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Explosion Hazards From Methane Emissions Related to Geologic Features in Coal Mines

Department of Health and Human Services
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ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cfd	cubic feet per day
ft	foot
ft^3	cubic foot
m	meter

EXPLOSION HAZARDS FROM METHANE EMISSIONS RELATED TO GEOLOGIC FEATURES IN COAL MINES

By James P. Ulery[1]

ABSTRACT

Explosions in U.S. coal mines have caused death and injury to miners and destruction of workings since the first reported explosion in 1810. These explosions are caused when buildups of explosive gas and/or dust in the mine are ignited by the presence of a flame or spark. Methane gas is inherently generated and held by adsorption in coal and is normally liberated during mining. Because this gas is explosive in the range of 5%–15% by volume, fresh air is constantly supplied to the working face to prevent the methane/air mixture from reaching this explosive range. The required amount of ventilation air is based on estimates of gas release under normal conditions. Occasionally, unanticipated and unusually high emissions are encountered, which, despite normal ventilation controls, result in an explosive mixture that a spark from a cutting bit or electrical equipment can easily ignite. Investigations have shown that such emissions are often associated with anomalous geologic features or conditions. Although most operators are aware that certain geologic features may adversely affect productivity, few are aware of their potential as a gas emission hazard. This report presents a historical framework detailing the impact of geologic features on excess gas emissions and resultant mine explosions. It also provides operators with specific information on recognizing and alleviating potential hazards from methane emissions related to these geologic features.[2]

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[2] Some material in this report was previously published by Ulery [2006]. However, the report contains additional material not reported elsewhere.

INTRODUCTION

The first recorded occurrence of a methane explosion and resultant deaths in a U.S. coal mine was in 1818 at an operation near Richmond, VA, known as Heath’s pits. Humphrey [1960] quotes an 1841 article, noting that in the area “large quantities of [flammable] gas are thrown out from the coal in the mines constantly.”

The first documented mine disaster occurred near Richmond at the Black Heath Mine where, on March 18, 1839, an explosion of methane gas killed 53 miners. The explosion was described as follows: “Nearly all the internal works of the mine were blown to atoms. Such was the force of the explosion, that a basket then descending, containing three men was blown nearly one hundred feet in the air” [Humphrey 1960].

The Richmond mines were undoubtedly located in the coal-bearing Triassic sedimentary basins, which are highly faulted and intruded by igneous sills and dikes. Limited information on the gas content of these coalbeds indicates very high methane contents [Diamond et al. 1986], and these early explosions were most likely caused by excess gas emissions related to the faulting and igneous activity. The impacts of faulting and igneous activity on methane emissions will be discussed more thoroughly later in this report.

By 1900, fatal explosions had occurred in nearly every state with significant underground coal mining activity, and many of these explosions were attributable to methane gas. During 1870–1890, state mine inspectors detailed 200 gas ignitions that resulted in 368 fatalities in Pennsylvania anthracite mines alone [Humphrey 1960].

Abnormal, unanticipated mine gas emissions in quantities sufficient to create hazardous conditions have often been attributed to various geologic features since the first documented methane explosions in mines. For example, geologic features such as faults have long been recognized as conduits for gas flow from strata adjacent to mined coalbeds. Other features such as sandstone paleochannels, clay veins, and localized folding have also been widely recognized for their impacts on gas emissions into mine workings.

It is not surprising that strata adjacent to mined coalbeds can emit great quantities of methane gas into active mine workings. Many researchers have recognized that during the burial and diagenesis of the organic matter that ultimately forms minable coalbeds, similar dispersed organic matter in adjacent strata can produce methane in quantities far exceeding the storage capacity of the coal and surrounding rock [Jüntgen and Klein 1975]. As a result, large quantities of methane can remain trapped in these strata. A potential hazard occurs when mining of a nearby coal seam creates a pressure regime allowing gas to flow from these strata into the mine workings. This flow may be either facilitated or temporarily impeded by the presence of intervening geologic structures or anomalies.

In this report, gas emissions associated with geologic features will be divided into two categories. The first category includes large-scale, immediately recognizable emission events such as blowers and outbursts that have a geologic component and often result in catastrophic explosions. The historical, documented disasters in U.S. coal mines from these features will be summarized. The second category includes emission events that are often distinctly associated with geologic features of a more varying scale, such as clay veins, faults, and paleochannel deposits. Although occasionally resulting in immediate and catastrophic explosions, more often these emissions are subtler and not easily detected without field reconnaissance and instrumentation. However, over time these emissions may also lead to hazardous accumulations of methane if not recognized and remedied. Catastrophic explosions associated with the second category are also documented in this report. In summarizing all of the explosion disasters, bear in mind that no distinction is made between the casualties resulting from the heat and force of the explosion and those attributable to the poisonous afterdamp gases generated by the combustion. Finally, established methods to recognize and remedy potential emission hazards related to geologic features are summarized.

GAS EMISSIONS ASSOCIATED WITH OUTBURSTS, BLOWERS, AND FEEDERS

Outbursts and blowers are distinguished mainly by their duration of occurrence. Outbursts are sudden, often violent expulsions involving large quantities of gas, usually methane. Often associated with outbursts are large-scale ejections of coal or rock material. Blowers, on the other hand, have historically been viewed as events expending large quantities of gas over an extended time period of months, or perhaps years. Blowers are not associated with expulsions of coal or rock material. Methane feeders, a subset of blowers, continually expend gas over a long period, but at a lower rate.

Effects of Outbursts

Although not presently regarded as widespread in U.S. coal mines, outbursts have a historical record of occurrence and fatalities in certain mining districts and occur with regularity in certain mining districts worldwide. Typically, mines in these districts operate in steeply dipping, gassy coal seams that can lie at great depths. The potential for gas outbursts will likely increase in the United States as shallower and more easily extracted reserves are depleted, forcing mining into deeper, gassier, and more structurally complex seams. In fact, gas outbursts have been documented throughout history in U.S. coal mines with similar conditions.

Large quantities of pressurized gas may also cause “heavy roof falls” or “the bottom [floor] to heave” [Beard 1920]. Often these events cause high volumes of gas to be released rapidly in outburst-like fashion and may result in hazardous methane accumulations. Humphrey [1960] cites the October 28, 1958, explosion at the Burton Mine, near Craigsville, WV, as being “caused when a large quantity of methane, released from formations in the roof by large falls or emitted from heaving bottom…accumulated in the active working areas and was ignited.” It could be argued that such a release is not a true outburst because large quantities of rock material were not ejected under pressure. On the other hand, there have been instances where roof falls are thought to be driven by gas pressure, so perhaps these instances may indeed be regarded as at least “outburst-like.” Other instances where gas outbursts are related to roof falls or floor heave are documented in the section below on adjacent source beds.

