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Safe gas content threshold value for safety against outbursts in the mining of the Bulli seam

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ABSTRACT: The paper presents data on safe gas content threshold values for the safe mining of the Bulli seam with rapidly advancing development headings. The proposed threshold values based upon total gas content are 9.4 m^3/t for pure methane and 6.4 m^3/t for carbon dioxide under conditions of mining close to the structures with a linear change for a mixture of seam gases. When the occurrence of minor outbursts (<20 tonnes) is accepted, these threshold values for the Bulli seam could be raised to 12 m^3/t for methane and 10 m^3/t for carbon dioxide at the prevailing depths up to 500 m. The data is compared with actual observations to support its validity and it is shown that this has a fair margin of safety factor to cater for inaccuracies in gas content estimation. The threshold values are compared with some overseas data using a simple outburst coefficient and it is shown that these threshold values are much safer than used overseas. * How? WHY?

1 INTRODUCTION

The phenomenon of outbursts has been occurring in the Bulli seam for almost 100 years. The first recorded occurrence of an outburst was in 1895 at Metropolitan Colliery which resulted in the death of three people. Since then 461 (Oct. 1994) outbursts have occurred in 12 mines. Details of the occurrences are given in Table 1. This table shows that all outbursts have occurred on structures and in * places where there was no substantial drainage of gas. A vast majority of outbursts have occurred in West Cliff Colliery, followed by Tahmoor, Metropolitan and Appin. Other mines have experienced a much smaller number of outbursts. The effect of five fatalities in the Bulli seam in the last three years has changed the concepts of safety and has resulted in great changes in the mining of the Bulli seam under high gas conditions. It has spurred development and application of management systems to overcome the problem. It has also put severe strain on the economics of many operators. Unless this problem is satisfactorily solved, the viability of mining of the Bulli seam is greatly in doubt. Old principles of localised measures for outburst control are no longer applicable under intensive longwall operations which form the backbone of underground mining of the Bulli seam. Solution of the outburst problem requires use of techniques which can prepare retreat longwall blocks for safe mining sufficiently in advance. As such removal of gas by gas drainage and reducing gas content levels to such a value that safe mining can be conducted has been uncritically accepted by the mining industry. This paper outlines the developments in the area of defining those threshold values which have now been accepted by most mines mining the Bulli seam.

2 MECHANISM OF OUTBURSTS

Though some of the earliest attempts to explain outbursts related to high gas (Briggs, 1921; Ruff, 1930), in modern theories three factors, gas pressure gradient and gas quantity, rock pressure and strength play a dominant role (Khodot, 1961; Christianovich, 1953; Christianovich and Salganik, 1985; Skochinski, 1954; Petukhov and Linkov, 1983). 3 key factors. The role of each of these factors may vary from place to place. Laboratory studies where micro outbursts have been induced in artificially prepared briquettes from coal and saturated with gas clearly show that both gas pressure gradient and stress play their role. These studies show that gas pressure gradient required to initiate an outburst depends upon type of gas and coal porosity, the higher the porosity, the lower the gas pressure (Bodzony & Nelicki, 1990). *Check this reference!! Projection of laboratory data to conditions occurring in the Bulli seam indicates that for carbon dioxide gas pressure of 0.35 MPa would be needed. The process of destruction of the coal is in multiple steps producing discing as in drilling in high stress zones. The thickness of the slice is determined by the gas pressure gradient and the tensile strength of coal (Ding Xiaoling, 1988), coal porosity, gas viscosity and filtration coefficient. The rate of destruction of the sample under laboratory conditions has been found to vary between 5-22 m/s in coal briquettes with high porosity and 5-15 m/s in coal briquettes with lower porosity (Bodziony, Nelicki and Topolnicki, 1990). The speed of propagation

Table 1. Outbursts in the Bulli seam

Colliery	No. of outbursts	Max. size of outburst, coal/tonne	Type of gas	Fatalities	Association with geological structure	Gas drainage status
Appin	20	100	Mostly CH_4 (One with CO_2 on dyke $CO_2 = 76\%$)	-	All associated with faults/dykes/mylonite, joints polished coal, etc. In two cases no info. some association with stress?	All at no substantial drainage, one suspect
Tower	19 (5 suspect)	80	CH_4	-	All outbursts on mylonite except one on jointed coal - suspect, possibly a rock-burst	All at no substantial drainage
Tahmoor	90	400	$CO_2 + CH_4$	1 (1986)	All associated with dykes/faults	All at no substantial drainage
West Cliff	252	400	CH_4	1 (1994)	All associated with shear zones or fault/dyke	All with no substantial drainage
South Bulli	13	120	Mostly CO_2 but also some CH_4	3 (1991)	With thrust faults, 5 cases suspect, perhaps not outbursts	No drainage
Old Bulli	2	30	CH_4	-	Fault	No drainage
Corrimal	5	40	CH_4	-	Mylonite and shear	No drainage
Kemira	2	100	CH_4	-	Fault + thrust, depth 200 m	No drainage
Metropolitan	54	250	Mostly CO_2 some CH_4 (5-20%)	7 (1895 = 3 1925 = 2 1954 = 2)	Dykes/faults on thrust zones. Also associated with blasting.	No drainage
Coal Cliff	1	20	CH_4	-	Dyke	No drainage
Darkes Forest	2	10	$CH_4 + CO_2$	-	Dyke	No drainage
Brimstone + Oakdale	2	40	$CH_4 + CO_2$	-	Fault	No drainage, non-violent outbursts

increases with gas pressure and size of the openings. CO_2 gives higher speed than CH_4 and N_2 (Famin, 1959). The higher destructive effect of CO_2 is not only due to higher quantity of CO_2 that coal is capable of sorption and higher rate of desorption, but also its effect on reducing the strength of coal by as much as 30%. CO_2 also has lower diffusion coefficient, higher viscosity and all this leads to higher free gas pressure gradients. At high pressures (20-30 atm), velocity of propagation in strong coals under high stress may reach 100 m/s (Kravchenko, 1955). Projection of the data to natural coal porosity levels of the Bulli seam indicates that the propagation rates would be of the order of 5 m/s. A large outburst of 200 tonnes reaching a depth of 35 m from an advancing face would thus be precipitated in 7 seconds. When stress plays a dominant role, the size of the outbursts may be small and the location may be governed by the stress directions and direction of drivage. When gas plays a dominant role, the geological structures with reduced coal strength will control the location and direction of propagation of the outbursts. Under high stresses associated with structures, the size of an outburst may increase dramatically.

