Black, D J and Aziz, N I, 2008. The evolution in coal mine gas extraction – a response to economic, environmental and community pressures, in *Proceedings of the 16th Coal Congress of Turkey*, Chamber of Mining Engineers of Turkey, Zonguldak, Turkey, 26-28 May, pp 149-156

The Evolution in Coal Mine Gas Extraction – A Response to Economic, Environmental and Community Pressures

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ABSTRACT

Effective gas management is vital to the success of the longwall mines operating in the Bulli seam, located in the Southern Sydney Basin, Australia. High gas emissions are characteristic of the region with specific gas emissions typically in the order of 30-45 m^3/t. The mines that operate in this area have, since 1980, relied on the use of extensive underground to inseam (UIS) drilling to drain gas both ahead of advancing roadway development and following longwall coal extraction. With the ever increasing production capacity of modern mining machinery the UIS methods are struggling to drain sufficient gas from the coal ahead of mining to avoid gas related production delays. A further consideration for the operations in this region is the rapid rate of urban development extending to the south of Sydney and the increasing pressure to reduce greenhouse gas emissions. This paper discusses the evolution of gas drainage methods in the Southern Sydney Basin along with a range of developments that have the potential to significantly reduce both the community impact and mine greenhouse gas (GHG) emissions.

INTRODUCTION

The mines operating in the Bulli seam of the Southern Sydney Basin are classified as gassy and require significant volumes of seam gas to be drainage both prior to mine roadway development (pre-drainage) and during longwall extraction (post-drainage). The primary role of pre-drainage is to reduce the gas content of the Bulli seam to below the prescribed Threshold Limit Value (TLV) which, although variable, requires in the order of 6 m^3/t to be drained ahead of roadway development. Various models exist for estimating the volume of gas liberated during longwall extraction. Meyer (2006) provides details of Flugge modelling at the West Cliff mine (Table 1) that indicates for every tonne of Bulli seam coal extracted by the longwall a combined total volume of 45m^3 of gas would be liberated from the various sources. Therefore in the case of the West Cliff mine the gas drainage management system must be capable of effectively managing gas emissions in excess of 50 m^3/t.

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Table 1: Flugge longwall gas emission modelling of West Cliff Colliery (Meyer, 2006)

Group	Formation	Thickness	Estimated average pore pressure (kPa)	Potential Gas Emission m3/m2	Potential Gas Emission m3/t	300m Flugge Release %	300m Flugge SGE m3/t
Wianamata	Wianamatta	29					
Hawkesbury	Hawkesbury Sandstone	184					
Narrabeen	Newport Formation	13					
	Garie Member	3					
	Baldhill Claystone	28					
	Bulgo Sandstone	141	3500	48.7	12.9	65	8.4
	Stanwell Park Claystone	7					
	Scarborough Sandstone	58	4300	24.4	6.5	72	4.7
	Wombarra Shale	49					
	Coalcliff Sandstone	22	4750	10.5	2.8	95	2.6
Illawarra Coal Measures	Bulli Coal	2.7					
	Loddon Sandstone	7					
	Balgownie Coal	1	5800	14.4	3.8	89	3.4
	Lawrence Sandstone	8					
	Cape Horn Coal	1	5900	26.1	6.9	75	5.2
	UN2	8					
	Woronora Coal	7					
	Novice Sandstone	4					
	Wongawilli Coal	10	6100	164.3	43.5	45	19.6
	Kembla Sandstone	8					
	American Creek Coal	2	6300	38.5	10.2	13	1.3
	Allans Creek Formation	18					
	Darkes Forest Sandstone	9					
	Bargo Claystone	14					
	Tongarra Coal	2	6700	25.6	6.8	0	0.0
					Total potential emmisions		45.1

BACKGROUND

The use of routine drilling programs for gas drainage began in Australia in 1980 and quickly spread among the gassy mines in both New South Wales and Queensland. The early drilling rigs utilised rotary drilling systems that were able to achieve directional accuracy in the order of ±15^{o} for borehole lengths of 400- 600m (Kelly 1983, Hebblewhite *et al.*, 1982 and Hebblewhite *et al.*, 1983). The rotary units were later replaced by down-hole motor drilling systems that were capable of achieving much greater drilling distances whilst maintaining survey accuracy in the order of ±0.5^{o} azimuth and ±0.2^{o} pitch (Brunner and Schoebel - Online).