In similar fashion, pillar robbing and weighting during retreat mining have also been associated with sudden, large, outburst-like releases of gas. These occurrences have resulted in ignitions with injuries and fatalities. Humphrey notes that on December 11, 1947, eight miners were killed by a methane explosion at the Franklin Colliery in Wilkes-Barre, PA, when “a rush of coal occurred…Methane was liberated [and]…an arc ignited the gas.”

As for actual outbursts, Humphrey also cites a November 25, 1922, explosion at the No. 4 Mine in Madrid, NM, that killed 12 miners. The subsequent disaster report noted: “The mine is gassy, and outbursts of gas had been occurring.”

Darton [1915] discusses three gas outbursts in Pennsylvania, two of which occurred in eastern anthracite mines in steeply pitching seams. The third took place in western Pennsylvania near Connellsville, where Darton notes that 100,000 ft^3 of fresh air per minute for 3 days was required to reduce the methane in mine air to safe limits. Darton also summarized extensive

European documentation of gas outbursts and concluded that these phenomena were usually related to crushed coal zones associated with folds, buckles, and faults.

Lama and Bodziony [1998] compiled a comprehensive overview of outbursts worldwide, including their causative factors and prevention. They concluded that the following factors contribute to outbursts: (1) gas content, (2) gas pressure, (3) permeability, (4) sorption/desorption characteristics, (5) stress conditions, (6) coal strength, and (7) geologic factors (often related to tectonic activity). Other modern research on these phenomena has demonstrated two major indicators of outburst potential in coal mines. The first indicator is the coal lithotype. Beamish and Crosdale [1998] demonstrated that coals with high vitrain and/or inertodetrinite lithotypes were more likely to retain the large quantities of gas needed to produce outbursts. A second indicator, documented by Cao et al. [2001], is the association of outbursts with tectonically altered and faulted coals. Cao et al. noted that outbursts in China seemed to be associated with tectonic activity that has produced regional thrust and reverse faulting. Such faulting often manifests itself in coalbeds because of their brittle nature compared to the surrounding strata. The coal adjacent to such faults is often severely crushed and pulverized, resulting in significant local changes in the gas storage and migration characteristics of the coal.

Effects of Blowers and Feeders

Gas blowers and feeders are not normally associated with modern coal mining in the United States, although they have been noted in other mining districts worldwide. Beard [1920] defined blowers and feeders as follows: “any continuous flow of gas from a crack or crevice in the strata is called a ‘gas feeder’ or simply a ‘feeder.’ The gas flowing from the crevice is known as ‘feeder gas.’ When a gas feeder is under high pressure so the gas issues with considerable velocity, the feeder is called a ‘blower’ and the gas ‘blower gas.’”

Darton [1915] summarized blower occurrences worldwide and noted the occurrence of “blower-like” features in the Pennsylvania anthracite district. Beard [1920] included the composition of blower gas from Wilkes-Barre, PA. The gas composition was methane 94.2%, ethane 0.4%, nitrogen 3.3%, carbon dioxide 1.1%, oxygen 0.9%, and carbon monoxide 0.4%. Chance [1883], in a report on Pennsylvania anthracite mining, noted that blowers were “very common in the mines of the Wyoming district and some of the deeper mines of the Schuylkill region… sometimes they are so powerful, and the amount of gas given off so great, that working must be suspended for a time.”

A review of Humphrey [1960] indicates that many major and minor explosions of mine gas resulted from the ignition of gas from audible feeders, the earliest of which occurred on October 27, 1881, when a miner was killed because his open light ignited a gas feeder in the Pittsburgh Coalbed in Washington County, PA.

In terms of fatalities, there were several significant explosions and numerous minor ones cited by Humphrey [1960] resulting from the ignition of gas feeders. At the Cumnock Mine in Cumnock, NC, an explosion occurred on December 19, 1895, killing 39 miners. In a report of the disaster it was noted that “[at the] face…little jets of gas exuded from the seam.” On August 1, 1911, an explosion at the Standard Pocahontas Shaft near Welch, WV, occurred due to ignition of gas “from audible feeders.” On December 10, 1925, 53 miners were killed at Overton No. 2 Mine in Irondale, AL, from a gas explosion. The disaster report noted: “Gas was issuing from a feeder in the face.” Other major fatal disasters attributed to gas feeders include:

- 13 fatalities at the Irvona No. 3 Mine, Coalport, PA (August 15, 1928);
- 10 fatalities at the Bates No. 2 Mine, Bates, AR (August 27, 1940);
- 12 fatalities at the Praco No. 10 Mine, Praco, AL (May 11, 1943);
- 25 fatalities at the Belva No. 1 Mine, Belva, KY (December 26, 1945); and
- 5 fatalities at the Buttonwood Colliery in Wilkes-Barre, PA (March 29, 1951).

Numerous minor disasters related to methane feeders are also listed by Humphrey [1960].

In a more recent report, Richmond et al. [1983] noted that methane feeders contributed to an explosion at the Dutch Creek Mine near Redstone, CO, killing nine miners on December 28, 1965. Gas feeders also contributed to an explosion at the Siltex Mine, Mount Hope, WV, on July 23, 1966, killing seven miners, and may have played a role in the two Scotia Mine explosions near Whitesburg, KY, that killed a total of 26 men on March 9 and 11, 1976. On June 30, 2000, the first of three explosions that resulted in the deaths of two miners at Willow Creek Mine, Helper, UT, was believed to be propagated in part by gas feeders at the face area. The source of the ignition was believed to be a roof fall initially igniting low flash point, higher hydrocarbon homologues of methane given off by liquid hydrocarbons found in roof strata at the mine [McKinney et al. 2001].

Based on past observations, outbursts and blowers are often associated with tectonically disturbed strata where gassy coals are mined at considerable depth. Thus, mine planners who are aware of such conditions should give some thought to the possibility that they will be extracting coal under conditions that have produced these phenomena in other mining districts.

If large-scale faulting is known and adequately mapped in future development areas, a detailed core-drilling program, coupled with gas content testing of core samples and in situ pressure measurements, can detect potential outburst-prone areas. Beamish and Crosdale [1998] recommend, as do Lama and Bodziony [1998], the use of any one of several published gas emission indices as an indicator of proneness to outbursts.

