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Methane drainage in longwall coal mining

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SYNOPSIS

This paper explores the behaviour of methane in the goaf during longwall mining, together with some methods for the control of methane emissions into the goaf, the working face, and the ventilation system. Experimental work done at Twistdraai Colliery, Sasol Coal, is referred to, as well as the gas-drainage system being practised at West Cliff Colliery in New South Wales, Australia. Gas drainage is discussed briefly, and certain suggestions are made in regard to coal mining in South Africa.

SAMEVATTING

Hierdie referaat ondersoek die gedrag van metaan in die dakpuingebied gedurende strookmynbou, tesame met 'n paar metodes om die afgee van metaan in die dakpuingebied, die werkfront en die ventilasiestelsel in te beheer. Daar word verwys na die eksperimentele werk wat by die Twistdraai-steenkoolmyn, Sasol Steenkool, asook die dreineerstelsel wat by die West Cliff Colliery, in Nieu-Suid-Wallis, Australië toegepas word. Gasdreinering word kortliks bespreek en daar word sekere voorstelle in verband met steenkoolmynbou in Suid-Afrika gemaak.

Introduction

Total-extraction methods for the mining of coal, which are necessary if South Africa's coal resources are to be utilized in an effective and responsible manner, are becoming more common. However, these extraction methods give rise to new problems, including those involving strata control, surface subsidence, water inflows, and methane control.

The behaviour of methane in the goaf during total-extraction methods is still relatively unknown, and is a cause for concern in that several incidents and a few serious accidents have already occurred in South Africa. Methane drainage from coal mines forms the subject of this paper, reference being made to practices at Twistdraai Colliery, Sasol Coal, and at West Cliff Colliery in Australia.

Methane in Coal

There are two forms of methane in coal: free gas within the microfissures in the coal, and adsorbed gas at the interface of the solid material in the microfissures and micropores. Two types of methane fluxes are taken into account in describing the flow process:

(a) the flow in the channels formed by the interconnected fissures, and
(b) the flow 'feeding' the fissures by desorbing gas.

The latter supplies the former.

The flow of methane is a function of several parameters.

(i) Permeability of the strata increases the flow of methane. Permeability is a function of stress. The natural stresses are modified around a mining excavation, particularly around a drainage borehole. Fractures in the strata, as caused by an excavation, increase the permeability.
(ii) Permeability also varies with the shrinkage of coal. As a coal seam loses gas and the methane molecules leave the surface of the coal particles, the molecules and the solid matter are reduced, leading to a reduction in particle size and a resulting increase in permeability.
(iii) The diffusion coefficient of the methane in the coal varies with pressure (or gas content), increasing as the coal loses gas.

There is usually a delay between the drop in gas pressure and the drop in average gas content of the coal owing to the fact that the free gas within the coal microfissures is more easily drained than the adsorbed gas in the micropores.

During the total extraction of a coal seam, the goaf area behind the advancing face becomes an area where large quantities of methane are trapped. This phenomenon is caused by the following.

(1) When the coal seam is placed under stress during the development of the panel and subsequent longwalling, fractures develop in the seam and there is a release of pressure in the coal strata in the vicinity of the exposed face. These factors increase the permeability of the coal, which permits the flow of methane into the workings.
(2) As the longwall face advances, the void behind the shields increases, not only in length but also in height. This is due to cracks that develop as a result of stress in the roof and floor, followed by falls of roof. These fractures radiate from the caving zone and intercept methane-bearing rock strata and coal beds in the roof and floor. This process increases the permeability of the underlying and overlying strata, which promotes the flow of methane into the goaf, especially when there is another coal seam above or below the mining horizon.

Formation and Shape of the Goaf

Caving of the roof strata behind the shields of a longwall face usually occurs in a series of falls (Fig. 1).

Tests at Twistdraai Colliery, Sasol Coal, on the shape and mechanism of goafing in a longwall panel indicated that caving of the roof strata depends on the geological structure of the overlying strata. Falls occur suddenly and in clearly defined, successive steps, each fall being of a homogeneous lithological unit and occurring in large blocks (Fig. 2). This caving pattern is typical of the Highveld Coalfield, where the coal seam is covered by competent overlying strata.

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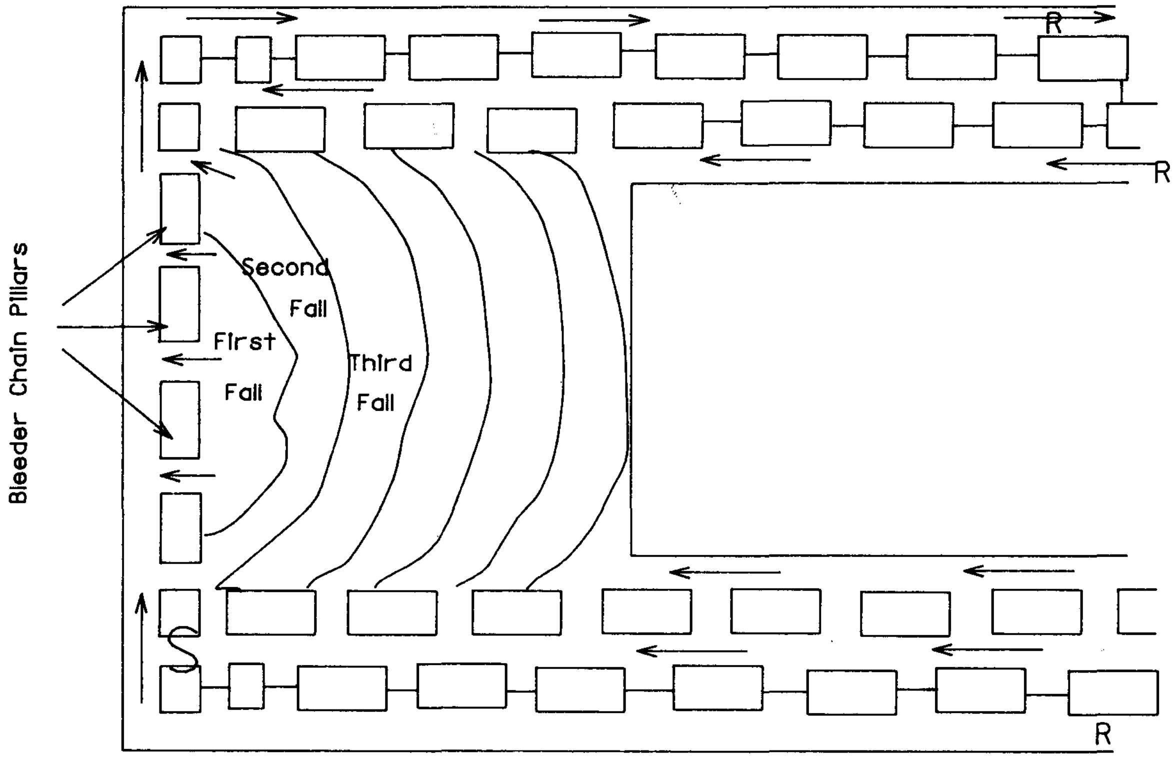