Check with CSIRO data !!

Free gas is an essential element in an outburst. This provides the energy for the ejection and transportation of the broken mass. The rate of desorption where sorbed gas changes into free gas is much higher for finer particle sizes. For example, for 90% free gas to be liberated from a particle, the time required is as follows (assuming defusion = 10^{-10} cm/s):

0.001 mm = 1.6 s
0.1 mm = 13 s
1 mm = One month
10 mm = 15 years

?

As such for an outburst to occur, there must be a large percentage of fine coal and high gas present. The larger the percentage of fine coals, the greater the severity and size of an outburst. Similarly, if high moisture is present, it will decrease desorption rate and hence the probability or the intensity of an outburst. Coal seams that have well developed micro-crack structure (lower strength) and lower permeability are thus much more liable to outbursts. Studies based upon data collected from Lower Silesian coal field on correlation of various factors and the degree of influence they exert on outbursts shows that the factors associated with gas (desorption rate, gas pressures, type of gas - CO_2 or CH_4) together influence 68% followed by seam thickness 18% and strength and stress 10%.

moisture slows desorp/ [illegible]

3 THE OCCURRENCE OF OUTBURSTS IN THE BULLI SEAM

The minimum depth of occurrence of the outbursts is reported at about 200 metres though this figure is suspect (depth is possibly 350 m). The largest outburst occurred at West Cliff and Tahmoor Collieries where 400 tonnes of coal were thrown out. The outburst at Tahmoor occurred in association with carbon dioxide and at West Cliff with methane. Five outbursts have resulted in the deaths of 11 mine workers. All deaths have been associated with carbon dioxide outbursts and all these fatal outbursts occurred at places without any gas drainage. Fig. 1 shows the frequency distribution of the size of outbursts in West Cliff and Tahmoor mines where together about 70% of total outbursts have occurred.

O/bursts [illegible]

In workings to date, West Cliff, which has experienced the largest number of outbursts, (55% of the total) had a gas composition basically methane which is now changing rapidly into carbon dioxide. Tahmoor, which has experienced approximately 20% of the total outbursts has gas composition varying between 30% methane to 70% methane. Metropolitan Colliery, which has experienced about 11% of the total outbursts has gas content varying from 70% CO_2 to 95% CO_2. In other mines, outbursts have been associated with high proportions of methane and carbon dioxide has been limited to 2-5% in general, though close to dykes high percentages have been recorded in outbursts.

Analysis of outbursts shows that these have always occurred in development headings. No outbursts have occurred on the longwalls in the Bulli seam. One outburst has been reported which occurred in a pillar panel during the drivage of a split at Tahmoor Colliery (splitting in the Bulli Seam is very akin to development). This outburst occurred on a fault/dyke face, when the structure was just penetrated, throwing out about 8 tonnes of coal with some release of gas. Another occurred during pillar extraction (Metropolitan Colliery - details not available). Most outbursts occur during actual extraction of the face without any time delay. Some outbursts 3-4 minutes after stoppage of cutting have been reported. Hargraves (1975) reports an occurrence during lunch break in a development heading.

Further analysis of outbursts in the Bulli seam has shown that as long as minimum distance from the structure is maintained, an outburst will not occur. Site studies of a number of outbursts at West Cliff showed that this minimum distance is 2.5 metres. Study of some outbursts which occurred from the side also showed that when the barrier width of solid coal and the rib line of a heading was reduced to under 2.5 m, an outburst precipitated. At South Bulli Colliery, where the gas content was about 12 m³/tonne (mostly CO_2), this barrier width was close to 0.8 m. At Tahmoor, the width of this barrier was found to be just under 2 m.

Safe distance from structure

Onsite studies also indicated that there were no signs of any induced stresses in coal in areas of outbursts. In the Bulli seam coal is highly fractured (pulverised) in places where shear zones are present. The low strength of sheared coal with fineness of coal particles present an ideal case for outbursts to occur at such structures. The outburst cavities at places of larger outbursts extend up to 30 m deep. Those structures when intersected at different angles to the axis of the headings precipitated outbursts which follow the structures quite independently of the stress distribution.

Studies also indicate that almost 98% of outbursts have occurred on structures. Only 6 outbursts (5 at Appin and 1 at Tower) have been reported not to have occurred directly on the structure. A small outburst that occurred at Coal Cliff (Darkes Forest lease) occurred close to a dyke. All these outbursts were small in size with the amount of coal thrown out less than 2 tonnes. There is a great doubt whether they were really outbursts, though existence of type of cone is reported in some cases.

O/bursts 98% occur @ structures

Based upon these studies, the mechanism of outbursts in the Bulli seam has been postulated, Fig. 2 shows a generalised concept. The phenomenon of outburst occurrence in the Bulli seam is placed in the third quadrant (high gas, low stress/strength ratio). As a structure is approached, the free gas pressure gradients close to the structure are high. This is the case both when shear zones are present or when a dyke or a fault exists ahead of the face. The shear zones are zones of low strength, high desorption rate due to the presence of very large pulverised material and high permeability and as such when intersected, they result in much high gas flows. The dykes and faults influence decrease of fracturing ahead of the face and lower permeability resulting in the build up of higher pressure gradient. The effect is that as the face approaches the structure and the minimum distance (thickness of barrier) is breached, the higher gas pressure displaces the material from the face and high flow rate provides the energy resulting in the initiation of an outburst.

