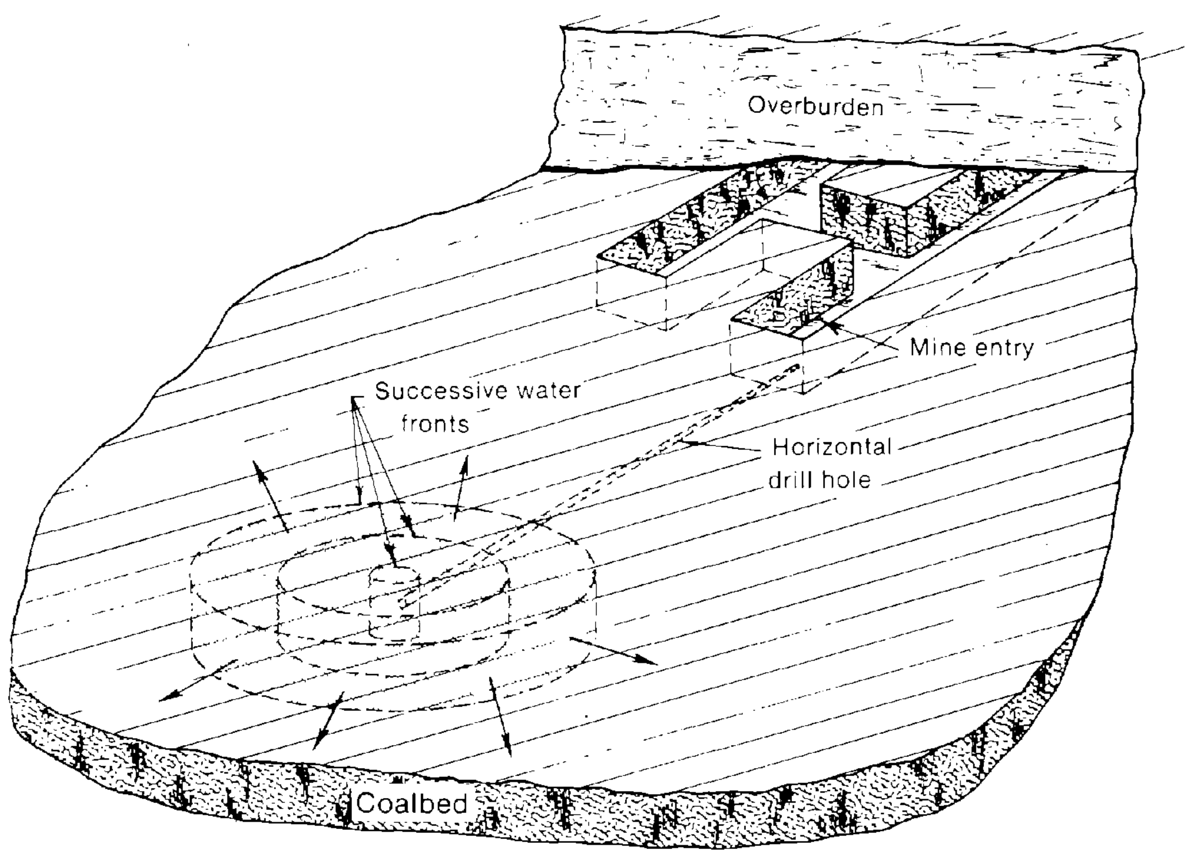
The emplacement of a waterbank across the section requires two or more horizontal holes, depending on the length of the holes. Generally, horizontal holes 125 to 150 feet in length can be drilled with handheld drill equipment used underground. In some mines, entries are advanced in about 100-foot increments. Integrating a drilling and infusion phase into the mining cycle presents no special problems when 125- to 150-foot-long holes are drilled.

Water infusion of the Pittsburgh coalbed in a section where the more permeable face cleat was at right angles to the direction of mining reduced methane emission at the face almost 80 pct. Another test in the same coalbed was conducted in a section being advanced parallel to the face cleat. Results indicated that the volume of methane diverted from the face area to the outside ribs was not significant. Because the infused water tended to run in the direction of mining (along the face cleats) faster than across the section, apparently zones that were not filled with water existed between holes and permitted methane to funnel through to the face.

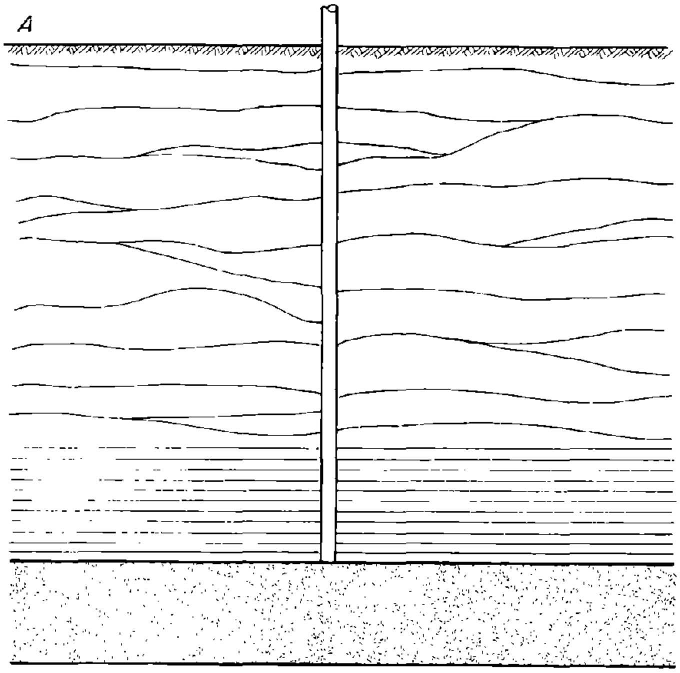
Water infusion has been tested twice in friable coalbeds, where fracture permeability tends to be constant in all directions, allowing infused water to spread uniformly outward from the hole. In one test, infusion of the Upper Kittanning coalbed reduced face emission by 89 pct. The other test, in the Upper Freeport coalbed, did not produce a significant reduction in methane flow from the faces of the section. The variable-length holes used in this study apparently failed to place a continuous water barrier across the section.

To improve the effectiveness of water infusion in situations such as the two tests above that were unsuccessful, two alternatives are available. The first is to increase the hole length. The second is to leave hole length the same but to increase the number of holes drilled across the section. Each of these procedures would tend to produce a continuous waterbank across the section.

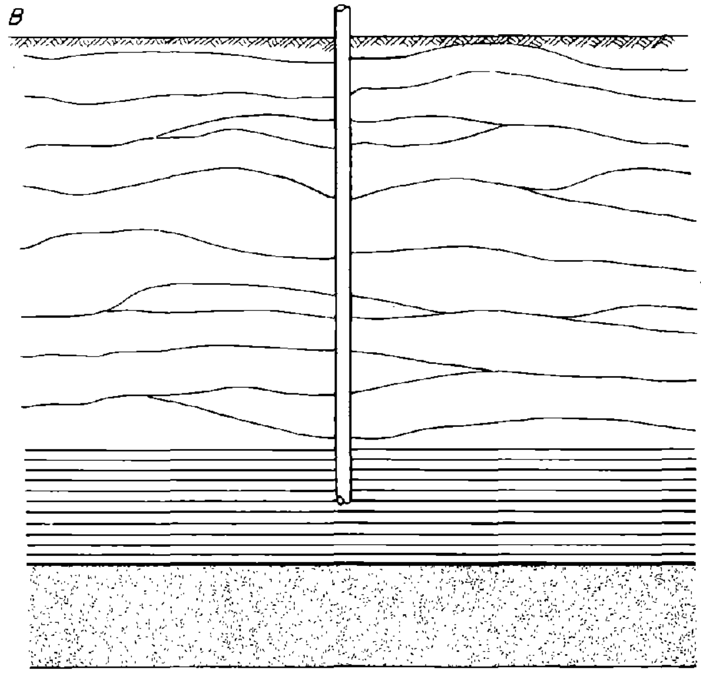
Water infusion has been demonstrated to be a practical methane control technique that can reduce methane emission at the face by 80 to 90 pct in coalbeds having good fracture permeability. The Island Creek Coal Co. (Pochahontas No. 3 coal seam) and Bethlehem Mines Corp. (Upper Kittanning coal seam) now routinely use water infusion to reduce methane emission at the working face.



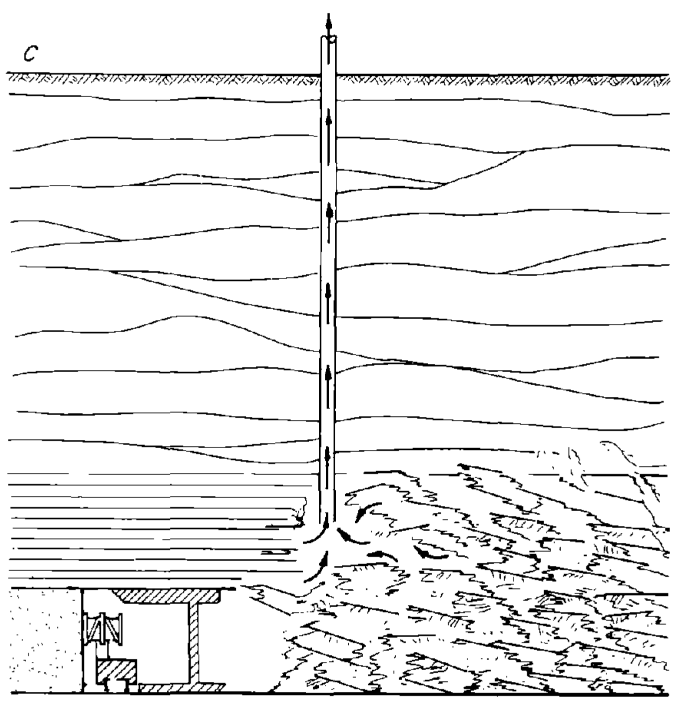
Water-infusion pumps water into the coalbed to divert methane away from areas of active mining.



Vertical boreholes for gob ventilation. A, conventional borehole is drilled to the coal before it is mined;



B, a short hole terminates in the strata above the coalbed;



C, when mining passes the borehole, the overlying strata cave in, releasing methane which is drawn out through the borehole instead of into the mine.

In coalbeds like the York Canyon and Mary Lee, which contain faults (large fractures along which displacement has occurred), water infusion has not been successful. Infused water short-circuits along the fault to the rib rather than moving across the face. In these coalbeds, other methods of controlling methane must be used.

Gob Drainage Through Vertical Boreholes

When virtually all the coal is extracted and the roof allowed to fall, a zone of tightly compacted rubble (gob) is created. Air does not flow easily through this rubble, and large quantities of methane may flow into the gob from the fractured strata above the coalbed. The large volumes of methane that accumulate in the gob areas frequently cause severe ventilation problems during mining of adjacent areas. When the barometer falls, the methane-laden air in the gob expands and may enter portions of the mine where a spark source is more likely to be found. Even if sealed, gobs are not completely airtight and can leak methane-laden air into the active portions of the mine.

To assist the conventional ventilation systems in some gassy mines, vertical boreholes are drilled from the surface into the overburden ahead of mining. When the mining face passes the hole, roof subsidence causes cracks in the overburden, and methane that normally would be released into the gob area flows to the borehole and is drawn to the surface. Such holes can remove as much as 1 MMcfd of methane from a mine and reduce methane emission underground by more than 50 pct. Bureau of Mines tests have shown that a "short hole," one that terminates well above the coal, is just as effective as a hole drilled within a few feet of it, is less expensive to drill, and discharges a gas having a higher methane content.

Flow rates from gob ventilation holes tend to drop rapidly, for example, from 1 MMcfd to only 0.1 MMcfd over a period of 1 year. The concentration of methane also decreases with time, from as much as 100 pct to 50 pct or less within several months. Despite these factors, gas drained from gobs can be used as boiler fuel or for gas turbine generation of electricity, and it can be upgraded and compressed to LNG. Since vertical boreholes to gob areas are simple, effective, and relatively inexpensive, they are being widely used in the coal mining industry; for example, Island Creek Coal Co., Bethlehem Mines Corp., Eastern Associated Coal Corp., and Consolidated Coal Corp. are now using the Bureau gob degasification technique.

