THE MECHANISM OF, AND ENERGY RELEASE ASSOCIATED WITH OUTBURSTS

By

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ABSTRACT

A study is presented of the theoretically possible initiation systems for outbursts and the subsequent propagation mechanism. Previous occurrences of outbursts and their correlation to the theoretical system are described. An estimation of the energy release from two energy sources, gas strain energy and rock/coal strain energy, is presented and the relative importance of each source in the severity of outbursts.

Summary: The description of mechanisms of outbursting follows the examination of these phenomena at Collinsville in Bowen No. 2 mine and at Leichhardt Colliery, Blackwater. Quantitative material contained in the paper refers to Leichhardt Colliery, Blackwater. Clearly from the work carried out to date gas release has a major part to play in the outbursting at both of these collieries. In the case of the December 1 1978 outburst at Leichhardt Colliery energy release estimates place gas strain energy release contributing eight times the energy of that from rock/coal strain energy. Even the normal outbursts at Leichhardt Colliery appear to show this trend.

Estimates of energy released are for comparative purposes between gas and rock strain energy and the values obtained may be regarded as approximate.

General Outburst Description.

An outburst is the failure of coal and its ejection by stored potential energy being converted to kinetic form. This failure is associated with the release of seam gas.

The failure is due to the stress and the strength characteristics of the coal, fluid pressure being an operative stress. The failure may be brought about totally by material stress combinations exceeding the strength of the coal and without the effect of gas at one extreme to the other extreme whereby internal gas pressure is sufficient to exceed the tensile strength of the coal in an unconfined state. Any combination between the extremes may exist.

Whatever the failure initiation is, the severity of that outburst is likely to be directly related to the energy release. In gassy outbursts the added problem of suffocating gas release occurs. The potential energy may be stored in two forms, the first of which is gas strain energy and the second rock/coal strain energy. In both cases the strain energy is converted to kinetic form by a change of strain. The potential energy release accelerates particles of coal and/or gas. The surrounding rock mass will also be accelerated.

Failure mechanisms

Gas initiated: Two variants may exist.

1) The tensile failure of unconfined coal. If gas pressures exceed the tensile strength of a solid coal then failure may be expected to

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occur. Such failures may be expected to follow planes of weakness in the coal such as the weakness planes that lead to structurally controlled fractures on mining. When sufficient drainage paths have opened and gas pressures have dropped, fracturing can be expected to cease.

2) The piping of sheared material.
This is fundamentally similar to that described above in that the local gas pressure exceeds the minimum confining stress, thus leading to failure. The term is more appropriately applied to mylonite zones where the particles have a soil type structure as the name itself is that applied to earth dams and embankments. One of the specific characteristics of such a failure is its ability to excavate its own opening as the gas flow from the material concentrates on the new cavity. Particles are carried from the failure by entrainment.

General failure under gas pressure and stress.

Using the Mohr Coulumb failure concept failure may be expressed in eqn (1).

$$Tf = C + Sn^1 \text{ Tan } \phi \qquad (1)$$

where Tf is the shear stress at failure
C is the cohesion
ϕ is the angle of internal friction
Sn^1 is the effective normal stress to the plane of failure.

Sn^1 is a function of particle area contact, particle and mass friction angles or of particle and mass compressibilities, and the pore pressure (μ) as shown by Skempton (1961).

For a point contact particles system the equation will tend towards the form in eqn (2).

$$Tf = C + (Sn - \mu) \text{ Tan } \phi \qquad (2)$$

In a system other than this it may be considered to take the form in eqn (3).

$$Tf = C + (Sn - f(\mu)) \text{ Tan } \phi \qquad (3)$$

where $f(\mu) < \mu$

The meaning of this is that a pore pressure will cause failure at a lower value than without it. Also failure will tend to follow planes of weakness which have the joint effect of lowering the particle contact area, a, and reducing cohesion. The effect of reducing a in raising f (μ) is probably not important though, as the coal is presumably fully sorbed at seam pressure.

In summary, normal failure levels could be expected without pore gas pressure and lower values could be expected with it.

Energy release

Whatever the failure mechanism is, once failure is initiated probably the most important study is into the energy release associated with that failure. If the relevant values of gas and rock/coal strain energy release can be compared, then measures to remove the source of the most stored potential energy can be taken. The importance of failure mechanism control is dependent on the variability of geology. It may be possible to control failure in normal seam conditions; if however a local anomaly occurs, such as a shear zone, then failure will possibly be initiated leading to the release of stored potential energy.

Gas strain energy release.

Instantly or near instantly released gas can be expected to expand and do work on itself and surrounding particles by accelerating them. If the expansion is fast enough it will approach the adiabatic case. On slower expansion heat will be absorbed from the coal and mine air with a resulting total greater gas energy release. The upper limit in the latter case will be the isothermal energy release. Some energy is probably absorbed from the gas as heat of sorption. This can be estimated.