Following the last fatal outburst that occurred in Australia in 1994 a directive was issued to all Bulli seam coal mine operators, under the authority of the Coal Mines Regulation Act 1982, prescribing Threshold Limit Values (TLV), and other actions, to be implemented to manage risk and prevent future coal and gas outbursts. In order to comply with the outburst mining guidelines and meet the TLV, drilling programs became far more ordered and generally the overall drilling effort increased. It is now common for mines operating in the Bulli seam to drill well in excess of 100,000 metres annually. An example of a typical drilling program at a Bulli seam operation is shown in Figure 1.

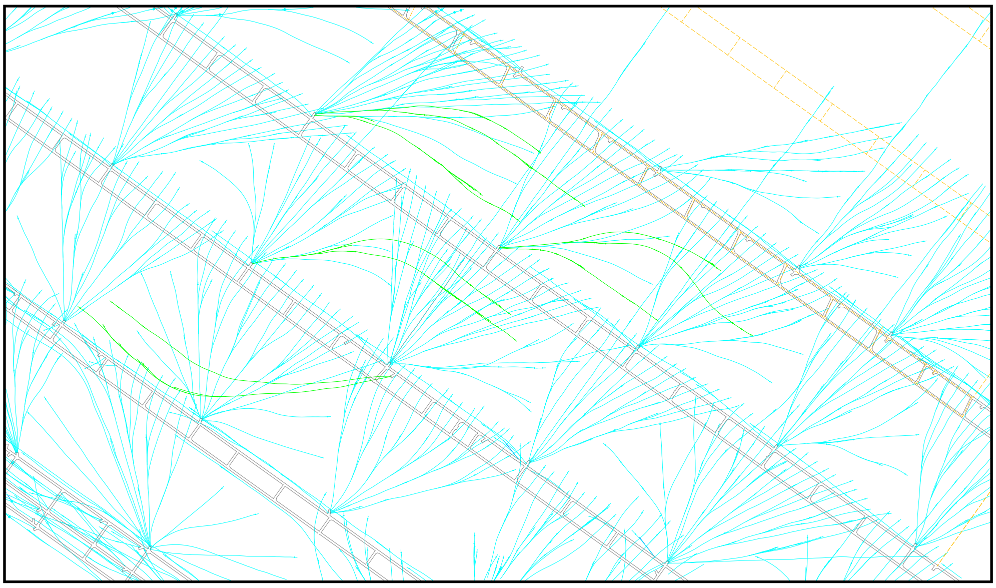

Figure 1: Typical drilling pattern at a Bulli seam operation.

In addition to the inseam drilling for pre-drainage, significant attention is also given to post-drainage gas capture methods. The failure of operations to effectively manage longwall gas emissions may result in the volume of gas liberated exceeding the diluting capacity of the mine ventilation system. In such situations the gas concentrations in the mine airways exceeds the prescribed statutory limit necessitating production to halt until such time as the concentration is reduced sufficiently.

With the increasing capability of modern mining machinery to achieve high production rates it is critical to the success of mining operations in this area to ensure that both pre-drainage and post-drainage gas management systems are efficient and capable of supporting the planned production targets of the operation. For example, a mine producing an average of 10,000 tpd that has a total specific gas emission of 50 m^3/t will liberate 182.5 million m^3 (2,254,787.5 $tCO_{2\text{-}e}$) of gas annually.

PRE-DRAINAGE

The preferred method of draining gas from the Bulli seam ahead of roadway development has been through the use of underground to inseam (UIS) drilling. UIS gas drainage programs typically involve drilling boreholes, of nominal 96 mm diameter, within the coal seam, from one set of development headings (gateroads), across the proposed longwall block and extending some 15 to 50 metres beyond the next adjacent development heading. The boreholes are typically drilled in fan patterns to minimise the frequency of drill rig relocations, and the spacing between boreholes varies according to seam permeability and overall drainage effectiveness. The inherent limitation with this method is that it is linked to the mining cycle i.e. drilling cannot commence until the gateroad has been developed, and the drainage lead time is dictated by the rate of advance of the adjacent gateroad. Therefore as the rate of gateroad advance increases the effective gas drainage lead time reduces. For many mines that operate in favourable gas drainage conditions, with permeability greater than 1-5 mD, that require relatively small gas content reduction to achieve TLV, this has not been an issue. However operators are finding an increasing number of areas in the Bulli seam that have low permeability (less than 0.5 mD), relatively high gas content (9-14 m^3/t), and high CO_2 concentration (greater than 60% CO_2) (Black and Aziz, 2008).

