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A Practical Approach to the Determination of Outburst Thresholds

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ABSTRACT: The current Australian reliance on gas content and DRI index used in Outburst Management Plans leads, in many cases, to an ultra-conservative approach to coal mine development. It is also contrary to overseas practice where other factors are taken into account. Outbursts must start with failure and that failure must produce fragments. It is therefore a process of fragmenting failure. For this to occur the coal must have some pre-existing structure within it. Determining whether a fragmenting failure will take place is dependent on the effective stress within the coal and the strength of the coal. Thus determining the strength of the coal and the structure within it are paramount, both on the small and large scales. A key element in the effective stress equation is the gas pressure. Once failure has occurred the question is whether that failure takes place with sufficient energy to provide a serious risk? The energy comes from gravitational effects, strain energy and expanding gas. The energy from expanding gas tends to dominate and is dependent on gas in pore space and desorbing gas. The desorption rate of the latter is dependent on the diffusive characteristics of the coal, the gas content and the fragment size. To be able to practically characterise a coal for its outburst proneness it is necessary to measure more than is current practice in Australia. What is required is determination of structure at various levels, the measurement of diffusion coefficient like behaviour, strength by Protodyakanov Index, or by rapid depressurisation (Pop Gun Test) as well as gas content.

INTRODUCTION

The purpose of this paper is to present an improved approach to the determination of outburst risk compared to current Australian practice. The need is to ensure safety in mining but not to prevent mining in circumstances that would present a minimal threat.

To be able to do this the paper endeavours to explain what an outburst is. It also examines current Australian practice and compares it to that used overseas. It then looks in a more fundamental level at the outburst process and the energy release that occurs during these events. Using a combination of practical tests, observations and theory it is possible to arrive at alternative approaches to those in current use in Australia. These provide a sounder basis than those currently used. These approaches are not however based on a simple single parameter test.

This paper is to a significant extent a synopsis of the work contained in the ACARP project C23014 (Wood and Gray 2015) and reference should be made to that substantial document and its appendices to gain the full description of the work and conclusions.

WHAT IS AN OUTBURST?

An outburst is a violent expulsion of coal and gas from a working face. Sometimes rock is also dislodged in the outburst. An outburst is a process that follows failure of the coal or rock. Whether the failure then transforms into an outburst is very much dependent on the mode of failure, the gas storage and gas generation during that process. Outbursts cause fatalities by two mechanisms; the first by mechanical injury caused by moving particles and gas, whilst the second by asphyxiation due to displacement of air by the gas evolved. Outbursts also occur from rock, notably porous sandstones and porous or vuggy salt deposits. It is suggested that the division between outbursts, rockbursts and gravitational slumps can be determined by plotting the potential energy release on a ternary diagram as shown in Figure 1.

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In examining what is a very extensive amount of literature on outbursts in coal from around the world it is apparent that the worst outbursts in coal have occurred during the entry from rock into sheared coal associated with faulting. Indeed Russian standards specifically require greater care to be taken on entering a seam as compared to driving a roadway in seam.
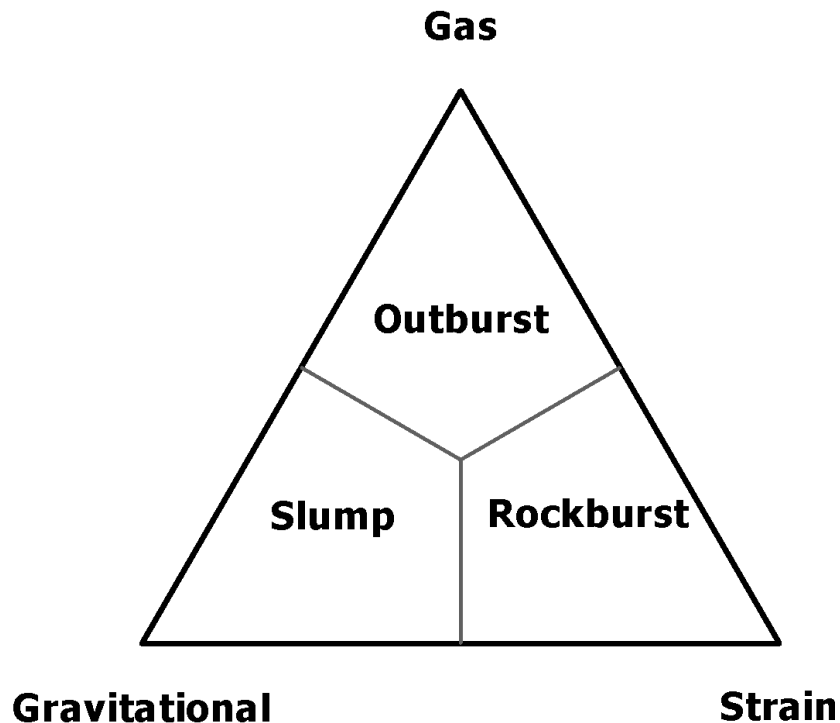
Gas

Outburst

Slump   **Rockburst**

Gravitational   **Strain**

Figure 1: The proposed basis of determining whether an event is an outburst, rockburst, or slump based upon the potential energy components

One large outburst occurred at Luling mine in Anhui province, China on 7 April 2002. It involved rock drivage into a coal seam at the location of a fault. It produced 8 730 tonne of coal and rock and 0.93 million cubic metres of gas. A sketch of the mining situation at Luling is given in Figure 2 and the result in terms of coal and rock ejected is shown in Figure 3. A similar case was that of Sanhui Mine in Sichuan where on 8 August 1975 an outburst occurred that produced 12 800 tonne of coal and rock with 1.4 million m^3 of gas. In both cases the gas was methane.

Large outbursts do also occur with mining in coal. On 25 April 2007 one occurred at Dashucun Mine in Hebei province. It involved mining in No 4 seam which should have been destressed and degassed by the mining of an adjacent seam. This did not take place because complex faulting had meant that a pillar was left in place. When No 4 seam was mined in the stressed environment 1270 tonne of coal and 9.3×10^4 m^3 of gas was released in an outburst.

