THE GASSINESS OF FACE COAL AND THE OCCURRENCE
OF GAS DYNAMIC PHENOMENA

By

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ABSTRACT

Gas dynamic phenomena, particularly instantaneous outbursts of coal and gas are
problems experienced in gassy, highly stressed coal, both usually the result of depth. Different
mining geometries present different opportunities for seam gas to escape, starting from
the virgin condition unaffected by mining and ending with the mining of the coal. The
mining of the coal varies from entering a virgin seam cross-measure, heading out into
virgin seam, advancing longwall faces into virgin seam and extracting developed blocks
from large longwall retreat blocks to small pillars. Each method has its particular gassiness
pattern and particular stress patterns, both changing to some extent with time, and
changing as mining progresses. Geological structural anomalies are the cause of gas and
stress anomalies, causing in turn greater gas and stress manifestations.

Pre-drainage of gas from the working seam not only degasifies the coal but causes it to
shrink and no may affect stress as well as gas patterns. Unfortunately prior degasification
is not all benefit, and there are some dis-advantages to its use. Also although it is
possible to degasify places ahead, gassiness will return if drainage holes are shut down or
sealed up and other deleterious aspects may be induced. Research should continue into the
problem of instantaneous outbursts of coal and gas.

INTRODUCTION

The need to prepare this paper arose from the
meeting of the Co-ordinating Committee for
Outburst Related Research held on 3,4/2/86.
A controversy arose about the potential for
instantaneous outbursts in longwall retreatig
operation. Although several references claimed
little or no prominence largely because of

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the assumption, supported historically, that instantaneous outbursts of coal and gas do not occur on retrograding longwall faces. Research into the prediction and control of instantaneous outbursts has real usefulness therefore, in development and longwall advancing only.

PREMISES

This paper is prepared on the basis of several premises relating to the escape/release of seam gas from coal, including instantaneous outbursts

1. In creating openings in virgin coal, gradients of seam gas pressure are created from atmospheric pressure at the face coal from which the gas is issuing to some value of undisturbed, virgin gas pressure some distance in the coal.

2. With standing faces in virgin coal, the gas pressure gradients progressively flatten with time, tending towards a steady state of constant gas pressure gradient with equilibrium between the virgin gas pressure and the gas properties of the coal.

3. Advance of faces steepens the gas pressure gradient ahead, and faster advances create steeper gas pressure gradients.

4. Where gas pressure gradients exist, gas will flow substantially at right angles to the isolines of gas pressure. Thus any gas pressure gradient, including a steady state gradient arising from a standing face in virgin coal, provides a source of gas for infinite time.

5. As distinct from virgin coal, isolated blocks of coal, such as pillars created in the workings, have a finite gas content continually bleeding away from all pillar ribalds, with diminishing gas content and gas pressure gradient as the gas escapes away to atmosphere and none is left above atmospheric pressure (in time hastened by barometric fluctuations).

6. Instantaneous outbursts are phenomena of the working seam, but not necessarily confined to the working section, and possibly including rocks of the immediate roof and/or floor. Although gas in adjoining unworked seams may cause violent phenomena, when such occur concurrent with instantaneous outbursts they are of separate source, and unconnected with the particular mechanism causing and arising in the instantaneous outburst. The following material depends on the acceptance of all these premises.

GAS DYNAMIC PHENOMENA

The historical relative proneness to instantaneous outbursts of the various mining activities, from exposing virgin seam to heading development, to longwall advancing, to longwall retrograding, to pillar extraction has been expressed by Hargraves (1960). The occurrence of instantaneous outbursts in longwall advancing (not practiced to any extent in Australia) lies somewhere between that of heading development and longwall retrograding. The nature of the gas situation on most longwall faces is obscured by the gas experienced mostly deriving from adjoining seams - itself sometimes a dynamic phenomenon - obscuring the generally smaller contribution by smaller emissions from face coal of the working seam. This fact is dramatically demonstrated in retrograding longwalls in the Bulli seam, N.S.W. where downhole drainage, itself not completely efficient, reduces gas content of ventilation air at the tailgate corner to 50% of the figure obtained without such seam gas drainage.