The material thrown out in the case of a shear zone is highly pulverised fine coal, but in the case of dykes and faults, it is more akin to normally fractured coal

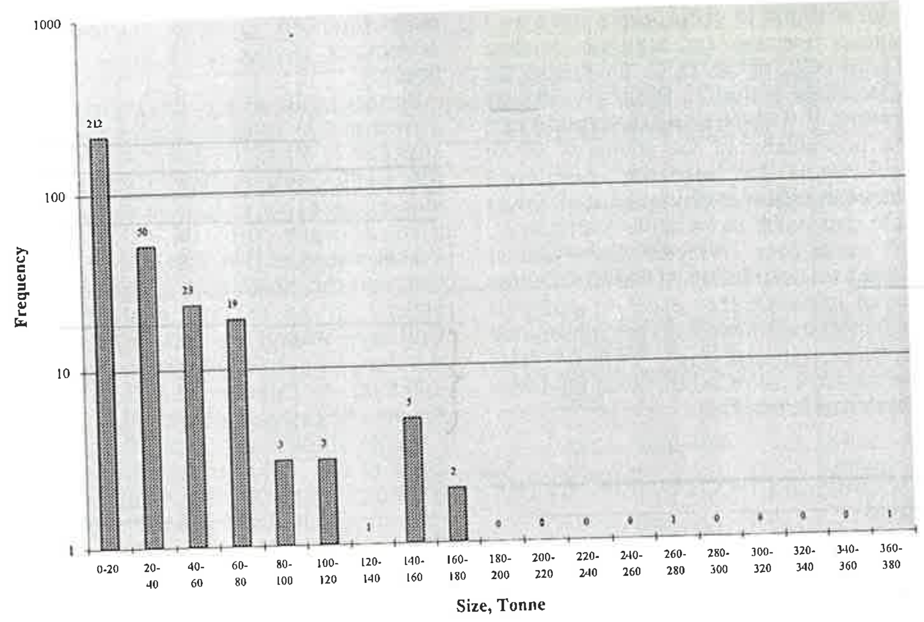

Fig. 1 Size distribution of outbursts at Tahmoor and West Cliff Mines

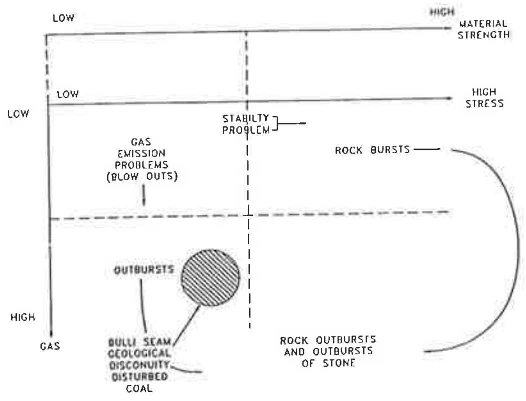

Fig. 2 Effect of stress and gas on stability of excavations

without any great differentiation from coal under normal mining.

The strength of the Bulli seam is placed somewhere in the middle of the band of coals strength around the world. The stress levels occurring in the seam are medium and since there is no indication of the role of stress, it is concluded that induced stress is not playing any important role in the outbursts in the Bulli seam. Ejection of coal in outbursts in the Bulli seam is all gas controlled. This is also supported by the fact that many structures have been mined through without outbursts in areas where gas content has been not so low though the depth of mining has been no different than usual depths.

Figs. 3a and 3b show outbursts that have occurred in the Bulli seam. For comparison purposes Fig. 3c which shows an outburst in Leichhardt Colliery is given to illustrate the difference. The Leichhardt outburst is a typical stress related outburst. The effect of stress is virtually absent in the Bulli seam. Some outbursts that have been reported at Tower and Appin may fall into this category, but these are suspect. The amount of material thrown out in these outburst has been very small.

The phenomenon of discing has been observed in high CO_2 areas in the Bulli seam when coring for measurement of gas content. This occurs when gas content exceeds 16 m³/t. The thickness of the disc varies depending upon the type of coal 5-10 mm in strong dull coals and ~1 mm in bright softer bands (Fig. 4). Discing has not been noticed in areas with methane up to 16 m³/t. It is felt that besides high desorption rates, the effect of CO_2 on strength of coal plays an important role. Decrease in shear strength of coal by 30% has been measured under laboratory conditions (Fig. 5).

It can also be concluded that virtually all outbursts in the Bulli seam are gas controlled and associated with structures, mostly shear structures, dykes and faults and that the safe zone varies from 1 m to 2.5 m.

4 MECHANICAL AND GAS PROPERTIES OF THE BULL SEAM

The Bulli seam forms the top most part of the Sydney Sub-group of the Illawarra coal measures. Its depth varies from outcrop to 700 m and thickness from 1.8 - 4.5 m. The present depth of workings is approximately 350 - 570 m. The dip of the seam varies from 2 - 5° with a regional structure of a