In the areas of increased CO_2 concentration the coal is deeply undersaturated in gas and requires far greater time to remove the water from the cleat and pore structure prior to any reasonable gas drainage occurring. Figure 2 shows a typical example of the relative saturation in both CH_4 and CO_2 zones and the comparative depressurising (dewatering) required to reach the critical desorption point on the respective isotherm curves after which gas desorption will occur.

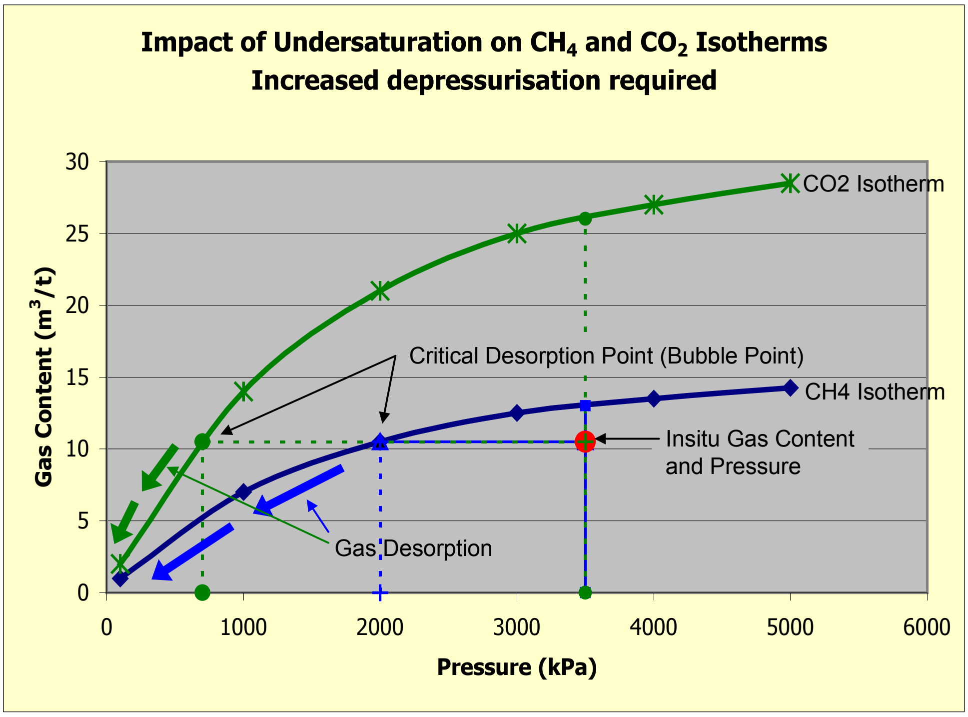

Figure 2: Relative saturation in typical Bulli seam conditions and depressurising (dewatering) required to reach critical desorption point.

Where such difficult drainage conditions exist, the UIS method of gas drainage does not have sufficient drainage time to effectively remove sufficient gas from the coal. A typical response of mine operators in such cases is to reassign drilling rigs from routine drilling into these areas to increase the borehole density. This action, although generally effective in removing sufficient gas to enable mining to advance, places additional pressure on future mining areas as available drainage lead time has been lost for the period the drill rig had been relocated.

As mining progresses toward areas of increased drainage difficulty, the impact is compounded, and in a number of cases production delays have resulted. In the most extreme cases, mine plans have been changed to avoid such problematic areas.

Surface-based gas drainage has significant potential to assist in the drainage of gas ahead of mining. Techniques such as vertical hydraulically fractured wells and medium-radius drilling (MRD) are becoming more common, particularly in the coalbed methane (CBM) industry. Figure 3 shows the components of an MRD gas drainage system.