DEVELOPMENT

General

The gas situation in development is simple because it does not involve the gas in adjoining seams, unless perhaps if close to the roof or in the floor. The simplest condition, a heading advancing far into virgin coal is not usually met in gassy conditions, as requirements to dilute emitting gas generally require ventilation quantities provided by separate intake and return headings. Dependent on the purpose of the development therefore, under gassy conditions headings are advanced in multiples, even sometimes seven or perhaps more. As continuous mining is the norm, and the one machine advances a number of headings, usually one heading (and usually the return) is developed one pillarlength first, then the remainder, with cutthroughs in turn, so that the panel front is asymmetrical. Accordingly the emission of gas from the working seam into headings will be discussed firstly as a single heading and then as a panel front comprising a number of headings. As headings (in Australia at least) are virtually horizontal, the virgin seam gas pressure, and with it the gas sorption in the coal would have been uniform in the environment of the heading. With the thick seams often mined in Australia, often working height is less than seam thickness. It is safe to assume in such cases, unless stoneworks separate leaves of the same seam, that the gas from the whole seam for the width of development will be experienced in development.

Single Headings

The simplest situation would be that of a single heading in isotropic, homogeneous coal of infinite extent. Then symmetry could be expected about the axis of the heading in regard to gas emission and with it the seam gas pressure and gas pressure gradient. The permeation of gas out of the coal establishes a gas pressure gradient from virgin pressure some distance in the coal to atmospheric pressure at the coal face or rib. Higher coal permeabilities should induce flatter gas pressure gradients and vice versa. It should be expected that lower permeability coal when mined would have a higher gas content, yet more slowly released gas compared with higher perm-
eability coal. Ventilation is provided by longitudinal tube or brattice partition to provide separate air intake to and return from near the face, usually, but not always, with the smaller, higher velocity area providing the return. As the ventilation separation is installed in increments this has the effect of making maximum and minimum limits between the face and the ventilation source. The shorter this distance is, the better will the face ventilation be, the more readily will the issuing gas be swept off the face coal, the flatter will the gas pressure gradient ahead of the face be and the stronger will the face coal be. Hand miners used this relationship and by leaving the bratticing back from the face and enduring poorer ventilation were able to hew their coal with less effort. Under outburst prone conditions by leaving the bratcice back, the hand miners were able to provoke small face bursts and win coal with less effort unless their judgment was incorrect and an overwhelming outburst ensued. Continuous miners generally, and perhaps full face bore miners in particular, by shrouding the face from ventilation movements, apart from the pick movements inducing air movement, may be assumed to create more outburst-prone conditions. Perhaps this shortcoming of continuous mining is outweighed by the natural choking-off effect on any outbursts beginning of the bulk of the continuous miner obstructing the free growth of an outburst, much like the magnitude-reducing barricades used in some countries.

Related to face aeration also is the nature of the face ventilation, whether exhausting tube or exhausting through the narrow side of the brattice (wide side ventilation, the norm in Australia) or narrow side ventilation, with fresh air blowing on the face at higher velocity from tube or narrow side of brattice.

Narrow side ventilation, by readily moving issuing gas from exposed coal surfaces, will tend to create flatter gas pressure gradients and harder face coal conditions less prone to outbursting.

These ventilation related situations are depicted relative to notional gas pressure isolines in Fig. 1.

Planes of weakness in the coal, whether bedding cleat, or any other natural or induced structure may present planes of movement for gas and change any symmetry of gas pressure gradient. The best known structure is the cleat plane, or the major plane of complementary cleat planes, the major or face cleat, contrasted to the weaker, or minor(butt)cleat. Hand miners used cleat planes as assistance in hewing; with the face parallel to the major, face cleat "face-on", a higher gas pressure gradient exists ahead of the face and work of winning the coal is easier. With the face at right angles to the face cleat, this "end-on" situation provides a flatter gas pressure gradient, harder coal, and work of winning the coal is harder. All other angles are possible, including "half-on" between "face-on" and "end-on" with appropriate intermediate assistance in winning and with an asymmetric pattern of gas pressure isolines, these cleat related situations are depicted relative to notional gas pressure isolines in Fig. 2.

In all face advances, whether of narrow development faces or of wider faces in virgin coal or in any width of face in any particular gas in coal situation, the higher the rate of advance the steeper will be the gas pressure gradient induced. These advance related situations are depicted relative to notional gas pressure isolines in Fig. 3.