Fig. 1—Initial caving sequence in a longwall panel

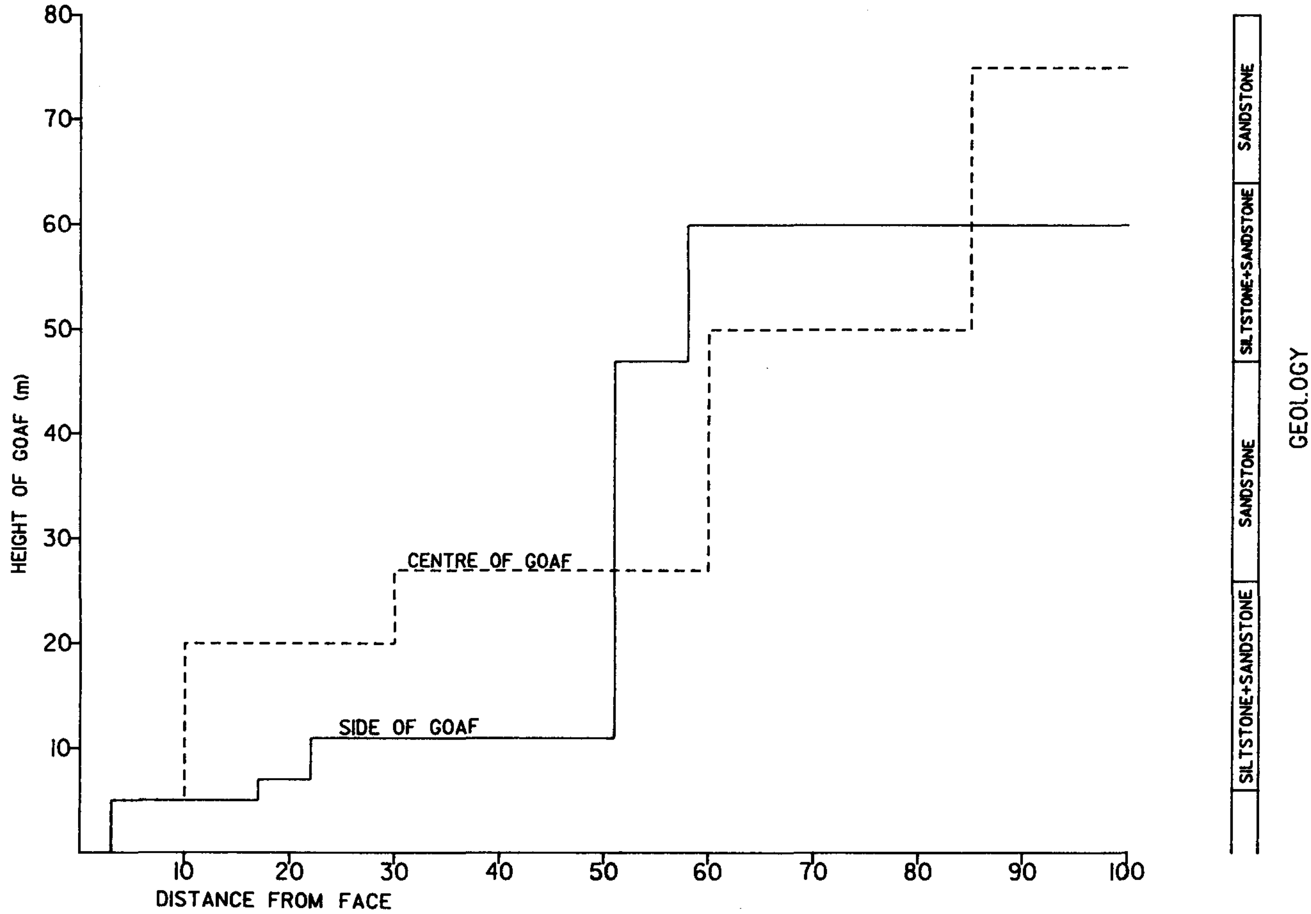

Fig. 2—Caving profile behind a longwall face

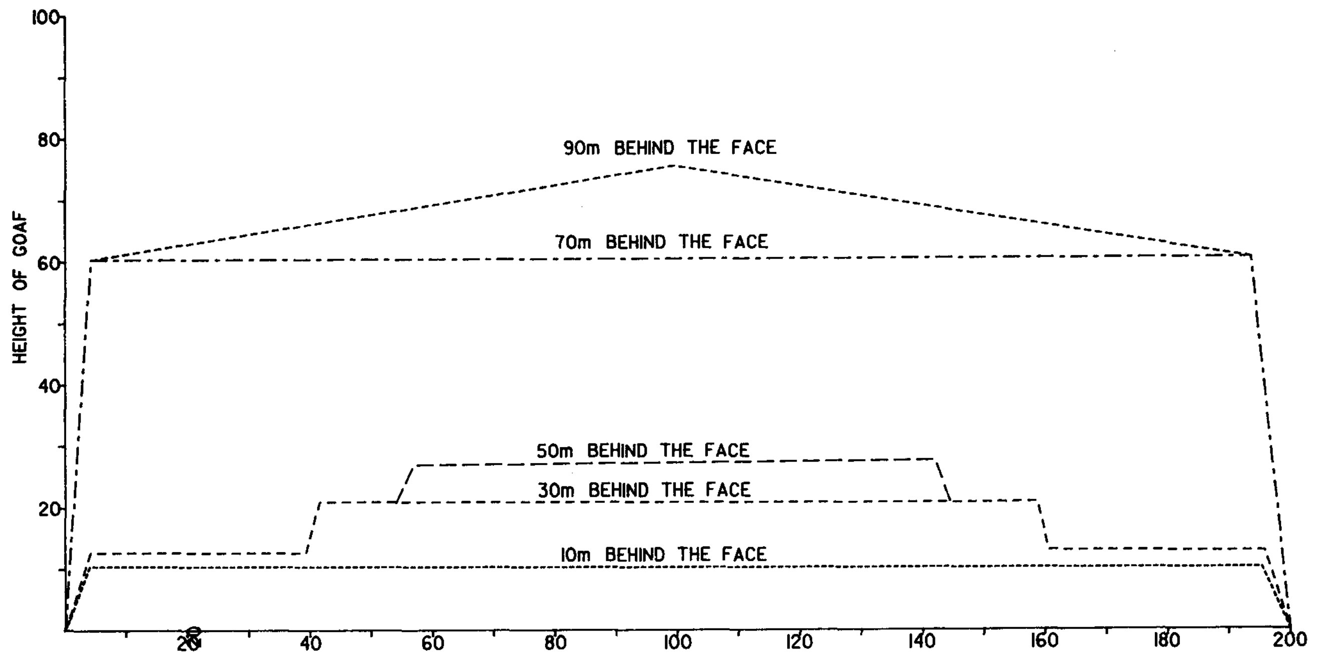

Fig. 3—Shape of goaf (looking in opposite direction to face advance)

The goaf develops relatively far behind the face (50 to 80 m) to its maximum height. The angle of repose of the broken rock is approximately 45 degrees measured behind the moving face, and approximately 15 degrees on the static side. The maximum height of the goaf is about 75 m, which means that there is a bulk factor of approximately 1,05 in the goaf (Fig. 3). (The comparable bulk factor in the Vaal Triangle coalfield is 1,4, which, again, illustrates the competent roof strata at Twistdraai.)

Hazards during Mining

Methane emissions during mining are affected by the methane content of the coal seam and of the adjacent strata, which may include coal seams, and the rate of mining and hence the exposure of fresh coal. The goaf area immediately behind a longwall face becomes a reservoir for methane as the permeability of the overlying and underlying strata increases, as explained earlier.

When the bulk factor is low, as in the competent strata at Twistdraai Colliery, there is normally a clearance between the broken rock and the roof in the goaf. This space is an ideal trap for the methane that is released from the coal and adjacent strata (Fig. 4). When there is a roof fall, the concussion can easily displace the methane in the direction of the face, which can result in the formation of an explosive mixture close to the face. (A decrease in barometric pressure has a similar effect.)

This explosive mixture can become ignited as the result of a spark produced by the impact or friction of sandstone on steel (for example, a roofbolt); by the impact or friction of sandstone on sandstone during a roof fall in the goaf; or by the impact or friction of steel on steel (for example, when a roofbolt breaks in the goaf).

Experience at Twistdraai Colliery has shown that the impact or friction of sandstone on sandstone during a roof fall in the goaf is the most common cause of methane ignitions.

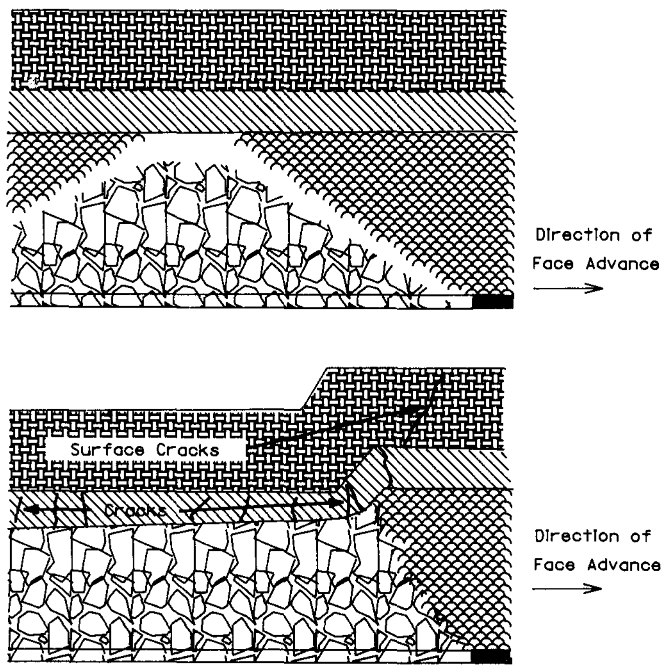

Fig. 4—Subsidence of overlying strata

Control of Methane during Mining

In principle, methane explosions in the goaf can be prevented by either of the following methods:

(a) the use of fresh air to reduce the concentration of methane below the lower explosive limit of the gas (below 5 per cent CH_4); or
(b) allowing the concentration of methane to build up to a level above the upper explosive limit of the gas (above 15 per cent CH_4).