The Sanhui mine outburst followed shotfiring while the Luling case followed the use of an air pick. Outbursts of this size can readily lead to the total loss of a mine, as there is gas to ignite and coal dust to explode.

Many of outbursts that are severe occur on geological structures in the coal seam that contain gouge (ground up) material. Some however occur from solid coal which fragments during the outburst. Examples of two kinds of outburst can be seen below.

Figure 4 shows a sketch of an outburst that occurred at Westcliff Colliery, NSW which moved the continuous miner backwards. The energy source of this outburst was a sheared zone of coal behind the face.

Figure 5 shows a sketch of a typical outburst that occurred from solid coal at Leichhardt Colliery, Queensland. Here the outbursts always occurred across the cleat, often preceded by an onion ring appearance in the face before buckling occurred outwards leaving a cone in the ribside. The size of these outbursts varied from 1 to 350 tonnes.
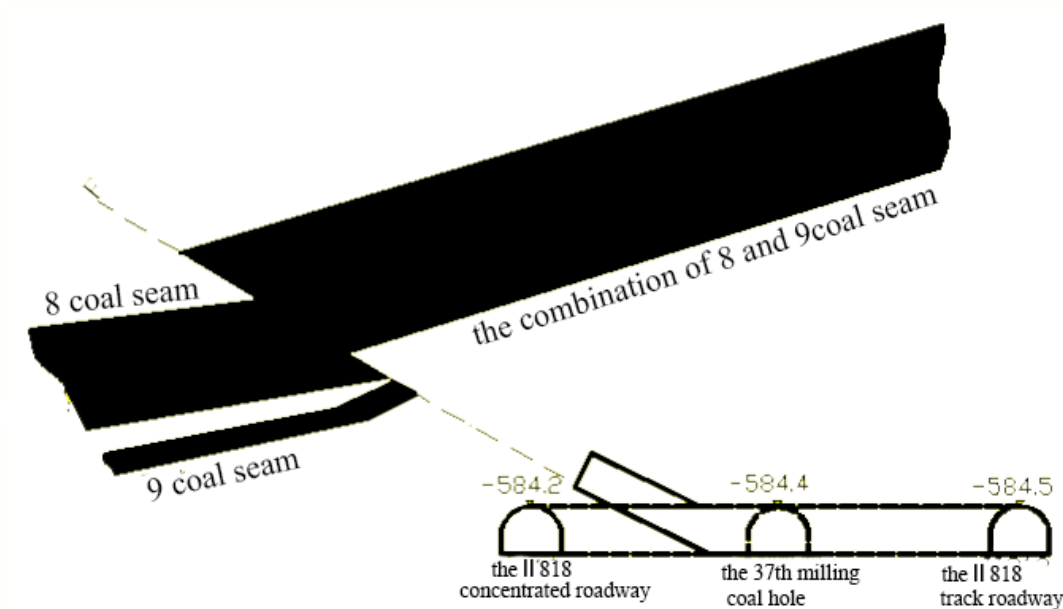

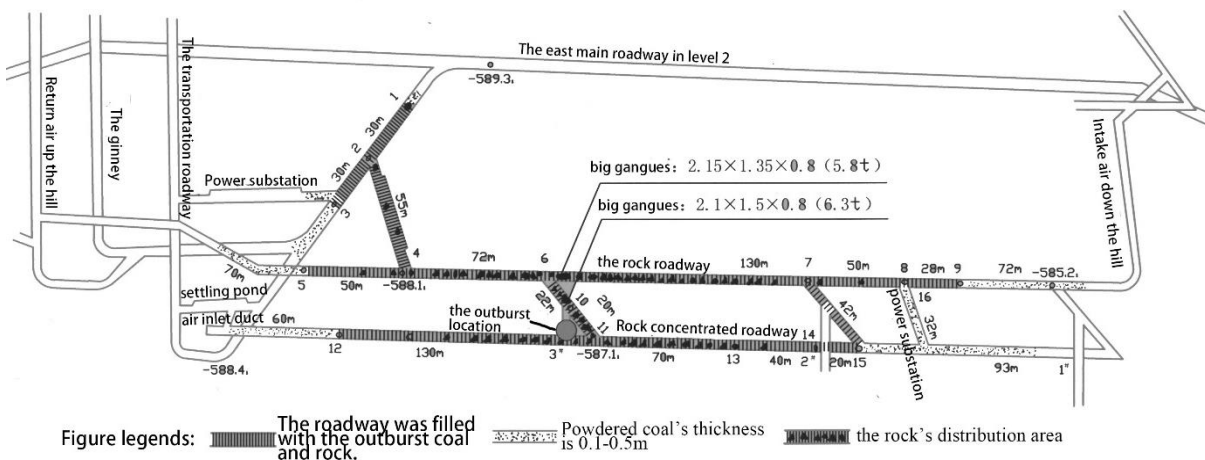**Figure 2: the schematic diagram of 8 and 9 coal seam**

Figure 3: The accumulation of the coal and rock ejected

For an outburst to occur, failure of the coal must first take place. Failure is commonplace in mining and is due to the effective stress exceeding the material (in this case coal) strength. In an outburst the failure is accompanied with the release of energy and gas. The key to understanding outbursts is determining the likely sources of energy release while the key to controlling them is in minimising the potential for energy release.

In their paper Black *et al.,* (2009) show some relaxation to the gas contents (Figure 6) for Tahmoor and Westcliff Collieries. In the case of Tahmoor some note is taken of coal structure.