Gas release from coal will depend on the state of the coal and the gas. If the coal is brecciated or mylonized as around a fault then a gross interconnected pore space can be expected to exist. Upon mechanical failure of such material the pore gas could be expected to be instantaneously available. A lesser pore space also exists within the coal structure and in small fractures. Gas released from this lesser pore space will become available after passing through the small fractures or after diffusing through the coal itself. Adsorbed gas will have to diffuse to the nearest boundary before desorption. Initially concentration gradients must be high at boundaries and therefore so must be the initial diffusion.

An estimate of energy release can be made if the gross interconnected pore space can be found and if a laboratory measurement of quickly desorbed gas from solids is made.. Seam gas pressure and temperature needs also to be known.

The energy release from an expanding gas may be written as shown in eqn (4).

$$E = \int_{V1}^{V2} PdV \qquad (4)$$

where E = energy, P = pressure and V = volume.

In adiabatic expansion the relation between pressure and volume is written in eqn (5).

$$P\,V^{\delta} = k \qquad (5)$$

where δ is the ratio of specific heats $\frac{CP}{CV}$

k is a constant

combining (4) and (5) to produce (6)

$$E = \int_{V1}^{V2} \frac{k}{V^{\delta}}\,dV$$

$$= \frac{k}{1-\delta}\,V^{1-\delta}\Big|_{V1}^{V2} \qquad (6)$$

Where V1 is the equivalent gas volume in seam, V2 is the volume at the end of adiabatic expansion of V1.

The equivalent gas volume in seam is taken as being the volume of quickly desorbed gas assuming it to exist in absorbed state in seam.

The energy release values in adiabatic expansion for a final released volume of one cubic metre of gas measured at the same temperature as it existed in seam are shown in figure 1 and are listed in table 1.

Table 1

Seam gas energy release under adiabatic expansion per m^3 of gas desorbed measured at seam temperature

Gauge Seam Pressure MPa	Adiabatically expanded volume (m^3)	Energy Release (J)
2.5	0.45	1.69×10^5
2.0	0.47	1.62×10^5
1.5	0.50	1.52×10^5
1.0	0.55	1.37×10^5
0.5	0.64	1.09×10^5
0.25	0.73	0.81×10^5
0.10	0.84	0.48×10^5

The energy release is proportional to the amount of gas desorbed. The energy release is less than proportional to the pressure in seam per unit volume of expanded gas to seam temperature.

Isothermal energy release values may be calculated as a limiting case on maximum energy release. Such a case could be approached by a slower desorption where heat is being transferred from the coal to gas.

For the isothermal case pressure and volume are related by eqn (7)

$$PV = k^1 \qquad (7)$$

where k^1 is a constant.

The energy release on expansion is shown in eqn (8)

$$E = \int_{V1}^{V2} PdV$$

$$= \int_{V1}^{V2} \frac{k^1}{v}\,dV$$

$$= Pat\ Vat\ \ln \frac{Pseam}{Pat} \qquad (8)$$

Where Pat is atmospheric pressure

Vat is volume of gas at atmospheric pressure

Pseam is seam pressure.

Values for energy release in isothermal expansion are given in Table 2 and shown in Fig. 1.

Table 2

Isothermal energy release per m^3 released gas

Gauge Seam Pressure MPa	Energy Release (J)
2.5	3.28×10^5
2.0	3.07×10^5
1.5	2.79×10^5
1.0	2.41×10^5
0.5	1.80×10^5
0.1	0.70×10^5

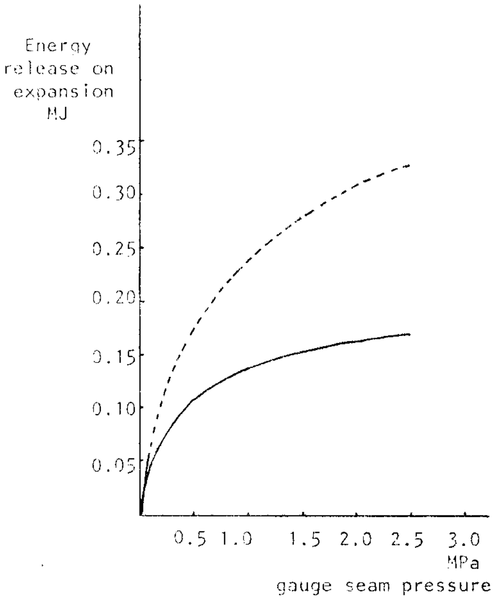

Fig. 1. Energy releases in adiabatic and isothermal expansion of gases from gauge seam pressure. Unit expanded volume at initial temperature considered.

N.B. $\gamma = 1.33$ in adiabatic case

$(PV^{\gamma} = k)$

Adiabatic ______________

Isothermal --------------

Estimation of desorption energy and heat transfer from coal to gas:

If the immediate desorbed volume can be measured then an estimate of heat loss or gain during desorption can be made. The equivalent gas volume in seam is estimated from the gas in its expanded state at room temperature. This equivalent volume can be expected to expand adiabatically unless energy is added or subtracted. The deviation of the immediately desorbed volume from that expected from adiabatic expansion will enable an estimate of the added heat to be made. Problems arise in that external heat from the apparatus will be transferred to the gas. Some estimation of this may be made by expanding compressed gas alone. Such a technique is proposed in preference to a slow desorption in a calorimeter as a measurement is being made of energy change at high rates not under low rate conditions.