Method (a) has two important disadvantages.

(i) If the concentration of methane is not reduced to zero, there is still the possibility of a methane ignition that could injure people.
(ii) As it is difficult during total extraction to determine whether all the methane has been removed from a goaf, an explosive mixture could be present without anyone knowing it.

The disadvantages of method (b) are as follows:

(i) If a high concentration, but non-explosive mixture, of methane is present in the goaf area, there would be a transition zone somewhere between the area of high concentration and the fresh air on the face, and this would have an explosive mixture of gas. The position of this transition zone could move with changes in barometric pressure or as a result of concussions produced by roof falls.
(ii) During the initial build-up of methane in the goaf of a newly established panel, there could be a period during which the gas mixture would be explosive until sufficient methane had built up.

To date, most efforts to reduce methane hazards in workings have followed method (a) which is as follows: increased ventilation in the workings, the establishment of bleeder roads from the goaf, surface borehole drainage, cross-measure borehole drainage, drainage chambers in the goaf, and drainage galleries driven in the roof or floor of the mined seam.

Increased Ventilation

Increasing the ventilation on the working face is the easiest way of reducing methane hazards on the face. Unfortunately, this does not remove the risk of methane ignitions in the goaf. However, it can move the zone containing an explosive mixture of fresh air and methane further back towards the goaf. This could reduce injuries if there were an ignition.

At Twistdraai Colliery it was found that the greatest risk of a methane ignition was in the goaf behind the shields on the tailgate side. A hydraulically driven venturi blower is being installed directly behind the tailgate shields to create the necessary turbulence in the goaf at the tailgate (Fig. 5). This method has successfully reduced methane ignitions.

Bleeder Roads from the Goaf

The establishment of bleeder roads from the goaf to a main return airway creates a negative pressure over the goaf. It promotes a flow of mixed air and methane from the goaf to the return airway. This reduces the concentration of methane in the goaf and moves the zone of explosive mixture deeper into the goaf away from the face. The risks of methane ignition near the face is reduced, but it is probable that there will still be an explosive zone deeper in the goaf area (Fig. 6).

It is essential that the bleeder roads should be unobstructed from roof falls and that there should be a pressure differential between the bleeder road and the goaf.

Drainage by Surface Boreholes

The purpose of surface boreholes, drilled to intersect the panel, is to intercept the fractures in the roof strata above the goaf and capture the methane released through these fractures. Furthermore, the hole captures the methane present in the cavity between the broken rock and the roof in the goaf (Fig. 7).

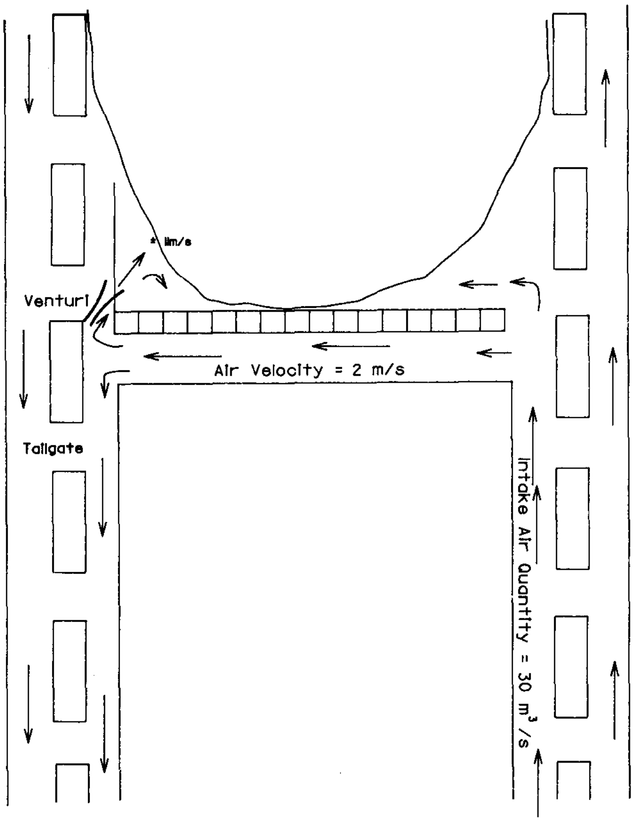

Fig. 5—Ventilation of the tailgate by venturi blower

The advantage of surface drainage holes is that access for the drilling of holes into the goaf is independent of the underground roadways. This is a distinct advantage over underground boreholes, especially in the case of a retreating longwall, which is the most common type of longwall in South Africa.

An experiment with surface drainage boreholes was carried out at Twistdraai Colliery. Two vertical boreholes with a diameter of 203 mm were drilled into the longwall panel of Section 70. One hole was drilled 10 m from the tailgate side of the panel, and the other was drilled in the middle of the panel measured across its width (Fig. 8). The two holes were subsequently undermined.

Air flowed down the hole at a rate of 8 m/s when it was intersected by the moving face. When the borehole was 2 m behind the face, air started to flow upwards at 3 m/s. The upcast air contained as much as 80 per cent methane. When an 11 kW exhaust fan was fitted to the borehole, a maximum velocity of 24 m/s or 0,6 m^3/s was obtained in the hole. More methane was drained from the hole drilled in the middle of the panel than from the hole drilled close to the tailgate.

A curve of roof subsidence in the goaf behind the shields is shown in Fig. 9. The first large roof fall usually occurs between 20 and 60 m from the face, and is followed by smaller falls. Measurements of the gas concentration in the goaf just behind the shields showed the concentration of CH_4 to decrease when the borehole was intersected by the face until the face was approximately

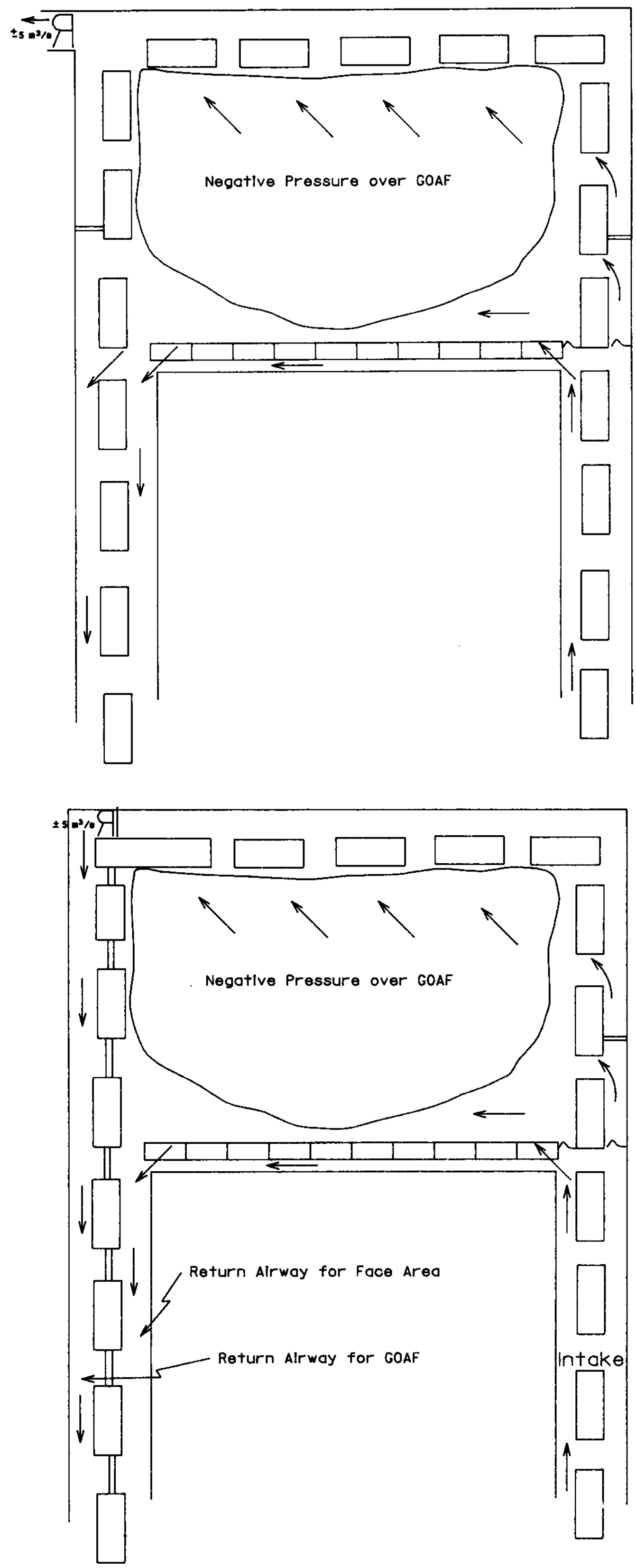

Fig. 6—Bleeder road for longwall panel

56 m ahead of the borehole. Then, the gas concentration remained constant up to approximately 76 m ahead of the borehole. As the face moved further ahead, the concentration of CH_4 increased (Fig. 10).