To complicate matters further GeoGAS introduced the Desorption Rate Index (DRI) as an indication of outburst proneness. This test involves the taking of a core for gas content measurement as per quick crush measurement (AS3980-1999). There is some initial but variable gas loss before the core is placed

in the canister. This is followed by additional gas loss while the initial rate of gas desorption is determined. The canister is then sealed and the gas content of the core approaches some state of equilibrium with the partial pressure of the gas in the canister. This is dependent on the amount of coal in the canister, its gas content prior to being placed in the canister, the dead volume of the canister and in addition the temperature of the canister. At the laboratory the canister is drained of gas, the volume of which is measured, and the core removed 3.
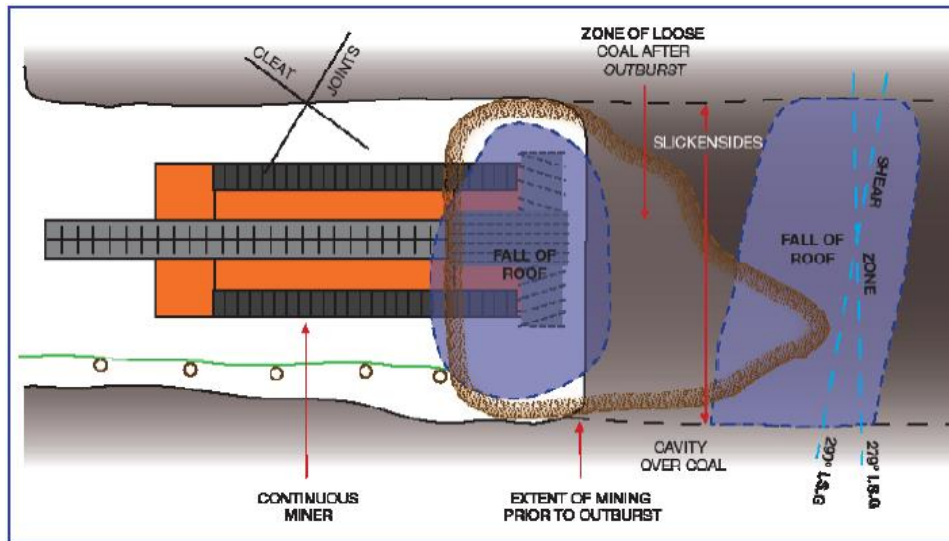

Figure 4: A plan of an outburst that occurred at Westcliff Colliery (Adapted from Marshall *et al.,* 1980)
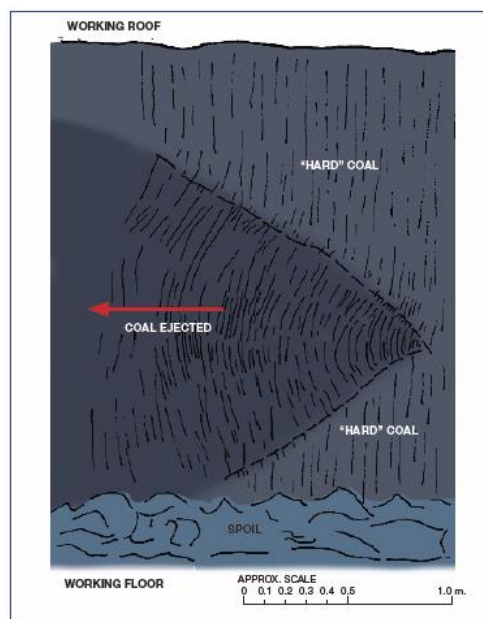

Figure 5: A typical view of the ribside after mining through small outburst cone at Leichhardt Colliery (Adapted from Moore and Hanes 1980)

A sample of approximately 200 g is then taken from the core and crushed (in a specific crusher) for 30 seconds and the gas volume that is released is measured. The gas release during this process will depend on the gas content of the coal taken from the canister, the degree to which the core breaks up on crushing and the diffusional behaviour of the coal fragments.

If the sample is of a different mass than 200 gm the volume released is corrected by ratio to this mass. The DRI value is then calculated by multiplying the volume released during the 30 second crush by the

ratio of the total gas content from the full desorption process to the gas released from the 200 g sample during the 30 second crush.
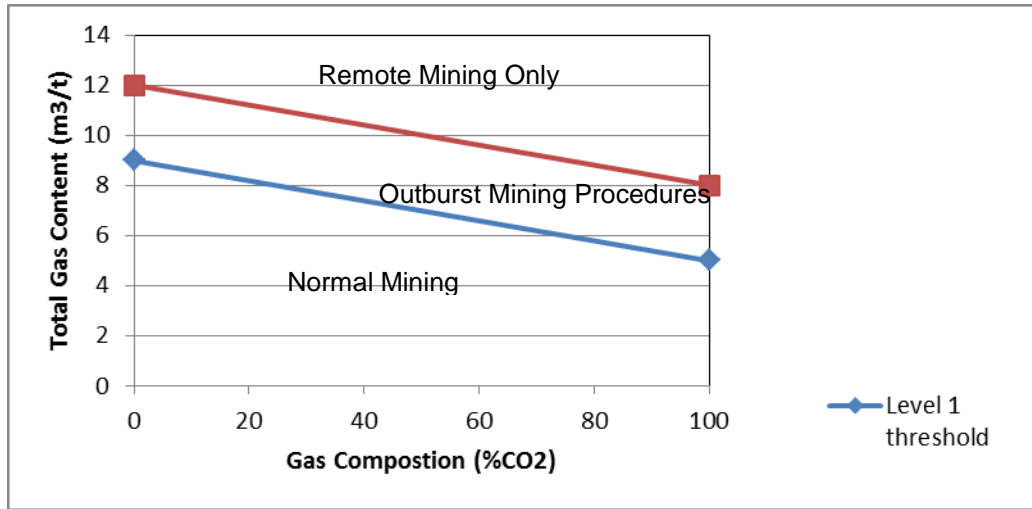

Figure 6: Example of threshold values used for mining within the Bulli Seam with respect to gas content and outburst risk