Ventilation

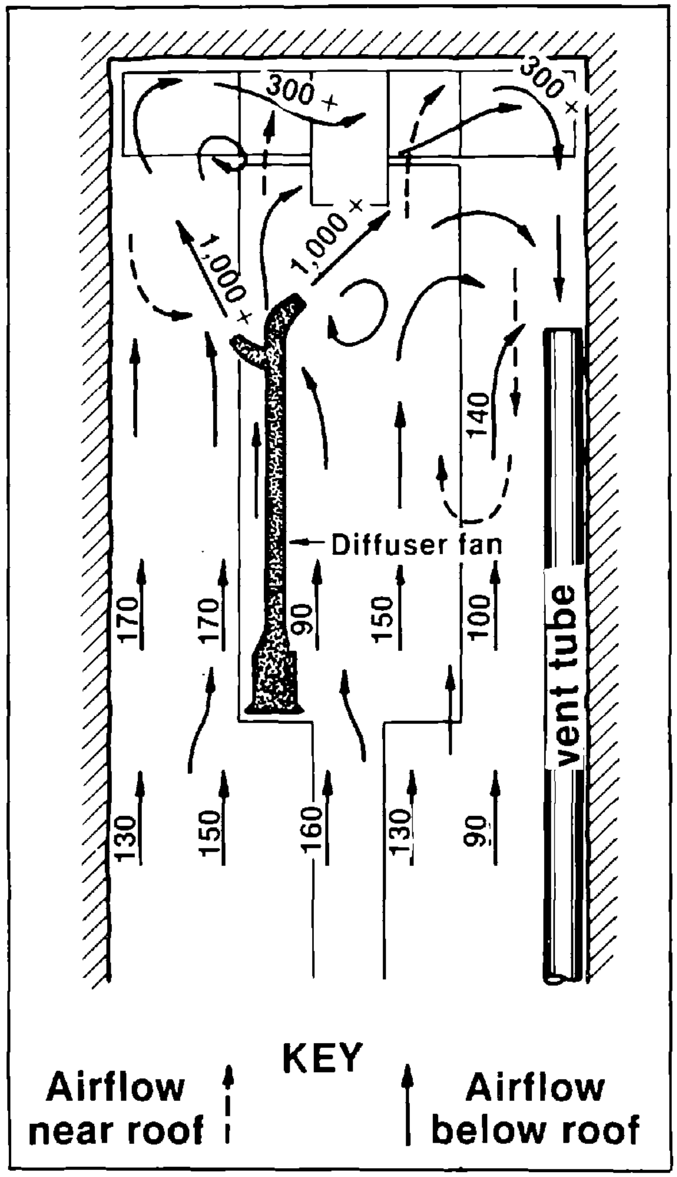
Mine ventilation systems bring fresh air to mine workers and carry away harmful gases and dust. Coal mines are ventilated by main fans located on the surface; fresh air moves along intake airways, and contaminated air is carried along separate passages called returns. Air is apportioned to various parts of the mine by underground regulators, and stoppings are used in crosscuts between intakes and returns to prevent the mixing of fresh and contaminated air. Worked-out portions of the mine (gobs) may be sealed or else ventilated with bleeder entries that skirt the periphery of the worked-out area.

Face Ventilation

In a gassy mine, large quantities of methane are liberated at the working face as coal is extracted. Delivering sufficient air to the face to dilute the gas to safe limits is often difficult. A continuous mining machine fills most of the entry and restricts easy movement of air. Theoretically, air should move toward the face along one side of the machine (intake), across the face, and then along the other side to the return airway, with a brattice being used to separate intake and exhaust air. The effectiveness of face ventilation depends on how well the ventilation air follows this pattern. Actually, most of the air brought to a working section never reaches the face.

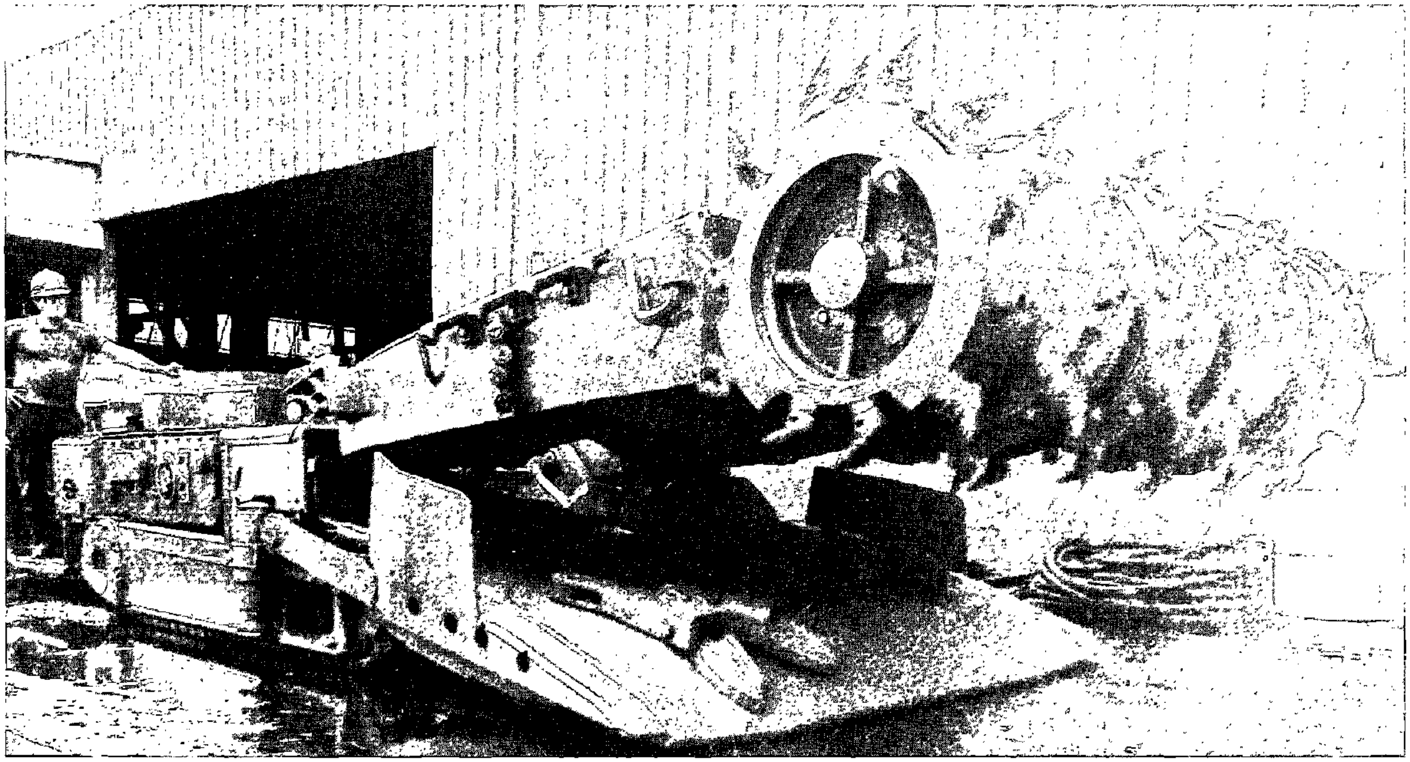
Tests in a full-scale, plywood mockup of a coal mine working face area showed that in many instances only about 20 pct of the fresh air actually gets to within 1 foot of the face. Most of the air shortcuts over the middle of the machine, even when the airflow is high and the brattice is correctly placed. The key to providing more air at the face is to enhance and move forward the natural airflow pattern. For example, if the natural airflow is from right to left across the machine, devices designed to enhance this natural pattern sweep away methane better than those that ignore this simple principle.

The diffuser fan is a proven method for reducing methane at coal mine working faces. The general approach has been simply to direct a few thousand cubic feet per minute of air in the general direction of the face. However, Bureau of Mines research has shown that proper placement of a low-volume diffuser fan enhances the natural airflow pattern. A twin-nozzle diffuser fan placed on the intake side of the mining machine increases ventilation efficiencies to 70 pct with an airflow of only 1,000 cfm. This means that if 9,000 cfm enters the brattice, 6,300 cfm reaches the last foot, in contrast to 1,800 cfm without the fan.

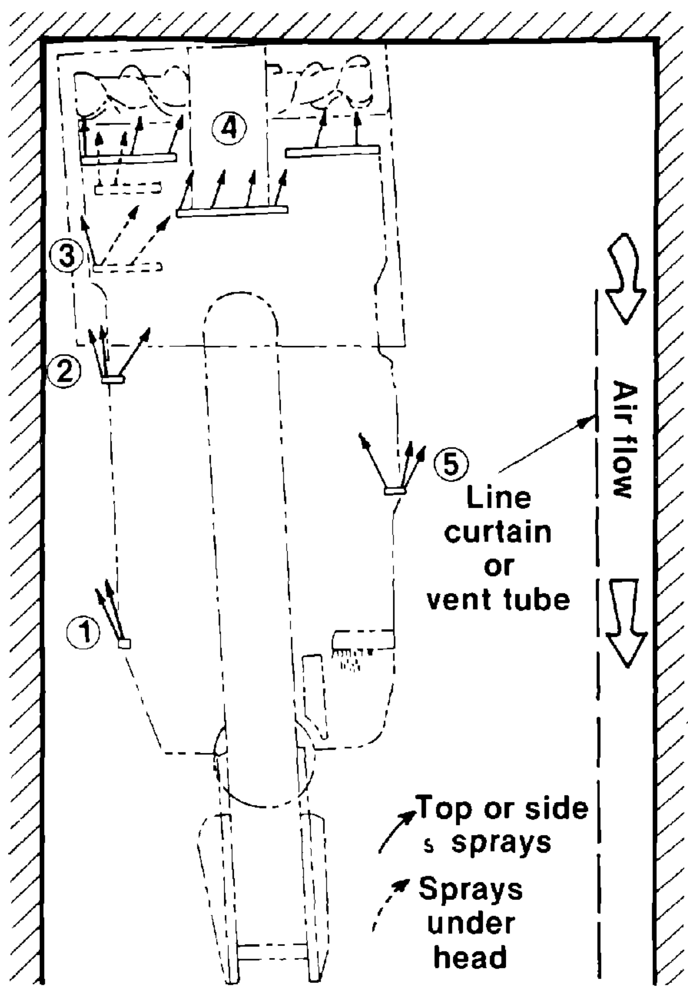


Schematic of the best diffuser fan system for a full-face mining machine.

Another simple and effective air mover is the conventional water spray used to control dust. If all the water sprays on the machine are realined to take advantage of their air-moving abilities, the natural airflow pattern is en-



Continuous mining machines such as the one shown above cause difficulties in effectively ventilating the face by usual methods. Four sprays are visible in the center of the photo, pointing at the reader; these are represented by location 5 in the schematic at bottom right, which demonstrates more fully the spray fan system developed by the Bureau of Mines.



hanced even more than with a diffuser fan. This realinement consists of placing a few nozzles on the intake side of the machine and also tilting the front sprays slightly to one side. Ventilation efficiencies as high as 75 to 85 pct can be achieved with this spray fan system. Data from an underground demonstration at Bethlehem Mines Corp.'s Marianna No. 58 Mine showed that the average peak methane concentration was cut in half. Moreover, the probability of reaching the maximum permissible concentration of 2 pct methane was reduced by a factor of 15.

The spray fan system is effective at both high and low coal faces. It is especially suitable for low coal (coal seams thinner than 42 inches) because the spray nozzles require virtually no extra space and provide a promising alternative to machine-mounted diffuser fans in terms of performance, reduced space requirements on the machine, and reduced noise levels for the machine operator. Industry acceptance has been good. By June 1979 Consolidation Coal Corp. had converted about 30 continuous miners for methane control by the spray fan method, Clinchfield Coal Co. had converted about 12, and a number of smaller companies had adopted the method.

Since any device that moves substantial quantities of air can improve ventilation in the face area, dust scrubbers, which typically move 3,000 to 6,000 cfm of air, should be capable of aiding normal face ventilation substantially. To evaluate the performance of a dust scrubber as a face ventilation aid, a fan was mounted towards the front of the mining machine. Inlet ducting was used to draw air from under the cutting head. Flexible ducting was used on the discharge, which allowed the discharge airflow to be aimed in almost any direction. It was found that when the discharge was directed towards the face, the increased circulation of air in the face area substantially improved the ventilation efficiency. The high-velocity discharge from the scrubber entrains and moves large quantities of otherwise still air. As with the water spray system, the dust scrubber can be used to increase the normal sweep of air across the face.

When machine-mounted dust scrubbers are used in the conventional way, a substantial part of the air passing through them is recirculated. The possibility of this recirculation resulting in a buildup of methane in the face area, thus increasing the chance of an explosion, was investigated. Experiments conducted in a full-scale model of a working face area indicated that methane levels in the area depend to a large extent on the directional flow of the scrubber exhaust, but that recirculation does not substantially increase the methane concentrations above the levels that would exist without the scrubbers operating.