Measurement of immediate or fast desorption.

The immediately desorbed, lesser pore space and adsorbed gas may be found empirically. The experiment involves the sorption of outburst size particles fully to the appropriate pressure in a test cylinder. This is followed by the release of pressure from the cylinder through a quick release valve to collection in a floating vessel over a non-sorbative liquid. The volume of gas contained in this is then measured via a wet test meter when it has come to temperature equilibrium. Subsequently the dead volume of the gas in the container is found by measuring the particle volume of the coal and subtracting it from the cylinder volume. The expected volume of gas from this dead volume can be subtracted from the actual released volume to yield that released from the coal.

Some judgment in the opening of the quick release valve is required as the over-sudden release of gas causes collection problems. A timing of two seconds to turn the valve on, two seconds open and a second to shut the valve has been adopted.

Outburst sized particles are used to avoid increasing the surface area capable of desorbing gas. Some relation can be expected to exist between surface area and immediate desorption capability of the coal.

A schematic diagram of the immediate desorption apparatus is shown in Figure 2.

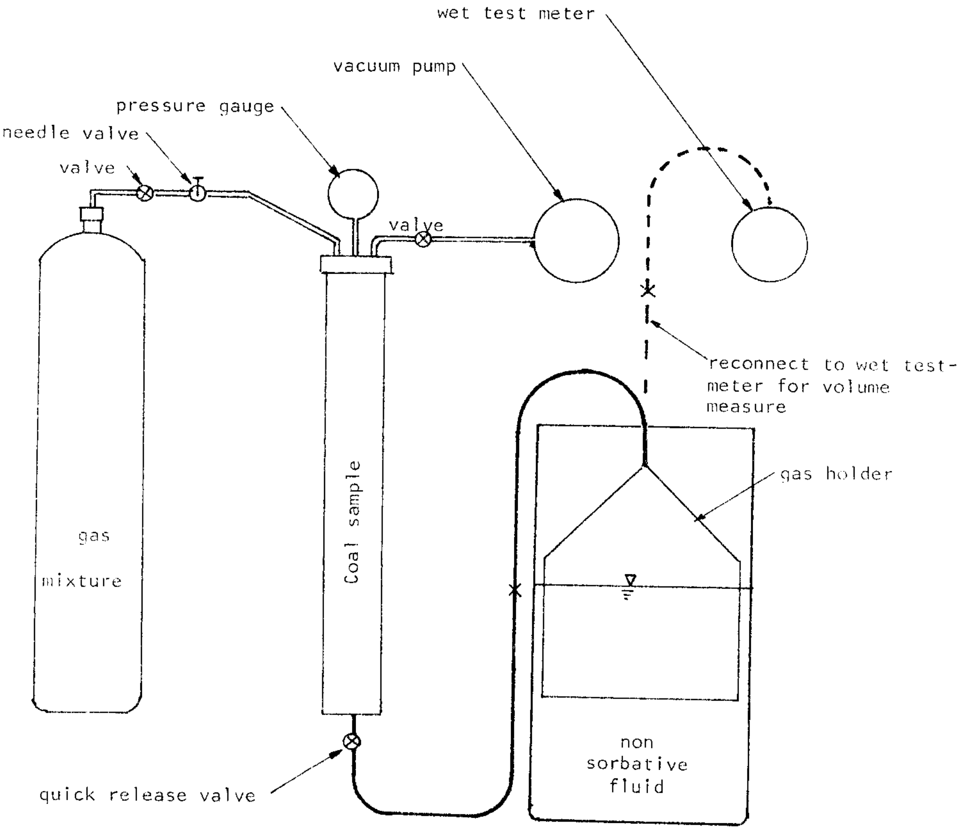

Fig. 2. Immediate or fast rate gas desorption measurement apparatus

Rock/Coal strain energy release estimates for cylindrical or cone-shaped outburst cavities:

The occurrence of rock strain energy release with failure is rockbursting. It may be expressed in terms of net strain energy change associated with failure. In simple one dimensional terms it is the area between the unloading curve of the unfailed material and of the failing material as shown in Figure 3.

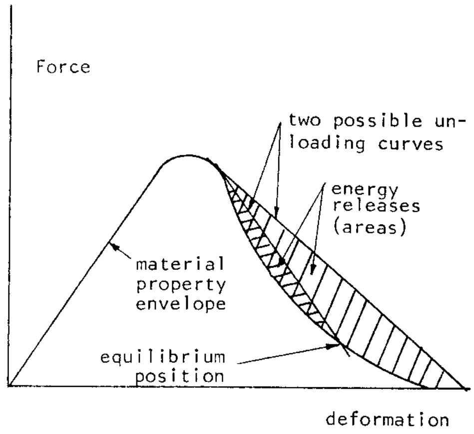

Fig. 3. One dimensional rockbursting

The energy release from the failure of a disc element in a uniform surrounding medium with a uniform initial stress distribution (shown in Figure 4).