Fig. 1. Effect of ventilation configuration and intensity on gas pressure gradient.

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Multiple Headings

Multiple headings are used primarily to assist in ventilating gassy developments, to allow all major mining work to be conducted in good intake air and under deep conditions (which are also normally gassy) for rock mechanics purposes. Under gassy conditions it is desirable to minimise the number of active heading faces requiring to be ventilated and so normally one place is advanced (beyond a cutthrough or beyond a short overridden stop) at one time. This short driveage, of maximum length one pillar length is ventilated by longitudinal tube or brattice partition to induce face ventilation.

With multiple headings, with the return driven first a frontal asymmetry develops including the forming pillar. With surrounding (and detachment) of the pillar, not only are new gas pressure gradients and changing pressure isoline patterns set in train, but the commencement of complete (to atmospheric pressure) drainage of the pillar(s). Fig. 4 depicts the changing gas pressure gradients developed as a multiple heading panel commences at right angles to pre-existing trunk roadways.

Remote from trunk roadways with long virgin ribspikes and flat lateral gas pressure gradients, higher seam gas pressures and higher gas pressure gradients are experienced in the multiple heading panel driveage, as shown in Fig. 5.

Multiple Panels

Multiple panels are required for the development of retreating extraction blocks such as for pillars extraction or for longwall retreatment. A typical seam gas pressure distribution in this situation was given by Hargraves and Lunarszewski (1985) and is reproduced as Fig. 6.

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Fig. 2. Effects of isotropy and homogeneity, and of various cleat configurations on gas pressure gradients.

Fig. 3. Effect of rate of advance on gas pressure gradient.

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EXTRACTION

General
All extractions, if sufficiently wide involve caving of superincumbent strata and relaxation of strata above the cave and below the floor of the working seam. If such caving and relaxation causes gas from adjoining seams and strata to be released into the workings, this must be regarded as normal for extractions.

whether gas release is sudden or not, and is not to be confused with or related to emissions from the working seam, also whether sudden or not.

Advancing Longwall
In regard to gas in the working seam longwall advancing is a special case of a heading - with a wider face and a correspondingly slower advance corrected for the comparatively continuous transport of machined coal away from the mechanised longwall face as compared to the normal incremental transport - in the Australian context - away from continuously mined heading faces. The face width may vary from short longwall (or shortwall) say 30m to over 200m for normal longwalls. (As stated

Fig. 5. Gas pressure isolines in continuing multiple heading development.

Fig. 6. Notion of seam gas pressures during development of successive parallel panels.

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above, any extraction, including longwall advancing, may involve release of gas from adjoining seams, if close enough, into the ventilation or caved areas of the working seam).

In regard to gas in and from the working seam, longwall advancing is a special case of a heading - with a wider face and a slower advance. The slower advance provides a flatter gas pressure gradient ahead of a longwall advancing face just as a slower advance in heading work provides a flatter gas pressure gradient than a faster advance. However the nature of the longwall face with more tendency to convergence over the cantered longwall roof than over the spanned roof of a heading place, leads to more cracking of coal ahead of the longwall face and consequently gas pressure gradients ahead of the face flatter still, due to mining method. This applies to a general progressive roof breaking after the goaf reaches a certain span. Between commencement of the face and this change to regular roof breaking other face conditions may apply.

The nature of longwall advancing makes difficult the machining of a strip off the face without first creating a deeper extraction ahead at the end(s) to allow the machine to work the buttck rather than to jump into the face. Thus "stables" are often used at one or both ends of the face, and these "stables" are often locations for instantaneous outbursts.

An apparently desirable way to eliminate "stabling" is to drive gate roads into virgin coal for some distance ahead of the longwall face - far enough ahead so that "stabling" is of minimum delay and does not intrude into production shifts. Thus, there is a variety of configurations of longwalls advancing, faces without "stables", faces with one or two "stables", faces with one or two gate roads extended ahead of one or both face ends and also combinations, including one centre (packquallied) gate road and two outside returns. The above, and some subsequent gas data will determine whichever variation will be desirable for any particular situation. Some of the possibilities with corresponding gas pressure isolines are shown in Fig. 7.