Since outbursts often occur in "nests" or clusters of several events, often within a distance of a few hundred feet laterally, gas drainage programs such as vertical surface degasification boreholes, degasification holes drilled horizontally ahead of the face, or (if outburst-prone strata are in the roof rock) cross-measure boreholes [Diamond 1994] may reduce the severity of these anomalies. Often, such boreholes will penetrate a fault system that has altered the coal structure and allowed large quantities of gas to accumulate at great pressure behind it. The boreholes are used to degas the outburst-prone area and relieve the gas overpressure that causes outbursts. Beamish and Crosdale [1998] also note that water infusion has been used successfully in some countries to reduce outburst hazards.

Blowers most often emanate from underlying strata. Remediation is recommended by using cross-measure holes angled downward from the mine heading to intercept the fissure or fault, which acts as a gas conduit. The borehole(s) may then be used to drain gas away from the blower outlet in the mine workings.

GAS EMISSIONS ASSOCIATED WITH GEOLOGIC FEATURES

In the United States, gas emission events associated with geologic features constitute a fairly common hazard in coal mining. These events are neither as obvious nor as immediate as outbursts or blowers; however, they do have the potential to pose significant risk. These events are often difficult to detect without the aid of instrumentation and underground surveys. Additionally, detailed mapping of geologic features can assist in predicting potential emission hazards and designing degasification strategies to alleviate these hazards. This section will consider techniques to detect and remediate abnormal gas emissions associated with geologic features such as adjacent source beds, roof falls, floor heave, clay veins and igneous intrusions, sandstone channels or lenses, joints, fractures, and faulting.

Effects of Adjacent Source Beds

Coalbeds adjacent to a mined seam can contribute significant quantities of methane gas to active workings [Finfinger and Cervik 1979; Ayruni 1984]. Although degasification of these seams may be accomplished through vertical or directional surface boreholes, more often, in-mine cross-measure, vertical, or directional boreholes are used to prevent explosive accumulations of gas [Finfinger and Cervik 1979; Ayruni 1984; Diamond 1994].

Shales and siltstones rich in organic matter often contain significant quantities of methane gas [Darton 1915; Johnson and Flores 1998] and may contribute unexpected emissions into active mine workings. As their permeabilities are typically low, the large amounts of gas stored in these strata may not be released until mining-induced fractures increase their permeability. In studying the gas content of U.K. coalbeds, Creedy [1988] concluded that the porosity and gas content of coal measure rocks were small. Nevertheless, he did allow that well-developed joint or fracture systems play a role in gas release from adjacent strata. It may be assumed that under some conditions certain organic-rich rocks adjacent to mined coalbeds have the potential to release methane gas at or near the working face in quantities sufficient to create explosive conditions.

Examples of disasters related to adjacent source beds include the disaster at the Blue Canyon Mine, Lake Whatcom, WA, on April 18, 1895. During drilling and blasting of bottom rock, an explosion occurred from "[g]as [that] was evident in quantity and under pressure in the strata" [Humphrey 1960]. A deadly explosion at the Stag Canon No. 2 Mine, Dawson, NM, on October 22, 1913, killed 263 men. The mine was not considered gassy and "was usually free of firedamp except for occasional pockets, coming from the roof" [Humphrey 1960]. It is, however, not entirely clear from the description if the gas was involved in the disaster. On January 13, 1926, an explosion at the No. 21 Mine, Wilburton, OK, killed 91 miners. The gas that was ignited here "had been coming in large quantities from roof cracks" [Humphrey 1960].

Remediations of gas emission hazards associated with adjacent source rocks may be accomplished through surface degas holes [Diamond 1994]. In deeper coalbeds, cross-measure degasification holes have been used to degas overlying strata in Europe and the United States with good success [Campoli et al. 1983; Venter and Stassen 1953]. Also, degasification by either in-mine boreholes (vertical or cross-measure) or directional boreholes from the surface may also be used for degasification of adjacent strata above or below the coalbed.

Effects of Roof Falls and Floor Heave

Humphrey [1960] documents numerous mine disasters related to the ignition of large quantities of gas released from roof falls or floor heave. One example is the January 27, 1891, explosion at the Mammouth No. 1 Mine, Mount Pleasant, PA. The explosion killed 109 miners and was caused by "fire-damp…mostly if not all generated by the [roof] fall" [Humphrey 1960]. Another example is the May 19, 1902, disaster at the Fraterville Mine, Coal Creek, TN, which killed 184 miners. The gas that exploded "was liberated from overhanging strata by the 'creep' that had begun with unusual violence shortly before the explosion." On February 8, 1906, at the

Parral Mine, Parral, WV, 23 miners were killed when a “heavy fall of roof in an intake aircourse liberated gas which…was ignited by [an] open light…Gas was liberated for several days after the explosion.” At the McClintock Mine, Johnston City, IL, 33 miners were killed on January 25, 1924, when “gas from the broken roof…came in contact with…open lights.” On January 28, 1931, 28 miners were killed at the Little Betty Mine, Dugger, IN, when “roof falls released gas and pushed it…over…open lights of loaders” [Humphrey 1960]. Another serious disaster cited by Humphrey is the July 15, 1940, methane explosion at the Sonman East Mine, Portage, PA, in which 63 men were killed. In this event, a “body of methane was released from overlying rock strata by a fall in a room.”

Excess, unanticipated methane emissions from floor strata have also been associated with fatal mine explosions. Humphrey [1960] cites an explosion at the Starr No. 3 Mine, Henryetta, OK, on April 8, 1943, that killed four miners and resulted from an “open light; gas from floor.” He also cites a May 9, 1943, explosion that killed three men at the Superfuel Mine, Paris, AR, that was caused by an “open light; methane released by heaving bottom.” The Sun Excelsior Mine, near Excelsior, AR, suffered a catastrophic explosion on February 8, 1948. Eight men were killed when “[h]eaving action of the floor…released methane,” which was subsequently ignited [Humphrey 1960].

In the Pennsylvania anthracite region, Humphrey [1960] cites an explosion that killed 10 miners at the Schooley Shaft, Exeter, PA, on April 10, 1947. “[M]ethane issued from crevices in the floor in finished workings” and was ignited. He also cites an explosion on September 11, 1933, at the Oakmont Mine, Barking, PA. Seven miners were killed when “gas…was ignited…from cracks in the bottom.”