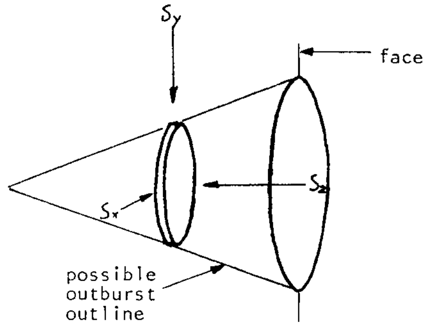

Fig. 4. Failing disc in relation to its initial surrounding stress state

If the disc is part of a cone or cylindrical failure propagating in the direction of the axis z (see Figure 4) then the first stress to be relieved may be thought of as Sz. In fact the removal of material from the x, y plane will unload Sz and simultaneously unload Sx and Sy. However, assuming that Sz is relieved elastically without contraction of the circumference of the disc, then the associated strain is given in equation 9.

$$\xi z = \frac{1}{E}\left(Sz\left(1 - 2\frac{\nu^2}{1-\nu}\right)\right) \tag{9}$$

where ξz is strain in Z direction

E is the Young's modulus

ν is the Poisson's ratio

The strain energy associated with this is given by eqn 10.

$$E = \int_V \tfrac{1}{2}\, Sz\, \xi z\, dV$$

$$= \frac{1}{2E}\int_V Sz^2 \left(1 - 2\frac{\nu^2}{1-\nu}\right) dV \tag{10}$$

Corresponding to the release of Sz under confined conditions will be a reduction in Sx and Sy existing within the disc. This difference in stress may be considered to exist from the onset of radial unloading, thereby ensuring energy release during this unloading mode.

The deformation due to radial unloading of a hole in an elastic medium is presented by Jaeger & Cook (1969) and is given in eqn 11.

$$Ur = R\,\frac{(1-\nu^2)}{E}\,\{(Sx+Sy)+2(Sx-Sy)\quad 2\theta\}-\nu\xi z \tag{11}$$

where Ur is the radial deformation at the hole wall

θ is angle from the x axis

ξz is the strain along the z axis

R is the hole diameter

In the plane strain case ξz is 0, reducing the radial deformation to that given in equation 12.

$$Ur = R\,\frac{1-\nu^2}{E}\,\{(Sx + Sy)+2(Sx-Sy)\ \ 2\theta\} \qquad (12)$$

Further simplification can be made if Sx = Sy = S and radial deformation will be given by equation 13.

$$Ur = 2R\,\frac{1-\nu^2}{E}\,S \qquad (13)$$

The energy release on such elastic unloading in the radial direction only is given in eqn 14 for a disc of length dL.

$$Er = \pi RS\ Ur\,dL \qquad (14)$$

Two major assumptions are made in this analysis of energy release due to elastic collapse. They are that hole wall failure does not occur and that the shear strain energy component is small. Deist (1965) has made an analytical assessment of strain energy release due to tunnel excavation in which tunnel wall failure is allowed for in a situation of otherwise total symmetry. To handle both aspects of the problem computer modelling techniques need be resorted to. At the time of writing insufficient seam data and no post failure seam data exist so this approach is not justified.

Energy is consumed by the biaxial loading failure of the central disc.

If failure to 0 stress is assumed and unloading characteristics Eu and νu are measured then the deflections in the radial mode may be calculated from equation 15.

$$\delta\xi r = \delta\ Sr\frac{1}{Eu} - \delta\ S^{1}_{r}\,\frac{\nu u}{Eu} \qquad (15)$$

where $\delta\xi r$ is the change in strain in the r direction

δSr is the stress change in the r direction

δSr^{1} is the stress change in the direction at right angles to r.

This reduces to eqn 16 for the symmetrical stress case

$$\delta\xi r = \delta S\,\frac{1-\nu u}{Eu} \qquad (16)$$

The intersection of unloading curves before 0 stress levels are achieved may occur as shown as the equilibrium point on Figure 3. If gas is forcing material out and preventing it from behaving as an energy absorber, then total energy release will rise.

The energy consumed by radial failure of such a disc is given in eqn 17.

$$\int_V \tfrac{1}{2}\,\delta\ \xi r\ \delta\ Sr\ dV \qquad (17)$$

Description of outbursts.

Bowen No 2 mine. All the recent outbursts clearly recognisable as such have occurred around a reverse fault in 53 level West workings. This fault has extensive shearing associated with it particularly in the bright bands. Dr R. Williams of Collinsville Coal has noted this and describes the texture as sugary. All the areas that have outbursted have been in this soft sheared material. Also Hargrave test emission values have been high (i.e. in the order of 1 cc/gm). The three outbursts that have occurred in this area have been small. Two have involved slumping of the sheared area by the face with an emission of gas. The third is best described by what is referred to as a piping failure. The resulting cone having eroded through sheared material to a mylonite band. In all cases the structure of the coal was such that it approached a soil.