A comparison of the graphs of CH_4 concentration behind the face with the curve of roof falls behind the face shows that the CH_4 concentrations decreased, as a result of the methane exhausted through the surface borehole, until the first major roof fall between the face and the borehole. The concentration of CH_4 then started to increase. As the first major roof fall occurred approximately 80 m behind the face when a panel was started up and thereafter at intervals of approximately 50 m, it was decided to space surface boreholes accordingly along the length of the panel in the middle of the face position.

Surface drainage boreholes have the advantage that, by draining methane from the goaf, the zone where fresh ventilation air along the face mixes with methane in the goaf to form an explosive mixture is displaced further behind the face. This reduces the risk of an ignition close to the face, especially during a drop in barometric pressure.

A surface drainage hole has the disadvantage that it requires an exhaust fan, which can be fitted to it on surface. Immediately after the face intersects the hole, air will flow down the hole as a result of a difference in barometric pressures. Such a situation could actually increase the flow of methane into the face, since the surface borehole could intersect or disturb fractures in roof strata filled with methane. Tests at Twistdraai Colliery showed that an 11 kW fan fitted to a surface drainage borehole of 200 mm diameter is unable to increase to an acceptable level the gradient of the methane drainage curve for the first 50 m behind the face.

Surface drainage holes would be more successful if holes of larger diameter were drilled and were fitted with suitable exhaust fans. This method is obviously more expensive.

Cross-measure Drainage Boreholes

Cross-measure borehole drainage involves the drilling of boreholes into the panel from the underground gateways surrounding the panel. The boreholes can be drilled horizontally into the coal seam, or at an angle into the roof strata above the panel or the floor strata below the panel. These boreholes are connected to an underground pipeline, which conveys the methane to the surface by means of a vacuum pump.

Coal in virgin strata is stressed and generally has very low permeability. Once mining begins, the pressure in the strata is released and the permeability increases, permitting the flow of large amounts of methane into the workings. In this situation, which is found in European mines, drainage is carried out at the goaf in the destressed zone. This practice is referred to as *post-drainage*.

On the other hand, in some deposits such as those in America and Australia, the coal is naturally more permeable. Furthermore, prolonged release of large amounts of methane may occur from distant zones during the driving of access roadways. In these cases, preliminary methane drainage has to be carried out during the road development in order to ensure good conditions for subsequent workings. This practice is referred to as *pre-drainage*.

Drainage efficiency is defined as the 'rate of drainage', which is the ratio of the amount of methane drained to the total amount of methane released by the working. The

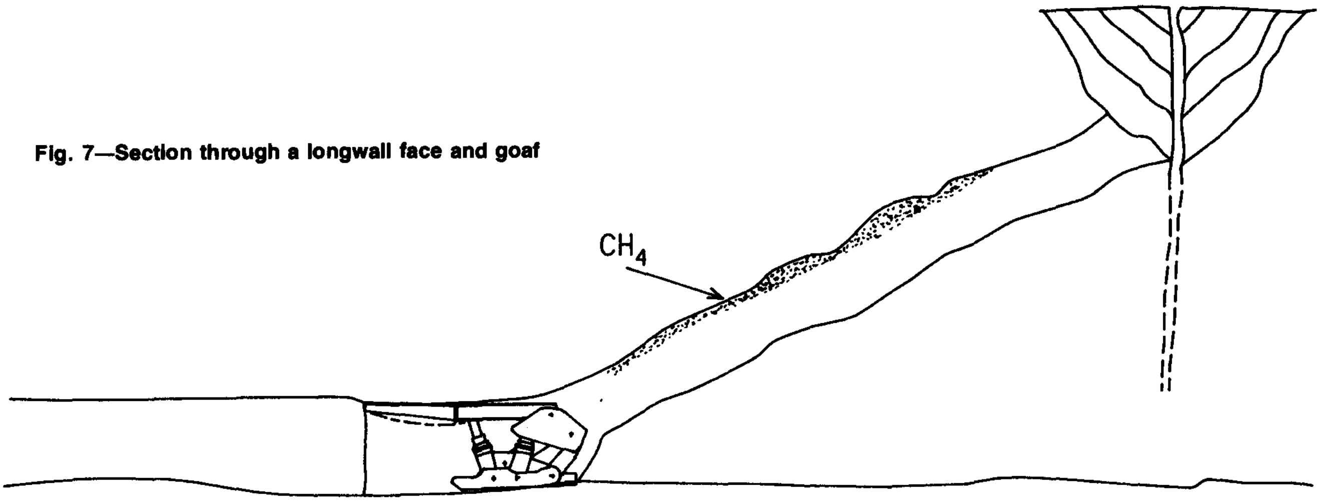

Fig. 7—Section through a longwall face and goaf

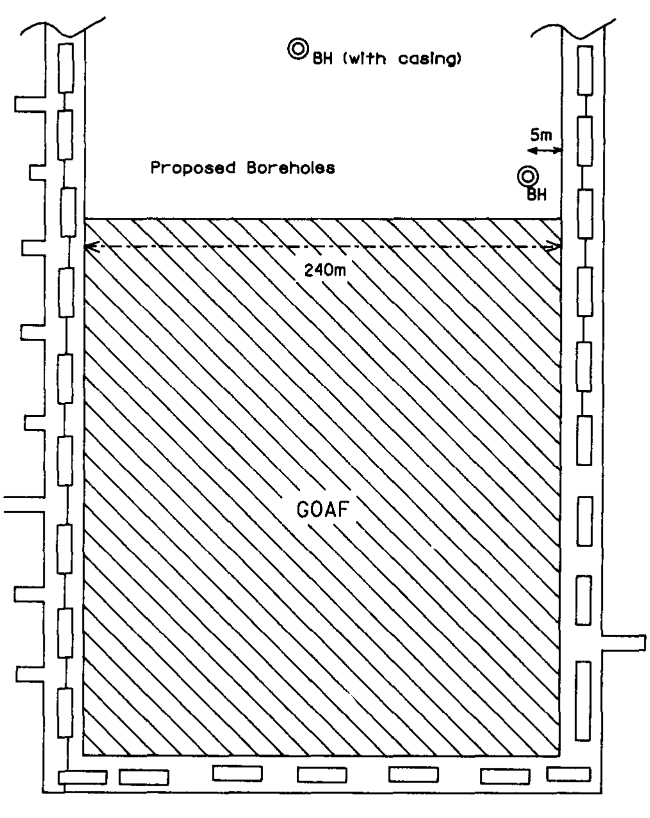

Fig. 8—Example of a typical longwall with proposed boreholes for gas drainage

drainage rate may reach 100 per cent for methane coming from seams lying in the roof of a mined seam. However, the drainage rate rarely exceeds 50 per cent for methane coming from underlying seams. In the best cases, the overall rate of drainage obtained for a face is between 60 and 70 per cent.

Experience in certain coalfields has shown that methane flow usually occurs from a cross-measure borehole after the undermining of each hole and the application of a partial vacuum by a vacuum pump (Fig. 11).

Experiments conducted by the US Bureau of Mines have shown that approximately 75 per cent of the methane in the goaf comes from newly fractured roof strata immediately behind the face (Fig. 12).

Cross-measure borehole systems are affected by a number of design parameters, including the location of methane-bearing strata in the roof, borehole length and angle with respect to the panel, borehole diameter, borehole spacing, pipeline diameter, and vacuum-pump capacity.