More recently, the first of two explosions that ultimately killed 13 miners on September 23, 2001, at Jim Walter Resources, Inc.’s No. 5 Mine, Tuscaloosa, AL, was attributed to release of gas from a roof fall [McKinney et al. 2002]. As mines continue to extract deeper seams, the potential for significant emissions from roof and floor strata must be considered in planning.

Due to the extremely unpredictable nature of phenomena such as floor heave and roof falls, remediation techniques beyond increased ventilation air quantities are not practical. However, if emissions from one of these events continue over an extended period, then some type of gas feeder is present. The source of the feeder should be determined and possible degasification strategies considered.

Effects of Clay Veins and Other Intrusions

Clay veins or clastic dikes are sedimentary intrusions, usually from overlying strata, that intercept the coal in a vertical or near-vertical orientation. Their appearance in cross-section is not unlike an igneous dike, hence their name. Clay veins, which are generally composed of very fine-grain sediment or clay, are virtually impermeable barriers to gas migration in coalbeds (Figure 1). Therefore, they tend to have a “damming” effect on gas flow when approached during mining. When a mining machine penetrates a clay vein in a gassy seam, high methane emissions may occur at the face. Clay veins tend to be systematic in occurrence and are often related to differential compaction/diagenetic processes, but can also be influenced by tectonic processes [Chase and Ulery 1987]. Historically, these features have also been referred to as slack veins, horsebacks, rolls, and clay slips.

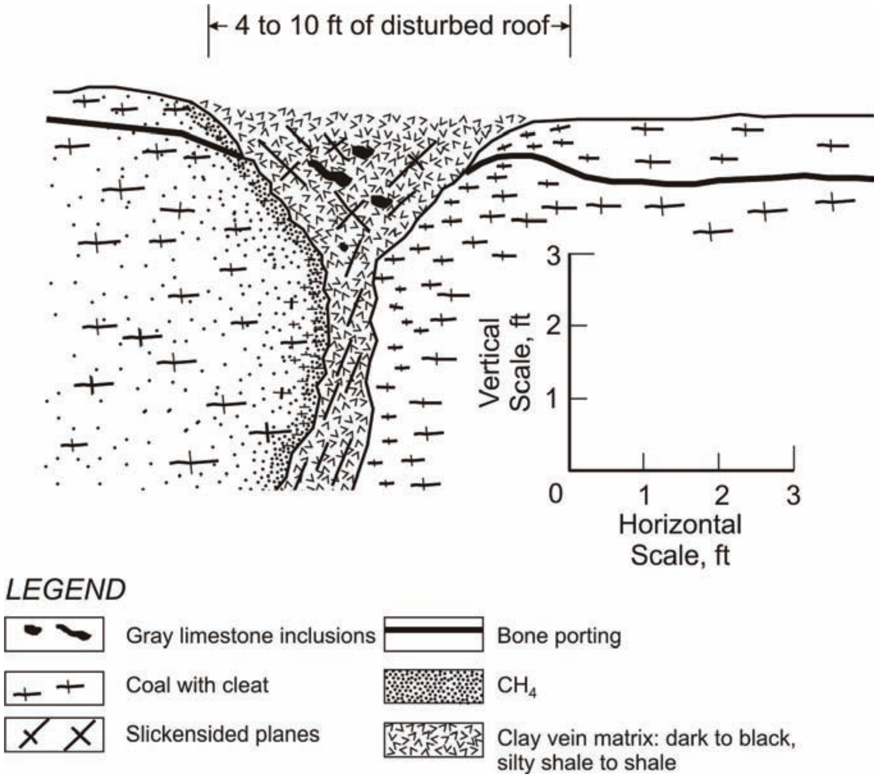

Figure 1.—Typical clay vein barrier to methane migration.

Clay veins have a well-documented history of causing unexpected high gas emissions in the Pittsburgh Coalbed during mining [McCulloch et al. 1975]. Studies in northern West Virginia have documented high gas flow rates (>80,000 cfd) from low-angle cross-measure holes penetrating clay veins near a gas-bearing sandstone above the Pittsburgh Coalbed [Ulery and Molinda 1984]. Gas flow increased from 47,000 to 80,000 cfd when a horizontal in-mine degasification borehole penetrated a clay vein approximately 800 ft from the face [Prosser et al. 1981]. In a different horizontal gas drainage borehole, the gas flow increased from 144,000 to 214,000 cfd after intercepting a clay vein approximately 2,200 ft from the face.

Clay veins and related features have also been responsible for documented mine disasters. On November 9, 1888, 40 miners were killed by a gas explosion at Shaft No. 2, Frontenac, KS. It was noted in the investigation that the operation had “never seen gas in the mine except when cutting horsebacks or slips” [Humphrey 1960]. At the Hillside No. 1 Mine in Johnstown, PA, five miners were killed by a gas explosion on August 9, 1928. The explosion was caused when “a nonpermissible mining machine cut through a clay slip in a room face, releasing gas, which was ignited by an arc from the machine” [Humphrey 1960].

Only in-mine experience can alert the operator to potential gas emission problems due to the presence of clay veins. If excessive gas emissions are encountered when mining through these features, then underground mapping of clay veins is needed to predict their locations in future developments. Since clay veins frequently can extend hundreds of feet along a given trend [Chase and Ulery 1987], predicting a vein’s occurrence in a developing section will allow the operator to anticipate and/or alleviate the potential problem.

Horizontal degasification boreholes drilled ahead of the face and penetrating the clay vein are the most economical means of controlling high emissions from a clay vein network (Figure 2, borehole A). Although mapping a clay vein network to delineate an isolated cell (Figure 3) allows it to be degassed through a surface borehole (Figure 2, borehole B), this is a cost-prohibitive method, necessitated only in extreme cases.

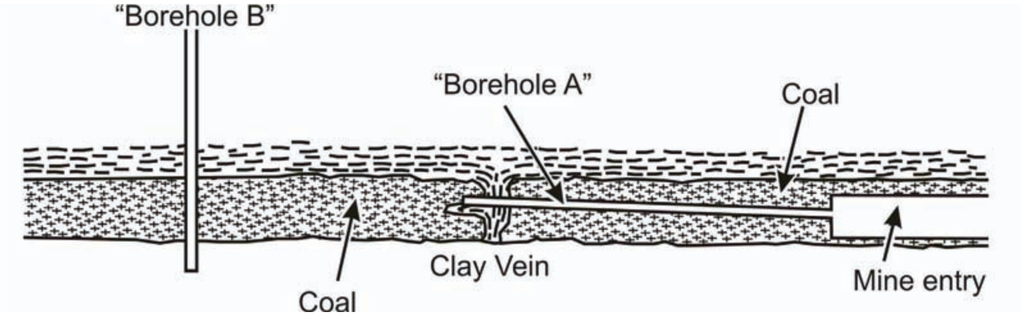

Figure 2.—Methane drainage of a clay vein flow barrier.