It is interesting to note that all of the outbursts in the State Mine at Collinsville were along faults also.

Leichhardt Colliery.

Normal outbursting. This has occurred when using a continuous miner or shotfiring into virgin areas. The failure occurs across the cleat, which is strongly defined, or across bedding planes. The outburst normally chokes itself off at the base of the outburst cone. The appearance of the remaining material and the impression gained is one of plate buckling. Each plate being defined by a locally intensified cleat pattern. The pattern could be one associated with either stress or gas behaviour. In the stress case plates being the growth of an existing discontinuity system that has been extended as Griffith cracks under high lateral stress. The material finally bulging out or being propelled by released strain energy as the cone collapses radially inwards. Or in the gas case,by the separation of cleating or bedding planes by high gas pressure as the confining stress is reduced. Separation would be expected across pre-existing fracture systems such as cleating or bedding planes, it would also provide a less fractured area for gas pressures to work on than an area in which long cleat drainage could readily occur. It is perhaps worthy of note that an area in the North West of the mine which suffered little from outbursting had a more developed butt cleat that may have allowed drainage during mining.

In fact both stress and gas processes are almost certainly responsible for the mine's outbursts. Gas is probably an initiating factor. If the higher pressures measured by the author are an indication of seam pressures encountered through the mine then these are greater than the tensile strength indicated by indirect tensile tests, Newman (1975).

Characteristic hard coal conditions were encountered before normal outbursting, indicating;

a) no release of strain energy ahead of mining

b) no readily available gas drainage paths.

The December 1, 1978, outburst:

This outburst was uncharacteristic for the mine both in size (300 m^3, 400 tonnes) and because it occurred on a shear zone which was

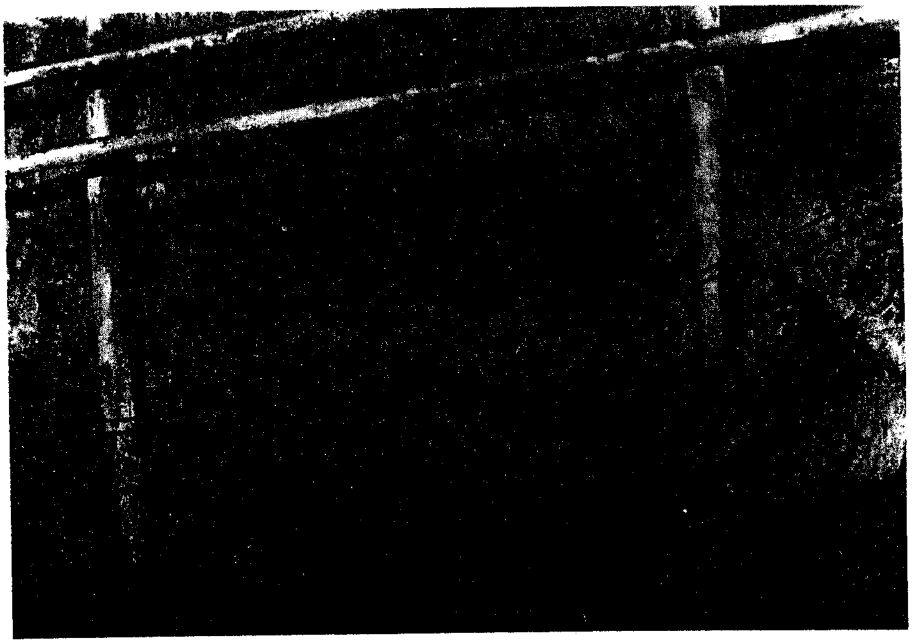

Fig. 5. Preserved signs of normal Leichhardt Colliery outburst

associated with a reverse fault. Figures 6 and 7 show the form of the outburst in plan and rib. The rib drawing shows that much of the ribside is composed of mylonite. This extends to form approximately 18 per cent of the outburst cavity volume. The mylonite is composed of a series of slickensided layers so that in places they can be separated like the leaves of a book.

The failure initiation was again associated with hard conditions as was the case with normal outbursting at the colliery. This case may have been different and what could have been occurring was a destressing of the face due to failure of the shear zones that would have existed in the face. Whether this occurred or not the shear zones in the coal almost certainly propagated the failure to its unusual depth by their high gas energy content and weakness.