This final correction tends to force all the DRI values to follow the gas content. Hence the linearity of the plot shown in Figure 7 which is used to justify the use of the DRI process. In Figure 7 it is possible to see that the value of DRI of 900 ml in the first 30 seconds of crushing corresponds to an initial gas content of 9 m^3/t of methane or 6 m^3/t of carbon dioxide in Bulli seam coal. These gas content values are Lama's (Lama, 1995) estimates of the gas contents that lead to outbursts. This is the justification by GeoGAS for the use of the value of DRI 900 as an indicator of outburst conditions.
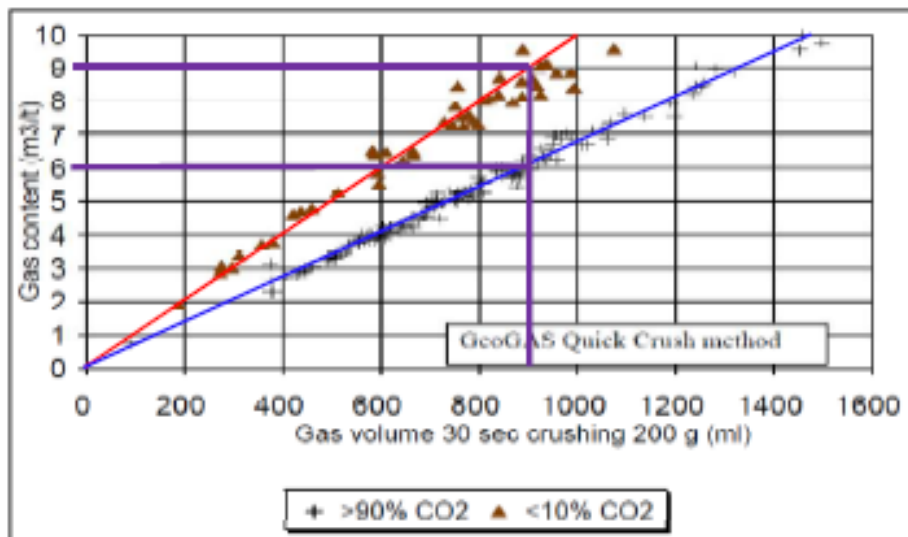
Figure 7: Presentation of GeoGAS desorption rate (DRI900) relative to Lama's outburst threshold limit values. Taken from *Black et al 2009*

The process of arriving at a DRI value is described further below with reference to the isotherms shown in Figure 8. The steps shown are:
1. The initial gas content and pressure
2. The gas content following some loss on coring
3. The gas content following further loss due to Q1 sampling
4. The drop in gas content and pressure as an equilibrium is approached between coal gas content and the canister pressure.

5.   The gas content at 1 atmosphere partial pressure of gas

The 30 second quick crush of the DRI approach obtains some of the gas between points 4 and 5 and then multiplies it by the ratio of the total gas content/gas released in 30 seconds.
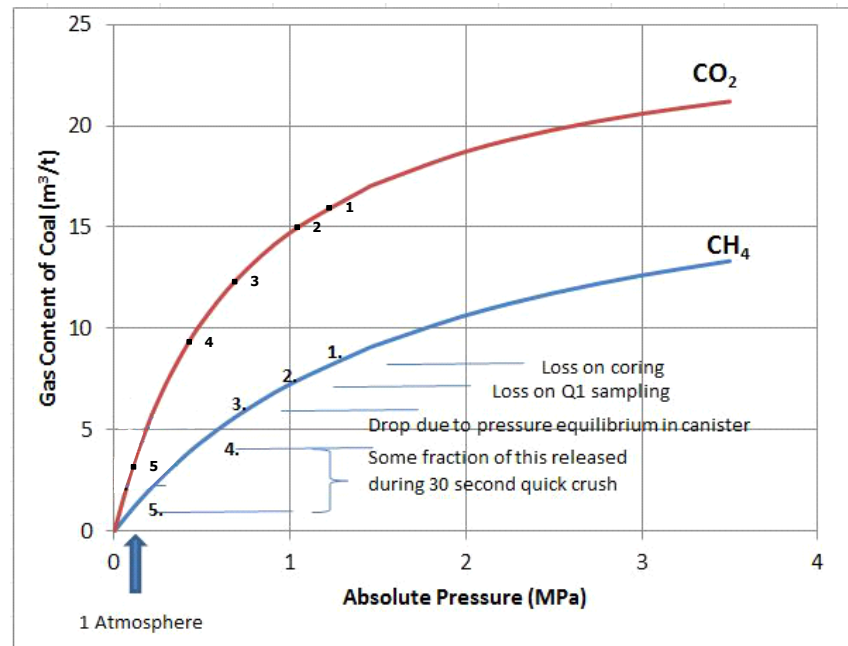

Figure 8: Methane and carbon dioxide isotherms showing the stages of pressure/volume drop through the process of gas content determination

Worryingly there has been a trend to use the DRI 900 value to determine whether non Bulli seam coals are outburst prone. This compounds the problems of measurement error with inconsistencies between coal seams. It is the opinion of the authors that the DRI 900 measurement is an unreliable indicator of outbursting conditions that is founded on pseudo-science fitting a straight line to some group of data without adequate thought to the measurement process and the errors it contains.

OVERSEAS OUTBURST RISK THRESHOLD DETERMINATION PRACTICE

The basic practice of outburst threshold determination may be broken into several categories. These are:
1.   A determination of mining area proneness obtained by experience
2.   Examination of the geology with particular reference to structure
3.   Tests conducted locally to determine parameters which can be broken into:
   a.   Pressure measurement
   b.   Toughness measurement
   c.   Drilling tests
   d.   Gas desorption indices

The process of determining the outburst proneness by experience is one that most miners would prefer to avoid.

The careful examination of geology is important. Changes in coal structure are often the key to conditions becoming outburst prone. The Chinese description of coal structure is useful here. It is shown in Table 1.

Gas pressure measurement is regarded as being of particular importance by the Chinese. Pressure is a fundamental parameter and great care is taken to measure it. This is done by drilling cross measure and cementing a pipe in through stone which is then connected to a pressure gauge. While some outbursts have been reported from 0.61 MPa gauge the threshold value for outbursting is considered to be 0.74 MPa gauge. The gas pressure threshold used in the coal seams of the Pechorskiy basin, Primorie and Sakhalin Island in Russia, is10 kgf/cm^2 (1 MPa).