Retreating Longwall

In regard to gas in and from the working seam, longwall retreating is a special case of a pillar but a large pillar. Customarily conventional small pillars, say 30m-50m minimum dimension, are only extracted after formation of a number, often a large number, and usually the emission of the finite gas contained in pillars is emitted quickly (Hargraves and Battino 1982) and usually almost completely (to near atmospheric pressure) before the pillar is extracted. Longwall retreating pillars, on the other hand are at least twice the width of conventional small pillars, say 100m-200m wide, and 20 or more times as long, say one kilometre or more, and extraction commences at one end and shortly after their formation, and so should be expected to

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Fig. 7. Notions of gas pressure isolines in various advancing longwalls.
contain more gas than conventional small pillars in the course of mining, unless some form of localised gas drainage is used. Longwall retreating pillars have only a finite amount of gas continuously emitting away, like conventional small pillars but unlike longwall advancing, in which the remaining coal is continuously replenished with gas from a virtually inexhaustible supply.

Fig. 8 gives notions of gas pressure isolines in the detached longwall block from immediately on completion of development to the end of extraction. In Fig. 8 from stage (a) to stage (b) all remaining roadways of the extraction block development are completed, face equipment and maingate equipment are installed, any additional support equipment and tailgate is commenced to allow the face to start. This will occupy several weeks, perhaps more, over which period retention of gas in the longwall block proceeds naturally, including from the latest exposed, starting end, where the gasiness is highest and the rate of gas emission highest. When mining commences, the starting end of the extraction block will already have lost significant gas and will have a flatter gas pressure gradient than at stage (a). The initial mining of the block is likely to be slower, so that steepening of the gas pressure gradient at the face is likely to be less. During later mining in the block, stages (c) and (d), with the coal further naturally degassed, the significance of high rates of advance will be less than at stage (b) in terms of steepening gas pressure gradient. The initial spanning of goaf, than the first real break, then the more regular breaking of cantilever roof with some cracking of face coal of longwall advancing applies equally to longwall retreating.

Pillar Extraction

Individual Pillars

The same gas content observations may be made for smaller individual pillars as for longwall retreating blocks except that the pillars, being smaller degas faster and are mined in less gassy conditions than, say, the starting faces of retreating longwalls. Usually many pillars are developed before extraction commences, but usually the pillars formed last are the first to be extracted, giving a higher gas in mined coal situation towards the beginning of extraction. Also a frequent method of pillar extraction is to commence by "splitting" the pillar with a roadway, penetrating the gasier coal at the core of the pillar before reducing the outside perimeter of the pillar - "open ending". In deep mining in the relatively impermeable Bulli seam, pillars (of minimum lateral dimension of the order of 40m) are relatively degassed in six months. Larger pillars take longer. A pillar of 110m minimum dimension at a depth of 450m with CO2 seam gas was found after 14 years to have only 0.45cc/gram at its centre, where virgin coal "gasiness" was over 3.5cc/gram (Hargraves, 1965, 1980). Notions of gas pressure isolines in pillar extraction are shown in Fig. 9.

Wongawilli System

This system, along with the Big Ben system and others like it, more closely resembles longwall retreating where surrounded but largely undeveloped blocks are divided up by long drivages 5m to 8m from a goaf edge, and partially mining "lifts" between the drivage and the goaf edge, retreating to the starting side of the block. The drivages are in low gas coal for most of the extraction, especially if alongside a previous goaf and especially after a fully caving goaf has formed, but in the first drivage for extraction may be in virtually virgin coal and the several drivages following before establishment of a fully caving goaf may be under more gassy conditions, somewhat analogous to the early extraction period of longwalls. Notions of seam gas pressure isolars in Wongawilli extractions are shown in Fig. 10.

NOTIONS OF STRESS FIELDS

General

Because of dependence of permeability on stress, (Bartosiewicz and Hargraves, 1985), because of the value of permeability determining gas pressure gradient in any particular geometry, because gas-dynamic phenomena apparently occur with steep gas pressure gradients and because gas-dynamic phenomena are also dependent upon stress magnitude it is pertinent to present notions of stress fields. Notion in the
for the most part virtually instantaneous. The removal of constraint at the exposed coal ribs allows lateral straining and therefore vertical shrinkage and inevitably roof weight redistribution with some roof and floor convergence and roof sag and floor lift.