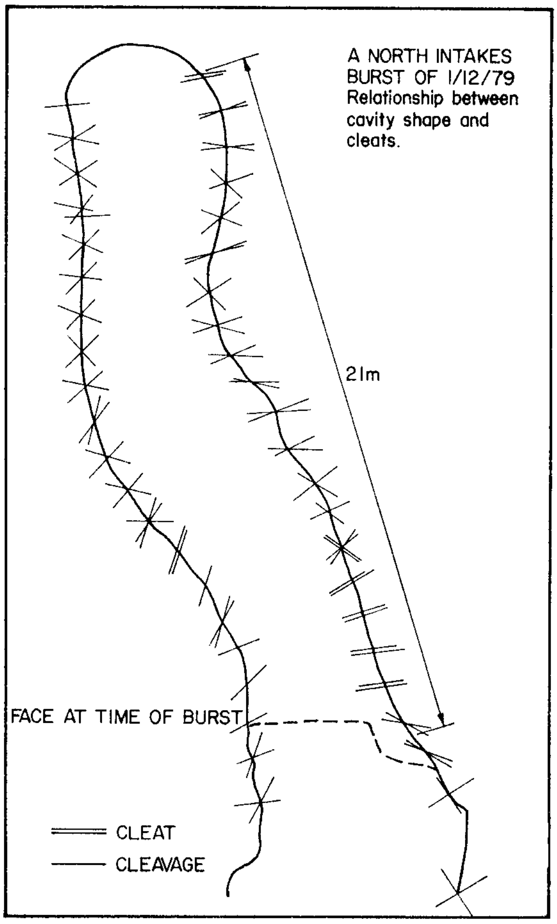

Fig. 6. Plan of December 1, 1978, outburst. From Hanes (1979).

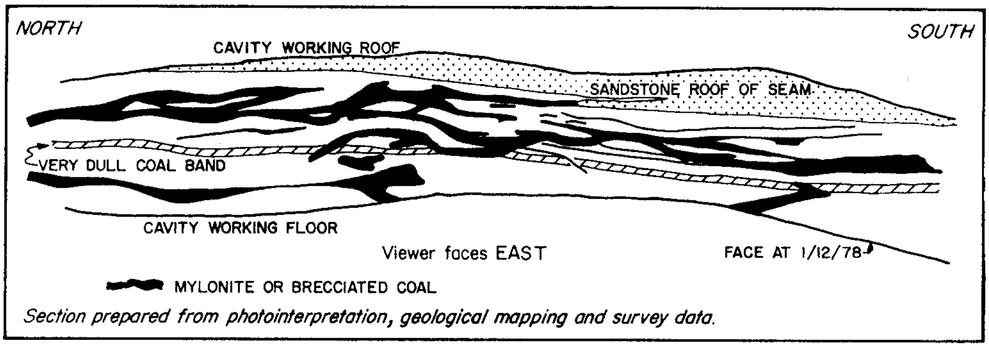

Fig. 7. View of eastern rib December 1, 1978, outburst, Leichhardt Colliery, showing the mylonite banding. From Hanes (1979).

Results of immediate desorption tests on Leichhardt Colliery outburst coals.

Three types of coal were selected from outbursts in the colliery. They were

a) normal outburst coal, D heading East, straddling the 3 m parting
b) Brecciated material from the ribs of the December 1st outburst
c) Mylonized material from the December 1st outburst.

Details on the samples may be found in Tables 3, 4 and 5. All samples were sorbed with methane.

Table 3

Normal outburst D heading East

Rank 1.24

Macerals %, Vitrinite 35, Exinite 1, Inertinite 59, Mineral Matter 5

Sizing mm	% retained
+ 12.7	31.0
6.35	26.6
3.18	18.1
1.00	15.0
0.50	4.8
0.25	2.6
0.125	1.0
0.0	0.9

Total surface area m^2/m^3 2907

Apparent relative density 1.215 gm/ml

Instant Desorption Values

Pressure MPa	Released Vol. at room temperature		Adiabatic energy release	Isothermal energy release
	m^3/m^3	m^3/tonne	MJ/m^3	MJ/m^3
2.24	5.70	4.70	0.94	1.81
1.18	2.50	2.06	0.36	0.64
0.65	0.83	0.69	0.10	0.17

Table 4

Brecciated material December 1 outburst

Rank 1.23

Macerals %, Vitrinite 51%, Exinite 0, Inertinite 43, Mineral matter 6

Sizing mm	% retained
+ 12.7	7.2
6.35	20.0
3.18	23.0
1.00	25.4
0.50	10.8
0.25	6.6
0.125	3.1
0.0	3.9

Total surface area m^2/m^3 7674

Apparent relative density 1.24 gm/ml

Instant desorption values

Pressure MPa	Released Vol. at room temperature m^3/m^3	m^3/tonne	Adiabatic energy release MJ/m^3	Isothermal energy release MJ/m^3
2.25	7.48	6.04	1.23	2.38
1.29	3.86	3.11	0.57	1.03
0.75	1.13	0.91	0.14	0.24

The surface area values are purely bulk estimates based on a cube.The mid size of each sizing range or in the case of material retained on the 12.7 mm sieve a 19.1 mm cube side was arbitrarily chosen. A relation clearly exists between bulk surface area and immediately desorbed volume as is shown in Figure 8.

Immediately desorbed volumes and the energy associated with them in adiabatic expansion are shown in Figures 9 and 10 respectively.

The adiabatic energy release values are shown and quoted as they are conservative. In fact very little volume increase took place between the time directly after immediate desorption and when the gas from that desorption had reached temperature equilibrium.