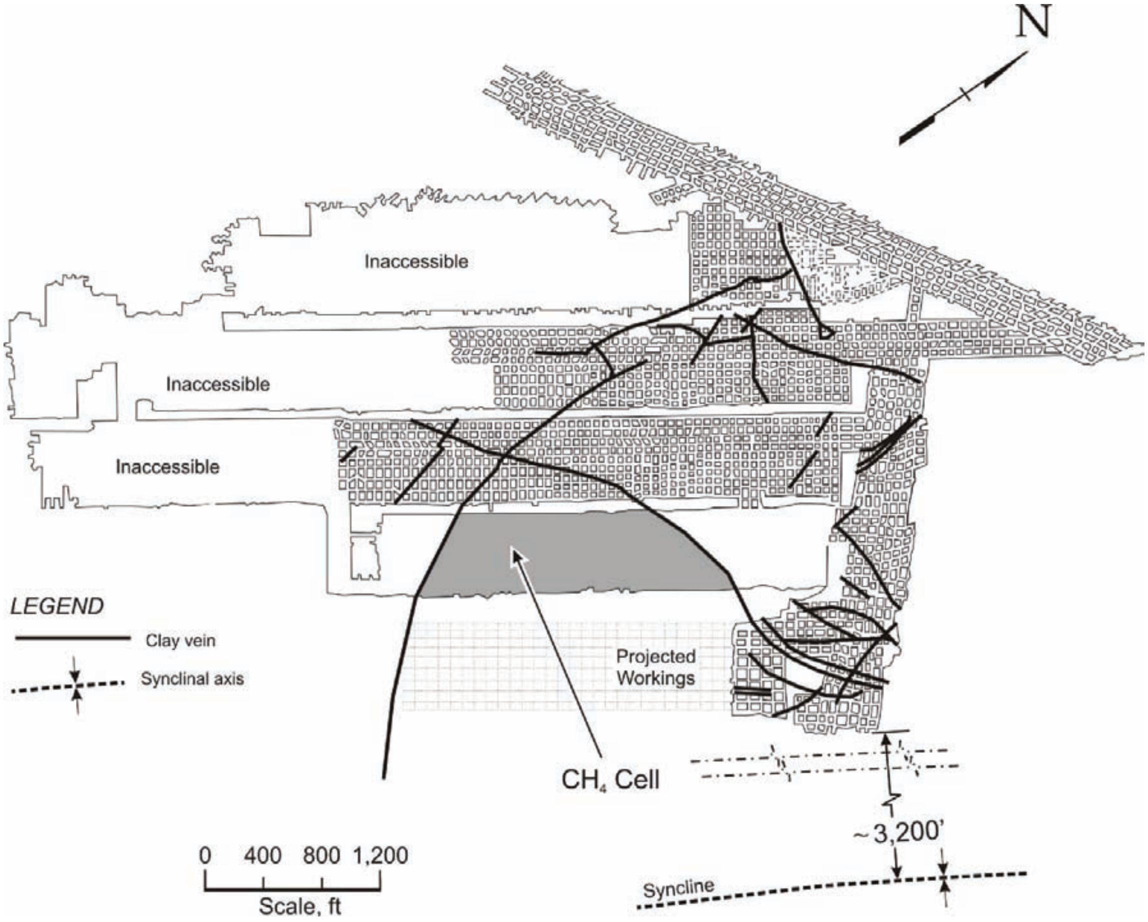

Figure 3.—Potential high methane cell bounded by clay veins.

In addition to clay veins, other intrusions can be igneous in nature. Igneous intrusions into coal seams and coal measure rocks generally will be either discordant features such as dikes, which cut across bedding planes, or concordant features such as sills, which are injected parallel to bedding. Such features are not found frequently in underground coal mines, but they are not uncommon either. However, massive discordant features such as plutons are rare in coal measure strata. Igneous intrusions typically inject magmatic rock at elevated temperatures, and their presence alters and increases the thermal maturity (rank) of nearby coal seams and organic matter in rocks [Dutcher et al. 1966]. The degree of coal alteration caused by an igneous intrusion depends on many factors, including the intrusion's temperature, thickness, distance from the coal seam, and cooling rate. Such thermal alteration of organic matter is accompanied by methane gas generation. For a given coalbed, areas affected by igneous intrusions can be expected to have higher gas contents than normal [Gurba and Weber 2001]. Larger igneous intrusions such as sills may also be responsible for potentially high carbon dioxide concentrations in some coal basins [Clayton 1998].

Discordant igneous dikes, like clastic dikes, can act as a barrier to gas migration and can present similar hazards when mined through. Predicting igneous dikes in developing sections is best accomplished by detailed underground mapping in adjacent developed sections. Controlling potential gas emission hazards associated with igneous dikes, as with clastic dikes, is best accomplished by horizontal boreholes drilled from the face and penetrating the dike.

Concordant igneous features such as sills usually cover a far greater lateral extent than dikes and can elevate the thermal maturity and gas content of a coalbed over a similarly large area [Gurba and Weber 2001]. The greater lateral extent of these features, however, is more conducive to prediction and mapping through conventional exploratory core drilling programs. If associated gas contents and emissions present a potential hazard, premining degasification through conventional surface degasification boreholes is the optimal method to alleviate this hazard.

Effects of Sandstone Deposits

Previous work by Darton [1915] and Price and Headlee [1943] documented the presence of sandstone paleochannel and other lenticular sandstone deposits adjacent to mined coalbeds as potential gas reservoirs. The gas in these deposits either migrated from subjacent coalbeds or organic-rich rock strata, or arose from organic matter deposited with the sand. These gas-bearing sandstones generally have a greater permeability than the surrounding rock strata, and once a pathway is established to mine workings via relaxation of natural joint patterns or other fissure systems, emissions from these sandstones may be quite pronounced.