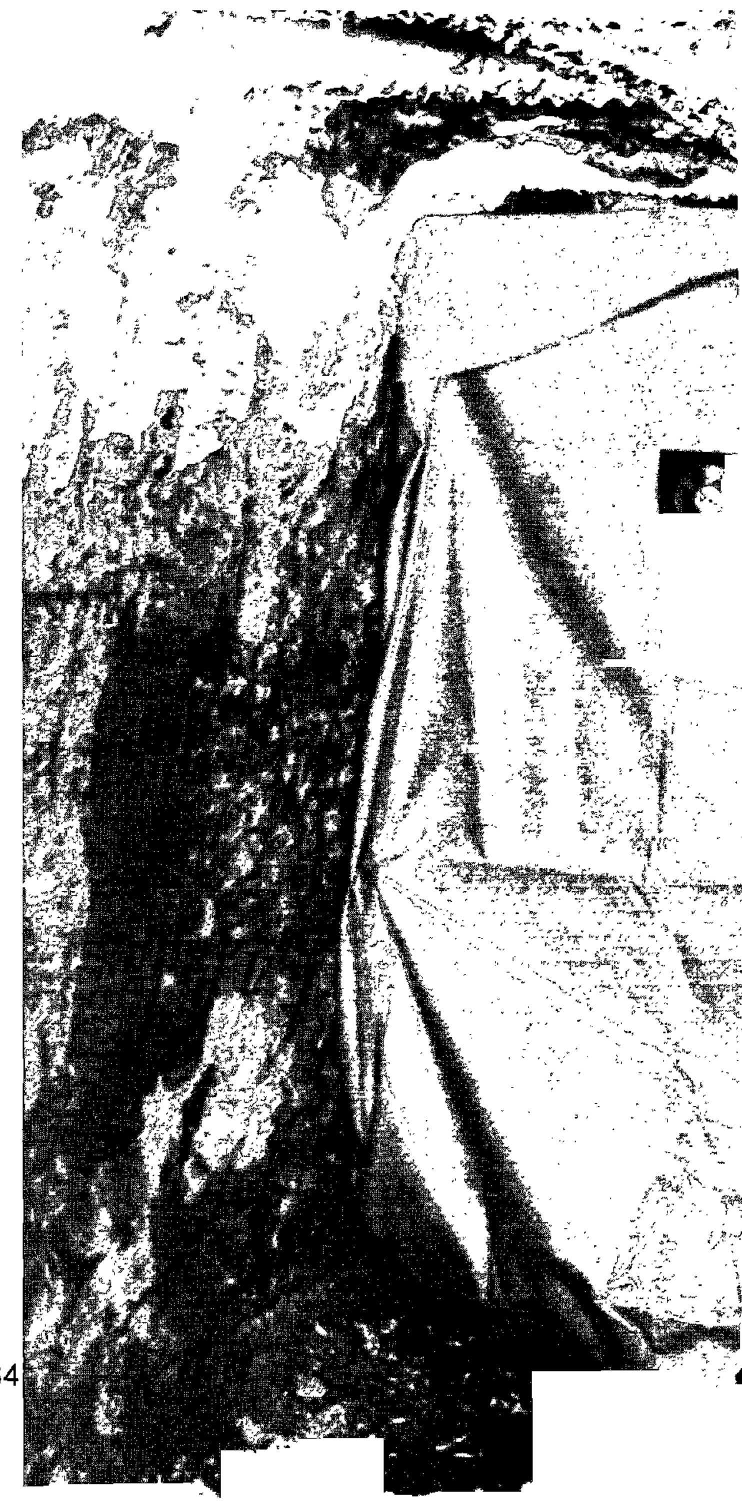
Analysis of two previous underground scrubber trials showed that scrubbers had no significant effect on methane levels. A study of gas explosions attributed to recirculation showed that these were characterized by a lack of fresh air as well as by recirculation. This indicates that dust scrubbers need not be hazardous, that recirculation may be more useful than previously thought, and that it can be practiced safely if the fresh air supply is adequate.

Studying Ventilation Problems

The efficiency of coal mine ventilation is normally low. Although stoppings are used to separate intake and return airways, as much as 60 to 80 pct of the fresh air entering a mine may leak directly into the returns, never reaching its intended location. Ventilation efficiency can be improved by eliminating the major leaks that occur at permanent stoppings. Eliminating air leaks through every permanent stopping in a ventilation system would be prohibitively expensive and time consuming. A more realistic approach is to measure the leakage across each stopping and repair those having a significant leakage rate.

Since the velocity of air leakage is too low to measure by conventional methods, the Bureau of Mines developed a procedure for measuring air leakage across permanent stoppings, called the "brattice window" method. This method offers a new way to determine leakage across stoppings accurately. Preliminary results indicate that it can be used to determine leakage rates as low as 300 cfm.

In this method, a temporary fabric stopping is erected in the same entry as the leaking permanent stopping. The temporary stopping has two windows or openings equipped with covers. The volumes of air passing through these



windows are measured and used in an equation to find the total volume of air leaking through the permanent stopping. To determine leakage rates accurately by this method requires only that the airflow through the windows be measured accurately, using a properly calibrated anemometer.

The study of other ventilation problems, such as leakage through gob areas, the effectiveness of auxiliary fans, and the short-circuiting of air, can be facilitated by use of a safe, reliable tracer gas. Sulfur hexafluoride (SF_6) was found to be an ideal gaseous tracer for studying mine ventilation systems. It is safe, odorless, chemically and thermally stable, has a low background concentration, and can be detected at concentrations as low as 1 part per billion. After the sulfur hexafluoride is released from a lecture bottle, samples of ventilation air at appropriate locations are collected in syringe bottles and analyzed by electron-capture gas chromatography. The tracer gas technique was used successfully in coal mines to determine the direction and quantity of leakage across a row of permanent stoppings that separate two intake airways, to indicate changes in ventilation required to eliminate a potential carbon monoxide problem, and to determine whether the air ventilating a pillared or caved gob area was being short-circuited.

With the brattice window method developed by the Bureau of Mines, airflow through a window in a brattice is measured to determine the amount of air leaking through a permanent stopping.

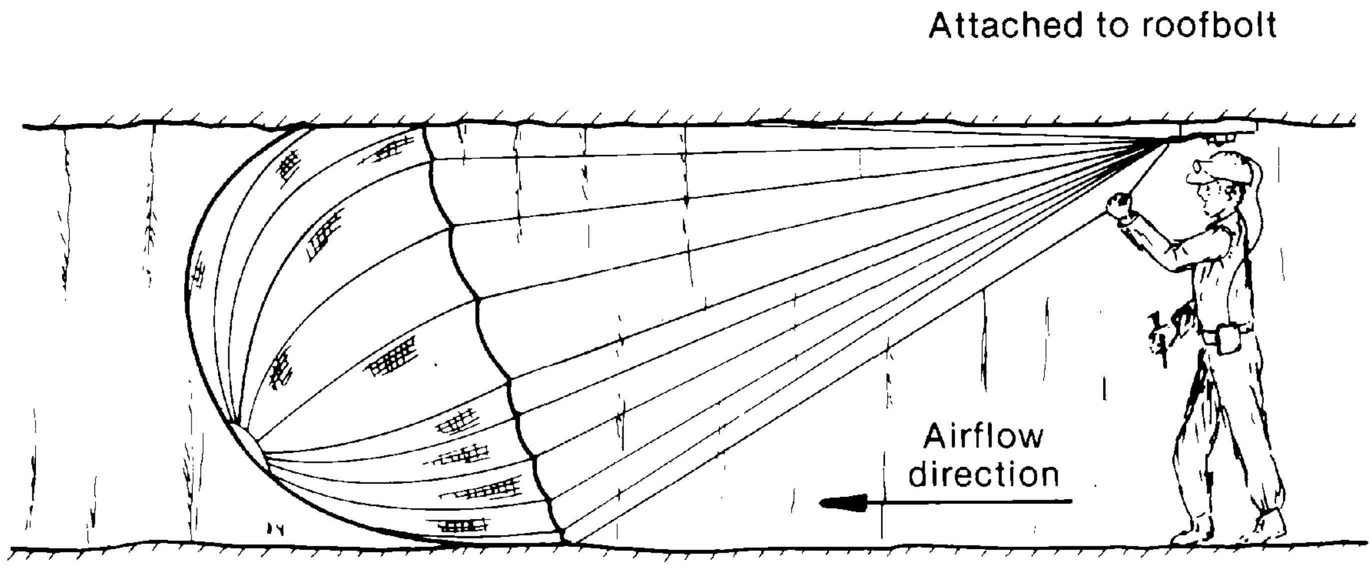
A means of periodically collecting air samples in remote locations without additional manpower would be useful in studying ventilation problems and particularly advantageous when using the tracer gas technique. A spiral sampler that meets this need has been developed. It shows promise as an inexpensive way of automatically collecting samples of air in mines or above ground.

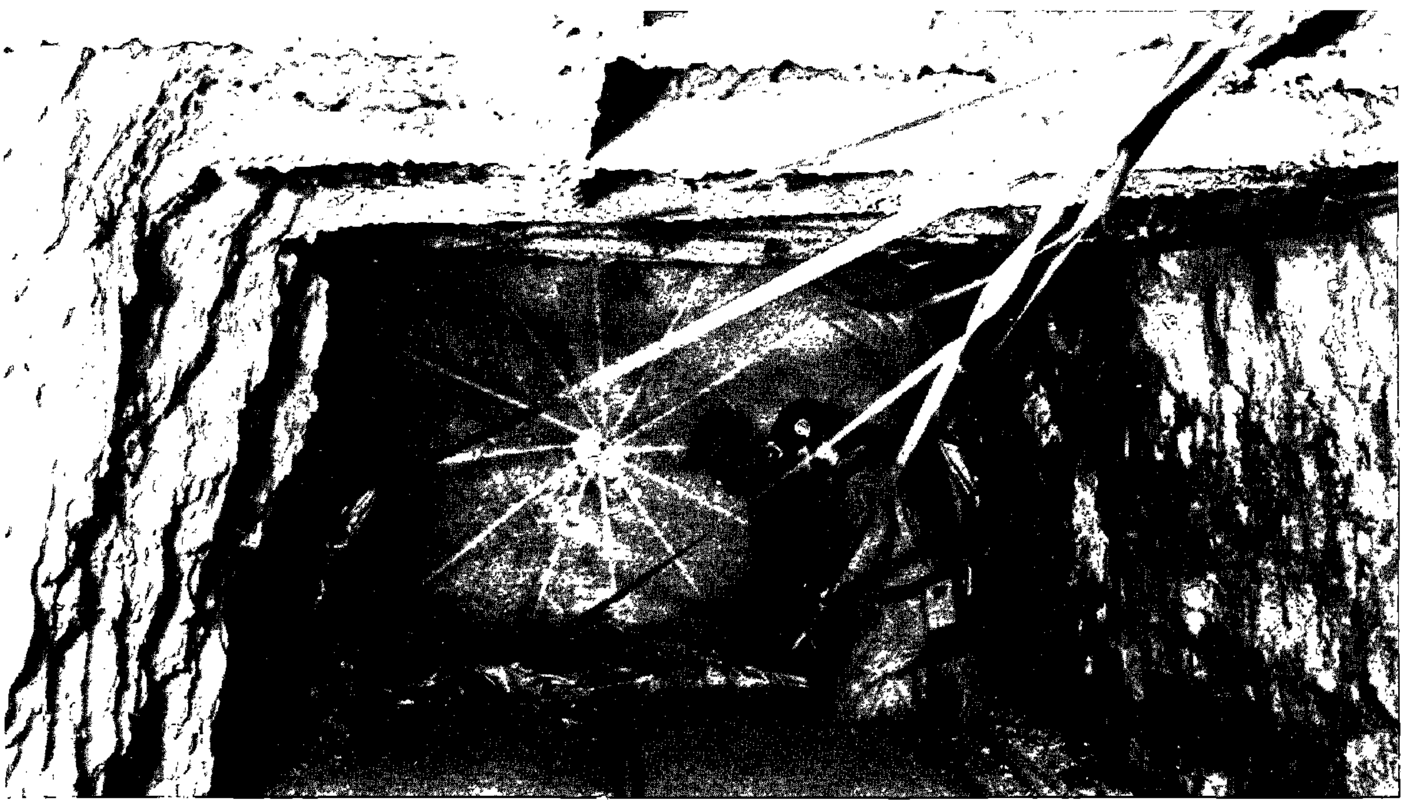
Fabric Stoppings

In underground mines a brattice or stopping is used to confine and direct the current of ventilating air. Stoppings are normally constructed of wood, concrete block, or brattice cloth attached to a wood frame. With such materials, construction of even temporary stoppings is time consuming and expensive. The Bureau of Mines has developed fabric stoppings for use in emergency situations where ventilation must be rerouted or reestablished quickly. These stoppings are also being used to make quick and/or temporary changes in ventilation in noncoal mines.

One of the fabric stoppings developed, shaped like an ordinary parachute, is called a "parachute stopping." It is made of fabric that is strong, impermeable, permissible, and lightweight (usually 8 ounces per square yard). To erect the stopping, the straps are attached to a roof bolt or other attachment point. The stopping is rolled out and lifted to catch the airflow. As the stopping lifts into place, the pressure across it forces its perimeter against the wall, roof, and floor, forming a good air seal. Total installation time is usually under 5 minutes.