The application of a partial vacuum to a cross-measure borehole creates a low-pressure zone around the borehole in the goaf. If these boreholes are spaced properly, the low-pressure zones overlap and create a continuous low-pressure zone within the goaf. If the boreholes are spaced too far apart, the low-pressure zones around the holes do not overlap and methane from higher levels in the goaf migrates into the workings between the holes.

Borehole spacing depends on the permeability of the goaf and the operating characteristics of the surface pump. As little is known about goaf permeability, borehole spacing is best determined by interference tests conducted underground. During such tests, all the boreholes are closed and the gas pressure in the goaf is allowed to stabilize. The boreholes are then opened to flow except for one borehole (test hole), which is monitored for changes in gas pressure. No change in pressure means that the adjacent boreholes are too far apart. A slight change in pressure shows the spacing to be adequate.

The angle, direction, and length of boreholes are determined primarily by the distance of gas-producing strata from the worked seam, the competence of the roof strata that determine the shape of the goaf, and the distance of the drilling position from the face.

The angle and length of the hole must be adapted to enable the hole to reach the front of the distressed zone, moving behind the working face. When the angle drilled is too shallow, bed separation in the immediate roof strata could dislocate the hole before proper goafing has taken place. If the angle of the hole is too steep, it will penetrate only the periphery of the distressed zone and miss the main part where the gas emission is greater.

When retreat mining is undertaken, boreholes can be drilled from a gate road, in a position ahead of the face, at an angle in the direction of the goaf. Alternatively, the holes can be drilled from the outer gate road either parallel to the face or at an angle in a direction ahead of the face. (This pattern is also used for the advancing of longwall systems.)