Table 1: Chinese strength definitions of structurally affected coal

Failure Mode	Structural Mode Name	Structural Features	Strength
I	Unbroken Coal	Layered and blocky structure;	Hard;
		Strips are obvious.	Hard to break by hand.
II	Broken Coal	Layered structure;	Medium hard;
		Strips are obvious with movements;	Easy to break by hand.
		Irregular shape with angle;	
		Compression properties.	
III	Seriously broken coal	Tectonic lens structure;	Low hardness;
		Small and schistose structure;	Easy to break into powder by hand.
		Fragments.	
IV	Comminuted coal	Cemented small particles.	Occasionally hard hardness;
			Easy to break into powder by hand.
V	Pulverized coal	Soil structure;	Loose;
		Gouge materials	Easy to break into powder by hand;

Toughness measurement is somewhat different in that it is not a measurement of a fundamental parameter of toughness which can be defined as the energy required to cause rupture per unit volume. This is difficult to achieve. What is used instead are two tests that are index tests. Index tests are tests that make a measurement that is dependent on several fundamental parameters. In the case of coal toughness, two tests are used, both of Russian origins. The first is the Protodyakanov Index which is used both in Russia and extensively in China and involves the use of a simple drop hammer. The second is a penetrometer gun that is used to test the toughness of coal plies underground.

The *Protodyakonov index* is measured by drop hammer test. This is a test on lump coal with measurement of the coal size reduction. The process involves four weighed sets of coal consisting of 5 subsamples each with size range 20 to 30 mm and weight 40-60 g. The subsample is placed in an apparatus (Figure 9) comprising a drop hammer of 2.4 kg weight with a 600 mm travel. The diameter of the hammer is 66 mm and the tube it falls within is 76 mm. The number of hammer blows depends on coal strength and is determined experimentally. The amount of fines of less than 0.5 mm diameter is measured in a measuring cylinder (a tube of 23 mm diameter). The height of fines in the measuring tube after crushing of one set (5 subsamples) should be in the range of 20 – 100 mm, otherwise the number of blows should be adjusted experimentally. For the coal usually one blow is enough, but for some strong coals 2-3 blows are required.

The *f* coefficient is defined by equation 1:

$$f_{20-30} = \frac{20*n}{h} \tag{1}$$

where f_{20-30} is the toughness index (for 20 to 30 mm size range), *n* is the number of hammer blows, *h* is the scale measurement in the cylinder after 5 subsample tests (mm).

The final result is an average of 4 measurements.

Slastunov reports that there is quite a wide variation in the *f* value of outburst and non outburst prone coals but that a value of *f* less than 0.54 indicates a high likelihood of outbursting in the Kuzbass. The general threshold value used in China is 0.5.

The Chinese extension to the test method for fine coal where it is not possible to obtain 20 to 30 mm lumps is to sieve the sample for the 1 to 3 mm range. This is then hammered three times and the size reduction noted by a measurement in the fines cylinder.

In this case, if $f_{1-3} > 0.25$ using equation1 with *n* = 3 then the equivalent

$$f_{20-30} = 1.57 \times f_{1-3} - 0.14 \tag{2}$$

Otherwise if $f_{1-3} \leq 0.25$ then $f_{20-30} \equiv f_{1-3}$ (3)

Russian penetrometer gun – Index q

This is a spring loaded penetrometer system that has to be wound up and fired into coal at the face. A number of tests need to be undertaken in each ply. Tests within plies need to be averaged and different plies show quite different results. The probe is designed to penetrate with energy of 27 J, however the mass and velocity are unknown. The device is shown in Figure 10. The *q* index is calculated from the penetration of the probe punching into the seam according to equation 4. The penetration result is determined from the average of 5 measurements with 5-10 cm distance between locations.

q = 100 — *l* (4)

where, q is the value of the q index, l is the depth of the probe penetration (mm).

If $q \leq 75$ the ply is considered to be outburst prone.

Figure 9: Drop hammer equipment – measuring cylinder with scale and tube with drop hammer

Figure 8: Russian penetrometer gun for q index test

The Russian literature seems to consider that there is a correlation between the *f* index derived from the Protodyakanov Hammer and the *q* value from the penetrometer gun. This relationship is given in equation 5, though the correlation is not exact.

f = 0.4 *q* (110- *q)*   (5)

Cuttings volume determination

Chinese, Russian and Kazakh operators use a measure of the cuttings volume generated on drilling as an indication of outburst risk. The Germans also used this system when they mined underground. The system did not however work when tried at Leichhardt Colliery in Queensland. The general idea is that a hole of a known diameter is drilled using air flush or a scroll (auger) drill and the volume of the cuttings

generated is measured and compared with the theoretical hole volume cut. The volumetric difference may be very great.

Cai and Luan (1995) report the drilling of a 43 mm hole. The nominal volume of such a hole is 1.45 litres/m. The partial outburst threshold is considered to be 7 litres/m of coal corresponding to an over break to a nominal diameter of 94.5 mm and is five times the expected hole volume. Slastunov (2014) reports French and Belgium experience where the over break volume in outburst prone areas was 5 to 8 fold for 115 mm diameter holes while in non-outburst prone zones it was 2 to 3 fold. The latter seems to be a large value.

Borehole Flow Tests

Another test used in China, Russia and Kazakhstan are those where a section of hole is drilled and a packer system inserted. The flow per unit length is then measured shortly after drilling. This test provides the desorption value, g (l/min). These tests have been used in extremely impermeable coals and seem to be more of a measure of the diffusion rate from the hole wall than a measurement towards deriving permeability. Indeed high permeability coals are less outburst prone because they drain ahead of the face provided that the advance rate is not too fast.

Desorption Indicies

A whole series of desorption tests have been developed for use on cuttings derived from drilling. Most of these are of the form where cuttings are collected within a certain period from drilling using a hand held auger (scroll) drill. They are then sieved to a size range and this is sealed within a container for a certain period after drilling. The desorption rate or pressure rise corresponding to it is then measured over this short period and regarded as being an outburst index. This is the nature of the Chinese Drilling Cuttings Desorption index (CDCDI) parameters. This yields the Parameters *Δh2* and *K1*. The Polish mines use a virtually identical instrument *(*Lunarzewski 1995 and Lama 1995 b*)*. The Chinese have also developed an electronic instrument for a similar measurement. Indeed the concept of these tests is not far different from the Hargraves' emission meter used in Australia until the early 1980's.