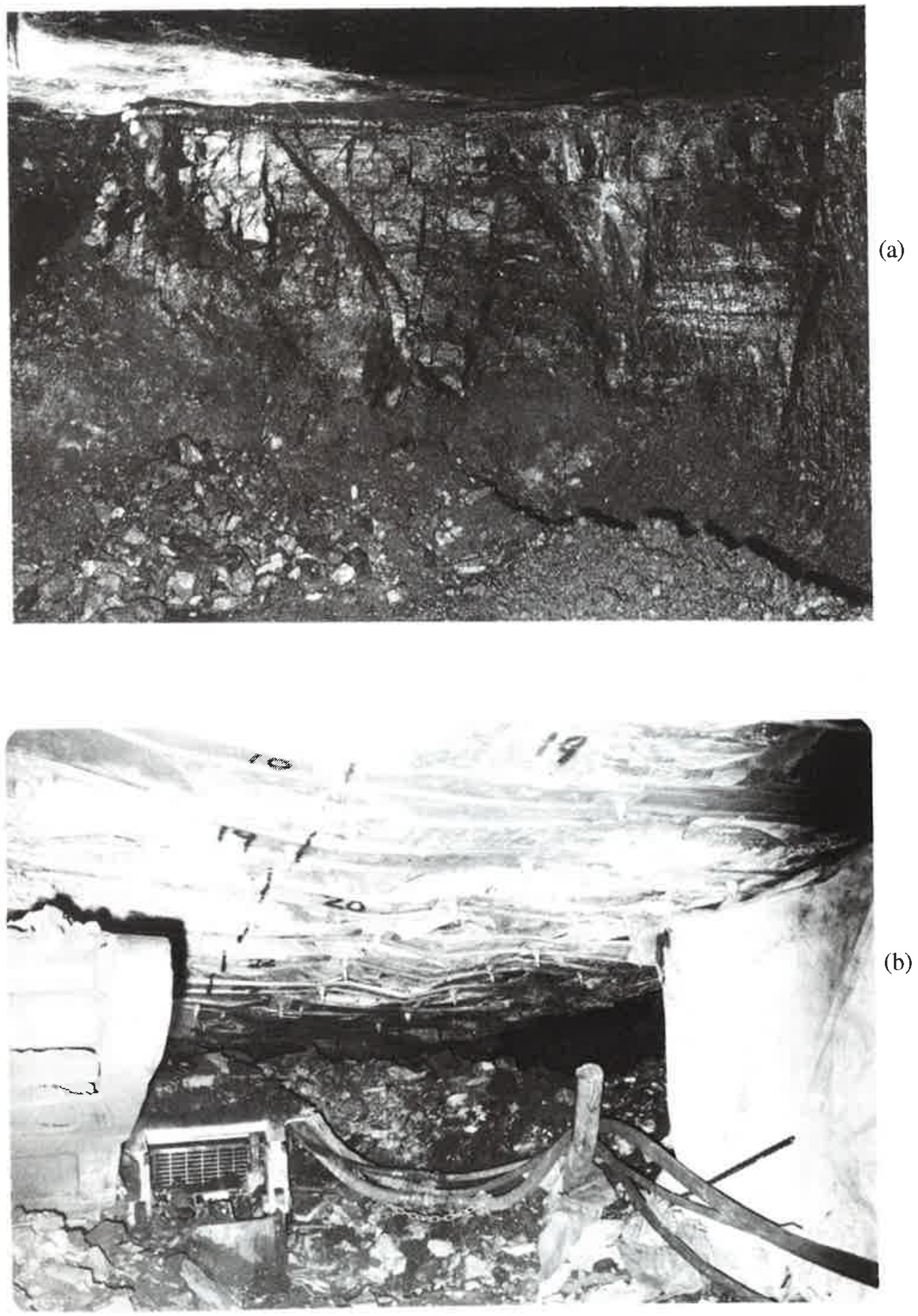

Fig. 3 Outbursts of coal and gas
(a) Methane outburst at shear zone, West Cliff Mine, NSW
(b) Carbon dioxide outburst at Tahmoor Mine, NSW

Fig. 3 (c) Outbursts of coal and gas
Stress controlled outburst
at Leichhardt Colliery, Qld. (now closed)

Fig. 4 Discing in coal core from the Bulli seam (465 m depth, 98% CO_2, 18 m^3/t)

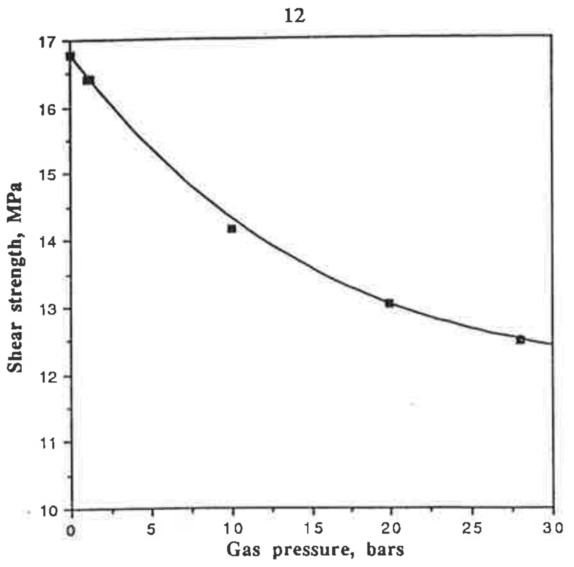

Fig. 5 Effect of carbon dioxide
on the shear strength of coal

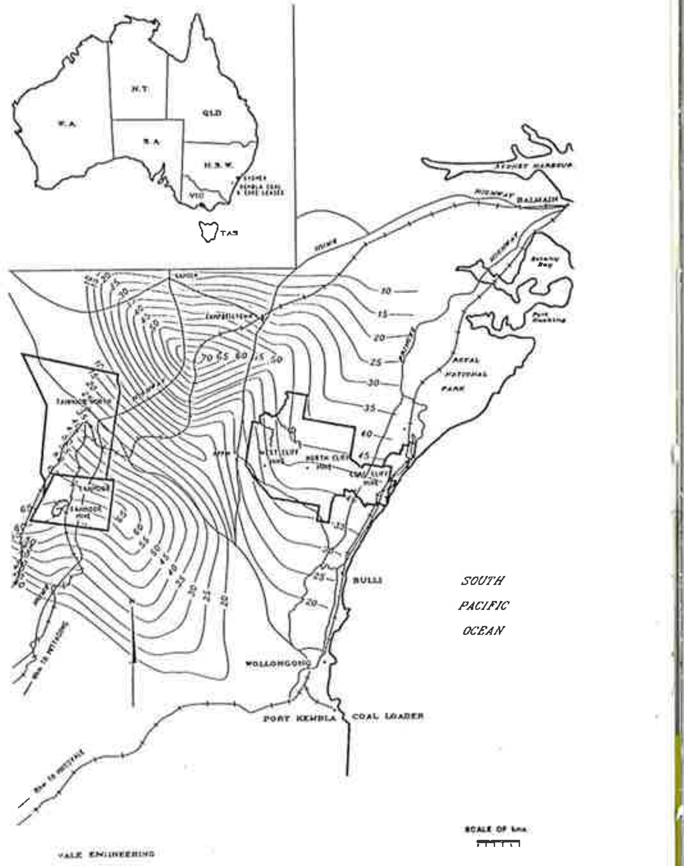

Fig. 6 Composition of gases in the Bulli seam
(40% - CO_2)

shallow syncline superimposed with additional synclinal and anticlinal structures trending north-west. The seam has been intersected by a number of major faults running north west with some minor faults trending north east, with some rotation of the structure clockwise towards the north and west. Igneous activity in the form of dykes has affected the margins of the basin and as a result some mines experience high CO_2 gas levels. The Bulli seam has a hard coking coal with medium volatiles. The volatile matter of the seam varies between 18 - 31% and ash content 8 - 23% with an average of 11.5%. The strength of the coal varies from 8 - 21 MPa and stress measurements show the ratio of the two horizontal stresses varying from 1.6 to 2.4 and the intermediate principal stress 1 - 1.6 times the vertical stress. The effect of high horizontal stress is to increase the depth of the fracture zone and cause a decrease in pressure gradients on the sides of the excavation.