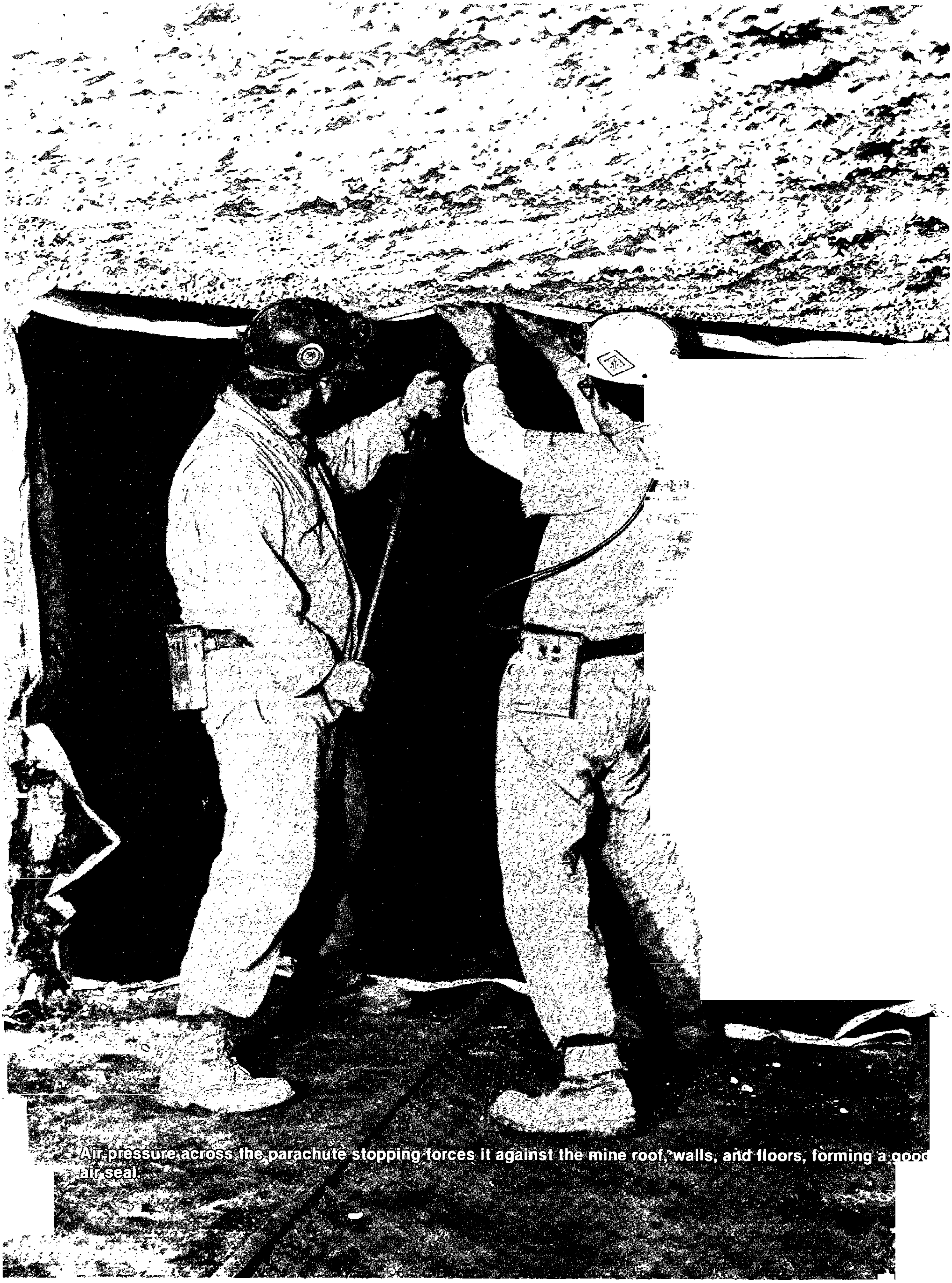
Releasing sulfure hexafluoride (SF_6), a safe, odorless tracer gas, in a mine airway enables an accurate study of mine ventilation systems.





Straps hooked on a roof bolt or other projection hold the parachute stopping in place. Air pressure across the parachute stopping forces it against the mine roof, walls, and floors, forming a good air seal.

A variation of the parachute stopping is the "self-sealing brattice" for use in rescue and recovery operations. In explosions, permanent stoppings are often damaged. Rescue operations usually require that ventilation be re-established quickly to bring fresh air to the affected area and to prevent the accumulation of explosive or harmful gases. A self-sealing brattice is hemispherical and made of very lightweight (less than 2 ounces per square yard) impermeable material. A 3-inch-wide strip of heavier material is sewn around the hemisphere's perimeter. Pins or spads are driven through the perimeter to hold the brattice in place. If the perimeter of the brattice is about 1½ times the perimeter of the passageway, even low airflows will inflate the lightweight fabric and seal it against the mine airway. Since the entire stopping weighs less than 10 pounds and since it can be erected in minutes, the self-sealing brattice is particularly suited to situations in which brattice must be carried into a mine and installed quickly.



Air pressure across the parachute stopping forces it against the mine roof, walls, and floors, forming a good air seal.

Methane Recovery and Use

Methane drainage was developed as a safety technique, a means of reducing methane emissions and thus explosion hazards, in underground bituminous coal mines. Because the methane emission rate during mining is related to gas pressure within the coalbed, reducing the gas pressure by removing some of the methane lowers the rate at which methane enters a mine. By 1973, some of the drainage technology previously described was being used to remove methane effectively from coal.

Originally, no plans were made to recover the methane drained from a coalbed, since methane, in coal mining, usually is viewed as a nuisance that simply adds to the cost of mining. Early tests had disclosed that the sustained drainage rate and the purity of drained gas may be comparable to those of a small gas well. When the necessity of making the best use of all available energy sources became a national priority, a substantial effort was directed toward the best methods of recovering and using methane, as well as the most effective methods of removing it from coal. Methane drainage is probably one of the few safety measures that produces a usable product while effectively reducing a hazard.

Although referred to as methane, the gas in coal is actually a mixture of gases. Methane is the major component, constituting between 80 and 99 pct of the gas. The higher molecular weight hydrocarbons, ethane, propane, butane, and pentane, are often present in coalbed gas along with carbon dioxide, oxygen, nitrogen, and, less frequently, hydrogen and helium. Coalbed gas does not contain carbon monoxide, sulfur compounds, or oxides of nitrogen and thus requires no cleanup or remedial treatment for direct use as a fuel. Like natural gas, methane from coal contains water that can be removed with a standard water trap. In those instances when the CO_2 content is higher than can be tolerated, it can be reduced with an absorption trap.

The heating value of gas drained directly from coalbeds is usually more than 900 Btu per cubic foot. Because it is very similar to natural gas in composition and heating value, methane from coal can be used in almost any system that normally uses natural gas and should be particularly valuable where there is a shortage of this fuel. The simplest method of using methane from virgin coal is direct addition to natural gas pipelines. However, it also can be used as a chemical feedstock, as boiler fuel, in a gas turbine to produce electricity, or for conversion to liquefied natural gas (LNG).

The gas accumulated in the gob areas of active and inactive mines is also a potential resource of methane. Where vertical boreholes are used to vent these gob areas, the exhausted gases typically contain 30 to 100 pct methane at volumes ranging from nearly zero to more than a million cubic feet per day. Although the flow rates and methane concentrations vary widely, gob gas can be used as boiler fuel or in gas turbines. These are its most practical uses because of the generally lower Btu content.

Problems in utilization of methane from coal are related primarily to market demand and the availability of surface facilities. For example, the use of gob gas as boiler fuel or in gas turbines is economically feasible when the coal mine itself is the consumer or when the user has an alternate supply of fuel readily available. Converting methane to LNG is practical in areas where a demand for LNG already exists and the price of LNG from coalbed methane, including transportation costs, is competitive. Adding drained methane to a natural gas pipeline requires that a pipeline reasonably close to the boreholes must either already exist or else be practicable to construct in terms of costs and right-of-way. Moreover, the pipeline pressure must not be so high that the cost of sufficiently compressing the methane for injection becomes uneconomic.

A potential impediment to the widespread use of coalbed methane is the question of legal ownership of the gas. Different parties frequently hold title to the coal and the natural gas in the same tract. Whether the coalbed gas is included with the coal rights or with the natural gas rights is not clear under most laws governing mineral rights. The answer to the question of ownership of this gas lies in interpretation of the wording and intent of individual leases. Past decisions have indicated that methane in coalbeds is a natural gas and does not belong to the owner of the coal lease. Upon coming under control (capture and use), it is the property of the gas lessee. Thus, until this legal precedent is challenged successfully, the gas in coalbeds on privately owned land must be assumed to belong to the party that holds the gas rights. Consequently, anyone desiring to produce and recover gas from coalbeds must either own the gas rights, obtain a lease from the owner of the gas rights, or be prepared for a legal suit.

However, when coal is mined, methane must be removed in order to comply with stringent mine safety regulations. Thus the coal mine operator is considered to have the right to remove the methane and expel it into the atmosphere, since depriving him of this right would deprive him of access to the coal. Both gas and coal producers have generally accepted this principle in the past.

Now with advances in the technology of methane drainage, the ever greater need to conserve fuel resources, and the increasing price of natural gas, any final determination of the ownership issue should consider certain factors that did not enter into past decisions. Mine safety is of paramount importance, and draining methane from coal as a necessary or desirable means of improving mine safety is at the discretion of the mine operator. If the methane is not removed prior to mining, it is dissipated when the coal is mined and thus lost as a source of fuel. Although draining methane is primarily a safety measure, recovery and utilization of the drained gas would benefit the public.

Particularly at a time of fuel shortages, every effort should be made to use every fuel resource, including coalbed gas. Where the gas is to be produced from minable coalbeds, reasonable parties should be able to agree to a system of royalty payments that will benefit the coal producer, the gas producer, and the holder of the gas rights. In any event, there is no valid reason that the question of legal ownership of the gas rights should impede the recovery and use of this valuable resource with a concurrent improvement in mine safety and productivity.

Although the technology is now available to drain and recover commercial quantities of gas from permeable coalbeds in advance of mining and also during mining

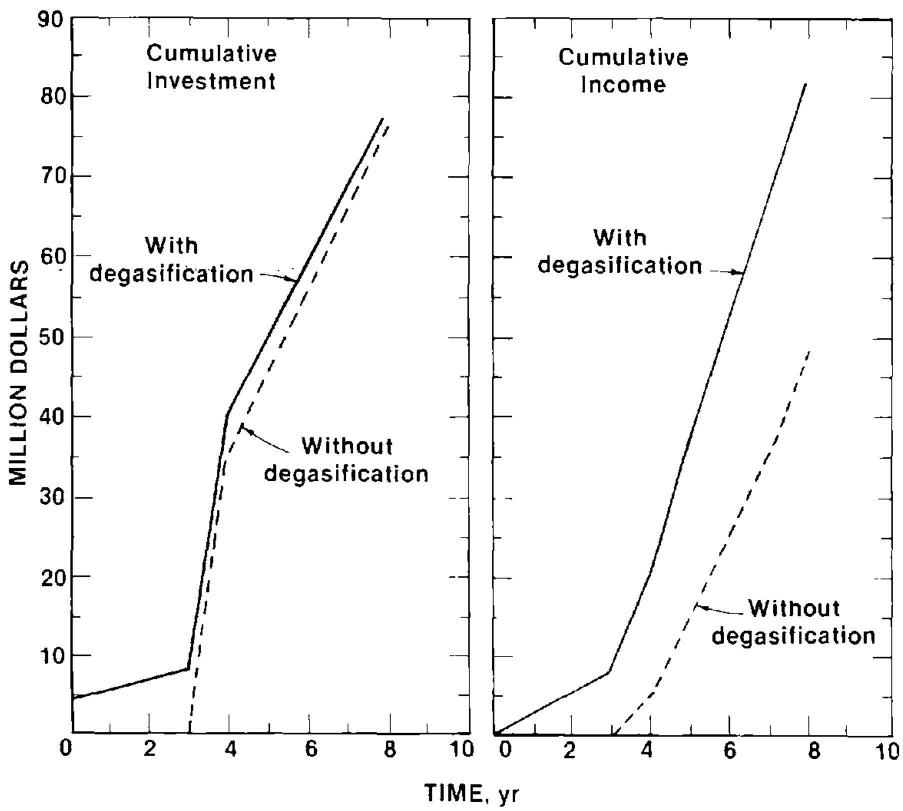
Methane drained from the Pittsburgh coalbed is piped from the wellhead and flared in a metal drum. This area of the coalbed was effectively dewatered by an adjacent borehole.

from ahead of the developing face, recovery and utilization of methane from coalbeds has not been adopted readily by the coal mining industry. Over 2 Bcf of gas has been drained from the two shafts at the Federal No. 2 mine in West Virginia, but only 660 MMcf had been sold by mid-June 1979.

In Bureau of Mines projects using vertical boreholes, more than 500 MMcf of gas has been drained from coals, but not one cubic foot has been used. In some instances, production rates were considered too low to warrant commercial development. Included in this group were wells producing 10 to 20 Mcfd, although such wells could supply a mine with sufficient energy for coal drying and space heating. At one location, however, gas was flared from wells that were producing over 100 Mcfd and thus were obvious candidates for commercialization. The coal company had a customer for the gas, but right-of-way problems, Federal regulations, applications for permits, and general inertia in the face of modest difficulties are the apparent reasons that the gas has been wasted for more than 15 months. During that period, in which the coldest winter on record caused shortages of natural gas, the coal company could have recovered its investment in degasification while supplying the daily gas needs of 800 consumers.

With in-mine drainage techniques now beginning to be applied, additional opportunities are becoming available for recovering and using methane from coal. In the project where gas from four horizontal drainage holes in the Pittsburgh coalbed is being conveyed from the mine through an underground pipeline, about 285 Mcfd is being discharged into the atmosphere. Two underground drainage holes in the Sunnyside coalbed produced a total of 60 MMcf of methane during the 14 months required for mining to advance beyond the ends of the holes. Of all the gas removed from coalbeds and piped to the surface in Bureau of Mines projects, less than one-third has been used. In a similar research program being conducted by a coal company on methane drainage from underground, none of the 250 MMcf of methane that was produced from the coal has been used.

Although the calorific value of the methane present in a ton of coal from gassy coalbeds is only 1 to 2 pct of that of the coal itself, the volumes of gas that might be obtained from methane drainage installations, as indicated by the demonstrations described above, could constitute a significant addition to the national fuel supply. The cumulative total of methane being discharged in the ventilation exhausts of deep coal mines now ranges from 200 to 250 MMcfd. The methane in this vented gas is very dilute, about 1 part per 200 parts of air, and so cannot be recovered economically. As deeper coalbeds are developed, the total quantity of methane vented to the atmosphere will increase unless drainage and capture of the methane are practiced. The capture and use of the gas being drained from the coal not only will prevent the waste of a valuable resource but also will pay at least part of the cost of degasification and may even be profitable. However, achieving widespread utilization of methane from coal will require the active interest and cooperation of the coal mining and natural gas industries.



In a hypothetical case, the Bureau of Mines estimated that an additional investment of less than $2 million for coalbed degasification through shafts would produce approximately $10 million in additional income.