The main problem with these desorption tests is that they look at a snapshot of the desorption process on a very controlled size range. The measurement period is not enough to define gas content or diffusional behaviour.

Another type of testing that was in vogue consisted of several kinds of adsorption tests. In these the samples uptake of gas was measured. One form of uptake test, the $\triangle P$ index, is used in China and forms the basis of one of their outburst proneness determinations.

Combinations of tests

Cai and Luan (1995) proposed the combined approach of these three measurements as being indicative of outburst conditions. Their criteria were that the volume of cuttings from a drilled length of a 43 mm diameter hole was 7 times the nominal drilled volume. In addition the initial measurement of gas flow rate per unit length of hole per metre within 2 minutes of drilling exceeded 3.8 litres/minute. Finally that Δhz gas desorption volume from 1 - 3 mm coal cuttings exceeded a set value.

Zhang (1995) describes another combined approach which is part of current Chinese outburst determination practice*.* In this Outburst conditions are considered to have been reached if *K* reaches some value.

$$K = \frac{\Delta P}{f} \tag{6}$$

Where, ΔP is the initial speed of desorption from coal and *f* is the Protodyakonov Index.

It is not the normal ΔP which is measured on absorption. This is presumably a function of gas content, particle size and diffusion coefficient and is possibly a pressure rise measurement in a borehole.

Zhang (1995) also describes the D Index which is part of the current Chinese outburst risk determination practice.

$$D = \left(\frac{0.0075H}{f} - 3\right)(P - 0.6) \tag{7}$$

where, H is the depth (m), P is the gas pressure (MPa), *f* is the Protodyakonov index on the softest ply of coal.

If *D* exceeds 0.25 the coal is considered to be outburst prone. The equation is however only consistent over a limited range of variables. Table 2 gives the current legal basis for mining to avoid outbursts in China.

Table 2: Combined Chinese parameters for discontinuing mining

Coal	Structural mode	Initial rate of gas adsorption, $\triangle P$ (mm Hg)	Coal hardness coefficient, *f*	Gas pressure, P (MPa)
Thresholds	Ⅲ, Ⅳ, Ⅴ	≥10	≤0.5	≥0.74

It would appear that where gas pressure cannot be satisfactorily measured a gas content of 8 m3/t has been fairly recently accepted. Measuring gas content in highly gassy coals, that are prone to disintegrate on coring, causes great problems in some Chinese mines.

Kuzbass - Outburst forecast during coal seam entry

As many of the worst outbursts have occurred on entry to a coal seam from workings in stone it is Russian practice to take great care before proceeding to do this. In the Kuznetskiy (Kuzbass) basin in it is practice to measure the maximum seam pressure from a hole through rock into the seam and to obtain core samples for testing with the Protodyakanov hammer. They use equation 8 to combine these two measurements.

$$\varPi_{\text{в}} = P_{\text{g.max}} - 14 f_{\text{min}}^2 \tag{8}$$

where, f_{min} is the minimum value of the Protodyakonov Index, $P_{\text{g.max}}$ is the maximum gas pressure in seam at a given depth, kgf/cm^2 (0.1 MPa) and $\varPi_{\text{в}}$ is the parameter determined by the equation.

If $\varPi_{\text{в}} \geq 0$ then the seam in the mining area is considered as outburst prone. This equation has a consistent form.

In the mines of the Rostov region outburst forecast in a mining area is based on desorption rate (*g*), iodine index ($\triangle I$), and the strength coefficient of the coal (*f*).The coal seam is not outburst prone if all of the following conditions apply: g $\leq$ 2 l/min; $\triangle I \leq$ 3.5 mg/g; $f \geq$ 0.6

The desorption rate g is measured in 43 mm diameter boreholes drilled from rock to the seam from a distance not more than 3 m to the seam. The desorption rate is measured in two boreholes not later than 2 min after drilling.

In summary it can be seen that these combined parameter assessments include pressure, toughness and sometimes depth and a diffusion rate term.

STRUCTURE IN COAL

As part of the recent ACARP Project C23014 (Wood and Gray 2015) an examination was conducted into the structure of apparently solid coal. This was driven by a need to understand the failure process in outbursting. An understanding was sought as to why failure occurred without a surface existing on which fluid pressure could act. Examination of some polished surfaces of Australian coals showed multiple pre-existing fracture planes within the coal. The spacing of these fractures was in the order of a few millimetres but varied substantially with the coal and ply. Figure 9 shows such a polished section. It is obvious from this that a large number of fractures exist within this sample. It is considered that these form the basis of the fragments that form on failure. Importantly they form the difference between failure and the fragmenting failure that characterises an outburst.