The gas content and gas composition of the Bulli seam over the area varies within wide limits. In the seams closer to the outcrop, the gas content is very low. As the distance from the outcrops increases, the gas content increases. The maximum desorbable gas content as measured in the coal seam approaches about 20 m^3/tonne. The composition of this gas varies widely too. Change in gas composition can be very rapid, CO_2 up to 85% has been measured within 10 metres of the faults in a predominantly CH_4 West Cliff Mine. There are areas where almost 95% of the gas contained in the Bulli seam consists of carbon dioxide (Metropolitan Colliery) while in other areas 98% of gas is methane. Fig. 6 shows changes in gas composition on a regional basis. Composition of mixed gases (CO_2 and CH_4) is very difficult to measure. Changes in gas desorbed occur when CH_4 is released first from a core, followed by increased % of CO_2 from the samples. In boreholes, it may be quite different, with a decrease in CH_4 with time. The state of the core (fracture density) plays a dominant role. Gas compositions assessment is, therefore, not easy.

Cf results disprove this!! ?

Results of studies conducted in the laboratory on adsorption of CO_2 and CH_4 gases in coal samples taken from wide areas of the Bulli seam are given in Fig. 7. Gas pressure measurements in the mines vary from place to place. Highest gas pressure measured is 4,600 kPa. Table 2 shows gas property data in various mines on the South Coast. Fig. 8 shows gas content changes as function of depth of the Bulli seam. Obviously, gas content at depths below 350 m has been very low and as such methane outbursts have not occurred at these depths.

5 OUTBURST PREDICTION CRITERIA AND SAFE THRESHOLD VALUES

The prediction criteria that a particular seam is liable to outburst or not is not simple. Attempts have been made by a number of authors using criteria such as

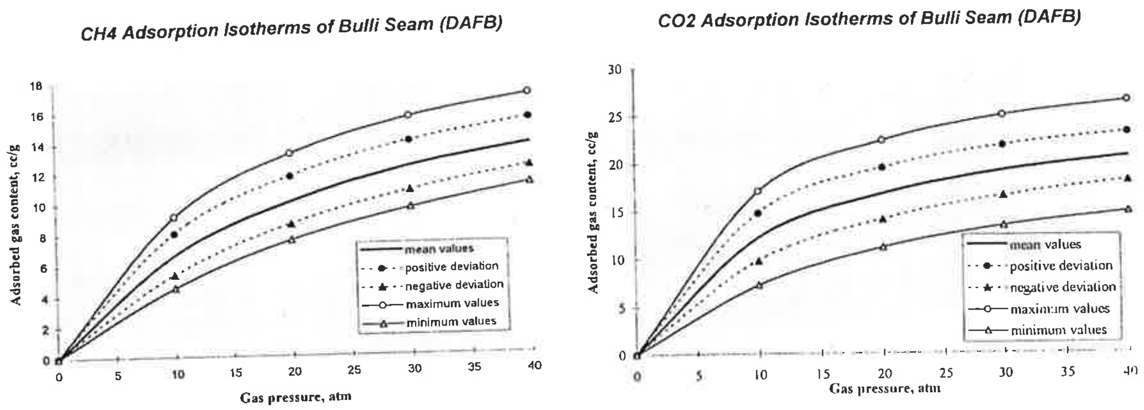

Fig. 7 Methane (left) and carbon dioxide (right) isotherms for the Bulli coal samples

Table 2. Summary of gas pressure measurements in the Bulli seam

Colliery	Dominant gas	Depth	Gas pressure	Ratio of (gas pressure/ Hydrostatic head)	Remarks on gas pressure measurement	Permeability MD
Appin	Methane	520	4200	0.81	Underground measurements	~2 - 5
West Cliff	Methane	465	2800 - 4200	0.60 - 0.91	Underground measurements	~ 0.5 - 2.5
North Cliff	Carbon dioxide & methane (25:75)	460	1530	0.33	Underground measurements	~2.5
Darkes Forest	Methane (90:10)	450	1830	0.46	Underground measurements	~3 - 5
Tahmoor	Carbon dioxide & methane (40:60)	430	1285 - 2200	0.30 - 0.51	Underground measurements	~ 2.5 - 4
South Bulli	Carbon dioxide & methane (80:20)	370	2500	0.59	Underground measurements	-
Tower	Methane	450 - 500	5800 2000	1.1* 0.42**	* Surface boreholes **Underground measurements	4 - 5
Cordeaux	Methane	450	900	0.2	Underground measurements	-

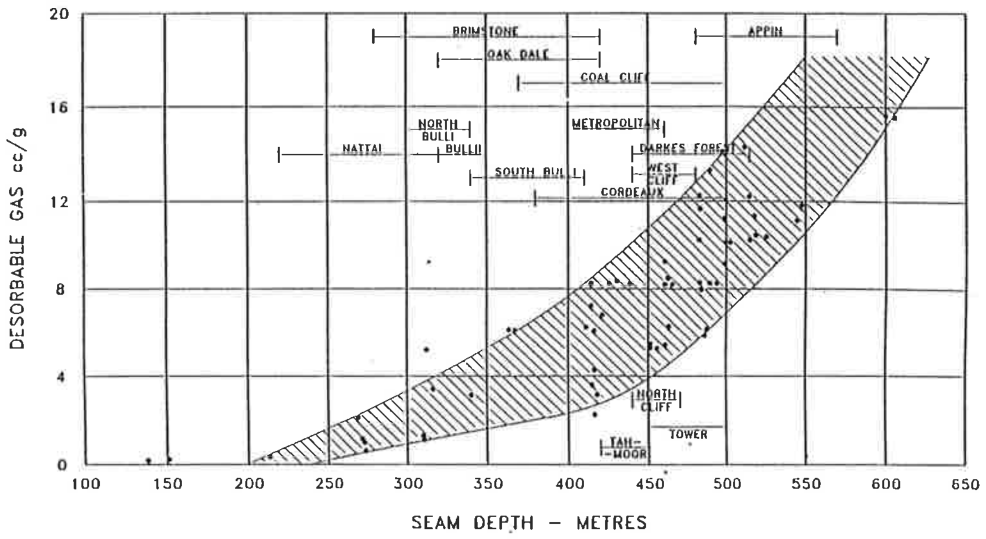

Fig. 8 Comparison of desorbable gas content of seam

gas content, rate of desorption, coal strength, coal cuttings volume from drill holes, phenomenological criteria, etc. Some of the work done in Australia and comparison of the parameters with conditions in other seams have lead to the suggested criteria given in Table 3 (Lama, 1980).