Table 5

Mylonite, December 1st outburst

Rank 1.28

Macerals %, Vitrinite 56%, Exinite 1, Inertinite 38, Mineral matter 5

Sizing mm	% retained
+ 12.7	12.3
6.35	14.2
3.18	16.2
1.00	21.2
0.50	11.8
0.25	10.8
0.125	6.1
0.0	8.0

Surface area m^2/m^3 13148.5 m^2

Apparent relative density 1.124 gm/ml

Instant desorption values

Pressure MPa	Released Vol. at room temperature m^3/m^3	m^3/tonne	Adiabatic energy release MJ/m^3	Isothermal energy release MJ/m^3
2.41	7.34	6.53	1.23	2.38
1.27	6.32	5.63	0.92	1.66
0.86	3.71	2.99	0.49	0.85

Difficulty in getting accurate volume measurements immediately after desorption from a rise in the floating container has led to these results not being published.

Energy values of adiabatic expansion lie between 0.8 and 1.2 MJ/m^3 for immediate desorption from 2 MPa gas pressure.

Energy release estimates for a normal Leichhardt Colliery outburst of 2.0 m diameter with an apex angle of 40°:

Gas energy release. The energy release values are based on the adiabatic expansion values of the sample from D heading East. They are shown in Table 6.

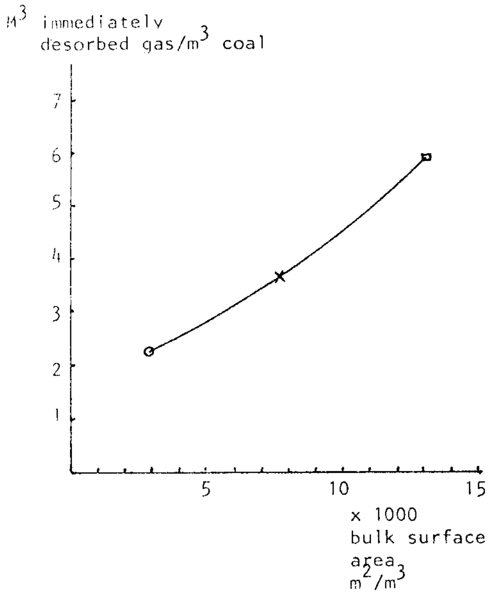

Fig. 8. Volume of gas released instantly per m^3 coal vs bulk surface area of particles.
Pressure of release 1.2 MPa.

Table 6

Gauge Seam Pressure MPa	Energy MJ/m^3	Total Energy MJ
2.0	0.79	2.28
1.5	0.51	1.47
1.0	0.26	0.75

Gas Energy release assuming adiabatic expansion for a normal 2 m diameter Leichhardt outburst

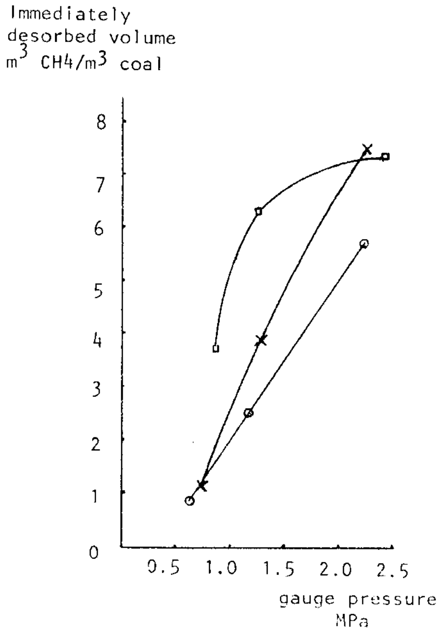

Fig. 9. Immediately desorbed gas volume vs pressure

- □ Mylonite Dec 1, 1978, outburst
- × Brecciated material Dec 1, 1978, outburst
- o Normal outburst D heading East

Strain energy of coal release. Two cases are examined, the first assuming no axial stress and the face in an imminent state of failure, i.e. 12 MPa all round stress. The second case assumes the coal to have some confinement (3MPa) and a subsequent imminent failure state of failure of 19.5 MPa all round stress conforming to a sample of 12 MPa uniaxial strength with an angle of friction of 25°. Both cases are considered to be in an infinite coal medium. The coal failure envelope is assumed to have an unloading stiffness of

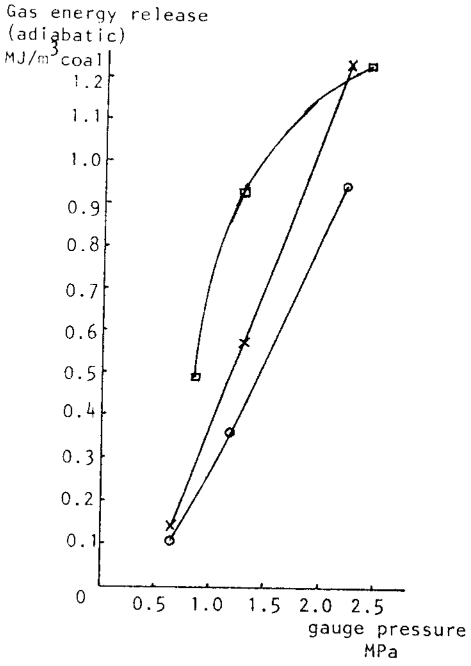

Fig. 10. Gas strain energy based on adiabatic expansion vs pressure.