Excess gas emissions from a sandstone paleochannel migrating through clay vein-related fractures have been documented at a mine in the Pittsburgh Coalbed in northern West Virginia. A sandstone paleochannel deposit above the Pittsburgh Coalbed acted as a significant gas reservoir, exhausting nearly 400,000 cfd of methane into a methane drainage system for 2 years [Ulery and Molinda 1984]. Humphrey [1960] cited an example of a disaster related to gas emissions from sandstone roof strata when "gas...released by breaking of the sandstone roof" was ignited at the Shannon Branch No. 3 Mine, Capels, WV. The explosion on May 13, 1927, killed eight miners.

Evaluation of the gas content of the sandstone using direct testing of cores, well testing, or direct gas measurements is necessary to determine if these emissions are sufficient to pose a potential hazard. The lateral extents and trends of the problematic sandstone deposits should be delineated using an exploratory core drilling program with appropriate hole spacings [Houseknecht 1982].

Remediation of these methane sources is best accomplished using vertical surface degasification boreholes (Figure 4, borehole A). If the sandstone body is in the roof or floor strata, in-mine degasification boreholes may be the most economically viable solution. Vertical, in-mine cross-measure, and horizontal degasification boreholes are shown in Figure 4 as boreholes B, C, and D, respectively. The same configurations of surface or in-mine boreholes would also be applicable to gassy sandstone deposits in floor strata.

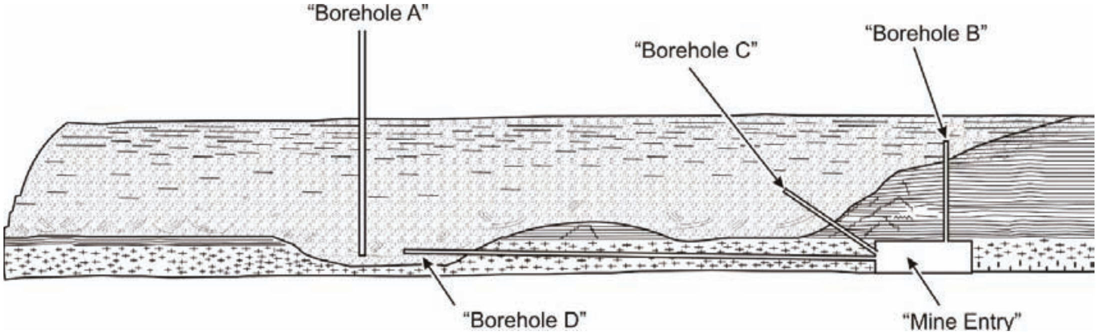

Figure 4.—Methane drainage scenarios for paleochannels.

Surface degasification wells usually require both dewatering and hydraulic fracturing to be most effective. Water must also be removed from horizontal, cross-measure, or vertical underground degasification boreholes to effectively produce gas [Diamond 1994].

Effects of Large- and Small-Scale Faulting

Large-scale faults are loosely designated as being tectonically activated, structurally mappable features, with areal extents greater than 500 m (1,640 ft) and vertical movement of at least 10–20 m (33–66 ft). Usually, the presence of large-scale faulting is known from regional geologic mapping and/or exploration coreholes. If the mined coalbed contains such faults and is of a gassy nature, the operator should be aware of the potential effects of these faults on premining gas drainage schemes and/or gas flow into mine workings [Diamond 1982].

These large faults may act as barriers to gas flow, especially if they contain impermeable fault gouge or if the displacement locates impermeable rock above or below the mined coal seam that abuts against it. If mine development proceeds through the fault by sloping the heading upward or downward into the displaced seam, the potential exists for excess methane emissions.

Large-scale faults may also act as conduits for potentially high emissions, or even blowers, from gas-enriched strata above or below the mined coal seam. Therefore, it would seem likely that such faults could easily become pathways for gas emissions into mine workings from adjacent source beds. In the United States, Clayton et al. [1993] noted similar findings in the Black Warrior Basin. Emissions may increase when there is stress redistribution as mining approaches a large-scale fault. In Germany, Thielemann et al. [2001] showed that in unmined regions, normal faults regularly act as gas conduits for surface emissions into the atmosphere from deep formations such as coalbeds. They further demonstrated that distinctly higher rates of surface gas emission occurred from normal faults in mined areas. This was presumably caused by the increased permeability of the fault and associated strata in response to mining.

Degasification of potential problem areas associated with large-scale faulting may best be accomplished through surface boreholes if the faulted areas in question are well mapped. Otherwise, unexpected problems associated with large-scale faulting may be alleviated through cross-measure boreholes designed to penetrate the fault zone and/or the source bed.

Humphrey [1960] cites three examples of mine disasters related to methane emissions and faults. On December 11, 1947, eight men were killed at the Franklin Colliery, Wilkes-Barre, PA, when gas associated where "the coal had pinched out at a fault" was ignited. On January 18, 1957, five miners were killed by a gas explosion at the Evan Jones Slope, Jonesville, AK, where "ventilation was inadequate to prevent accumulations of methane…along the fault line." Twelve men were killed on April 18, 1946, at the Great Valley Mine, McCoy, VA, when "[g]as released from a fault in the face…was ignited."

Small-scale faults are distinguished from large-scale faults by their limited mappable extent both laterally and vertically. Small-scale faults have limited extent and are often vertically confined to one or two strata. They may also be related to differential sediment compaction phenomena. Examples of small-scale faults are illustrated by Iannacchione et al. [1981].

Little documentation is available on the effects of such features on gas emissions. These types of faults, should they impact methane emissions, could possibly act as barriers to gas migration, forming "dams" of potentially dangerous gas buildups behind them [Iannacchione et al. 1981]. When these features are mined through, the "dammed" gas may release suddenly, possibly creating explosive conditions. Although prediction of these small-scale features can be difficult even with detailed underground mapping, degasification through short horizontal or cross-measure boreholes ahead of the working face is feasible if the faults can be anticipated and mapped. The coalbed near these features often displays abnormal thickening, undulations, or pulverizations, possibly indicating that faults are being approached.

Whether large- or small-scale, faults are generally classified as either normal or reverse. Normal faults are usually associated with tensile forces and are likely to act as conduits for gas flow. Reverse faults are often associated with mountain building tectonics and regional compression forces. Low-angle reverse faults are termed "thrust faults" and are often very large-scale regional features. Since these faults are associated with compression forces, they are likely to be barriers to gas flow.