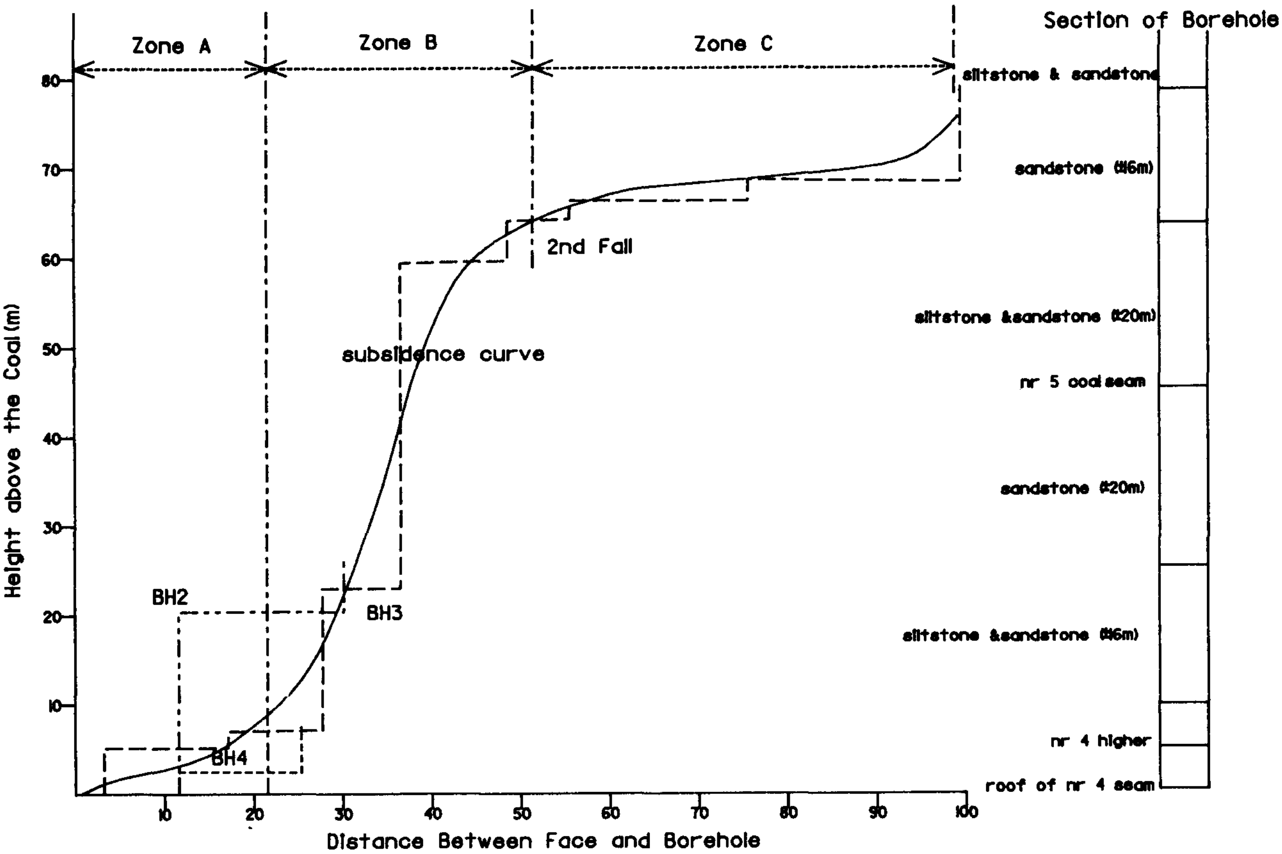

Fig. 9—Curve of roof subsidence behind advancing face

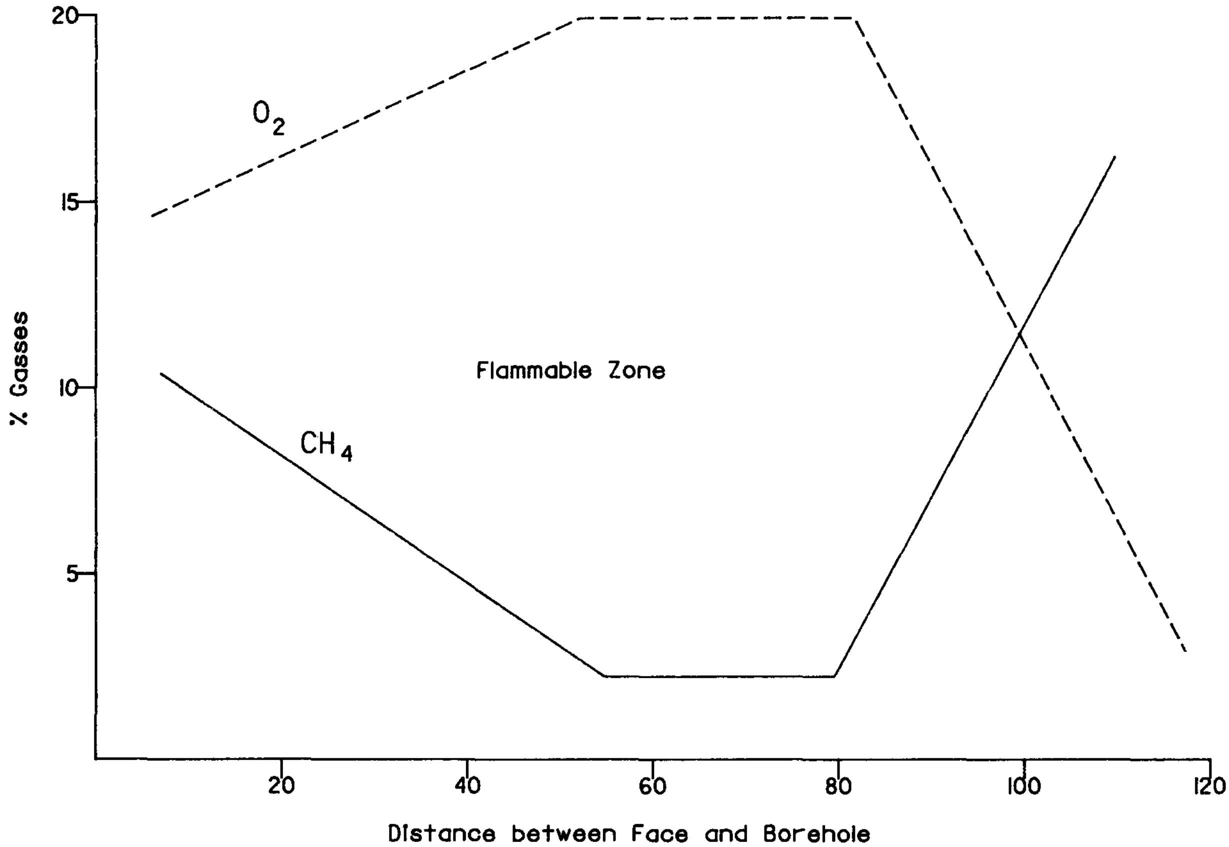

Fig. 10—Gas concentrations in goaf

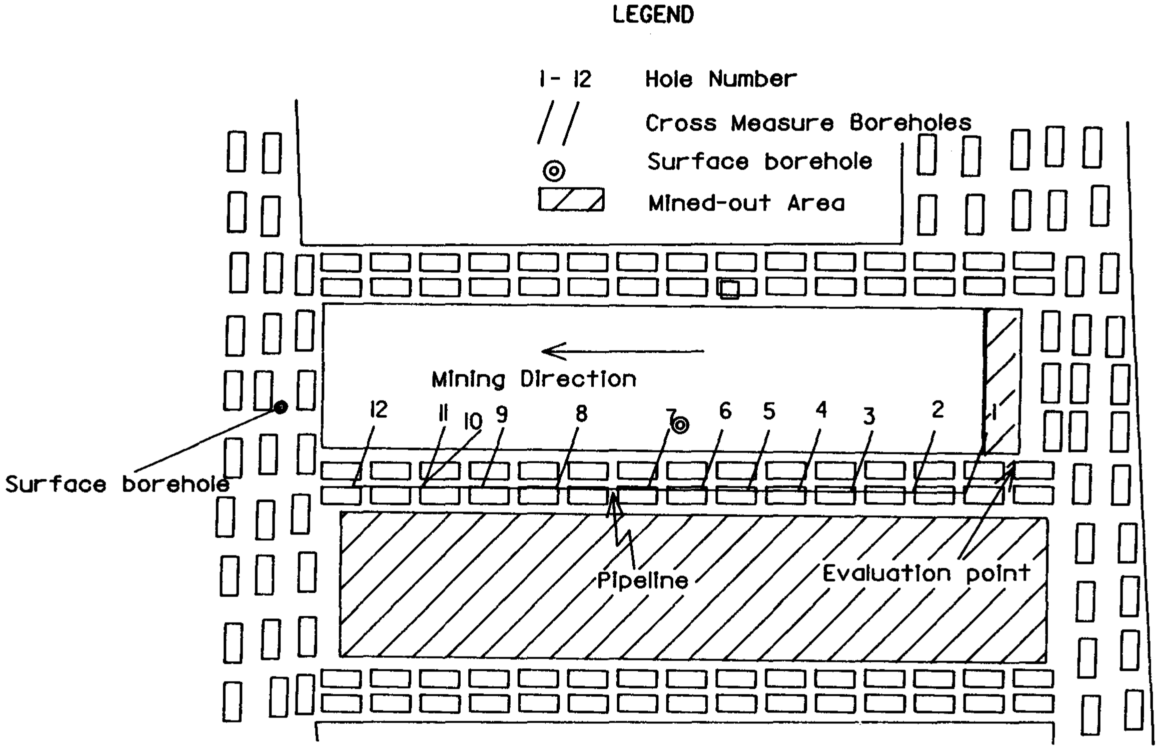

Fig. 11—The placing of cross-measure boreholes

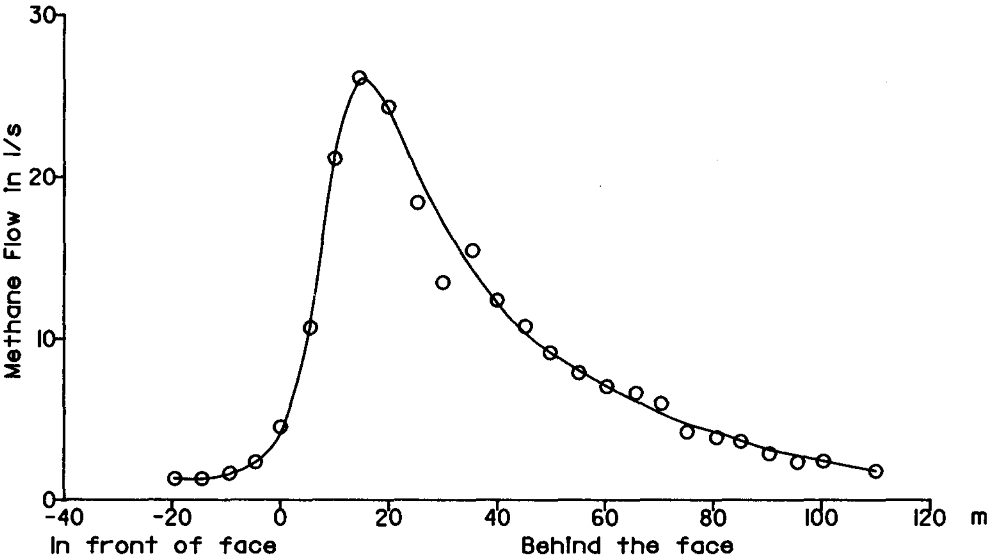

Fig. 12—Gas flow from roofholes plotted against face position (US Bureau of Mines)

Floor holes are usually drilled when there are methane-bearing strata below the worked seam. The floor holes are usually fewer in number because mining causes less disturbance in the floor strata, resulting in a lower permeability in those strata. Floor holes tend to be drilled at shallower angles to cover the largest possible area of disturbed strata below the working and to simplify the dewatering of holes.

Cross-measure Borehole Drainage Practice in Australia

In the West Cliff Colliery in New South Wales, the bully seam, which has an average width of 2,5 m, is mined at a depth of approximately 480 m. Measurements from the borehole cores in the seam have indicated that the gas content of the seam is approximately 13 m^3 per ton *in situ*. The composition of the seam gas varies over the lease from 98 per cent CH_4 and traces of CO_2 up to 30 per cent CH_4 and 70 per cent CO_2. These levels of gas are high by world standards, and outbursts in the workings due to strata stress and seam-gas pressures are not uncommon.

A system of cross-measure borehole drainage was implemented for the following reasons.