Thereafter at least two agencies apply to prolong the stress adjustment process, firstly the shrinkage of the coal as the suction of gas is reduced (Hargraves, 1963) tending to vary the stress abutment somewhat and secondly non-elastic time dependent strains occurring in the coal and constraining rocks tending to reduce peak stresses and generally broaden stress abutments.

Development

Cross measure into seams In the Australian context this is usually only represented by sinking vertically into a virgin seam or inclined cross-measuring usually down, sometimes up, into a virgin seam. In either event the seam of coal, under virgin pressure, is relieved of vertical stress shortly before exposure and there is a stress abutment surrounding first the projected intersection and then the intersection itself. This abutment is identified as a closed loop of stress around the excavated part of the seam, perhaps with cracked and yielded coal between the abutment and the exposed coal rib in the plane of the seam. Because facilities for gas escape from the virgin coal cross-measure virtually do not exist and gas escape is not possible until the creation of ribs of coal in the intersection itself, steeper gas pressure gradients exist but, dependent on geometry, perhaps lower stress gradients. As outbursts occur more with steeper gas pressure gradients they are therefore more likely in cross-measure intersections.

Single heading In heading into a seam the single heading removes coal and the normally uniform stress now deflected from the cavity, causes stress abutments (in all directions). For the vertical direction in plan, a zone of stress abutment is seen around the heading face so that beyond some distance above and below the seam where virtually normal uniform virgin stress fields occur whilst within those distances the superincumbent load is deflected to provide the stress abutments, as shown in Fig. 11. Obviously for equilibrium the sum of the products of the local stress and the relevant incremental areas in the total plan will equal the product of the original, uniform virgin stress and the total areas.

Multiple headings Where headings are separated by small pillars perhaps the dimension of the pillar is insufficient to bear significant superincumbent weight and the pillar may even be regarded as yielded. Large pillars, on the other hand will have a central...
core which in itself may constitute an abutment whilst the largest pillars may be ringed by a stress abutment with more normally loaded coal within. These possibilities are shown in two heading developments in Fig. 12 and these give direction to the notions of stress abutment patterns for three and more heading developments.

Extraction

General Extraction in the Australian context is without stowage and involves a considerable span of goaf where the roof is either self-supporting or only partly supported by caved material. Indications are that front abutments are a few metres ahead of extraction faces, although the influence of the front abutment may commence one hundred or more metres ahead of the face. The rear abutment, where roof pressure in excess of superincumbent can be sustained by the goaf is often one hundred metres behind the extraction face, with influence noticeable as much as 200m behind. Generally these distances are influenced by the minimum span of goaf at the time, whether transverse or longitudinal, but after the goaf becomes square in plan a more or less constant situation relative to the extraction face exists. The goaves wider in their minimum dimensions should be expected to have abutments of greater magnitude than those narrower.

Another aspect which has an influence is in pillar extraction where odd stooks are left in the goaf and depending on their size and on tendency for roof to sag or roof and floor to converge may sustain some superincumbent weight between the main front and rear abutments, and, incidentally may have some influence on the regularity of redistribution of abutments and caving of roof with extraction advance.

Longwall advancing Although this method is not yet a feature of Australian mechanised mining it is relevant to discuss in the context of the occurrence of gas dynamic phenomena because it is important overseas, because it highlights the differences between longwall advancing and retreating and because in some form or other, there seems to be a place for it in Australian mining, as discussed below. The packs which are built in the goaf to maintain gateroad access to the face act as pillars behind the face to give some support to the roof and effectively reduce the transverse span of goaf somewhat. The notion of stress distributions is given in Fig. 13 for the simple face condition considered for gas in Fig. 7. The adaptation of pumpack (packwall) supported longwall advancing as a gateroad development for longwall retreating was presented by Hargraves (1978), employing a short longwall face to allow more rapid gateroad development (Fig. 14). A similar scheme was proposed by Marshall and Lama (1986) (Fig. 15). The stress motions in Fig. 7 apply equally well to such shortwall advancing propositions.

Longwall advancing and pillar extraction Less attention will be paid to these extraction techniques as gas dynamic phenomena primarily involving gas and stress in the working seam are not significantly represented. Any gas dynamic phenomena on record in those environments are customarily associated with geological anomalies and will be treated in the following section. Meanwhile it is sufficient to say that detached blocks of coal whether

Fig. 11. Stress abutments in single heading development.

