A Review of Coal Bursts

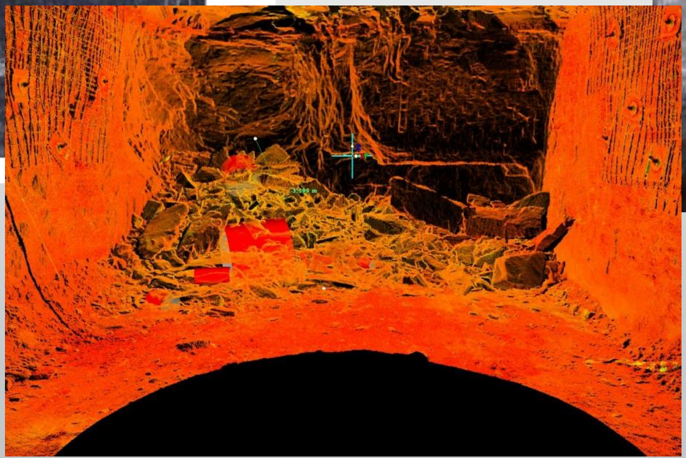
With Reference to Energy Considerations.

Winton Gale SCT Operations

ACARP PROJECT C26066

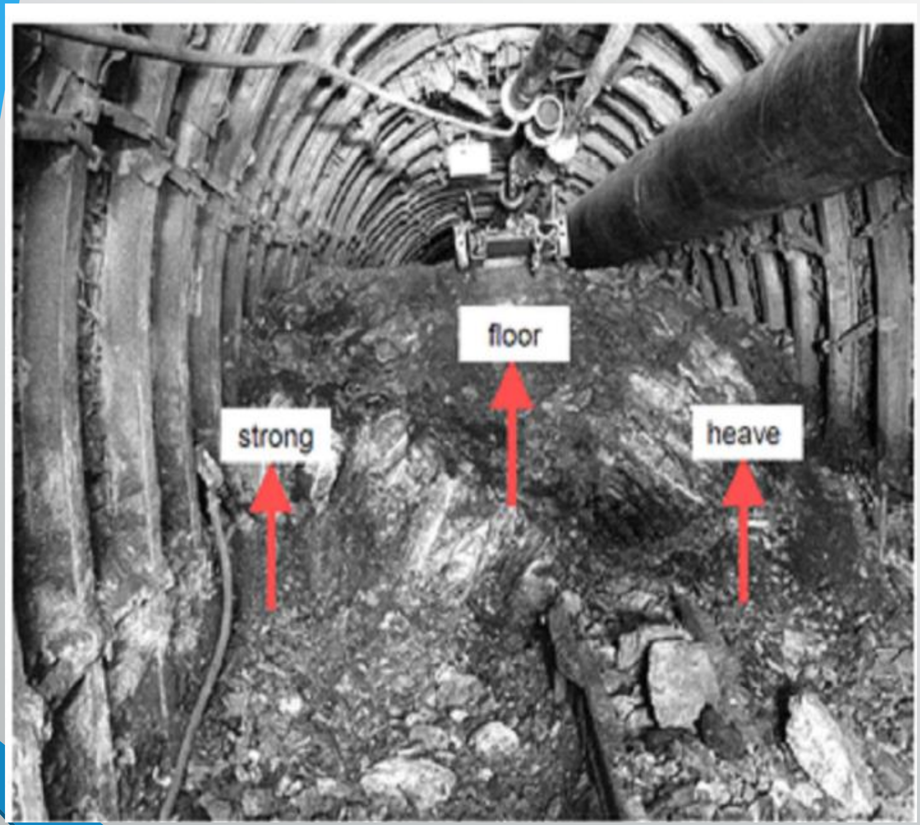
Definition of a coal burst

- Rapid propulsion of a significant volume of coal from a face or ribside into the mining area