Methane Drainage Outside the United States

In coal-producing countries outside the United States, methane drainage has been used for many years to supplement ventilation in maintaining safe concentrations of methane in the mine air. The first system of removing methane from the mine independently of the ventilating air was introduced in Germany in 1943. Initial output was more than 500 Mcfd of methane, and a total of almost 200 MMcf was produced in a period of about 20 months. Following World War II, both the faster rates obtained with mechanized mining and the mining of deeper and more gassy coalbeds made methane drainage a necessary procedure in the European coal-producing countries.

The coal mining technology employed in these countries usually differs from United States practice, at least partly because of the different physical conditions that prevail. Coal basins in Europe tend to be more tectonically disturbed than those in the United States. Steeply dipping coalbeds are common, multiple-seam mining is the rule rather than the exception as in the United States, and the average mining depth is much greater. In addition, methane occurs in the roof and floor strata of many European coalfields, and such occurences complicate the problems of methane emission.

In Europe and Great Britain, coal is mined predominantly by the longwall method. The advancing system is predominant, but the retreating system, which is virtually the only one used with U.S. longwalls, is employed in many operations. In European longwall mining, the panels are outlined by single entries supported by steel arches at intervals of about 3 feet. This contrasts with the usual operations in the United States, where multiple entries are driven to outline the longwall panels. Because the coalbeds in Europe are closely spaced and steeply dipping, the mines are designed to operate in several coalbeds and levels. Crosscuts are driven through rock at several levels and intercept a number of coalbeds. From the crosscuts, development entries are driven into the minable coalbeds.

At depths greater than about 800 feet, methane emission into the mine workings became so great that ventilation alone was unable to maintain safe working conditions. In order to realize the full production capacity of the mining system, methane drainage became necessary. The methods used for draining methane can be classified according to the development stage of the mine, as follows:

1. Advance drainage through surface boreholes.
2. Advance drainage from development workings.
3. Drainage during longwall operations.
4. Drainage of gob areas.

The first two techniques are used extensively in Czechoslovakia and somewhat less in Poland. Both are ineffective at depth greater than about 800 feet because of decreased fracture permeability of the coalbeds and surrounding sandstone reservoirs.

In Poland, surface boreholes were used to drain methane from coal measure strata in two coalfields. In one of these, 30 holes spaced over an area of about 6 square miles drained 11.7 Bcf of methane in 25 years. Four holes in the other field produced about 230 MMcf of methane in 6 years.

Strata degasification by surface boreholes was applied on a much larger scale in Czechoslovakia, where the method was used to drain methane from shallow coalbeds in four coalfields. Over a 15-year period, 72 Bcf of methane was produced.

During the first phase of development of shallow mines, two techniques of methane drainage from development workings ahead of mining are used in parallel. In the crosscuts driven through rock to intercept minable coalbeds, methane drainage holes are drilled ahead of the face from niches driven into the entry walls. Drilling of methane drainage holes ahead of the face is continued as development entries are driven into the minable coalbeds that are intercepted. From the walls of these development entries, drainage holes are also drilled fanwise into the overlying and underlying rock strata and coalbeds. This pattern of holes is repeated every 165 feet.

Degasification in advance of mining is not effective at depths below about 800 feet, and, in general, techniques to do this are of minor importance in Europe. At present, methane drainage during longwall operations is the most important technique applied throughout Europe. Removal of the coal by the longwall method results in relaxation and fracturing of the overlying and underlying strata. This process greatly increases the permeability of the coalbeds, and they become the main source of the methane that enters the mine opening. Methane is emitted from the roof and floor layers from the time of their relaxation until they have settled and again tightened. The relaxed zone extends from a distance of about 30 feet ahead of the longwall face to about 650 feet into the gob. The largest flows of methane occur in the interval from 30 feet ahead of the face to 165 feet into the gob.

Methane drainage during longwall operations in Europe is accomplished predominantly through boreholes. Usually these holes are drilled from the top road or return side of the longwall toward the methane source, but in extremely gassy workings, drilling from the bottom road or intake side is permitted. Borehole length ranges from about 65 to 500 feet, depending upon geologic and mining conditions. Various borehole diameters also are used to meet the specific need. For example, in Poland the usual practice is to drill a large number of small-diameter (1.9- to 3-inch) holes. This is to obtain a faster drilling rate in the very hard rock encountered and give less chance of being squeezed in soft rock. In Germany, the holes drilled are fewer but have a larger diameter (3 to 4.5 inches).

The results obtained with methane drainage during longwall operations depend on the mining system used and geologic conditions. Control of methane is best with a longwall advancing along the strike, since borehole drainage is then possible along the whole length of the relaxed zone. Results are much poorer for retreat mining along the strike with a single entry, inasmuch as methane cannot be drained from the first 165 feet of gob because the area has collapsed. However, when a double entry is driven with the retreating longwall in order to maintain acceptable methane concentrations, borehole drainage is as effective in retreating longwalls as it is in the advancing system.

Sealing of gob areas is common practice in Europe. The seals are 3 to 10 feet thick and filled with a grout mixture of sand and fines. Methane emission into the sealed gobs continues long after mining operations in that part of the mine have been completed. To prevent its infiltrating nearby mine workings, the excess gob gas is drawn off through a pipeline that extends about 30 feet behind the seal. The rate of removing the gas is adjusted to keep the methane content above 30 pct in the mixture.

Degasification of gob areas in Polish mines is also accomplished through boreholes drilled over protective pillars at the ends of longwalls. These drainage holes communicate with the fractured zone above the longwall. This method yields gas mixtures with a higher methane content and will produce for a longer period.

The gas removed by the various drainage techniques (ahead of mining, during longwall operations, and from gob areas) is almost always transported to the surface by pipeline but sometimes is diluted to safe concentrations with ventilation air underground. The drainage boreholes are connected to an underground system of steel pipelines that are suspended from steel arches in return air entries.

In 1970, a total of about 63 Bcf of methane was drained from the coal mines of Poland, Czechoslovakia, and the Western European nations. In succeeding years, methane drainage in these countries has continued at about this same level. In 1975, more than 90 pct of the methane was utilized in Belgium, Czechoslovakia, and Poland, and more than 50 pct in France and West Germany.

Control of the methane hazard in European coal-producing countries is becoming increasingly difficult, with the high methane content of the strata and the steady progression of mining to deeper coals. Large sums of money are allotted for research on controlling dangerous accumulations of methane and for introducing this control into mining operations. Methane drainage has been fully integrated into coal mining throughout Europe and is essential to maintaining coal production.

The Program Ahead

Although the technology for draining methane from United States coalbeds now has been developed to a high level, the coal mining industry has been slow to incorporate it into the mining cycle. Hence, the effort to achieve voluntary introduction of methane drainage technology by industry must be intensified through additional selective cooperative demonstrations of the practical techniques that have been developed. In addition, research to further improve methane drainage technology and extend its applicability will address the following technical needs:

- Improved technology for drilling long horizontal holes; particularly, the capability of drilling longer holes and a method of changing bit direction more quickly.
- A proven, practical, continuous, in-hole system for surveying horizontal holes.
- In-hole sensors to determine position of drill bit in coalbed.
- Improved methods for grouting horizontal holes preparatory to being mined through.
- Methods for temporarily plugging horizontal holes and reconnecting them for continued drainage after being mined through.
- Increased drainage rates of gas and water from low-permeability coalbeds.
- Improved stimulation methods for vertical drainage holes.
- Quantification of the effect of methane drainage on ventilation costs and productivity.
- Determination of cost effectiveness of different methane control methods for various coalbeds and conditions.
- Increased data base for the gas content of coalbeds.
- Improved ventilation systems.
- Alternate methods for controlling gob gas.

Research is underway to some extent on all these problems. As progress is made, methane drainage will become easier, more widely applicable, more effective, and more efficient.

Research results, of course, are unpredictable, and the time required for locating suitable test sites and obtaining the necessary agreements with coal mining companies is indeterminable. Consequently, the duration of the program cannot be predicted with certainty. However, the desired end results can be defined as follows:

- Methods of methane control have been developed and demonstrated sufficiently that they are being adopted voluntarily by industry.
- Conditions that preclude successful methane drainage are understood and can be predicted or determined readily.
- A correlation has been developed between the gas content of a coalbed and ventilation requirements for a mine.
- The direct method of determining the gas content of coalbeds has been developed as a tool to be used in assessing a ventilation plan prior to approval by the Mine Safety and Health Administration.
- A clear understanding has been developed of the location of the gassy, minable (less than 3,000 feet below the surface) coalbeds of the United States and the degree of gassiness.

When these objectives have been achieved, the level of effort will have decreased substantially with completion of the necessary demonstrations. Subsequently, a program should be continued at a relatively low level of funding to address problems arising in ventilation and other methane control methods.

Summary

Methane has been a hazard in United States coal mines ever since coal has been mined underground. Coal mine explosions have taken a large toll in lives of miners and damage to mine workings and equipment. Most major explosions have been attributed either solely to an accumulation of methane or else to initiation by a localized methane ignition.

Methane is an integral component of coal and is emitted wherever coal is uncovered by mining or erosion. The rate of emission underground has been shown to depend on both mining depth and coal production rate. In the 1970's, coal production in the United States reached an all-time high. Present predictions are for the demand for coal to increase further, reaching 1.2 billion tons per year by 1985 and 2 billion tons per year by the end of the century. As shallow reserves of coal are depleted, more mines will be opened in deeper parts of coalfields. Such new deep mines will very probably be extremely gassy. As a result, using ventilation alone to control methane will almost certainly be unsatisfactory, as high methane emissions increasingly limit productivity and increased ventilation becomes prohibitively expensive. Considerations of safety and productivity most likely will require methane drainage from the coal and new techniques to improve the effectiveness of ventilation.

Control of the methane hazard in European coal-producing countries is also becoming increasingly difficult as mining steadily progresses to deeper coals. Methane drainage has been used for many years in coal-producing countries outside the United States to supplement ventilation in maintaining safe concentrations of methane in the mine air. However, the coal mining technology employed in these countries usually differs from the U.S. practice, at least partly because of the different physical conditions that prevail. Consequently, the methods used for methane drainage differ in many respects from those found applicable in the United States.

The Bureau of Mines has developed the basic technology for draining methane from coal and a number of effective improvements in ventilation. Field tests and demonstrations have been conducted at mines in Pennsylvania, West Virginia, Virginia, Ohio, Colorado, Oklahoma, Alabama, Illinois, and Utah. In the course of this work, the Bureau has achieved an outstanding record of cooperation with coal producers, coal miners, and State and other Federal agencies.

In the segment of the program that was concerned primarily with increasing productivity, the first cost-sharing, cost-reimbursable contract for a pattern of vertical boreholes to drain, capture, and use methane from a coalbed was undertaken with the United States Steel Corporation. Later, a similar contract for tests in a different coalbed was initiated with the Clinchfield Coal Co. These contracts, which were transferred to the U.S. Department of Energy (DOE) when it was activated on October 1, 1977, are still underway. Initial interest was generated and preliminary plans were developed with Bethlehem Mines Corp. to utilize the gob gas at its Mine No. 33. This evolved into the project currently sponsored by DOE to demonstrate the use of gob gas to generate electric power with a gas turbine.

Of the methane drainage technology demonstrated by the Bureau of Mines, the technique arousing the most interest is removal of methane from the coal ahead of the face through horizontal holes drilled from underground. At least 10 companies have started using, or have plans to use, this method. Some of these are cooperative efforts with the Bureau of Mines, while others are being undertaken independently.

Equipment developed as an adjunct to methane control research is now available commercially. Because of the benefits of methane drainage, a growing number of coal producers are using the technology to reduce hazards in their mines; many gas producers are investigating potential gas resources in coalbeds; and related companies see methane drainage as a promising commercial market for their products and services.

The research on methane control and ventilation is now directed toward demonstrating the effectiveness of technology thus far developed, further improving the techniques now available, and developing solutions to any additional problems in methane control and ventilation. The current program includes studies on improving drilling and its control, increasing drainage rates from coalbeds, supplementing required data on coalbeds, improving face ventilation, pinpointing ventilation problems, developing more suitable stoppings, improving packers for water infusion, and evaluating the effect of methane drainage on ventilation costs and productivity.

Because of the effectiveness of methane control techniques that have been developed by the Bureau of Mines, many coal producers are now using one or more of them to decrease methane problems and thus reduce the traditional hazards of underground mining.