Fig. 12. Stress abutments in multiple heading development.

Fig. 13. Stress patterns in simple longwall advancing.
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The case of Wongailli type extractions involving development and extraction on the retreat, and perhaps such development in blocks incompletely detached, especially in the first stages of extraction when creating a goaf, may have some similarities to the establishment of faces for longwall advancing, and each geometry would be the subject of separate consideration.

NOTIONS OF GAS AND STRESS INFLUENCES OF GEOLOGICAL STRUCTURE

Worldwide

Geological structure associated with gas dynamic phenomena range widely from
1. Seam variations especially thickness. This form is not prevalent in Australia.
2. Intrusions, whether dyke or sill involving devolatilisation of the coal from simple increase in rank, even anthracitisation to the creation of a coke with obliteration of bedding and joint structure and replacement by columnar structure in the coke, columns normal to the plane of the intrusion.
3. Faulting ranging from movement.
   (a) In the plane of the seam, perhaps metering a particular horizon in the seam, with examples in Australia, perhaps metering the entire seam, leaving it with slickensides or even higgledy-piggledy oriented shear planes, (without examples in Australia).
   (b) Movements traversing the seam, perhaps clearly, perhaps favouring bedding planes and moving progressively from bedding plane to bedding plane with steeper movement connections in between, perhaps with or without clear displacement of the seam to be regarded as strike slip faulting, in any variation with more or less homogenised coal in association, movements whether normal or reverse, and movements whether involving fracturing or not such as monoclines, drag folds, and inevitably changes on strike of the movements from one form to another between the commencement and dying out. All of these are prevalent in Australia.
4. Associations of 2, 3 and/or 4 such as dykes with apparent vertical displacements, dykes and complex faulting in association, etc.

The effect of such structures on gas conditions

It has long been recognised that any regularity in gas experience is disturbed in the vicinity of faults, dykes, etc. In general, if the coal rank is not significantly changed the gas sorption capacity in the vicinity of geological structure should be unaltered. If rank is increased, sorptive capacity should be altered, probably increased. Any change in sorptive capacity will probably be accompanied by a change in microporability. Macro-permeability and seam permeability will be affected by geological structure — if more planes of weakness are created, presum-
ably permeability increases, but the formation of mylonitic material, virtually a gouge of coal, could be a barrier of lowered permeability, under the constrained environment in situ. A dyke, if fresh could present a barrier of low permeability to transfer of gas from one side to the other - a weathered dyke, if moist and clayey could also be a barrier. A dry weathered dyke, or one wet with ground water could represent less of a barrier. Therefore no standard effect is seen in gas conditions by the existence of a geological structure just ahead of the face, just changed conditions and this would include unusual conditions of gas pressure gradient.

The effect of such structures on stress conditions
In the absence of gas, stress phenomena are more likely at the intersection of a geological structural anomaly than in plain seam.

Wherever there are changes in rock composition or in rock texture there are changes in elastic moduli of the rock, and in an otherwise uniform stress field, it is at such anomalies where changes in stress pattern are likely to occur. If the virgin condition was such a stress field made uniform by plastic adjustments since the last stress episode, stress due to mining would disturb the uniformity with abutments. Thus considering the ideal conditions of Phillips (1945) mentioned above the importance of a stress change at an elastic modulus anomaly will have the effect of developing differential lateral stresses in different rocks alongside each other, a situation difficult to visualise except in terms of slippage or fracture on bounding planes with consequent stress redistributions, and tendency to equalise. The effect of such structures on gas conditions considered above did not take account of permeability changes with concurrent stress changes, and the presumed reduction of sorptive capacity with increase of stress or as a corollary, for unchanged gas sorbed, the increase of sorption pressure with increase of stress. Thus the effect of stress abutments is twofold, they superimpose extra stresses on gasey coal, increasing gas pressure at abutments for the time being but reducing permeability thereby to hinder the escape of gas and restoration of smooth gas pressure gradients. Another effect of changing gas contents is the shrinkage of coal with reduction of sorbed gas content; this in turn will affect stress distributions and patterns progressively as gas content changes.

COMPARISONS

Considering all these factors and their understandable influence on phenomena gas dynamic phenomena the following observations evolve.