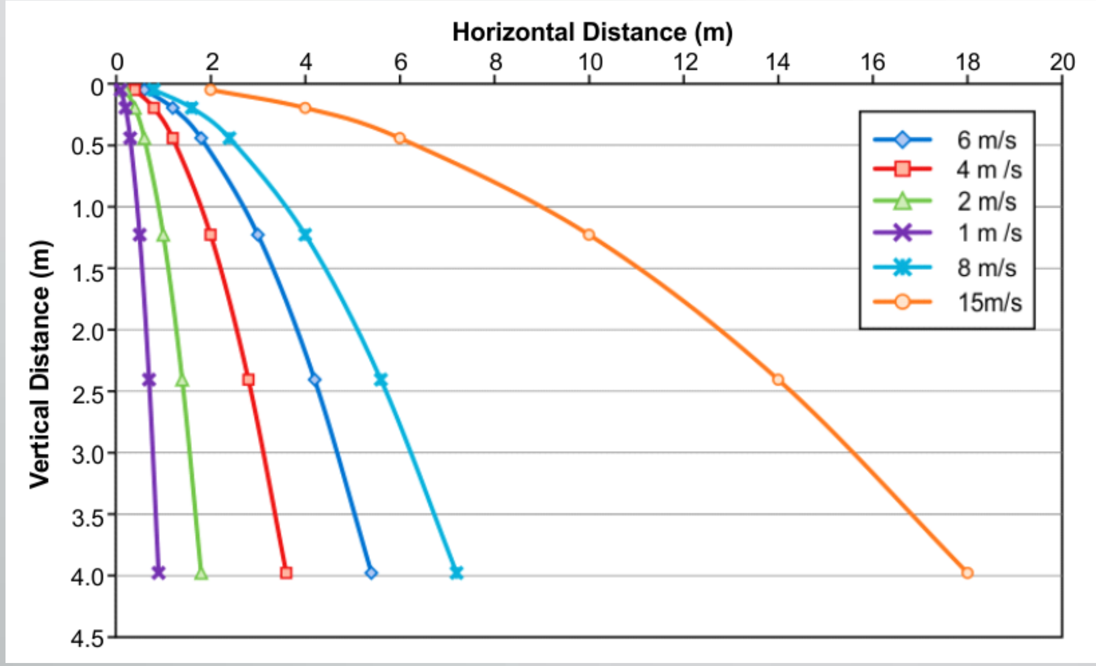


Definition of a coal burst

- Rapid closure of a roadway



Estimation of burst velocity



Block trajectory for various velocities

Requirement for a burst

- Energy stored , potential or applied to the material about the excavation
- Enough energy available to fail and *rapidly* displace / propel the material about the excavation

Approach to Study and Prediction

- Descriptive analysis

  based on case histories looking for common factors

  depth, structures, rock type and thickness, mine layout

- Energy source analysis

  based on the type , magnitude and availability of energy about

  excavations and structures to displace material

Descriptive

- Based on circumstantial factors associated with burst locations
- Multi-variate analyses or subjective assessment to determine “weighting factors” and “ranking factors”
- Data can be “*trained*” with weighting and ranking factors to match experience at a site or district impacted by similar circumstances
- Risk profile based on summation of factors and training factors

- Very difficult to transfer from one site to another due to the local training of the data weighting and ranking.

Example of a trained data set

No	Coal Burst Factor	Definition of Factor	Weighting Value
1	Depth of mining	<400m	0
		400 to 700m	1
		> 700m	3
2	Occurrence of coal bursts after 1980 in the given mine or in neighbouring mines or documented coal bursts after 1970	Coal bursts in the given seam did not occur	-2
		Coal bursts occurred in the given seam	0
		Coal bursts occurred in the given seam and its part when using a similar method of work conducting	3
3	Susceptibility of coal to coal bursts or coal UCS	Coal not susceptible to coal bursts UCS ≤ 16 MPa	0
		Coal susceptible to coal bursts UCS > 16 MPa	2
4	Proximity of thick (≥ 20m) layers of strong rocks with a UCS of ≥ 60 MPa to the roof	>100m	0
		100 to 50m	2
		<50m	4
5	Proximity of workings to a goaf edge	>60m	0
		60 to 30m	2
		<30m	4
6	Summing up of distance between workings and at least two goaf edges	>100m	0
		100 to 50m	2
		50 to 30m	3
		<30m	5
7	Conducting workings in the destressed layer of a thick seam	≥1m in thick bed of coal in roof or floor	3
8	Seam thickness	<3m	0
		3 to 4m	1
		>4m	3
9	Width of longwall between two goafs	>300m	0
		300 to 150m	2
		<150m	4
10	Pillar size between roadways and goaf	Without or with rip of coal up to 3m	0
		Leaving a coal solid zone 3 to 10m	2
		With pillar 10 to 50m	4
11	Approaching of face to goafs at a distance less than 50m	Roadway	2
		Longwall	3
12	Approaching of roadway to roadway at a distance less than 30m	With stowing	1
		Without stowing	2
13	Approaching of roadway to roadway at a distance less than 50m	With stowing	1
		Without stowing	2
14	Approaching of face to the place of excessive seam development at a distance less than 50m	Roadway or longwall	3
15	Approaching of face at a distance lower than 50m to a fault with a throw of ≥3 m or approaching of face to the neighbourhood of a hinge fault extinction	Hanging wall	1
		Footwall	2
16	Approaching of face at a distance of less than 50m to a fold	>15°	2
17	Approaching of face to the pillar near goafs at a distance lower than 50m	Roadway	1
		Longwall	3
18	Conducting of working in the neighbourhood of washout line or seam connection	Roadway or longwall	2
19	Seam destressing by means of overworking or underworking	Weak	-1
		Medium	-2
		Good	-4