Bibliography

1. Alabama, Geological Survey of. Data Accumulation on Selected Coal Measures in the Warrior Basin of Alabama. BuMines OFR 50–77, 1976, 73 pp. *NTIS, PB 265 182/AS.*
2. Bench, B. M., W. P. Diamond, and C. M. McCulloch. Methods of Determining the Orientations of Bedrock Fracture Systems in Southwestern Pennsylvania and Northern West Virginia. BuMines RI 8217, 1977, 35 pp.
3. Bertard, C., B. Bruyet, and J. Gunther. Determination of Desorbable Gas Concentration of Coal (Direct Method). Internat. J. Rock Mech. Min. Sci., v. 7, 1970, pp. 43–65.
4. Bielicki, R. J., and F. N. Kissell. Statistical Analysis of Methane Concentration Fluctuations Produced by Incomplete Mixing of Methane and Air at a Model Coal Mine Working Face. BuMines RI 7987, 1974, 21 pp.
5. Bielicki, R. J., J. H. Perkins, and F. N. Kissell. Methane Diffusion Parameters for Sized Coal Particles. A Measuring Apparatus and Some Preliminary Results. BuMines RI 7697, 1972, 12 pp.
6. Bielicki, R. J., E. D. Thimons, and F. N. Kissell. Replacing Brattice Cloth at Coal Faces With Air Curtains and Diffuser Fans. A Preliminary Study. BuMines RI 8052, 1975, 8 pp.
7. Bloetscher, Fredrick, and Jerry J. Fry (Goodyear Aerospace Corp.). Improving the Brattice Window Method of Measuring Mine Stopping Leakage. BuMines OFR 20–79, 1978, 54 pp. *NTIS, PB 293 032/AS.*
8. Bromilow, J. G., and J. H. Jones. Drainage and Utilization of Fire Damp. Colliery Eng., v. 32, No. 6, June 1955, pp. 222–232.
9. Cervik, J. An Investigation of the Behavior and Control of Methane Gas. Min. Cong. J., v. 53, No. 7, July 1967, pp. 52–57.
10. ———. Behavior of Coal-Gas Reservoirs. Pres. at 4th Ann. Eastern Regional Meeting, Soc. Petrol. Eng., AIME, Pittsburgh, Pa., Nov. 2–3, 1967, SPE Preprint 1973, 4 pp.
11. ———. Behavior of Coal-Gas Reservoirs. BuMines TPR 10, 1969, 10 pp.
12. ———. Water Infusion for Dust Control. Paper in Respirable Dust Control. Proceedings: Bureau of Mines Technology Transfer Seminars, Pittsburgh, Pa., September 21, 1976, and St. Louis, Mo., September 23, 1976, compiled by Staff—Mining Research, Bureau of Mines, Pittsburgh, Pa. BuMines IC 8753, 1977, pp. 63–77.
13. Cervik, J., and C. H. Elder. Removing Methane From Coalbeds in Advance of Mining by Surface Vertical Boreholes. Proc. Conf. on Underground Mining Environment, Oct. 27–29, 1971, Univ. of Missouri, Rolla, Mo., 1972, pp. 209–228.
14. Cervik, J., H. H. Fields, and G. N. Aul. Rotary Drilling Holes in Coalbeds for Degasification. BuMines RI 8097, 1975, 21 pp.
15. Cervik, J., A. Sainato, and M. Deul. Water Infusion of Coalbeds for Methane and Dust Control. BuMines RI 8241, 1977, 27 pp.
16. Cetinbas, A., R. P. Vinson, J. Cervik, and M. G. Zabetakis. Methane and Dust Control by Water Infusion, Pittsburgh Coalbed (Fairview, W. Va.). BuMines RI 7640, 1972, 17 pp.
17. ——. Methane and Dust Controls for Longwalls: Pocahontas No. 3 Coalbed, Grundy, Va. BuMines RI 7849, 1974, 16 pp.
18. Chamberlin, R. T. Notes on Explosive Mine Gases and Dusts, With Especial Reference to Explosions in the Monongah, Darr, and Naomi Coal Mines. BuMines Bull. 26, 1911, 67 pp.
19. Chang, Shih-Chi, and Peter E. Brown (Duquesne University). Investigation of the Adsorption Process in Coal Using X-ray Diffraction. BuMines OFR 8–72, 1972, 14 pp.
20. Cobbs, J. H. (Cobbs Engineering). Design and Development of Horizontal Borehole Packers for Use in Coal Beds. BuMines OFR 6–72, 1972, 26 pp. *NTIS, PB 207 363.*
21. Cobbs, J. H., and J. D. Hadden. New Packer Helps Control Methane in Coal Mines. Coal Age, v. 78, No. 1, January 1973, pp. 60–62.
22. Cook, J. C. (Teledyne Geotech). A Study of Radar Exploration of Coalbeds. BuMines OFR 5–72, 1971, 83 pp. *NTIS, PB 207 362.*
23. Deul, M. Gas Production From Coalbeds—Accomplishments and Prospects. Proc. Transmission Conf., Operating Section, AGA, Bal Harbour, Fla., May 19–21, 1975, pp. T-227–T-229.
24. ———. Geologic Assessment of the Health and Safety Hazards Associated With Subterranean Excavations. Abstract in Proc., 1974 Rapid Excavation and Tunneling Conf., Soc. Min. Eng., AIME, San Francisco, Calif., June 24–27, 1974, v. 1, 1975, pp. 541–542.
25. ———. Geologic Studies as a Basis for Methane Drainage From Coalbeds. Pres. at 1976 Ann. Meeting, Geol. Soc. of America, Denver, Colo., Nov. 8–11, 1976, abs. with Programs, v. 8 No. 6, September 1976, p. 836.
26. ———. How To Plan Your Mine for Methane Control. Proc. Ann. Meeting, Ill. Min. Inst., Springfield, Ill., Oct. 9–10, 1969, pp. 23–30.
27. ———. Low Cost Fuel From Degasification of Coalbeds. Pres. at 169th Nat. Meeting, ACS, Div. Fuel Chem., Philadelphia, Pa., Apr. 6–11, 1975, v. 20, No. 2, 1975, pp. 1–2.
28. ———. The Methane Content of Coalbeds in Region III. Proc. Dept. of Energy Symp. on Methane Gas From Coalbeds: Development, Production, and Utilization, Coraopolis, Pa., Jan. 18, 1978, pp. 5–7.
29. ———. Methane Drainage From Coalbeds: A Program of Applied Research. Proc. 60th Meeting, Rocky Mountain Coal Min. Inst., Boulder, Colo., June 30–July 1, 1964, pp. 54–60.
30. ———. Natural Gas From Coalbeds. Pres. at Forum on Natural Gas Potential of Unexploited Sources, Nat. Res. Council, Washington, D.C., Jan. 15, 1975 (Ch. in Natural Gas From Unconventional Geologic Sources, 1976, pp. 193–205).
31. ———. Parameters To Be Considered in Water Infusing for Dust Control. Paper in Proceedings of the Symposium on Respirable Coal Mine Dust, Washington, D.C., November 3–4, 1969, comp. by R. M. Gooding. BuMines IC 8458, 1970, pp. 133–152.
32. ———. Recover Coalbed Gas. Hydrocarbon Proc., July 1975, pp. 86–87.
33. ———. The Scientific Basis for Evaluation of the Methane Problem in New Mines. Proc. W. Va. Coal Min. Inst., Charleston, W. Va., October 1970, pp. 19–23.
34. ———. Structural Control of Methane Migration Through Bituminous Coalbeds. Abs. Geol. Soc. America Bull., v. 3, No. 7, October 1971, p. 542.
35. Deul, M., and J. Cervik. Methane Drainage in the Pittsburgh Coalbed. Proc. XVII Internat. Conf. on Safety of Mining Works, Varna, Bulgaria, 1977, pp. 9–15.
36. Deul, M., J. Cervik, H. H. Fields, and C. H. Elder. Methane Control in Mines by Coalbed Degasification. Preprints, Internat. Conf., Coal Mine Safety Res., Washington, D.C., Sept. 22–26, 1975, pp. V 6.1–V 6.11.
37. Deul, M., H. H. Fields, and C. H. Elder. Degasification of Coalbeds: A Commercial Source of Pipeline Gas. Pres. at Ill. Inst. Technol. Symp., Clean Fuels From Coal, Inst. Gas Technol., Chicago, Ill., Sept. 10–14, 1973, 9 pp.; AGA Monthly, v. 56, No. 1, January 1974, pp. 4–6.
38. Deul, M., and A. G. Kim. Methane Drainage—An Update. Min. Cong., J., v. 64, No. 7, July 1978, pp. 38–42.
39. ———. Coal Beds: A Source of Natural Gas. Oil and Gas J., v. 73, No. 24, June 16, 1975, pp. 47–49.
40. ———. Degasification of Coalbeds—A Commercial Source of Pipeline Gas. Proc. Symp. on Clean Fuels From Coal, II, Inst. Gas Technol., Chicago, Ill., June 22–27, 1975. AGA Monthly, v. 58, No. 5, May 1976, pp. 7–9.
41. ———. Origin of Hydrocarbon Gases in Coal. Pres. at Ann. Meeting, Geol. Soc. of America, Salt Lake City, Utah, Oct. 20–22, 1975, abs. with Programs, v. 7, No. 7, September 1975, pp. 1050–1051.

42. ———. Safety and Economic Implications of the Degasification of Coalbeds. Pres. at NCA/BCR Coal Conf. and Expo II, Louisville, Ky., Oct. 21–23, 1975. Proc. 1st Symp. on Underground Mining, v. 1, 1975, pp. 1–8.
43. ———. Methane in Coal: From Liability to Asset. Min. Cong. J., v. 61, No. 11, November 1975, pp. 28–32.
44. Deul, M., and F. N. Kissell. Factors Affecting Methane Emission and Their Implications Regarding the Selection of Control Techniques. Proc. Conf. on Underground Mining Environment, Oct. 27–29, 1971, Univ. of Missouri, Rolla, Mo., 1972, pp. 229–240.
45. Deul, M., and M. L. Skow. Speeding Coal Mining Operations by Recovering and Utilizing Methane From Coal Beds. Coal Age, v. 80, No. 8, July 1975, pp. 104–106.
46. Deul, M., M. L. Skow, and A. G. Kim. Helping Finance New Mines With Revenues From Coalbed Degasification. Pres. at NCA/BCR Coal Conf. and Expo IV, Louisville, Ky., Oct. 18–20, 1977. Proc. 3d Symp. on Underground Mining, 1977, pp. 25–41.
47. Diamond, W. P., C. M. McCulloch, and B. M. Bench. Estimation of Coal-Cleat Orientation Using Surface-Joint and Photolinear Analysis. Geology, v. 3, No. 12, December 1975, pp. 687–690.
48. ———. Use of Surface Joint and Photolinear Data for Predicting Subsurface Coal Cleat Orientation. BuMines RI 8120, 1976, 13 pp.
49. Diamond, W. P., and G. W. Murrie. Methane Gas Content of the Pittsburgh Coalbed and Evaluation Drilling Results at a Major Degasification Installation. Pres. at Northeastern Section Ann. Meeting, Geol. Soc. of America, Binghamton, N.Y., Mar. 31–Apr. 2, 1977, abs. with Programs, v. 9, No. 3, February 1977, p. 256.
50. Diamond, W. P., G. W. Murrie, and C. M. McCulloch. Estimation of the Methane Gas Content of the Mary Lee Group of Coalbeds, Warrior Basin, Alabama. Pres. at Joint Northeastern Section-Southeastern Section Ann. Meeting, Geol. Soc. of America, Arlington, Va., Mar. 25–27, 1976, abs. with Programs, v. 8, No. 2, February 1976, pp. 161–162.
51. ———. Methane Gas Content of the Mary Lee Group of Coalbeds, Jefferson, Tuscaloosa, and Walker Counties, Ala. BuMines RI 8117, 1976, 9 pp.
52. Diamond, W. P., D. C. Oyler, and H. H. Field. Directionally Controlled Drilling To Horizontally Intercept Selected Strata, Upper Freeport Coalbed, Greene County Pa. BuMines RI 8231, 1977, 21 pp.
53. Eisner, H. S., J. K. W. Davies, and F. R. Brookes. Mine Explosions: The Current Hazard. Proc. Symp. on Health, Safety, and Progress, Harrogate, London, Oct. 27–29, 1976, pp. 8.1—8.8.
54. Elder, C. H. Effects on Hydraulic Stimulation of Coalbeds and Associated Strata. BuMines RI 8260, 1977, 20 pp.
55. ———. Use of Vertical Boreholes for Assisting Ventilation of Longwall Gob Areas. BuMines TPR 13, 1969, 6 pp.
56. Elder, C. H., and M. Deul. Degasification of the Mary Lee Coalbed Near Oak Grove, Jefferson County, Ala., by Vertical Borehole in Advance of Mining. BuMines RI 7968, 1974, 21 pp.
57. ———. Hydraulic Stimulation Increases Degasification Rate of Coalbeds. BuMines RI 8047, 1975, 17 pp.
58. Elder, C. H., and M. C. Irani. Geology and Gas Content of Coalbeds in Vicinity of Bureau of Mines, Bruceton, Pa. BuMines RI 8247, 1977, 22 pp.
59. Elder, C. H., P. W. Jeran, and D. A. Keck. Geologic Structure Analysis Using Radar Imagery of the Coal Mining Area of Buchanan County, Va. BuMines RI 7869, 1974, 29 pp.
60. Ferguson, P. Methane Control by Boreholes. Coal Age, v. 77, No. 1, January 1972, pp. 76–77.
61. Fields, H. H., J. Cervik, and T. W. Goodman. Degasification and Production of Natural Gas From an Air Shaft in the Pittsburgh Coalbed. BuMines RI 8173, 1976, 23 pp.
62. Fields, H. H., S. Krickovic, A. Sainato, and M. G. Zabetakis. Degasification of Virgin Pittsburgh Coalbed Through a Large Borehole. BuMines RI 7800, 1973, 27 pp.
63. Fields, H. H., J. H. Perry, and M. Deul. Commercial-Quality Gas From a Multipurpose Borehole Located in the Pittsburgh Coalbed. BuMines RI 8025, 1975, 14 pp.
64. Findlay, C., S. Krickovic, and J. E. Carpetta. Methane Control by Isolation of a Major Coal Panel—Pittsburgh Coalbed. BuMines RI 7790, 1973, 11 pp.
65. Finfinger, G. L., and J. Cervik. Drainage of Methane From the Overlying Pocahontas No. 4 Coalbed From Workings in the Pocahontas No. 3 Coalbed. BuMines RI 8359, 1979, 15 pp.
66. Geiger, G. E. (University of Pittsburgh). Development of an Air Quality Simulator for Coal Mines. BuMines OFR 37–72, 1972, 229 pp. *NTIS, PB 213 833.*
67. Gift, Ralph D. (Atlantic Research Corp.). Evaluation of Methanometry in Coal Mines. BuMines OFR 8–73, 1972, 106 pp. *NTIS, PB 215 164.*
68. Hadden, J. D., and J. Cervik. Design and Development of Drill Equipment. BuMines TPR 11, 1969, 11 pp.
69. Hadden, J. D., and A. Sainato. Gas Migration Characteristics of Coalbeds. BuMines TPR 12, 1969, 10 pp.
70. Haliburton Services. Grouting of Horizontal Holes in Coalbeds. BuMines OFR 13–72, 1972, 35 pp. *NTIS, PB 209 575.*
71. Humphrey, H. B. Historical Summary of Coal-Mine Explosions in the United States. BuMines IC 7900, 1959, 275 pp.
72. Iannacchione, A. T., and D. G. Puglio. Geology of the Lower Kittanning Coalbed and Related Mining and Methane Emission Problems in Cambria County, Pa. BuMines RI 8354, 1979, 31 pp.
73. Irani, M. C., J. H. Jansky, P. W. Jeran, and G. L. Hassett. Methane Emission From U.S. Coal Mines in 1975, A Survey. A Supplement to Information Circulars 8558 and 8659. BuMines IC 8733, 1977, 55 pp.
74. Irani, M. C., and P. W. Jeran. A Continuous-Recording Methanometer for Exhaust Fan Monitoring. Proc. 2d W. Va. Univ. Conf. on Coal Mine Electrotechnology, Morgantown, W. Va., June 12–14, 1974, pp. 15–1 to 15–16.
75. Irani, M. C., P. W. Jeran, and M. Deul. Methane Emission From U.S. Coal Mines in 1973, A Survey, A Supplement to IC 8558. BuMines IC 8659, 1974, 47 pp.
76. Irani, M. C., P. W. Jeran, and D. H. Lawhead. Methane Analyzer System To Record Continously the Methane Content of Coal Mine Ventilation Air. BuMines RI 8009, 1975, 14 pp.
77. Irani, M. C., A. Tall, B. M. Bench, and P. W. Jeran. A Continuous-Recording Methanometer for Exhaust Fan Monitoring. BuMines RI 7951, 1974, 18 pp.
78. Irani, M. C., E. D. Thimons, T. G. Bobick, M. Deul, and M. G. Zabetakis. Methane Emission From U.S. Coal Mines, A Survey. BuMines IC 8558, 1972, 58 pp.
79. Jeran, P. W., D. H. Lawhead, and M. C. Irani. Methane Emissions From an Advancing Coal Mine Section in the Pittsburgh Coalbed. BuMines RI 8132, 1976, 10 pp.
80. ———. Methane Emissions From Four Working Places in the Beckley Mine, Raleigh County, W. Va. BuMines RI 8212, 1977, 16 pp.
81. Jeran, P. W., and J. R. Mashey. A Computer Program for the Stereographic Analysis of Coal Fractures and Cleats. BuMines IC 8454, 1970, 34 pp.
82. Jolliffe, G. W. The Emission of Methane From Rapidly Advancing Coalfaces. Min. Eng., v. 129, No. 113, pp. 325–341.
83. Kalasky, J. D. Ventilation of Deep Coal Mines. Min. Cong. J., v. 58, No. 9, September 1972, pp. 43–48.
84. Kalasky, J. D., and S. Krickovic. Ventilation of Pillared Areas by Bleeder Entries, Bleeder Systems, or Equivalent Means. Trans. SME-AIME, v. 254, December 1973, pp. 284–291.