1. Breaking into a virgin seam cross-measure means encountering a seam in its passivest state exposed suddenly through impermeable rock strata without the existence of a significant gas pressure gradient in the seam, and with a stress abutment condition - whether vertical or lateral - in the coal. It is understandable that this is the situation of highest proneness to instantaneous outbursts.

2. Heading into a virgin seam means establishment of a gas pressure gradient together with a vertical stress abutment ahead of the face. The gradient moves ahead of the moving face, if the face stops the gradient flattens, if the face advances faster, it steepens. Probably with faster advance the stress abutment is closer to the face also, to recede when the face stops. The rate of advance and narrowness of headings progressively means that the gas pressure gradient in the steepest and the abutment is closer to the face than in any other activity, especially the corners of the heading face.

3. Normal longwall advancing can be regarded as a special case of a heading (in regard to the coal in advance of the face) with slower rate of advance. This and the action of the cantilevering and sagging roof (and heaving floor) tends to crack the face further ahead than in the case of a heading (especially towards the centre of the longwall face). Thus gas pressure gradients are flatter and stress abutments tend to be further ahead of the face although, as with headings, gas pressure gradients on headings are steeper and abutments are closer at face corners. Where gateroads are advanced ahead of advancing faces, the conditions of headings apply except that the advance rate of the headings will be slower, more like the advance of the face, and so gas pressure gradients will be flatter and stress abutments further ahead. Although the proneness of the heading is therefore a little less than a normal heading, its pre-draining effect and moving of the stress abutment further ahead of the longwall face coal should make the adjoining part of the face less prone.

4. Longwall retreating conditions at the start of a face may have gassiness conditions and stress conditions approaching those of longwall advancing near the centre of the face. As the face retreats into the block, the degasification benefits of longer time since development and the effect of the cantilevering roof converging, fracturing face coal and moving stress abutments further ahead and flattening gas pressure gradients still further will dramatically reduce proneness. Thus on retreating faces outbursts, if any, could only be expected towards the centre of the face when the face is very young. If lateral pre-drainage had traversed the longwall block to prepare for gateroad panel development (Hargraves and Lamanowski, 1985) this possibility would be virtually eliminated.
5. In pillar extraction, with gassiness of pillars diminishing rapidly after formation, the only risk of instantaneous outbursts is in pillars absolutely fresh, and probably only large in both dimensions and formed quickly. As the gassiest condition of pillars is roughly at the centre, depending on history of formation, the most prone situations, if any, is in the splitting of large young pillars with rapid drivage towards the core or towards the infill side.

In the case of Wongawilli extraction, the situation of proneness will depend on geometry and time, if any, since the detachment of the Wongawilli block from virgin coal. But in general, except in the initial stages of starting a Wongawilli extraction in virgin coal the potential for proneness can be compared with longwall retreating in regard to gas pressure gradient and the stress abutment pattern.

Unless near virgin coal pillars are split immediately their gassiness will be minimal. However, this circumstance does not apply to normal pillar extraction activities, particularly as adjacent extraction lines will induce fracturing of pillar sides and hasten degasification of small pillars as a whole.

6. To all of the above considerations it must be conceded that if abnormal geological structure exists in the mining environment, then the proneness to instantaneous outbursts increases by say a factor of one.

Pre-Drainage

Until the last decade the success of drainage from virgin coal ahead of development was limited to instances where such drainage was comparatively easy. During the past decade persistence with experimentation and long-term experimentation revealed the wider possibilities of pre-drainage in less permeable coal, based on intensive pre-boring patterned, and in many cases, extraction by suction. As far as is known, the overall economic comparison of the alternatives, suction to an exhausting plant and free flow from a larger pattern of holes has never been made. Usually suction is used, perhaps because most mines with pre-drainage have post-drainage also. For most post-drainage suction is necessary and Australia has followed this path. So now it is possible to reduce the magnitude of gassiness, one of the two contributing factors to gas dynamic phenomena, perhaps to reduce the magnitude far enough to prevent such occurrences. But experience has shown that for such preventive effect the drivage must be clearly between drainage holes which have had sufficient time to drain the intervening coal. The alignment of the butts of the holes can be likened to a ribside, with gassiness (and proneness) increasing beyond (Hargraves 1980) although in the near vicinity of the alignment any occurrences of instantaneous outbursts may be of modified form (Marshall et al., 1982). But the use of pre-drainage in prevention is not as simple as understanding their immediate effect.