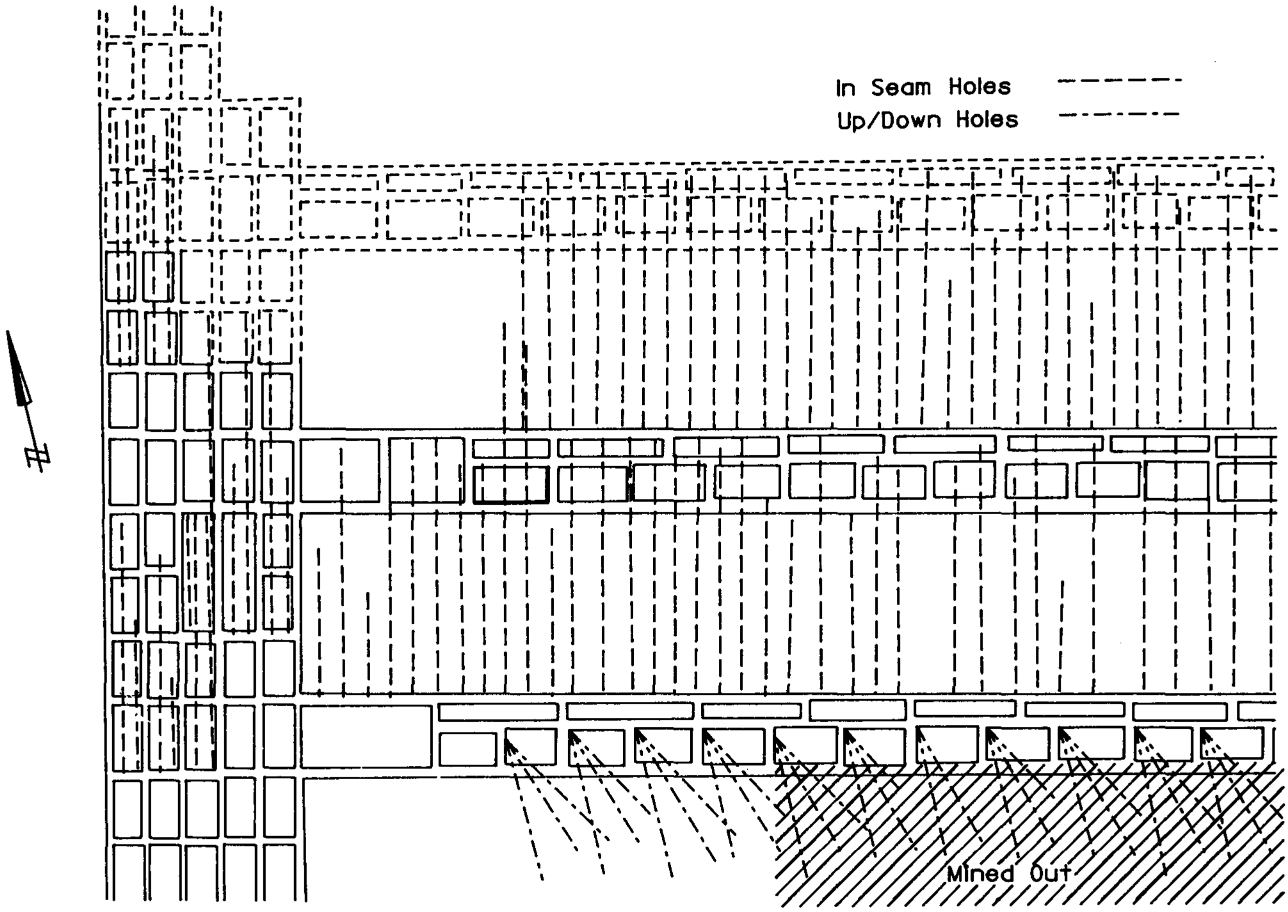

Fig. 13—Layout of gas-drainage holes at West Cliff Colliery

(a) The system ensures that the gas given off from the virgin coal is controlled so that the concentrations of gas in the airways and at the working faces are kept below the statutory limits, and so that the coal-production rates are not governed by the gas-emission rates. This is done by degasification of the virgin coal prior to mining, i.e. pre-drainage.
(b) The system ensures that the gas given off from the adjacent strata, mainly the lower coal seams, after an area of coal has been extracted, is controlled so that the gas percentages in the airways are kept below the statutory limits. This is achieved by post-drainage.
(c) The system assists in the alleviation of outbursts of coal and gas.

Pre-drainage

In pre-drainage practice, boreholes of 80 mm diameter are drilled horizontally into virgin areas of coal in advance of the planned development drivages (Fig. 13). These holes are up to 200 m in length and 18 m apart, and are connected to the gas-drainage pipelines conveying the gas to the surface.

This system has been particularly successful in the total drainage of gas from 150 m by 1500 m longwall blocks, allowing the uninterrupted safe extraction of coal. In addition, the violence of the gas outbursts during the development of the gate roads has been reduced dramatically.

Post-drainage

The post-drainage system is implemented mainly to minimize the concentration of gas in return airways. There are two methods of achieving this.

(a) Worked-out areas are sealed off with drainage pipes that penetrate the seals, the build-up of gas in the goaf being drained via the gas-drainage pipelines to the surface.
(b) To minimize the quantity of gas reaching the goaf and the working place during the extraction of coal, a series of downward inclined boreholes is drilled to intercept the lower seams (Fig. 14). The released gas is conveyed via the gas-drainage pipelines to the surface. These holes are 55 mm in diameter and have a length of 141 m. Upward holes are also drilled, to capture the gas missed by the downward holes. This gas rises naturally into the upper cavity of the goaf.

Drainage Practice

The drainage holes at West Cliff are drilled by four Atlas Copco Diamec 250 drill rigs, which are mounted on caterpillar tracks and driven by a 25 kW air motor. These machines drill holes independent of diesel or electrical power. To prevent possible dilution of the drained gas, each borehole is sealed to the atmosphere by the grouting of a 9 m standpipe into the mouth of the hole (Fig. 15).

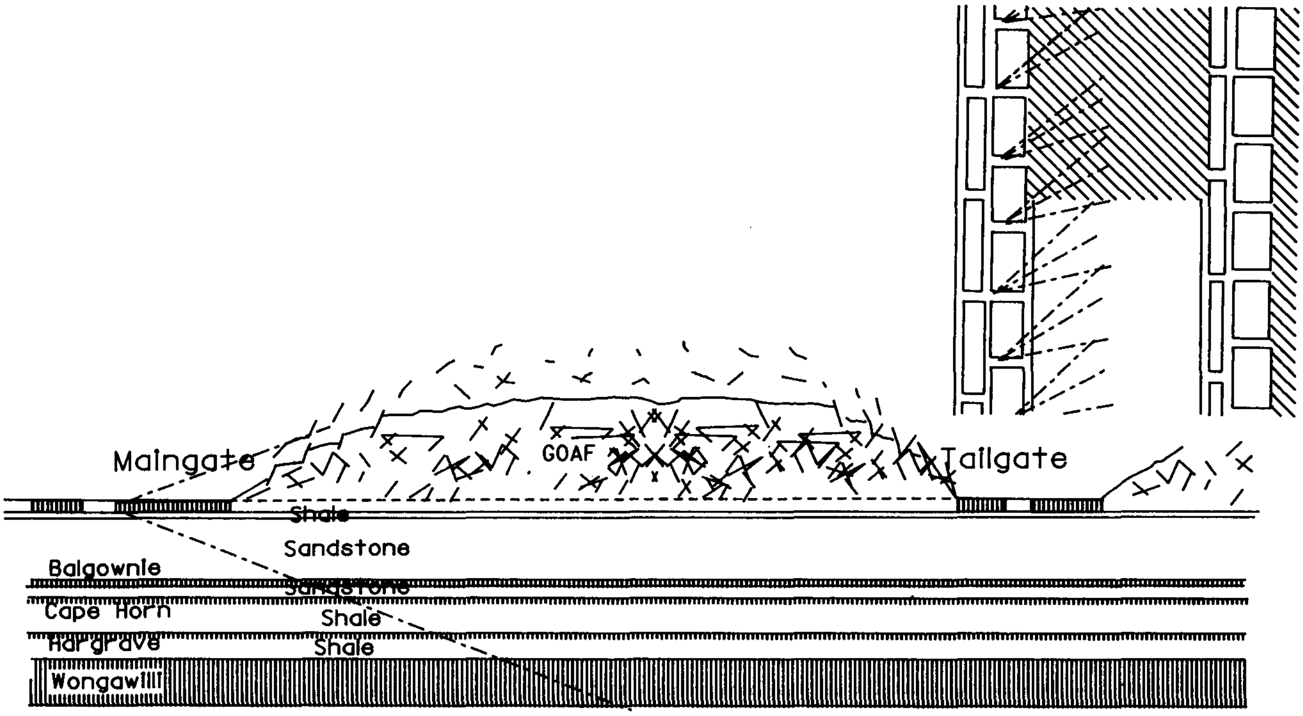

Fig. 14—Stratigraphic section of longwall at West Cliff Colliery, showing below-seam gas-drainage holes

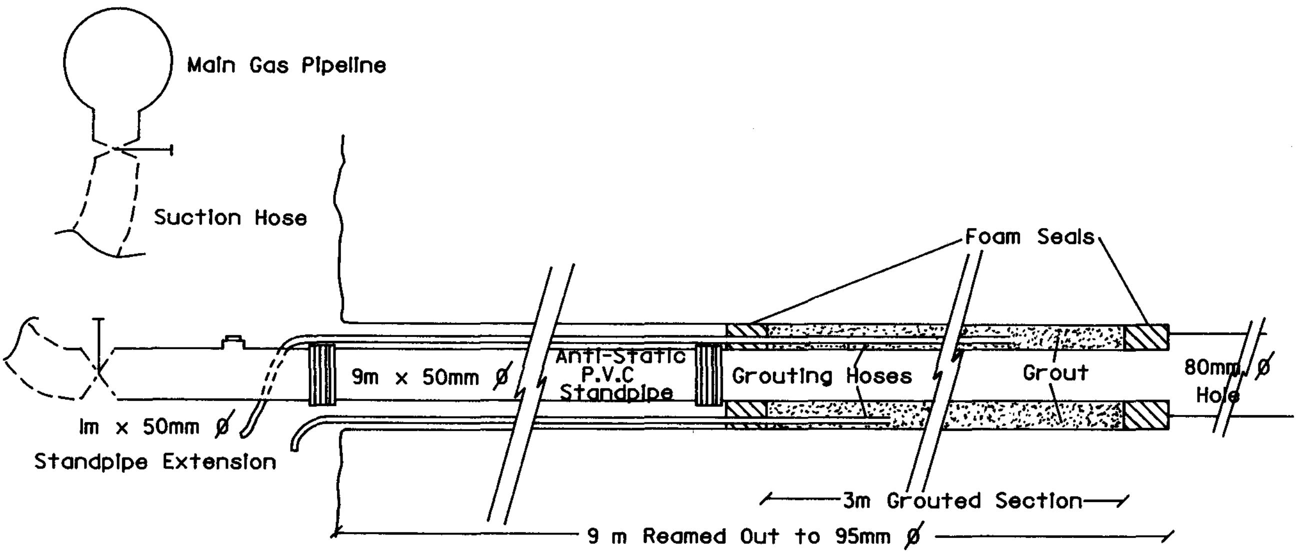

Fig. 15—Standpipe sealing arrangement for gas-drainage boreholes at West Cliff Colliery

Gas is conveyed through a network of pipes, starting with pipes of 100 mm in diameter up to 450 mm in diameter, and going to a steel-cased vertical borehole of 485 mm diameter, which emerges at the surface at the vacuum pumps. These pumps generate a negative pressure of 25 to 45 kPa, which, in turn, exerts a suction on each drainage hole of 10 to 30 kPa. Water traps are installed in the drainage pipelines to release water without allowing air in.