(ii) Summary Table

Denotation of the Hazard Degree	State of Coal Burst Hazard	Sum of Weighting Points
a	Non-endangered	≤ 12
b	Weakly endangered	13 to 20
c	Medium endangered	21 to 30
d	Strongly endangered	31 to 40

Approach to Study and Prediction

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  based on case histories looking for common factors

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  based on the type , magnitude and availability of energy about

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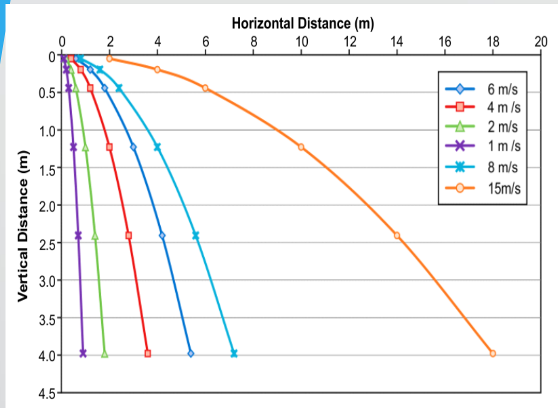


Energy source analysis

- How much energy is "locked up" or can be transmitted to the ground about an excavation

  faults, bedding planes, rock material, seismic events, gas , stress and mine geometry effects

- How much energy is needed to cause a burst

- What energy sources are likely in various circumstances (risk factors)

Energy source analysis

Sources of energy

- Strain energy (stress locked up in rock mass and released at failure)
- Seismic energy (vibration from major rock failure event)
- Gas (stored in pore volume or potential energy within adsorbed gas in coal)
- *How is this energy translated into a body force to propel*

Energy source analysis

Strain energy (stress locked up in rock mass and released at failure)

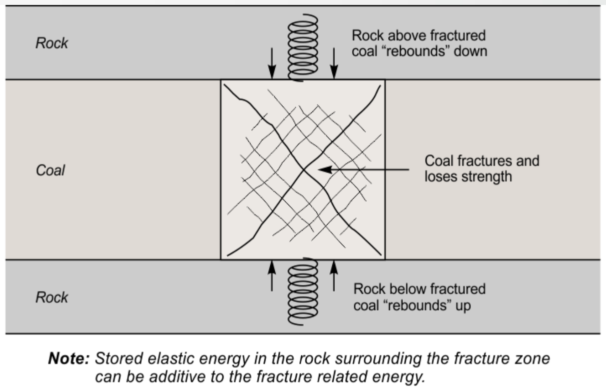
- $E_n = \frac{\sigma^2}{2E}$ *or derivatives*. A function of stress and Youngs modulus of the rock
- The energy released is the stress change $\frac{\Delta\sigma^2}{2E}$ associated with rock failure and $\frac{\Delta t^2}{2G}$ for slip along bedding or fault planes
- Where the rock is confined a significant part of the strain energy is taken up in the fracture process and is transferred to heat and vibration.
- Bursts commonly occur when additional energy is provided to the system from movement or unloading of adjacent rock.

$$\text{The energy available contribute to a burst} = \Delta\sigma^2/2 \; * \left(\frac{1}{E_r} - \frac{1}{E_c}\right)$$