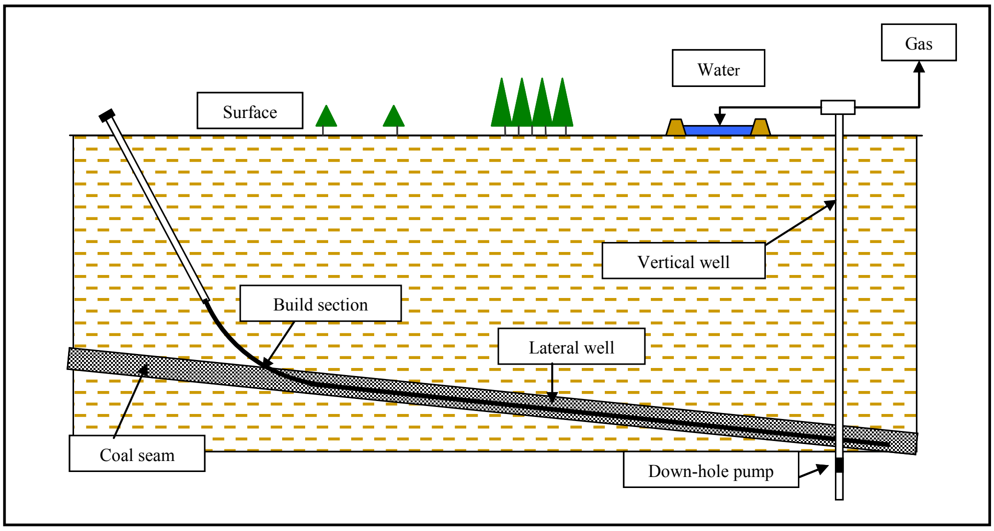

Figure 3: Components of an MRD borehole and vertical gas drainage production well.

The benefit of such methods is that the drilling and production of the wells are independent of the mine workings and therefore can be installed many years in advance of the planned mine workings, therefore providing far greater drainage lead time.

Such techniques have been trialled in the Southern Sydney Basin however they have not to date become common place. Two of the main reasons for the lack of uptake are the relatively high cost of such wells compared to UIS, given the drilling depth to reach the Bulli seam is typically in the order of 500 metres, and the significant constraints and limitations relating to gaining surface access for such programs. Many of the mines in the Southern Sydney Basin are located below a variety of significant surface features, such dams and catchment, state forest, urban development, creeks/rivers and road and rail networks, which limit the ability to undertake certain activities, including coal extraction.

POST DRAINAGE

The major source of gas emission within a mine occurs in the longwall goaf. Typically a mine will aim to maintain in the order of 150 m^3/s of mine ventilation air to the longwall ventilation circuit for the purpose of diluting gas and maintaining a safe working environment. Subject to the design of the gas drainage system, a portion of the gas liberated during longwall extraction will be released into the mine ventilation network. In the case of a mine that maintains 150m^3/s of mine ventilation air to the longwall, that has an SGE of 45 m^3/t and an average daily production target of 10,000 tonnes, it will be necessary for the mine to capture at least 20 m^3/t (44.5%) in order to maintain the general body gas concentration below the 2.0% statutory limit. The percentage of the total gas emission that is captured by the mine gas drainage system and prevented from entering the mine ventilation network is known as the post drainage capture efficiency (PDCE).

There have been many methods of longwall goaf gas capture used by mines in the Southern Sydney Basin. These methods include cross-measure drilling, back-of-block drainage, goaf seal drainage and directional boreholes.

Cross-measure drilling involves the drilling of boreholes from the maingate travel road at an angle into the floor to intersect the lower coal seams in the sequence. Due to limited access cross-measure holes generally cannot be drilled in the longwall tailgate.

Back-of-block boreholes involve the drilling of a series of boreholes up into the roof above the longwall, from the behind the longwall installation face, prior to the commencement of extraction in the panel. Following the commencement of extraction and goaf formation these boreholes become exposed to the fractured goaf and extract high purity gas. As the distance between the longwall face and the start point increases these holes become less effective in reducing gas emissions close to the face.

Goaf seal drainage involves the drawing of gas out of the goaf through an existing goaf seal. The effectiveness of such a method is dependent upon pressure distribution within the goaf.

Directional boreholes involve the use of down-hole motors to drill long boreholes approximately perpendicular to the longwall face located in the caving zone above and/or below the Bulli seam. Although effective in draining gas, this method is not favoured by many of the Bulli seam mines due to the potential for borehole failure and the increased risk of losing all of the down-hole drilling and survey equipment.

With increasing longwall production these methods have struggled to drain sufficient gas to prevent production gas delays and alternative drainage methods were pursued. In 2006, goaf drainage was trialled at West Cliff Colliery (Meyer, 2006). This method involved drilling a series of boreholes from the surface that connected to the goaf following the passing of the longwall face, through which goaf gas was drawn to the surface using a vacuum pump to overcome the mine ventilation pressure. Figure 4 provides an indication of the location and effect of the goaf drainage borehole in removing gas from the longwall goaf.