Table 3. Criteria for prediction of outburst conditions in mines

Parameters	Value
$\left(\frac{\text{Uniaxial compressive strength}}{\text{Vertical stress}}\right)$ ratio	<1.2
Fracture surface energy of coal, ergs/cm^2	<1.5 x 10^5
$\left(\frac{\text{Apparent porosity}}{\text{True porosity}}\right)$ ratio	<0.5
Mean pore radius	<0.005
Gas content, m^3/t	>7 (for CO_2) >10 (for CH_4
Rate of change of gas desorption rate (for CH_4)	>0.75
(Gas pressure/equivalent hydraulic depth)	>0.6
Presence of geological anomalies	Shear zones, reverse faults and zones of compression favour outbursts

The above criteria can be used for defining the proneness of a seam or a part of the seam prior to mining, but this is only a descriptive method and does not help in forecasting an outburst condition.

A number of different predictive methods on the occurrence of an outburst have been used in various countries. Some of the most commonly accepted are (Lama, 1991):

* heavy on Lama 1991 references

(a) Measurement of quantity of cuttings collected during drilling ahead of the face (Poland, Germany, China, Russia).

* (b) Rate of flow of gas from boreholes/unit length (Poland, Russia, Czech Republic). locate!!

(c) Temperature changes (-ve) in boreholes (Poland and Russia).

(d) Over pressure CH_4 (0.8 atm), CO_2 (0.3 atm) (Poland).

?(e) Desorption intensity (120 mm H_2O) or 1.44 m^3/g depending upon the equipment used (Borowski, Poland and Somnier in France).

(g) $\Delta P_{o\text{-}6}$ value >15 (Germany).

(h) Reduction in E (by a factor of 2), UCS (by a factor of 1.4), deformability increase (by a factor of 3) in lignite mines in Valenic - Slovenia.

(i) Gas content values (8-16 m^3/tonne depending upon local situation) (Poland, Russia, China). *

Safety barriers used in different countries vary from 2.5 to 5 m depending upon the seam thickness and is taken as approximately 2 times the seam thickness. * [illegible]

6 EARLIER WORK IN THE BULLI SEAM

The earliest attempts to develop safe threshold values were based upon measurement of gas emission rate practiced in many overseas countries in the late fifties and early sixties. A version of the French, Belgian and Polish emission meter was introduced to Australian mines by Hargraves (1962, 1963), Hargraves et al (1964) where a 4 g sample of -14 to +25 mesh (-0.047 in to 0.0236 in) fraction is taken and gas emission over a period of 2 - 6 minutes is measured. Certain indices were developed which showed that if the gas emission is more than 1.5 cc/g for methane and 1.2 cc for carbon dioxide, then the face is liable to outbursts. Drilling of large diameter holes (up to 300 mm) was tried to release stress (and gas content) as both stress and gas content were considered as the main reasons of outbursts. These indices were changed to suit local conditions particularly in CO_2 areas where the value was dropped to 1 cc/g equal to the index suggested in the late fifties in French mines.

Several problems existed with the determination of this index which are well documented by investigators who have used it both in Australia, France, Belgium and Poland. These include effect of moisture, variability of coal ply, location (face or corner), depth of hole, etc. With the introduction of high performance machines and particularly longwall mining, this method which requires frequent measurement in hole depth of 2 - 3 m, was found to be unsuitable and fell into disrepute as it greatly impinged upon the productivity and was at the same time unreliable.

Studies using large diameter holes (4 - 6 holes up to 300 mm) apparently designed for stress relieving (Hargraves et al, 1964) were used in Metropolitan Colliery. These holes effectively drained gas and were successful in lowering gas emission values.

Preliminary studies at West Cliff Mine in the late seventies showed that areas where shear zones have been drained and flow rates from holes have dropped to <2.5 l/min/m, these could be mined without the occurrence of an outburst. A major shear zone which has been the locii of a number of large outbursts was drained and mined through without any violence with only slumping of the coal and tripping off the miner.

Analysis of locii of outbursts on shear zones and their relationship with elapsed time the spacing (Fig. 9) showed distinctly the effect of face drainage, gas content and outbursts (Lama, 1982). Similar work on gas drainage at Tahmoor showed that when an area had been drained to gas levels between 9 - 10.7 m^3/t with CO_2 percentage 40 - 45%, there were no violent events even when structures such as dykes were present in the area. When the gas content was between 11 - 12 m^3/t with gas pressure of 1700 kPa, outburst mining precipitated an outburst with the emission of almost 3000 m^3 of gas. When gas levels were dropped to 6 m^3/t, no outbursts occurred. At Metropolitan Colliery which has experienced a number of fatal outbursts, the seam had been successfully mines with E_v values (Hargraves emission meter) below 0.6 and desorbable gas content of 4 m^3/t in 90% CO_2 areas.

A general summary of observations on gas content and gas pressures from direct observations and indirect method is given in Table 4.

7 RECENT STUDIES ON THRESHOLD VALUES - DESORBABLE GAS CONTENT

Based upon these studies and comparison with overseas data, threshold values for the safe mining of the Bulli seam were proposed in 1991 (Table 5). These threshold values took into consideration the differences in the initial desorption rate of methane and carbon dioxide as well as the effect of carbon dioxide on the strength of coal. Data on carbon dioxide and methane from Bulli coal samples shows that the 15 second desorption rates at 4 m^3 of CO_2 is almost equal to that of methane at 8 m^3/t and CO_2 decreased the shear strength of coal by 30%.

Table 4. Experience on the control of outbursts in the Bulli seam

Colliery	Desorbable gas content, m^3/tonne	Gas pressure, kPa	Gas type	Remarks
Metropolitan	< 4 m^3 ~ 6 m^3	350 * 475 *	90% CO_2 50% CO_2	No outbursts - shear zone present No outburst
West Cliff	10 * 10 * 8 * 11.5 *	1100 1100 600 1350	>95% CH_4 >95% CH_4 >95% CH_4 >95% CH_4	No outburst - thin shear zone present No outbursts - shear zone present No outbursts - shear zone present Minor outbursts - shear zone
Tahmoor	6.5 2.4 9-10.7% 7 m^3/t 11-12 m^3/t	500 * 250 * 700 * 600 750 *	CO_2 - 40-45% CO_2 - 40-50% CO_2 - 42% CO_2 - 40% CO_2 - 60%	No outbursts - dyke/fault present No outbursts - dyke/fault present Several peaks of gas emission but no outbursts - dyke/fault present No outbursts - dyke and fault zone present Outburst