When a mine entry approaches a normal fault on the footwall side, the remaining coal reserve ahead of (and below due to the fault) the approaching entry often poses an emissions hazard (Figure 5). Although the normal fault may potentially be an effective gas conduit, it is not as open to flow as the normal coal cleat system until mining redistributes the stresses. Therefore, potentially hazardous gas buildups may occur at the coal/fault interface. When ramping downward to extract the remaining reserves, hazardous conditions may arise when the built-up gas is released into the mine entry. Optimum degasification of such potential hazards is best accomplished using surface degasification wells (Figure 5, borehole B) or directional drilling from the mine entry (Figure 5, borehole A). A normal fault encountered from the lower "hanging" wall side (Figure 6) can best be degassed using vertical surface degasification wells (Figure 6, borehole A).

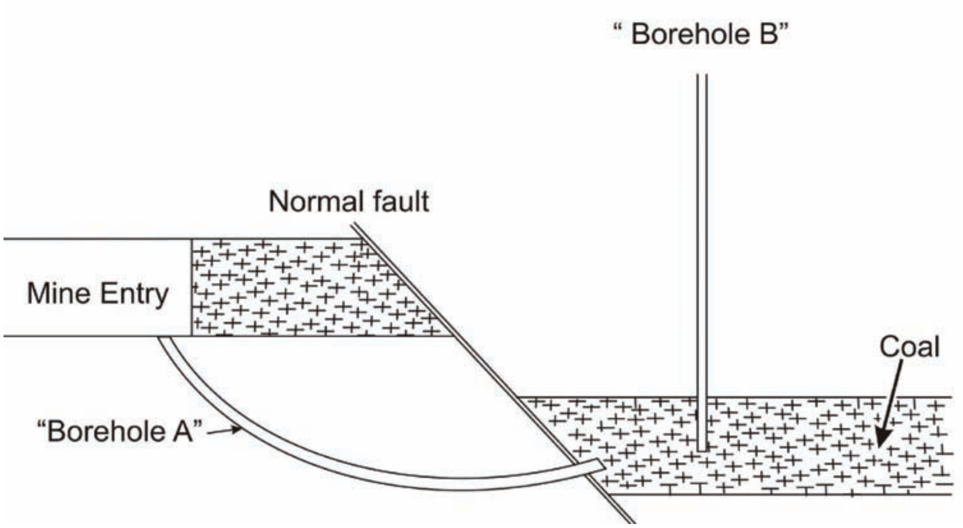

Figure 5.—Methane drainage of a normal fault from the footwall side.

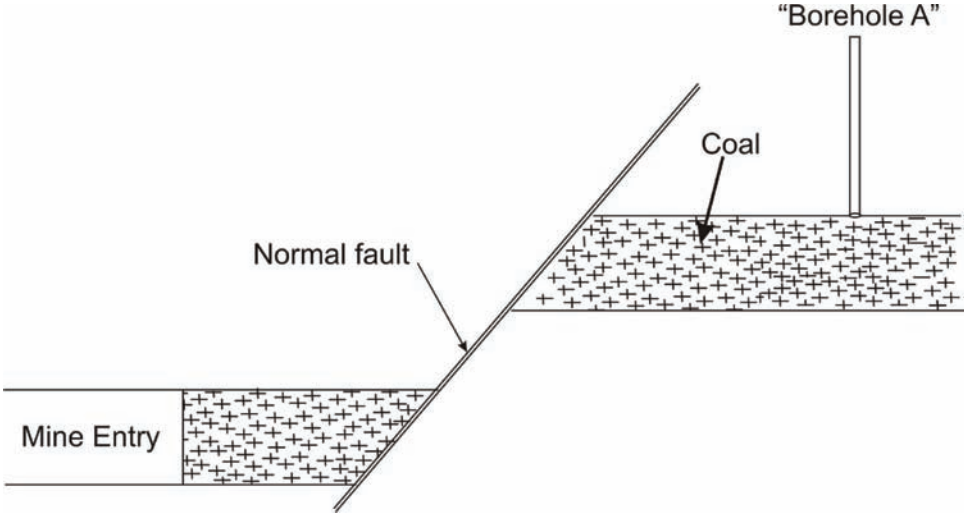

Figure 6.—Methane drainage of a normal fault from the hanging wall side.

Degasification of a reverse fault, approached on the hanging wall side (Figure 7), is best accomplished using surface degasification wells (Figure 7, borehole C). Other options include vertical in-mine boreholes (Figure 7, borehole A) or directional in-mine boreholes (Figure 7, borehole B). A reverse fault approached on the footwall side can be degassed with cross-measure holes (Figure 8, borehole A) or surface degasification holes (Figure 8, borehole B).

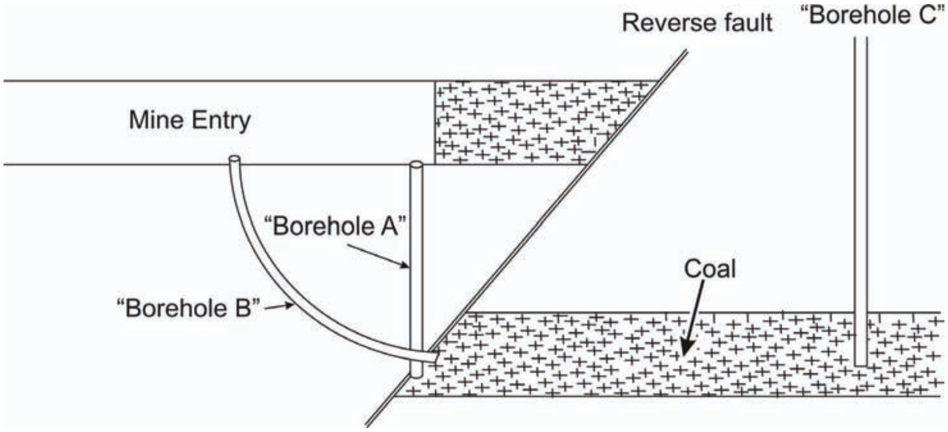

Figure 7.—Methane drainage of a reverse fault from the hanging wall side.