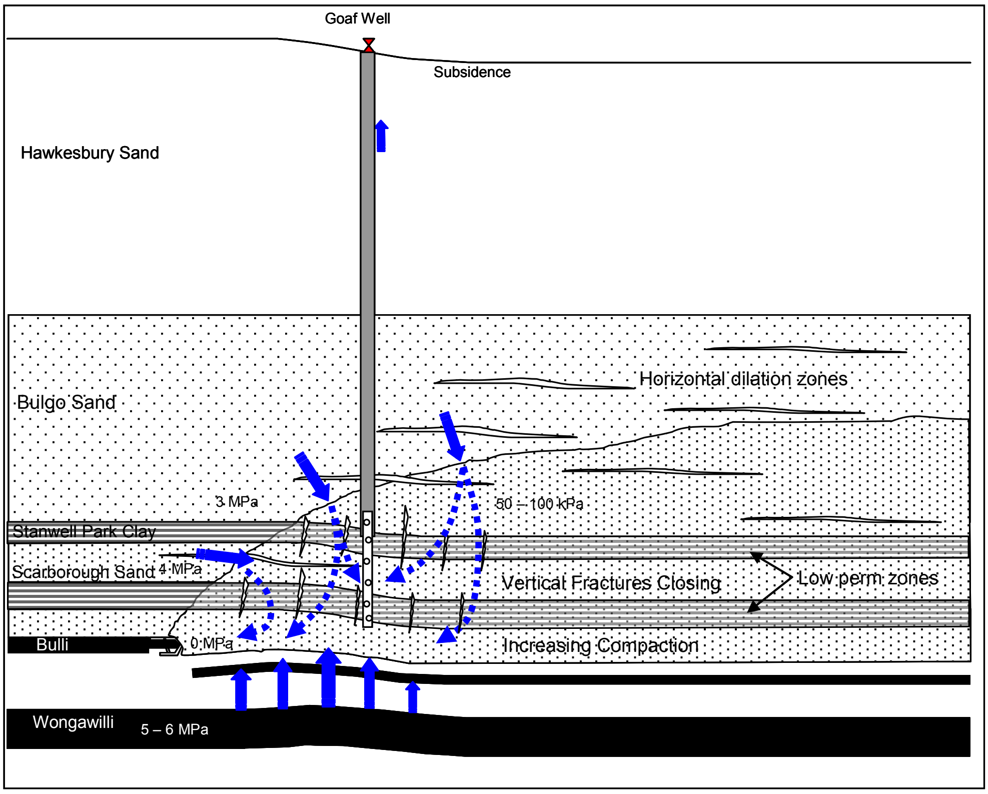

Figure 4 Illustration of the effect of surface gas drainage boreholes in draining longwall goaf gas emissions (Meyer, 2006).

The West Cliff Colliery experience with surface-based goaf gas drainage has demonstrated an ability to drain goaf gas at an average rate of approximately 400 lps (peak 800-1,000 lps). The production data from three separate goaf drainage wells, SGW#1, SGW#2 and SGW#3 (Figure 5), show the characteristic production profile of such wells. Following the initial connection to the goaf the production rate rapidly increases to the maximum which is sustained for several weeks followed by a rapid decline to a steady state production rate that is maintained until the well is removed from service. The primary reason for this decline is compaction of the material within the goaf which increases resistance and therefore reduces the rate of gas flow into the borehole. Also, similar to the back-of-block boreholes mentioned previously, the SGWs become less effective at reducing the gas emissions in close proximity to the longwall face as the distance between the two increases.