* Indirect method

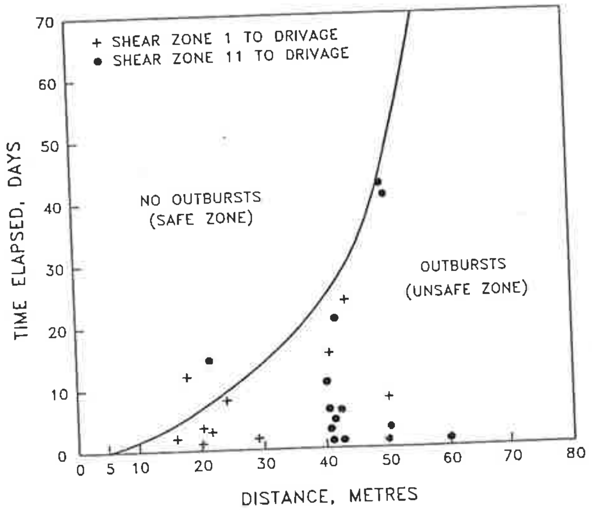

Fig. 9 Relationship between outburst spacing and elapsed time

Table 5 Threshold values for safe mining of the Bulli seam (Lama, 1991)

Conditions	Desorbable gas content, m^3/t.		Gas pressure, kPa (gauge)	
	Methane	Carbon dioxide	Methane	Carbon dioxide
Absence of a structure	10	7	1,000	700
Presence of a structure	8	4	700	400

These values were conservative and were proposed to take into account high rates of development of headings. Mathematical modelling had shown that the difference between high rates of development (75 m/day) and low rates of development (25 m/day) the gas pressure ahead of mining in the zone within 5 m of the face would be higher by a factor of at least 1.2. The above threshold values thus proposed included this factor.

Mining operations require that an answer to the gas content be available quickly so that mining can proceed. This has resulted in changes in the method of estimation of gas content. Instead of desorbing gas over longer periods, the core samples are crushed and total gas content values are measured. This does not allow separation of desorbable and residual gas content. The above threshold values need to be changed to total gas content values.

8 COMPARISON OF THESE THRESHOLD VALUES WITH OVERSEAS DATA

It is now accepted that the factors that influence an outburst are

(i) Tensile strength of coal
(ii Gas emission rate
(iii) Gas pressure gradient
(iv) Moisture level
(v) Depth or stress levels

Stress controls fracturing, and hence initiation of rapid desorption. The equilibrium between desorption and dissipation, when disturbed, leads to excessive build up of the free gas (static pressure gradient) and is the result of dislodgment of the coal and precipitation of an outburst. Threshold values based upon desorbable gas content, used in different countries depth of occurrence and strength values are given in Table 6. The relationship between tensile strength, gas content and depth was graphically established by Chernow and Puzyriew (1979) based upon data from Siberian coal fields. The outburst coefficient (OB Coeff) is calculated using the relationship suggested by Tarnowski (1990)

$$\text{OB Coeff} = \frac{\text{Depth x THV}}{\text{4000 x UCS}}$$

The table shows that the suggested threshold values for the Bulli seam give minimum OB Coefficient and is lowest compared to that suggested and used in other overseas countries and is much safer even when high rates of advance of faces are considered.

If an outburst was to occur in the Bulli seam without the presence of a structure, the gas content value will have to be at least 13 m^3/t of desorbable gas, or 15.5 m^3/t of total gas. Studies on failure of bore holes have shown that gas content is 18 m^3/t (total) where outbursts in bore holes have occurred in CO_2 areas.

9 THRESHOLD VALUES USING TOTAL GAS CONTENT

The total desorbable gas content data at atmospheric pressure, by definition, means the amount of gas that shall be liberated from a coal sample when allowed to desorb with time under one atmospheric pressure conditions.

The process of desorption however is very complex. It is associated both with the flow of gas through the crack system as well as the diffusion of gas from the coal matrix into the crack system. Flow of gas through the crack system with the open space at standard pressure temperature (unit atmosphere at 20°C) will stop as soon as the equilibrium between the pressure in the open cracks and the space surrounding the sample is established. The diffusion process however is not (only) pressure dependent, but concentration dependent. As such if the concentration of gas (CO_2 or CH_4) molecules in the

Table 6.

Country	Type of coal	Range of uniaxial compressive strength, MPa	Depth of occurrence, m	Threshold values, THV, cc/g (desorbable)		Minimum OB Coeff.	
				CO_2	CH_4	CO_2	CH_4
Australia Structure No structure	 Coking Coking	4 - 30	350 - 550 350 - 550	4 7	8 10	0.13 0.22	0.175 0.28
Poland (i) (ii)	Coking Coking	2 - 4 10 - 20	400 - 600 400 - 700	8	8 16	0.4 -	0.40 0.16
Russia	Coking & Anthracite	2 - 7	600 - 1,300		10 -12		0.90
Germany	Coking	6 - 10	800 - 1,300		9	-	0.30
Bulgaria	Coking	1.2 - 7	250		8	-	0.42
China	Coking & Anthracite	1 - 1.1	>10,000		8	-	0.40

space surrounding the sample falls below a certain level (0.7142 g/l for CH_4 and 1.964 g/l for CO_2), the diffusion of gas from the coal into the surrounding space will continue with the exchange of air molecules penetrating the coal matrix. The diffusion process is very slow and this takes a long time, but theoretically, if a coal sample is allowed to desorb in an open space, it will slowly lose all the gas.

It is therefore obvious that if the volume of coal enclosed in a canister is small compared to the volume of the canister, allowing sufficient time with frequent emptying of the canister, the residual gas in the sample will be lower than if the canister volume was much smaller.

AS 3980/91 and also methods used in USA (USBM) do not define the size of the container and its relationship with the sample size. There are no prescribed procedures which state when the desorption is complete for the determination of desorbable gas, except that the tests should be continued till "no" gas is liberated. The question of "no" gas depends upon the accuracy of the system and the methods used. Certain publications suggest that these should be continued till there are no emissions over the next 48 hours (or less than 0.01 cc/g over the 24 hour period or at least one negative value) or that the change in weight is less than 0.01 g over the 24 hour period when gravimetric methods are used.

In the tests conducted by the author the general rule followed is that desorption is complete when there is no gas emitted over the next 48 hours or there is at least one negative value observed as a result of minor pressure and temperature changes causing resorption of gas from the surroundings into the coal sample. The sample is then removed from the canister and crushed to measure the residual gas. The sum total of the desorbable gas and the residual gas gives the total gas.