The gas flow in the drainage pipelines is monitored via an oriface plate for methane concentration and vacuum levels. This information is available to the computerized mine-monitoring system. A minimum gas purity of 30 per cent CH_4 is maintained at the standpipe. When lower concentrations are encountered, suction is reduced.

Gas drainage is an integral part of mining operations at West Cliff, and is manned by permanent operating crews. The gas from the gas-extraction station on the surface is used to drive a gas turbine, which drives an electric generator. The mine gas drained per month ($4,11 \times 10^6$ m^3) contains $2,62 \times 10^6$ CH_4. This generates 10 MW of electricity. At present, it is cheaper for the mine to generate electricity from drained methane than to buy it.

Methane Drainage in South Africa

Methane drainage in the South African coal-mining industry is limited at present to increased ventilation and the establishment of bleeder roads from the goaf. Only one instance is known of methane drainage by surface boreholes.

As the quantity of methane adsorbed and the permeability of the coal seams being mined are comparatively low by world standards, pre-drainage by cross-measure boreholes has a very limited application.

Surface drainage boreholes are particularly applicable where the coal seam being mined is covered by competent roof strata as in the Highveld Coalfield. This is because there is a cavity between the broken rock in the goaf and the roof strata, where methane is usually trapped as described earlier. The probability that a surface borehole will intercept this cavity is much greater than for a cross-measure borehole. The facts that the coal seams being mined at present in the country are relatively shallow and are covered by surface areas of relatively low population make surface boreholes more attractive.

The application of cross-measure post-drainage boreholes is a practice that warrants further investigation. Underground post-drainage systems have the added advantage that water can simultaneously be drained out of the goafs by use of a gas-water separator. (Fig. 16 illustrates a gas-water separator developed by the US Bureau of Mines.)

Total-extraction methods are at present resulting in increased areas of roof subsidence, with the result that water-handling problems underground in collieries are increasing, especially during periods of heavy rainfall. The utilization of post-drainage cross-measure boreholes to drain methane and water from the goafs before they enter the mine workings is a practice that justifies serious investigation.

Conclusion

Methane drainage by means of boreholes is a relatively unknown practice in South African collieries, mainly because total-extraction mining methods are not yet used extensively and have been developed only recently.

In the future, large areas of the coalfields in South Africa will consist of subsided roof strata and overburden, where the total extraction of coal seams has taken place. This will lead to an increased flow of water and methane into workings as the permeability of the roof strata is increased. Methane drainage combined with water drainage is a practice that can provide a possible solution to the problems expected.

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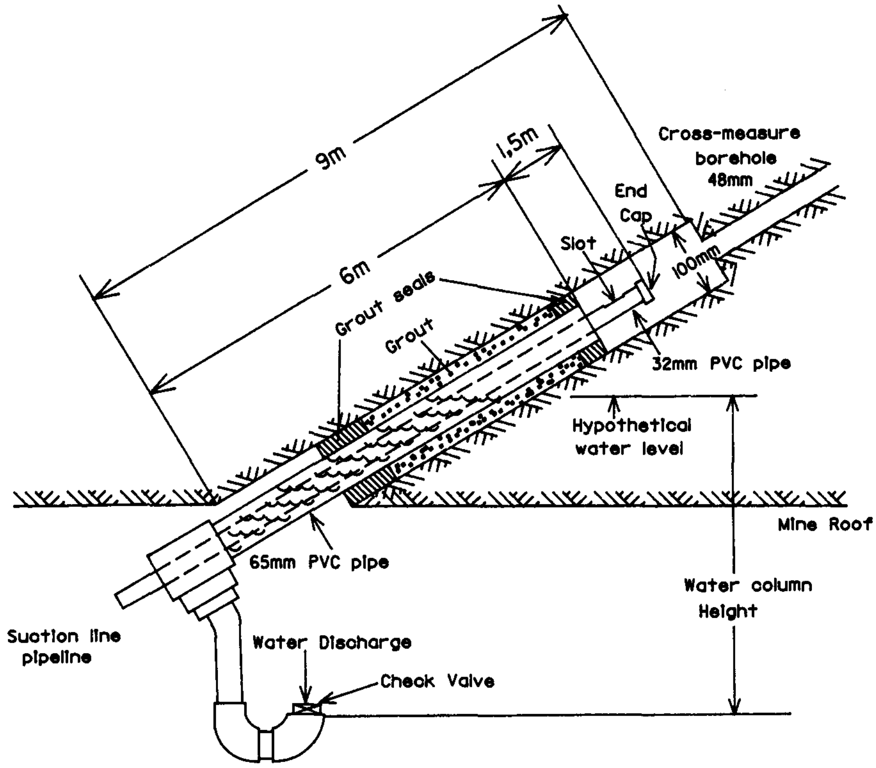

Fig. 16—Gas-water separator for cross-measure boreholes at West Cliff Colliery

Lama, Manager Mining Technology, Kembla Coal and Coke (Pty) Limited, Wollongong, New South Wales, Australia, for the enthusiastic way in which he provided me with additional information on cross-measure borehole methane drainage.

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Metalworking

International Symposia and Exhibitions Ltd announce Metalworking '90 International, which is to be held at The National Exhibition Centre, Birmingham, from 2nd to 6th April, 1990. Metalworking International, which is held every four years, was last held as part of the mammoth Metals Engineering '86 event. Running alongside Metalworking '90 International, the fifth in the series, will be two other exhibitions Subcon '90 and Metcut '90, which also accompanied the event in 1986.

Sponsored by the Metalforming Machinery Makers' Association and supported by the journal *Sheet Metal Industries*, Metalworking '90 International will provide a market-place where visitors can see displays of metal-forming and metal-shaping machinery and equipment, together with the control systems that can be applied to them. The exhibition will be of interest to purchasing directors, managers, design engineers, technologists, and other key personnel holding major purchasing and specifying influences within their organizations.

For further information, contact

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Anniversary Fellowship for Analytical Chemistry

The Council of the Analytical Division of The Royal Society of Chemistry has approved proposals for a Robert Boyle Fellowship in Analytical Chemistry to mark the 150th Anniversary in 1991 of the founding of The Chemical Society. The Fellowship will be awarded by the Trustees of the Analytical Chemistry Trust Fund. It is intended that the Fellowship be awarded to an applicant making the most prestigious proposal within the realm of analytical chemistry and of direct benefit to the advancement of analytical chemistry in the modern world.

Although the initiative for the Fellowship arises from the desire to mark the 150th Anniversary of The Chemical Society, founded in 1841, it is noted that 1991 marks the tercentenary of the death of Robert Boyle (1627–1691), whose work included the beginnings of modern chemical analysis. Therefore, the Fellowship is also dedicated to him.

It is expected that the Fellow appointed will be at work at the time of the 150th Anniversary Celebrations of The Royal Society of Chemistry, which are to be held at Imperial College, University of London, between 9th and 12th April, 1991. Within The Royal Society of Chemistry are amalgamated The Chemical Society, The Royal Institute of Chemistry, The Society for Analytical Chemistry, and The Faraday Society.

The Fellowship will be tenable at a British university, polytechnic, or research establishment having facilities to meet the approval of the Trustees. Prospective applicants should register their interest with the Secretary of the Analytical Division at the following address:

Analytical Division
Burlington House
London W1V OBN
UK.

Telephone: 01-437 8656.