- ◘ Mylonite Dec 1, 1978, outburst
- X Brecciated material Dec 1, 1978, outburst
- o Normal outburst D heading East

2.3 x 10^3 MPa, the same as the loading case. Experience with quasi full failure envelope tests by ACIRL suggests the failure side of the failure envelope to have a similar slope to the loading side. Coal properties are therefore

$E = 2.3 \times 10^3$ MPa

$\nu = 0.24$

ν unload = 0.3

The assumptions that the coal surrounding the failure is infinite in extent and that the stress 360° around the outburst cone are at failure level will tend to overestimate the energy release. Values of strain energy release are in Table 7.

Table 7

No axial stress	
Energy release due to wall collapse	0.34 MJ
Energy absorbed due to core crushing	0.06 MJ
Net energy release	0.28 MJ
3 MPa axial stress	
Energy release due to axial unloading of the core	0.001 MJ
Energy release due to wall collapse	0.90 MJ
Energy absorbed due to core crushing	0.06 MJ
Net energy release	0.84 MJ

Strain energy releases in a 2 m diameter normal Leichhardt colliery outburst

Two points become clear from the above; they are

a) The development of confinement away from an opening will strongly affect potential coal strain energy release.

b) Gas strain energy release would appear to be the most important if pressures close the face are near the high values measured at the colliery (2 MPa).

Energy release estimates for the December 1, 1978, outburst at Leichhardt Colliery.

Consider the outburst to be a cylindrical void of 330 m^3 volume 21 m long and 4.5 m diameter. The outburst cavity is aligned North South with an estimated stress field of 10 MPa axially, 10 MPa vertically and 20 MPa horizontally. These stresses are consistent with regional tectonic knowledge and overburden load.

Gas strain energy release.

Measured values of seam gas pressure indicate a value in the area of the outburst of 2 MPa. The cavity ribs have a mylonite content of 18 per cent and this value will be assumed to hold throughout the outburst zone. Other failed coal has been estimated at 40 per cent falling in the class of brecciated material and 42 per cent block coal not contributing gas to the outburst.

The energy release values are in Table 8.

Table 8

Material	%	Adiabatic energy release MJ/m^3	Energy release MJ
Mylonite	18	1.18	70
Brecciated	40	1.13	149
Block	40	0	0
Total gas energy release			219 MJ

Gas strain energy releases for Leichhardt Colliery's December 1, 1978, outburst

Rock/coal strain energy release.

Cases all assume here failure in a virgin stress state; this would have been approached on the outburst propagated. Several cases are treated in an endeavour to show up the importance of changes in parameters.

They are

a) failure in coal without energy absorption due to coal core failure

b) failure in coal with coal core absorption included

c) failure in rock without coal core failure unloading characteristics

d) failure in rock with coal core failure characteristics taken into account.

Coal properties are taken as

$E = 2.3 \times 10^3$ MPa

$\nu = 0.24$

E (unload) = 2.3×10^3 MPa

ν (unload) = 0.3

Rock properties are derived from work by Newman (1975). They are the values of E and ν averaged using an inverse weighting from 0 to 15 m away from the seam. These properties measured close to the seam received increased weighting. The values were

$E = 11.73 \times 10^3$ MPa

$\nu = 0.21$ MPa

Strain energy release values

a) Failure in coal without energy absorption due to coal core failure

axial unloading	6.1 MJ
radial wall collapse	67.1 MJ
	73.2 MJ

b) Failure in coal with coal core absorption included

axial unloading and radial wall collapse	73.2 MJ
- core energy absorption	- 8.3
	64.9 MJ

c) Failure in rock without coal core unloading failure characteristics

axial unloading	6.1 MJ
radial wall collapse	13.4 MJ
	19.5 MJ

d) Failure in rock with coal core failure characteristics taken into account

axial unloading	6.1 MJ
radial wall collapse controlled by coal core	1.1 MJ
	7.2 MJ

The results presented give a range of an order of magnitude. However as the stiff rock can be expected to control collapse of the wall and gas did clear some material, a guestimate of the actual rock/coal strain energy release would be 20 - 30 MJ.

This is well behind the gas strain energy release estimate.

Conclusion

An endeavour has been made to obtain estimates of energy release in outbursting. In absolute terms the estimates cannot be very accurate. However, they do highlight the relative importance of factors involved and give a basis for estimation of the importance of the factors at other collieries. The importance of gas strain energy release is highlighted subject to the further measurement of gas pressures around an opening in virgin conditions. It suggests strongly the development of gas drainage as an effective outburst prevention measure. At Leichhardt Colliery it is interesting to note that no outbursting has occurred since the resumption of mining in areas degassed into previous workings. The mining method has however changed to shotfiring.

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