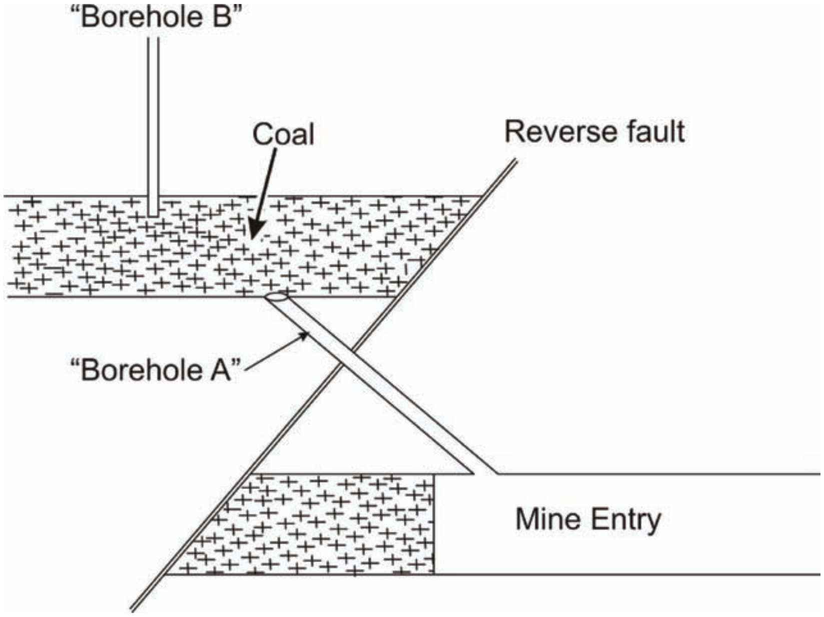

Figure 8.—Methane drainage of a reverse fault from the footwall side.

Effects of Joints, Cleats, and Fractures

Joints, cleats, and fractures are related to the confining stress fields during burial, diagenesis, and uplift. Joints are closely spaced with even walls, while fractures are more widely spaced with irregular walls. Joints usually occur in pairs at an approximately 90° orientation, and in coal seams these joint sets are called cleats. The main joints and cleats, termed "systematic joints" and "face cleats," of any given set are generally more continuous and offer major migration pathways for gas. Nonsystematic joints and butt cleats are turned 90° to the main features and generally abut against the systematic joints and face cleats, making them notably less continuous. Coal seam extraction allows the cleats to expand through a redistribution of the stresses, which in turn encourages gas migration through the coal. Stress redistribution also opens joints and fractures in roof and floor strata, allowing gas migration from adjacent strata.

Prediction and remediation of abnormal gas emissions are difficult given the unpredictable spacing of fractures. Joints and fractures act as conduits for gas to reach the mine workings from great distances within the seam and/or other source beds adjacent to the worked seam. It is probably safe to assume that many gas blowers and feeders are associated with jointing and/or fracturing of the coal and adjacent strata. These types of hazards are most often recognized when mining equipment is deenergized due to excess face emissions.

The most obvious solution to this problem would be to increase ventilation to the face. If past experience indicates that excess emissions may be encountered in a developing section, the mine operator should consider a horizontal borehole drainage system or surface methane drainage holes to degas the section prior to mining. Mine operators should always be aware of regional joint and fracture trends to facilitate prediction and remediation of abnormal emissions associated with these geologic features.

GENERAL REMEDIATION CONSIDERATIONS

When abnormal methane emissions occur in quantities sufficient to cause repeated production interruptions, operators must consider the possibility that they have a gas problem. To determine the most appropriate course of remediation, the operator must make thorough evaluation of the cause, extent, and severity of the problem. For many smaller mine operators, little in-house expertise is available to make such evaluations. These operators must rely on outside or contracted assistance.

The cause of the gas emission problem can range from underestimating the original gas content of the seam to dealing with gas sources outside the mined seam. Determining the extent of the problem may involve additional gas content testing [Diamond and Schatzel 1998] of the mined coalbed through exploratory boreholes or may involve extensive underground surveys, mapping, and instrumentation. Remediation may involve increasing face airflow or may entail labor-intensive drilling of surface or in-mine degasification boreholes. Surface degasification programs generally require fewer boreholes, but need good geologic control to effectively target and hit the gas-bearing zone. Both dewatering and hydraulic fracturing are required for surface degasification to be optimally effective. In-mine programs generally require more boreholes and dewatering, but less hydraulic fracturing. In-mine degasification programs require a piping network to transmit gas from the boreholes to the surface. If either the surface or in-mine degasification program affects the mine ventilation system, an alternate ventilation plan must be submitted and approved by the Mine Safety and Health Administration. Using the gas for cogeneration applications may reduce energy costs to the mine operator and help offset the costs of the degasification program.

Additional considerations for implementing any degasification system are equipment mobilization costs and accessibility to borehole drilling sites. Surface degasification sites may be inaccessible due to topography, landowner issues, or environmental constraints. In-mine programs may also have accessibility constraints due to poor roof or floor conditions or other mining-related issues.

Finally, operators must consider who will operate and maintain the system once installed. If installed in-house, personnel may need to be permanently assigned to the project. If outside contractors are used for installation, they may need to be retained for long-term operation, and maintenance or mine personnel may need training to operate and maintain the system once the contractor departs.

The economics of any degasification system under consideration involves weighing the pros and cons of all of these factors. A flowchart and excellent overview of this decision-making process are presented by Wang and Mutmansky [1998].

SUMMARY

Geologic features have a long historical association with excess gas emissions in coal mines and fatal disasters. Occasionally, these emissions are of such volume that the normal mine ventilation practices are inadequate to maintain a safe environment. In such cases, explosive mixtures of gas and air can occur and, if ignited, can lead to catastrophic results. Mine operators need to be cognizant of how such features may lead to hazardous explosive conditions and vigilant for signs of any unusual gas emissions. Operators of deeper, gassier mines in structurally complex areas must be aware that although outburst and blowers are not common, the potential and precedent for their occurrence exists. Finally, operators should be prepared to evaluate potential problems and implement remedial measures best suited to the specific geologic anomaly present.

Large sandstone units above or below the mined seam are a common cause of excess emissions. These features are mappable and readily degassed through surface or cross-measure borehole drainage configurations. Large- and small-scale faults can also impact emissions by either damming gas flow behind them or acting as a conduit to allow gas migration from adjacent units. Depending on the fault configuration and source of excess emissions (the seam itself or the adjacent strata), degasification is accomplished via in-seam, cross-measure, or surface boreholes.

Jointing and fractures may act as pathways for feeders or blowers. Increasing frequency of these features in gassy mines often necessitates increased ventilation. Clay veins and igneous dikes can also influence emissions, but are much more difficult to map and predict. Usually these features act as dams to gas flow and are best relieved through in-seam horizontal or cross-measure boreholes.

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