For the purpose of modification of the threshold values from desorbable gas to total gas liberated on crushing the core, the data from the following tests has been used.

1. Results of tests carried out on core samples taken from surface boreholes over large areas of West Cliff mine.
2. Results of samples taken from underground drilling at West Cliff and Tahmoor.
3. Results of laboratory studies on sorption of gas into coal samples.
4. Data obtained by other independent laboratories.

Results are given in Table 7.

Obviously, the above mean values are influenced by higher values obtained from the laboratory sorption data. High laboratory sorption data is due to high vacuum and time applied particularly for dry samples and carbon dioxide gas. If the value for CO_2 (dry) is halved the means values for residual gases are as follows:

For CH_4, Residual gas, cc/g, $\bar{x} = 2.01$ ($\sigma = 0.21$)

For CO_2, Residual gas, cc/g, $\bar{x} = 2.4$ ($\sigma = 1.14$)

The recommendation for the new threshold values based upon total desorbable gas at one atmospheric pressure after crushing of coal cores ($Q_1 + Q_2 + Q_3$) is, therefore, as shown in Table 8.

Table 7. Residual gas in Bulli coal samples

Method		Residual gas, cc/g	
		CH_4	CO_2
Laboratory sorption	Dry	$\bar{x} = 2.21$ $\sigma = 0.32$	$\bar{x} = 6.76$ $\sigma = 0.93$
	Moist	$\bar{x} = 1.67$ $\sigma = 0.29$	$\bar{x} = 3.72$ $\sigma = 0.45$
U.G. sampling		$\bar{x} = 2.01$ $\sigma = 0.20$	$\bar{x} = 1.96$ $\sigma = 0.20$
Surface borehole sampling		$\bar{x} = 2.13$ $\sigma = 0.85$	$\bar{x} = 1.09$ $\sigma = 0.55$
Other independent labs. (underground sampling from KCC operations)		$\bar{x} = 2.0$	$\bar{x} = 2.90$
Mean	$\bar{x}$	2.00 (0.09)	3.27
	σ	0.21	2.14

Table 8. Recommended threshold values for safe mining of the Bulli seam (total gas)

Seam status	100% CH_4 m^3/t $[(Q_1 + Q_2) + Q_3]$	100% CO_2 m^3/t $[(Q_1 + Q_2) + Q_3]$
No structures present	10 + 2 = 12	7 + 2.4 = 9.4
Presence of structure	8 + 2 = 10	4 + 2.4 = 6.4

10 MONITORING OF OUTBURST SITES

Over the last three years, gas contents of sites which have been mined through have been monitored and the data so obtained has been analysed. The data from the sites where headings have been driven through the structures (geological discontinuities prone to outbursts) with or without outbursts is given in Fig. 10. The threshold lines plots (solid for structures and dotted without structures) clearly show that these values are safe and that a safety factor of 19% (1.1 m^3/t) which is higher than the errors in the gas content measurement using coring methods. A number of points lying between the two threshold lines (with structures and without structures) show outbursts occurring on structures. These outbursts are really small. Details of the tonnage is given in Table 9. As seen from this data, the size of outbursts

Table 9.

Point		Remarks
A (This point represents four outbursts)	1 2 3 4	Reclassified as no outburst Material thrown out = 1/4 of a car. Material thrown out = 1/3 of a car. Material thrown out = 1 car
B (This point represents three outbursts)	1 2 3	Material thrown out = nil Material thrown out = nil Material thrown out = nil
C (This point represents two outbursts)	1 2	Material thrown out = 1 & 1/3 cars Material thrown out = nil
D (This point represents six outbursts)	1 2 3 4 5 6	Material thrown out = 1.2 cars Material thrown out = 1/3 of a car Material thrown out = nil Material thrown out = nil Material thrown out = 3 cars Material thrown out = 1 car
E		Rollout, number of cars thrown out = nil
F		Rollout, number of cars thrown out = nil
G		Rollout, number of cars thrown out = nil
H		Violet outburst, but only three tonnes of material thrown out
I		Outburst occurring due to the presence of thrust fault immediately in the roof of the heading Number of cars thrown out = 4

lying between the threshold value for structure free and structured coal area resulted in outbursts which were too small to cause any major damage or endanger life of personnel. The lower threshold values of 6.4 m³/t and 9.4 m³/t for CO_2 and CH_4 are definitely safe under all circumstances even when the rate of advance is raised to 50 m/day. If the rates of advance are lower, and in the range of 10-12 m/day, the above values should be multiplied by a factor of 1.2.

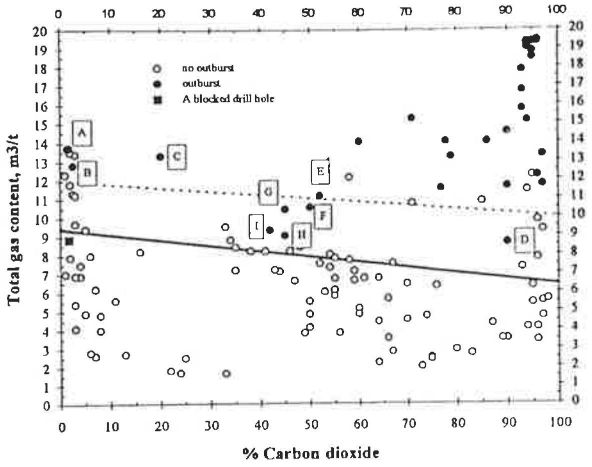

Fig. 10 Total gas content data close to structures*, Tahmoor and West Cliff Mines

CONCLUSIONS

Threshold values for safe mining of the Bulli seam occurring in the Illawarra region of NSW have been forecasted. The proposed threshold values based upon total gas content using coal sampling from underground are 9.4 m³/t for methane and 6.4 m³/t for carbon dioxide under conditions when mining close to geological structures and high rate of advance (25 m/day). These threshold values can be raised to 12 m³/t for methane and 10 m³/t for carbon dioxide when it is known that no geological structures are present within 5 m of the excavation during development of headings in the virgin areas. These threshold values have proven to be safe where a number of structures have been mined through over the three year period. The suggested threshold values present outburst coefficients for the Bulli seam that are safer when compared with those used in many overseas countries.

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[*] Structure is defined here as a discontinuity which is prone to an outburst. The size of the discontinuity is difficult to determine with the present technology.

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