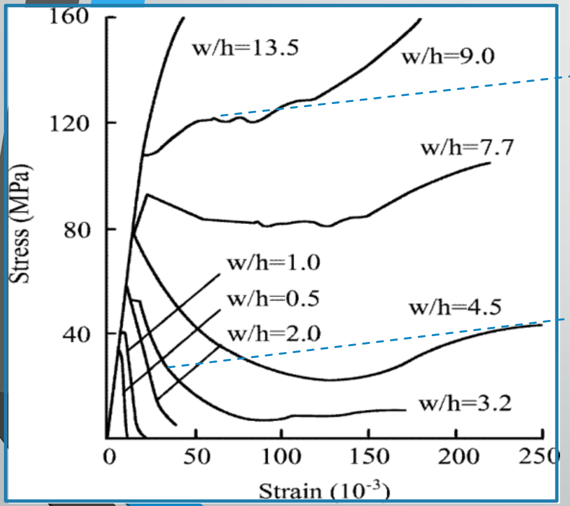
Strain energy in pillars

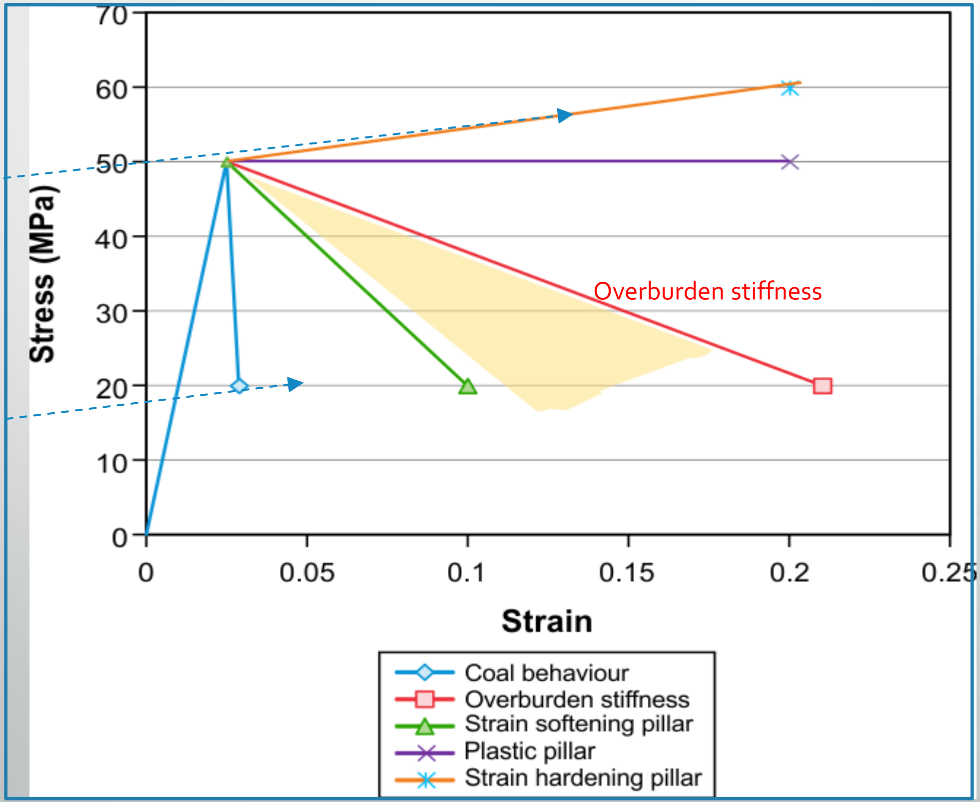
- Pillar failure near goaf edges or between goafs is a classic example of large scale overburden movement providing energy for a pillar or ribside burst

- Major strain bursts are typically associated with low adjacent ground stiffness



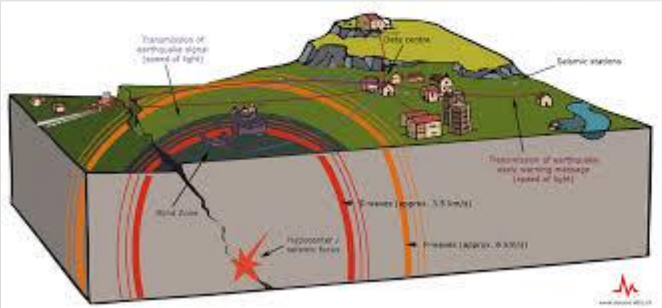
a) **Concept of stored elastic energy in the surrounding rock being released during fracturing of the coal.**