85. Kim, A. G. The Composition of Coalbed Gas. BuMines RI 7762, 1973, 9 pp.
86. ———. Estimating Methane Content of Bituminous Coalbeds From Adsorption Data. BuMines RI 8245, 1977, 22 pp.
87. ———. Low-Temperature Evolution of Hydrocarbon Gases From Coal. BuMines RI 7965, 1974, 23 pp.
88. ———. Methane Drainage From Coalbeds: Research and Utilization. Proc. Dept. of Energy Symp. on Methane Gas From Coalbeds: Development, Production, and Utilization, Coraopolis, Pa., Jan. 18, 1978, pp. 12–17.
89. ———. Methane in the Pittsburgh Coalbed, Greene County, Pa. BuMines RI 8026, 1975, 10 pp.
90. ———. Methane in the Pittsburgh Coalbed, Washington County, Pa. BuMines RI 7969, 1974, 16 pp.
91. Kim, A. G., and M. Deul. Degasification of United States Coalbeds. The New Sketch—Organ for Coal and Minerals, Jan. 26, 1978, pp. 182–185.
92. Kim, A. G., and L. J. Douglas. Gas Chromatographic Method for Analyzing Gases Associated With Coal. BuMines RI 7903, 1974, 9 pp.
93. ———. A Gas Chromatographic Method for Analyzing Mixtures of Hydrocarbon and Inorganic Gases. J. Chromatographic Sci., v. 11, December 1973, pp. 615–617.
94. ———. Gases Desorbed From Five Coals of Low Gas Content. BuMines RI 7768, 1973, 9 pp.
95. ———. Hydrocarbon Gases Produced in a Simulated Swamp Environment. BuMines RI 7690, 1972, 15 pp.
96. Kissell, F. N. The Methane Migration and Storage Characteristics of the Pittsburgh, Pocahontas No. 3, and Oklahoma Hartshorne Coalbeds. BuMines RI 7667, 1972, 22 pp.
97. ———. Methane Migration Characteristics of the Pocahontas No. 3 Coalbed. BuMines RI 7649, 1972, 19 pp.
98. ———. The Potential Hazards of Methane Gas in Oil Shale Mines. Proc. Environmental Oil Shale Symp., Colorado School of Mines, Denver, Colo., v. 70, No. 4, 1975, pp. 19–27.
99. Kissell, F. N., J. L. Banfield, Jr., R. W. Dalzell, and M. G. Zabetakis. Peak Methane Concentrations During Coal Mining. An Analysis. BuMines RI 7885, 1974, 17 pp.
100 Kissell, F. N., and R. J. Bielicki. An In-Situ Diffusion Parameter for the Pittsburgh and Pocahontas No. 3 Coalbeds. BuMines RI 7668, 1972, 13 pp.
101 ———. Methane Buildup Hazards Caused by Dust Scrubber Recirculation at Coal Mine Working Faces, A Preliminary Estimate. BuMines RI 8015, 1975, 25 pp.
102. ———. Ventilation Eddy Zones at a Model Coal Mine Working Face. BuMines RI 7991, 1974, 14 pp.
103. Kissell, F. N., and M. Deul. Effect of Coal Breakage on Methane Emission. Trans. SME-AIME, v. 256, June 1974, pp. 182–184.
104. Kissell, F. N., and J. C. Edwards. Two-Phase Flow in Coalbeds. BuMines RI 8066, 1975, 16 pp.
105. Kissell, F. N., C. M. McCulloch, and C. H. Elder. The Direct Method of Determining Methane Content of Coalbeds for Ventilation Design. BuMines RI 7767, 1973, 17 pp.
106. Kissell, F. N., A. E. Nagel, and M. G. Zabetakis. Coal Mine Explosions—Seasonal Trends. Science, v. 173, Mar. 2, 1973, pp. 891–892.
107. Kissell, F. N., and E. D. Thimons. Self-Sealing Brattice for Coal Mine Rescue and Recovery. BuMines TPR 98, 1976, 7 pp.
108. Kissell, F. N., E. D. Thimons, and R. P. Vinson. The Parachute Stopping—Preliminary Experiments. BuMines TPR 90, 1975, 6 pp.
109. Kissell, F. N., and R. P. Vinson (assigned to U.S. Department of the Interior). Sampling Method and Apparatus. U.S. Pat. 4,010,647, Mar. 8, 1977.
110. Kissell, F. N., and R. E. Wallhagen. Some New Approaches to Improved Ventilation of the Working Face. Pres. at NCA/BCR Coal Conf. and Expo III, Louisville, Ky., Oct. 19–21, 1976. Proc. 2d Symp. on Underground Mining, 1976, pp. 325–338.
111. Krickovic, S., and C. Findlay. Methane Emission Rate Studies in a Central Pennsylvania Mine. BuMines RI 7591, 1971, 9 pp.
112. Krickovic, S., C. Findlay, and W. M. Merritts. Methane Emission Rate Studies in a Northern West Virginia Mine. BuMines TPR 28, 1970, 11 pp.
113. Krickovic, S., and J. D. Kalasky. Methane Emission Rate Study in a Deep Pocahontas No. 3 Coalbed Mine in Conjunction With Drilling Degasification Holes in the Coalbed. BuMines RI 7703, 1972, 12 pp.
114. Krickovic, S., T. D. Moore, Jr., and J. E. Carpetta. Bleeder System in Virgin Area in a Pittsburgh Coalbed Mine. BuMines RI 7805, 1973, 8 pp.
115. Krisko, W. J. (Donaldson Co.). Evaluation of the Use of Air Curtains To Increase Face Ventilation. BuMines OFR 157-77, 1977, 126 pp. *NTIS, PB 274 324.*
116. Lambert, S. W., and M. A. Trevits. Effective Placement of Coalbed Gas Drainage Wells. Dept. of Energy RI-PMOC-2(78), September 1978, 16 pp.
117. ———. Improved Methods for Monitoring Production From Vertical Degasification Wells. BuMines RI 8309, 1978, 14 pp.
118. ———. Methane Drainage Ahead of Mining Using Foam Stimulation, Mary Lee Coalbed, Alabama. Dept. of Energy RI-PMTC-3(79), January 1979, 22 pp.
119. ———. Methane Drainage: Experience With Hydraulic Stimulation Through Slotted Casing. BuMines RI 8295, 1978, 16 pp.
120. LaScola, J. C., and J. Cervik. Development of Recording Methanometers and Recording Anemometers for Use in Underground Coal Mines. BuMines TPR 15, 1969, 17 pp.
121. Lidin, G. D., A. T. Airuni, F. S. Klebanov, and N. G. Matvienko. Control of Methane in Coal Mines. Translated from the Russian. Israel Program for Scientific Translations, Jerusalem, 1964, 108 pp.
122. Little, Arthur D., Inc. Economic Feasibility of Recovering and Utilizing Methane Emitted From Coal. BuMines OFR 18-76, 1975, 254 pp. *NTIS, PB 249 728/AS.*
123. McCoy, J. F. (Walden Research Corp.). Evaluation of Anemometers for Use in Coal Mines. BuMines OFR 22-72, 1972, 63 pp. *NTIS, PB 211 412.*
124. McCulloch, C. M. Applying Computer-Drawn Maps of Geologic Data to Analysis of Mining Problems. BuMines RI 8151, 1976, 26 pp.
125. McCulloch, C. M., and M. Deul. Geologic Factors Causing Roof Instability and Methane Emission Problems. BuMines RI 7769, 1973, 25 pp.
126. ———. Methane From Coal. Proc. 1976 Symp. on the Geology of Rocky Mountain Coal, Denver, Colo., Apr. 26–29, 1976, pp. 121–136.
127. McCulloch, C. M., M. Deul, and P. W. Jeran. Cleat in Bituminous Coalbeds. BuMines RI 7910, 1974, 25 pp.
128. McCulloch, C. M., and W. P. Diamond. Inexpensive Method Helps Predict Methane Content of Coal Beds. Coal Age, v. 81, No. 6, June 1976, pp. 102–106.
129. McCulloch, C. M., W. P. Diamond, B. M. Bench, and M. Deul. Selected Geologic Factors Affecting Mining of the Pittsburgh Coalbed. BuMines RI 8093, 1975 72 pp.
130. McCulloch, C. M., P. W. Jeran, and C. D. Sullivan. Geologic Investigations of Underground Coal Mining Problems. BuMines RI 8022, 1975, 30 pp.
131. McCulloch, C. M., S. W. Lambert, and J. R. White. Determining Cleat Orientation of Deeper Coalbeds From Overlying Coals. BuMines RI 8116, 1976, 19 pp.
132. McCulloch, C. M., J. R. Levine, F. N. Kissell, and M. Deul. Meas-

uring the Methane Content of Bituminous Coalbeds. BuMines RI 8043, 1975, 22 pp.

133. ———. Measuring the Methane Content of Coalbeds for Resource Evaluation. Pres. at Ann. Meeting, Geol. Soc. of America, Salt Lake City, Utah, Oct. 20–22, 1975, abs. with Programs, v. 7, No. 7, September 1975, pp. 1194–1195.

134. Maksimovic, S. D., C. H. Elder, and F. N. Kissell. Hydraulic Stimulation of a Surface Borehole for Gob Degasification. BuMines RI 8228, 1977, 17 pp.

135. Matta, J. E., J. C. LaScola, and F. N. Kissell. Methane Absorption in Oil Shale and Its Potential Mine Hazard. BuMines RI 8243, 1977, 13 pp.

136. ———. Methane Emissions From Gassy Coals in Storage Silos. BuMines RI 8269, 1978, 14 pp.

137. Matuszewski, J., and W. Sikora. Report on the Technology of Degasification of Mines in Poland and Other European Countries. DOI/SFCP Project No. 14–01–0001–1447, January 1978.