A test was devised to determine whether fragmentation on sudden desorption did indeed take place on these fractures. This involved cutting a specimen from very close to the core shown in Figure 9. This was cut in half and one part placed in a vessel where it was pressurised for 3 weeks and then suddenly depressurised. The fragment size was measured. The second half was examined for pre-existing structure. It was found that the fragmentation that took place was of a very similar sizing to the inter fracture spacing. The test equipment used for this purpose has been endearingly described as the Pop Gun.
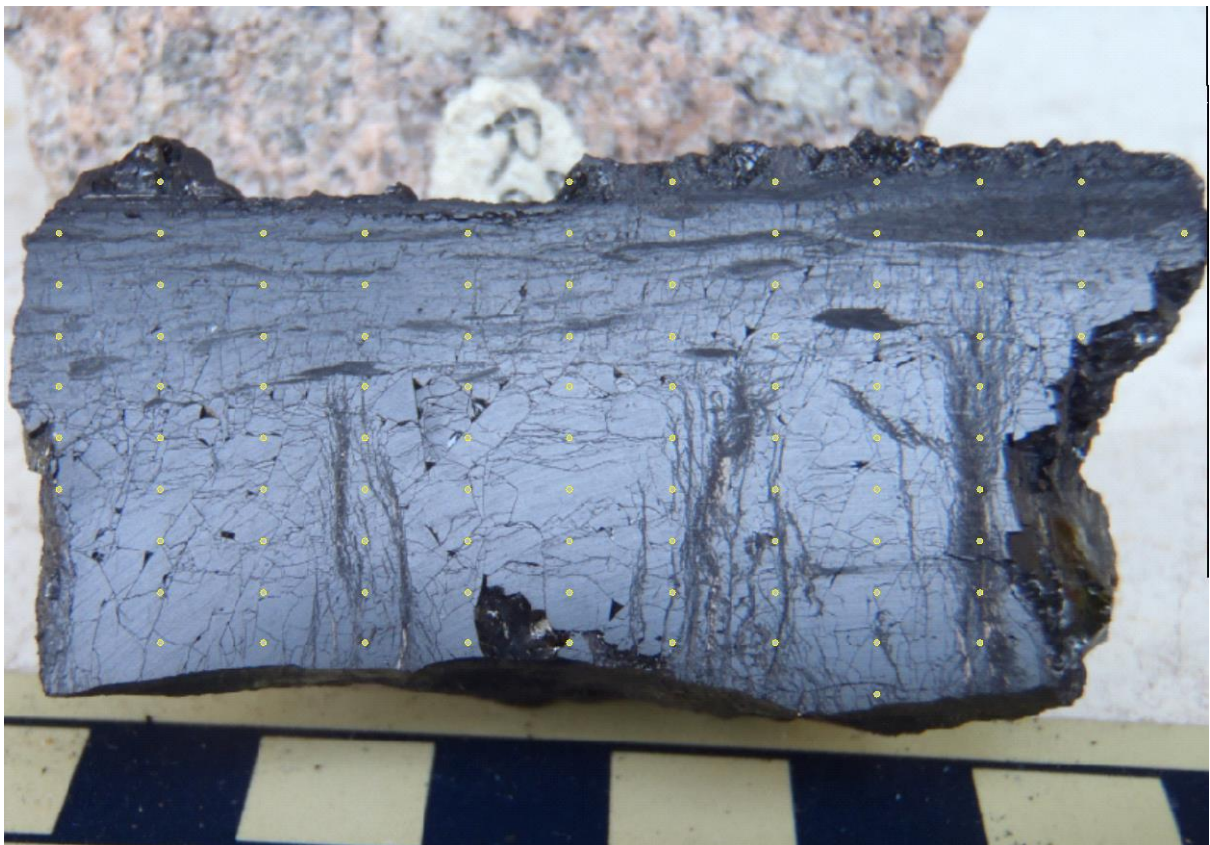

Figure 9: Polished section of HQ (61 mm) core showing structure. Vertical dots at 2.5 mm spacing, horizontal dots at 5 mm spacing

ENERGY APPROACH

In the work by Gray (2006) for ACARP and revised by Wood and Gray (2015) the total energy available for release was considered to be fundamental in determining the severity of an outburst. The sources of energy for an outburst are considered to be:

- Strain Energy from Rock and Coal – This is dependent on the state of stress in the coal and its elastic properties. Very often the state of maximum stress is limited by failure at the face. In the case of outbursts that progressively erode from the face into solid coal, the state of stress varies from that at the face, which is limited by the unconfined coal strength, to that in the virgin condition. Strain energy may also be supplied to an outburst by the inward movement of the surrounding strata.

- The Expansion of Gas from Free Void Space – This comes from the adiabatic expansion of gas from the free void space (cleats). It is a virtually linear function of void space and gas pressure. If the coal is water saturated then there is no gas in the cleats to expand.

- The Diffusion of Gas from Coal Particles – Gas may diffuse from the coal particles to an intermediate pressure within the failing coal mass in an outburst. In reaching this intermediate pressure the gas can do work. This gas may then further expand adiabatically to provide energy. The key to the energy release is the gas content which is linked to the gas pressure through the sorption isotherm, the coal particle size distribution and the diffusion coefficient. These factors determine the rate of gas release.

There is also significant energy absorbed during the failure process which reduces the total outburst energy. It is related to the toughness of the coal. Toughness is by definition a measure of energy absorbed in causing failure. The approach of examining the energy release components is valuable in determining the important energy contributions to an outburst or slump. In a slump the principal energy contributor comes from gravity alone. The process of determining the level of risk from an outburst is one of estimating the energy release per unit volume of the outburst and the likely volume of coal that may be involved. The latter may in some circumstances be defined by the extent of gouge material that may be affected.

The energy absorbed by coal failure per unit volume is difficult to measure but indications of the coal toughness may come from grindability testing, drop hammer tests or by gassing up solid stressed coal and suddenly releasing the pressure to determine the level of fracturing that may occur. More work certainly needs to be done to quantify the energy consumed in breaking up coal.

Potential energy release calculations have been undertaken for the outburst situation that might have existed at Leichhardt Colliery. The properties and estimated energy release values are summarised in Table 3. As a reference, the kinetic energy that 1 m^3 of coal would have if it fell 1 m (0.014 MJ/m3) is marked at the bottom of the table. It is similar to the potential energy release from gas stored in pore space. These values are however dwarfed by the potential elastic energy stored in the coal and the surrounding rock and by the amount of energy that might be released from desorbing coal. The latter is very dependent on the particle size that is created and the diffusion coefficient of these particles. Small particle size and high diffusion coefficients lead to very high potential energy release values. As a caveat the use of Fickian diffusional behaviour has been made for mathematical convenience. The real process is probably something incorporating both Darcy flow and Knudsen diffusion.

DISCUSSION

The current Australian outburst threshold determination is simply based on gas content or a contortion of it in the form of the GeoGAS DRI index. The latter should be removed as it provides no improvement to the assessment of outburst risk and is based on faulty logic.

The basis for outburst risk determination needs to take account of the outburst process. This is one of failure with fragmentation and energy release. By definition of an outburst as opposed to a fall, slump or rockburst, gas is an important contributor. It is suggested that a basis for a definition between outbursts, rockbursts and slumps should be based upon the ternary diagram shown in Figure 1.