The limitations are:

1. Limitation to well drained coal and only positively within the compass of the drainage pattern as defined by lines connecting the butts of the holes, as defined above, perhaps with the lines bowed towards the collars of the holes.

2. Limitations of present drilling technology which does not ensure that drainage reaches reach target, nor ensure that they maintain alignment, nor ensure that they do not cross projected alignments of development. Thus, in advance pre-drainage holes virtually parallel to the heading alignment may deflect across it; in lateral pre-drainage, similar deflection in holes virtually at right angles to the projected alignment may deflect either way, increasing distance between butts of some holes and prolonging degasification. Also in lateral pre-drainage there is the limitation to effect of holes stopping short of total panel alignments and the limitation of intersected holes blowing into development openings where holes traverse the projected panel alignments.

3. Limitation to backfilling of holes to prevent gas from intersected holes blowing into development openings. Firstly the backfilling with grit of holes hundreds of metres long, still draining gas from throughout their length, but especially near the butts, with pressures, if closed in, of perhaps up to more than 7MPa is a most complex problem. Secondly, as holes in highly stressed environments are often stress relieved and somewhat collapsed, or the holes may have plastic tubes inverted to hold them open if they have tendency to collapse, these make the problem of sealing even greater.

Thirdly, immediately holes are backfilled the gas condition of the coal will tend to return to its previous, undrained situation, possibly in time of the same order as the drainage time.

4. Limitation in that the benefit of degasification could be outweighed by hazards in development by intersection of drainage holes blowing pure gas into development headings, perhaps onto electrical equipment, perhaps onto sites of frictional sparking.

5. Limitation where there is geological structure. Where structural anomalies exist there are probably also gas and stress anomalies as stated above. Whereas a geometric pattern of holes would tend to provide a uniform degassing effect, and with it a general coal shrinkage effect (Hargraves, 1963) and thus, in uniform seams a more regular general destressing effect (apart from any local destressing with failures around holes), with the heterogeneities of geological structure any pattern of destressing and degasification would be one more of surmise - and relief of proneness could be partial or doubtful.

Summing up about pre-drainage, it has evolved as a means of reducing proneness to...
gas dynamic phenomena but cannot be a complete answer to the problem until some equipment is improved and some pattern aspects are better understood.

CONCLUSIONS

It can be seen from the foregoing that there are many and complex factors contributing to instantaneous outbursts of coal and gas, apart from a virgin high-gas-high-stress environment. The experience based notions of gas and stress conditions in the several phases of mining confirm the prominence of the various working methods to be

1. Cross-measuring into the working seam - most prone
2. Heading into virgin seam
3. Longwall advancing
4. Longwall retreating
5. Woungauwi extraction, and
6. Conventional pillar extraction - least prone.

Where geological structures occur, the proneness in any category will increase. The possibilities of occurrences in category 4 are virtually nil, and the possibilities of occurrences in categories 5 and 6 are very slight, being limited to deep splitting, usually unnecessary and avoidable, and to fast advances in the earliest mined and gaseous coals of a completed pillar and invariably on geological structures, usually structures already defined by surrounding roadways.

The development of degassing (and to some extent destressing) techniques by pre-drainage holes, either with or without suction has reached a stage where reliable design is possible but some shortcomings remain in drilling technology. Gasless monitoring can be used to establish effectiveness before subsequent mining. Any possible slight problems in early mining of longwall retreating and Woungauwi extraction blocks should yield to simple drainage hole patterns.

It is clear that mining in instantaneous outbursting seams is not yet possible absolutely without risk of occurrence. However, the contributions of mining method and geometry and the reduction of proneness toward zero by choice of method and by further degassing and destressing techniques including some limitations are substantially understood. In the Australian context, heading in virgin seam should be minimised by method design or should be made absolutely safe by pre-drainage. Unless longwall advancing methods are introduced the problems of gas-dynamic phenomena in Australia are restricted to cross-measuring into the working seam, experienced in shaft sinking and occasional seam re-entries at faults and the major problem of heading in virgin seam. Any money or effort spent on the other categories would be comparatively unnecessary and ill advised, robbing the major (heading) problem of these resources.

REFERENCES


The AusIMM Illawarra Branch, Ground Movement and Control related to Coal Mining Symposium August 1986