138. Mazza, R. L., and M. P. Mlinar. (Continental Oil Co.). Reducing Methane in Coal Mine Gob Areas With Vertical Boreholes. BuMines OFR 142–77, 1977, 145 pp. *NTIS, PB 272 768.*

139. Mehring, R. D. (Goodyear Aerospace Corp.). Improving the Self-Sealing Brattice. BuMines OFR 59–79, 1978, 91 pp. *NTIS, PB 297 263/AS.*

140. Merritts, W. M., W. N. Poundstone, and B. A. Light. Removing Methane (Degasification) From the Pittsburgh Coalbed in Northern West Virginia. BuMines RI 5977, 1962, 39 pp.

141. Merritts, W. M., C. R. Waine, L. P. Mokwa, and M. J. Ackerman. Removing Methane (Degasification) From the Pocahontas No. 4 Coalbed in Southern West Virginia. BuMines RI 6326, 1963, 39 pp.

142. Monaghan, D. A., and D. R. Berry (Foster Miller Associates, Inc.). Extensible Face Ventilation Systems—Duct and Brattice. BuMines OFR 48–77, 1976, 205 pp. *NTIS, PB 265 067/AS.*

143. Moore, T. D., Jr., M. Deul, and F. N. Kissell. Longwall Gob Degasification With Surface Ventilation Boreholes Above the Lower Kittanning Coalbed. BuMines RI 8195, 1976, 13 pp.

144. Moore, T. D., Jr., and M. G. Zabetakis. Effect of a Surface Borehole on Longwall Gob Degasification (Pocahontas No. 3 Coalbed). BuMines RI 7657, 1972, 9 pp.

145. Murrie, G. W. Coal and Gas Resources of the Lower Hartshorne Coalbed in LeFlore and Haskell Counties, Oklahoma. Pres. at South-Central Section Meeting, Geol. Soc. of America, El Paso, Tex., Mar. 17–18, 1977, abs. with Programs, v. 9, No. 1, January 1977, pp. 65–66.

146. Murrie, G. W., W. P. Diamond, and S. W. Lambert. Geology of the Mary Lee Group Coalbeds, Black Warrior Coal Basin, Alabama. BuMines RI 8189, 1976, 49 pp.

147. Perkins, J. H., and J. Cervik. Sorption Investigations of Methane on Coal. BuMines TPR 14, 1969, 6 pp.

148. Popp, J. T., and W. W. Carmen. Mining Problems Related to Geology in the Beckley Coalbed, Raleigh County, West Virginia. Pres. at 1976 Ann. Meeting, Geol. Soc. of America, Denver, Colo., Nov. 8–11, 1976, abs. with Programs, v. 8, No. 6, September 1976, p. 1052.

149. Popp, J. T., and C. M. McCulloch. Geological Factors Affecting Methane in the Beckley Coalbed. BuMines RI 8137, 1976, 35 pp.

150. ———. The Methane Content of the Beckley Coalbed and Its Relationship to Geology. Pres. at Joint Northeastern-Southeastern Section Ann. Meeting, Geol. Soc. of America, Arlington, Va., Mar. 25–27, 1976, abs. with Programs, v. 8, No. 2, February 1976, pp. 248–249.

151. Price, H. S., and A. A. Abdalla (Intercomp). A Mathematical Model Simulating Flow of Methane and Water in Coal. BuMines OFR 10–72, 1972, 39 pp. *NTIS, PB 209 273.*

152. Price, H. S., R. G. McCulloch, J. E. Edwards, and F. N. Kissell. A Computer Model Study of Methane Migration in Coalbeds. CIM Bull., September 1973, 10 pp.; Min. and Met. Bull., September 1973, pp. 103–112.

153. Pritchard, F. W. Predrainage of Coal Seams by Hydrofracture. Colliery Guardian, v. 224, September 1956, pp. 461–462.

154. Rollins, Ronald R., George B. Clark, and Calvin J. Kayna (University of Missouri-Rolla). Investigation of Shaped Explosive Charges for Increasing the Permeability of Coal. BuMines OFR 14–72, 1970, 98 pp.

155. Rommel, Robert R., and L. A. Rives. Advanced Techniques for Drilling 1,000-ft. Small Diameter Horizontal Holes in a Coal Seam. V. 1. BuMines OFR 17(1)-76, 1973, 109 pp. *NTIS, PB 249 713/AS.*

156. Schlager, Paul, Hans Ludwig Jacob, and Hans Christensen. Increasing Face Output by Planned Predrainage. Gluckauf (English Transl.), v. 114, July 6, 1978, pp. 288–290.

157. Sommerton, W. H., I. M. Soylemezoglu, and R. C. Dudley (University of California-Berkeley). Effect of Stress on the Permeability of Coal. BuMines OFR 45–74, 1974, 55 pp. *NTIS, PB 235 854/AS.*

158. Spindler, G. R., and W. N. Poundstone. Experimental Work in the Degasification of the Pittsburgh Coal Seam by Horizontal and Vertical Drilling. Trans. AIME, v. 220, 1961, pp. 37–46.

159. Steidl, P. F. Foam Stimulation To Enhance Production From Degasification Wells in the Pittsburgh Coalbed. BuMines RI 8286, 1978, 10 pp.

160. ———. Geology and Methane Content of the Upper Freeport Coalbed in Fayette County, Pa. BuMines RI 8226r, 1977, 17 pp.

161. Taber, J. J., and P. F. Fulton (University of Pittsburgh). A Study of the Use of Foam To Control Methane Emission in Coal Mines. BuMines OFR 40–76, 1976, 97 pp. *NTIS, PB 250 367/AS.*

162. Taber, J. J., P. F. Fulton, M. K. Dabous, and A. A. Reznik (University of Pittsburgh). Development of Techniques and the Measurement of Relative Permeability and Capillary Pressure Relationships in Coal. BuMines OFR 22–74, 1974, 80 pp. *NTIS, PB 232 244/AS.*

163. Telcom, Inc. Advanced Techniques for Drilling 1,000-ft. Small Diameter Horizontal Holes in a Coal Seam. V. 2. Survey System Design and Fabrication. BuMines OFR 17(2)–76, 1973, 167 pp. *NTIS, PB 249 714/AS.*

164. Thimons, E. D., R. J. Bielicki, and F. N. Kissell. Using Sulfur Hexafluoride as a Gaseous Tracer To Study Ventilation Systems in Mines. BuMines 7916, 1974, 22 pp.

165. Thimons, E. D., and F. N. Kissell. Diffusion of Methane Through Coal. Fuel, v. 52, October 1973, pp. 274–280.

166. ———. An Evaluation of Emergency Inflatable Stoppings for Use in Metal Mine Fire Rescue and Recovery Operations. BuMines RI 8162, 1976, 13 pp.

167. ———. Tracer Gas as an Aid in Mine Ventilation Analysis. BuMines RI 7917, 1974, 17 pp.

168. Thimons, E. D., R. P. Vinson, and A. Tall (assigned to U.S. Department of the Interior). Window Method for Measuring Leakage. U.S. Pat. 4,055,074, Oct. 25, 1977.

169. Tongue, D. W., D. D. Schuster, R. Niedbala, and D. M. Bondurant (Energy Applications Inc.). Design and Recommended Specifications for a Safety Methane Gas Piping System. BuMines OFR 109–76, 1976, 97 pp. *NTIS, PB 259 340/AS.*

170. Tulsa, University of. Development of a Porosimeter for Coal Mines. BuMines OFR 38–72, 1972, 72 pp. *NTIS, PB 213 725.*

171. U.S. Bureau of Mines. Methane Control in Eastern U.S. Coal Mines. Proceedings of the Symposium of the Bureau of Mines/Industry Technology Transfer Seminar, Morgantown, W. Va., May 30–31, 1973. BuMines IC 8621, 1973, 96 pp.

172. Venter, J., and P. Stassen. Drainage and Utilization of Firedamp. BuMines IC 7670, 1953, 22 pp.

173. Vinson, R. P., and F. N. Kissell. A Spiral Sequential Sampler for Air and Liquids. Preliminary Results. BuMines RI 8153, 1976, 8 pp.
174. ———. Three Coal Mine Ventilation Studies Using Sulfur Hexafluoride Tracer Gas. BuMines RI 8142, 1976, 19 pp.
175. Vinson, R. P., E. D. Thimons, and F. N. Kissell. Brattice Window Method for Measuring Leakage Through Mine Stoppings. BuMines RI 8240, 1977, 17 pp.
176. ———. Methane Accumulations in Coal Mine Roof Cavities. BuMines RI 8267, 1978, 15 pp.
177. Wallhagen, R. E. (Foster Miller Associates). Development of Optimized Diffuser and Spray Fan Systems for Coal Mine Face Ventilation. BuMines OFR 14–78, 1977, 256 pp. *NTIS, PB 277 987.*
178. Williamson, T. N. (Jacobs Associates). Evaluation of Horizontal Drilling Techniques in Coal Beds. BuMines OFR 34–72, 1970, 131 pp. *NTIS, PB 212 746.*
179. Zabetakis, M. G., M. Deul, and M. L. Skow. Methane Control in United States Coal Mines—1972. BuMines IC 8600, 1973, 22 pp.
180. Zabetakis, M. G., T. D. Moore, Jr., A. E. Nagel, and J. E. Carpetta. Methane Emission in Coal Mines: Effects of Oil and Gas Wells. BuMines RI 7658, 1972, 9 pp.

Abbreviations

MMcfd	Million cubic feet per day
Mcfd	Thousand cubic feet per day
pct	Percent
vol-pct	Volume-percent
Bcf	Billion cubic feet
cfd	Cubic feet per day
cfm	Cubic feet per minute
LNG	Liquefied natural gas
Btu	British thermal units

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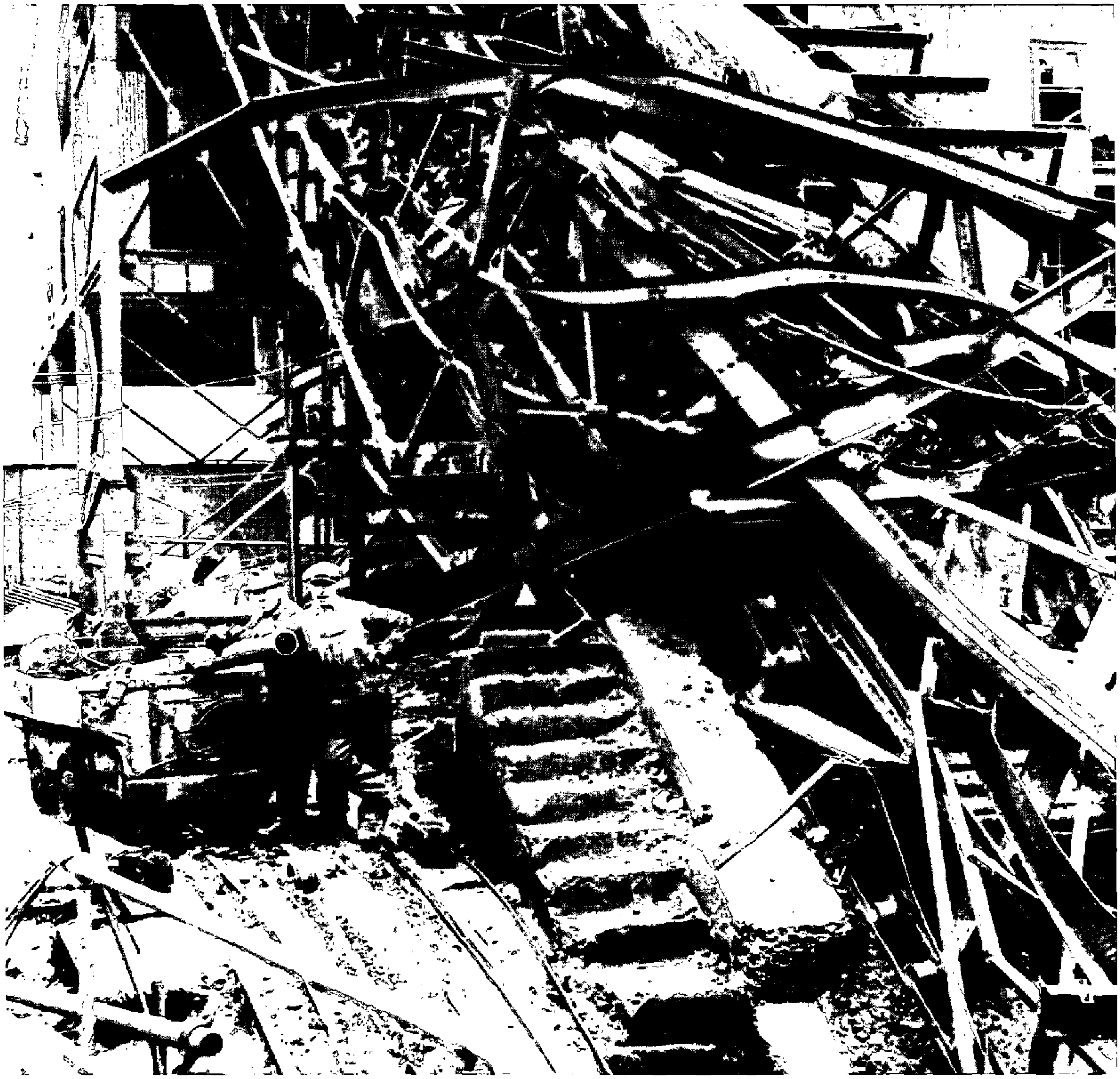

The force of an underground explosion wrecked the tipple at the Kimlock Mine, Parnassas, Pa., in 1929. (Photo from Bureau of Mines files.)