Table 3: Potential Energy Releases for 1 m³ of stressed, gassy coal. Note no account is taken of energy consumed in the failure process

PROPERTIES	UNITS	VALUE
Young's Modulus	GPa	2
Poisson's Ratio		0.3
UCS	MPa	12
Mean stress	MPa	12
Sorption Pressure	MPa	4
Gas content	m3/t	14.8
Void ratio		0.005

Strain Energy	MJ/m³	0.16
Pore gas expansion	MJ/m³	0.03

Diffusion Coefficient	m²/s	1x10⁻⁸	1x10⁻¹⁰	Particle Size mm
Diffusional Energy	MJ/m³	0.94	0.47	0.1
Diffusional Energy	MJ/m³	0.47	0.009	1
Diffusional Energy	MJ/m³	0.009	0.001	10

Energy in Falling 1 m	MJ/m³	0.014

Properties	
Units	
Energy Terms	
Energy Values	

If failure does not take place then an outburst cannot. Thus determining whether failure will occur is an important part of the process of determination as to whether an outburst will take place. For failure to lead to an outburst, fragmentation must also take place. This fragmentation appears to be controlled by pre-existing structure, either in the form of already sheared coal or coal that will fragment. Thus determination of the structure is vitally important. This can be arrived at by examination of borecore by the process shown in Figure 9 and by use of the Pop Gun Test.   Such examination and tests can however only be undertaken where core can be retrieved. If the coal is too sheared or fragments on core drilling then collecting cuttings from open hole drilling is an alternative. These may then be examined for particle size distribution. Despite the resistance within Australia this is best undertaken using air flush drilling as it provides virtually instant cuttings retrieval and therefore good sample location (Gray, 2011). Air flush is the only mode of drilling that is successful in some highly disturbed coals such as those in the Karaganda Basin of Kazakhstan and does not produce ignitions.

The next test of whether a coal will fail is its toughness. The Protodyakanov Index and q Index tests are measures of toughness. They too are dependent on the structure of coal on the scale that is tested. These simple tests form the basis for both Russian and Chinese determination as to whether a coal will outburst or not. In the Chinese case they are used in combination with a coal structural definition a measure of gas pressure and an adsorption rate index in the determination of outburst conditions. In the case of mines in the Kuzbass an equation linking pressure and toughness as determined by the Protodyakanov Index is used.

If fragmenting failure is likely to take place then the important question is what is the acceptable level of energy release that is associated with it? This energy release can be estimated by the processes used to arrive at Table 3 and detailed by Wood and Gray (2015). This should be estimated on the basis of energy per unit volume and expected energy release of the entire failed mass. Thus the total effect of an outburst from large faulted zones can be estimated. Given the apparently low transfer of potential energy into kinetic energy during the outburst process it would appear that a value of 0.1 MJ/m^3 is a realistic initial threshold value of potential energy for a medium sized outbursting volume (100 m^3) yielding a total potential energy of 10 MJ. However 10 MJ still represents a lot of energy if it were by the nature of the outburst process to be delivered in its entirety to the entrained particles. If the structure is expected to be larger than 100 m^3 then the allowable energy per unit volume should probably be reduced to a lower value. The degree to which it should be reduced is uncertain and deserves further attention as indeed does the 0.1 MJ/m^3 threshold.

The process of outburst threshold determination is seen as:

1) Determining whether the coal is already in broken form in the ground.
2) Determining whether the coal will fail (contains sufficient structure that it will fragment) under mining conditions
3) In the event of failure by either method then estimating the potential energy that may be liberated.

Determining that the coal has failed or may fail can be achieved by the inability to retrieve intact core. It may also be possible to determine it by the return of more finely broken cuttings than would normally be the case with open hole drilling. The measurement of an excessively large volume of cuttings from open hole drilling is also an indicator that this is the case. The determination of whether coal will fragment and its likely sizing appears to be able to be determined by the examination of core or coal lump in polished section as shown in Figure 9. This may also be confirmed by the use of the Pop Gun Test. In the latter case a pressure of fragmentation may be determined and a good safety margin allowed below this for safe mining. Once it has been decided that failure will take place then the focus should be on what can be done to limit the potential energy release. One option is gas drainage to a level where the expected coal fragment size would not have enough energy to pose a serious problem. The other is to de-stress the seam to be mined which will also achieve the release of gas. This is the common process in Eastern Europe, Russia and China. A seam is chosen that is less prone to outbursting usually because it is tough and has less structure. It is mined and then the adjacent seams are de-stressed and de-gas through drainage of the relaxed structure. These can then be safely mined.

CONCLUSIONS

This paper describes the some of the approaches used to outburst risk determination worldwide. These take into account gas pressure (by preference to gas content), desorption rate, coal toughness and structure. The Australian approach is by comparison extremely limited, taking into account only gas content or a limited variant of it in the form of the DRI index introduced by GeoGAS Pty Ltd. This approach is inadequate and fails to take into account the other factors that contribute to outbursting.

It is quite possible to mine coals at higher gas content thresholds than are currently permitted in Australia provided that the other contributory factors to outbursting are not present. This has very

significant consequences for improving mine productivity. Conversely where such factors as fine gouge material exist in a faulted zone it is quite possible that the gas content part of the threshold parameters may need to be lowered below currently in use.

The determination of outburst risk should therefore be revised to take account of these additional factors. This could be undertaken in a similar basis to that used overseas, namely taking into account the structural geology in combination with the results of several measured parameters either used separately or combined in some equation.

The alternative revision is to determine the conditions required for failure and to apply a good margin of safety to these. If failure is not considered to be likely then mining may proceed. If however failure is considered to be a possibility then the approach needs to change to one of determining what the potential energy release may be. If this energy release is too high, taking into account the volume of the likely failure, then measures must be adopted to reduce the energy release. These include gas drainage and stress relief techniques.

If either of the alternative approaches are adopted it will mean more measurements and in particular a determination of changing coal structure. This will require a different level of alertness by operators, especially in their drilling operations and the measurement process associated with them. A failure to incorporate the determination of changes in coal structure would automatically lead to an assumption of poor conditions and therefore the need to change the threshold values of the other contributing factors to outbursts.

The option is to maintain the status quo based on gas content measurement. This has generally been successful in preventing outbursts because of the rigour by which it is applied. This is enabled by the very simple nature of the process. It has however cost Australian mining very dearly in terms of lost productivity.

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