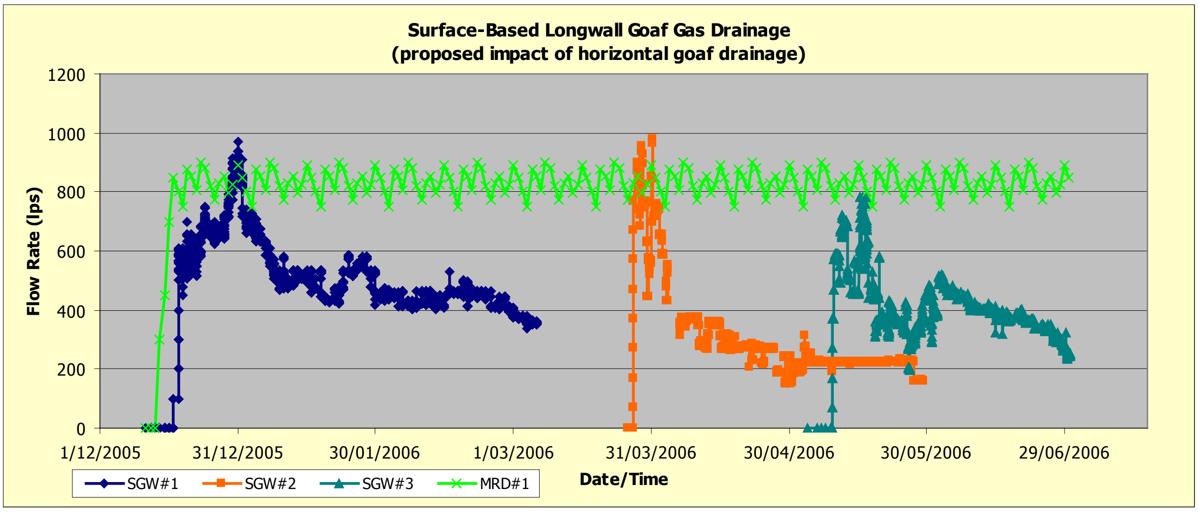

Figure 5: Surface-based longwall goaf drainage production data and estimated MRD well gas production rate.

An alternative method of surface-based goaf drainage, which is proposed by the Author for trial in Australia, is the use of MRD drilling technology to drill horizontal boreholes above and/or below the production seam into the partial caving zone prior to goaf formation. As the longwall retreats, the MRD drainage boreholes connect to the goaf and are used to draw gas to the surface using a suction plant, similar to that used with the vertical system. The significant potential advantages of the MRD goaf gas drainage method include:

- The point of connection between the drainage borehole and the longwall face remains relatively consistent therefore the gas production rate is expected to be less variable than the vertical well alternative (Figure 5);
- The effect on reducing gas emissions close to the longwall face will be maintained for the life of the borehole; and
- Significantly less surface disturbance will be necessary as a single MRD surface installation has the potential to service two separate longwall panels and replace at least three vertical SGWs in each panel.

Figure 6 provides an illustration of the lateral section of an MRD borehole relative to the operating longwall face and the proposed flow of goaf gas into the borehole(s).

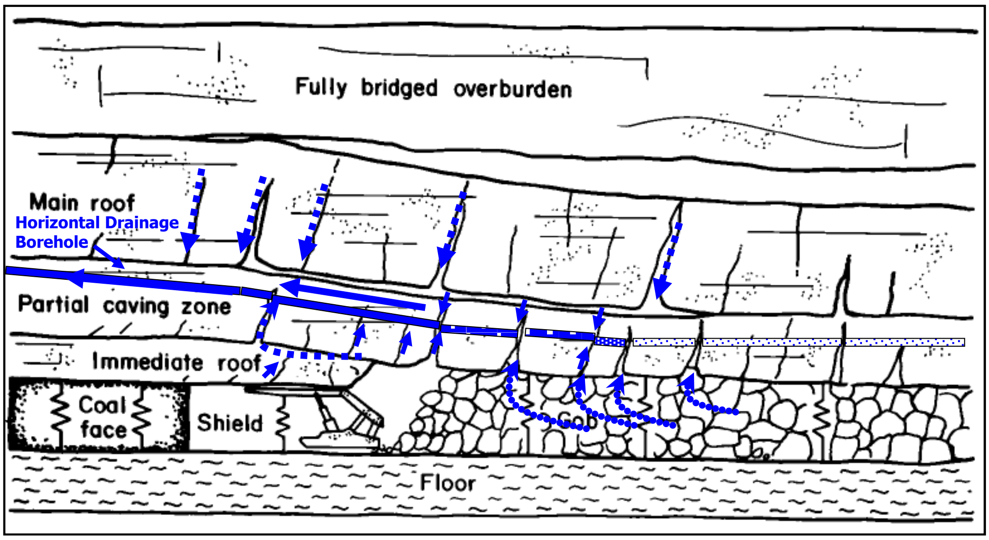

Figure 6: Illustration of the goaf gas capture into a lateral section of an MRD goaf drainage borehole.

CONCLUSIONS

The continued use of underground gas drainage methods alone will not be capable of draining sufficient gas in the relatively short lead time available to support high production rates by longwall mines operating in gassy conditions.

The use of surface based gas drainage methods has the ability to enable drainage to be conducted independent of mine operations and enable far greater drainage lead times to be achieved. Although surface-based drilling is generally more expensive than UIS drilling and has an obvious environmental and community impact, it does have the potential to improve gas drainage effectiveness and adequately reduce gas concentrations ahead of mining to avoid production delays and loss of reserves.

The use of drilling technologies such a MRD has the added benefit of being able to drill and drain gas from long distances which is very attractive from an environmental and community impact perspective as there is an overall reduction in the total number of surface installations required.

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