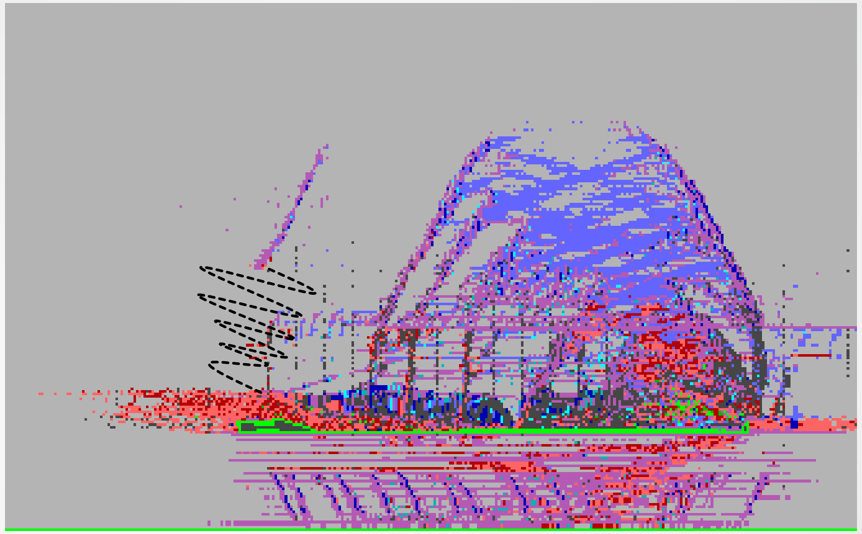


Energy in isolated pillars in the goaf > 3 MJ m^{-3} is possible

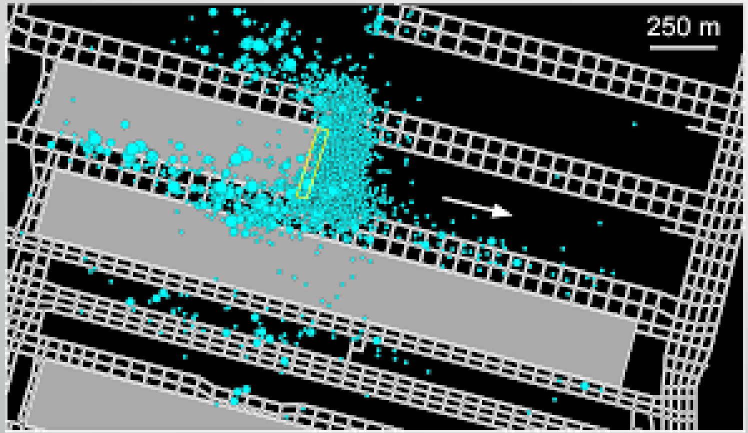
Seismic Energy



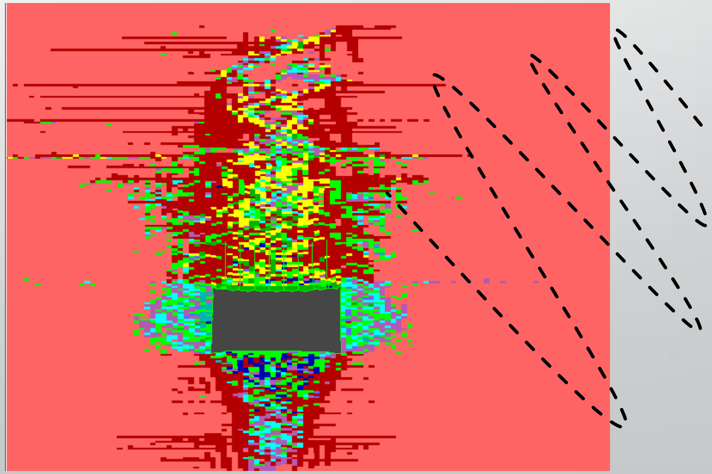
Energy = $\frac{\Delta t^2}{2G}$ and variants



Seismic vibration from caving fractures

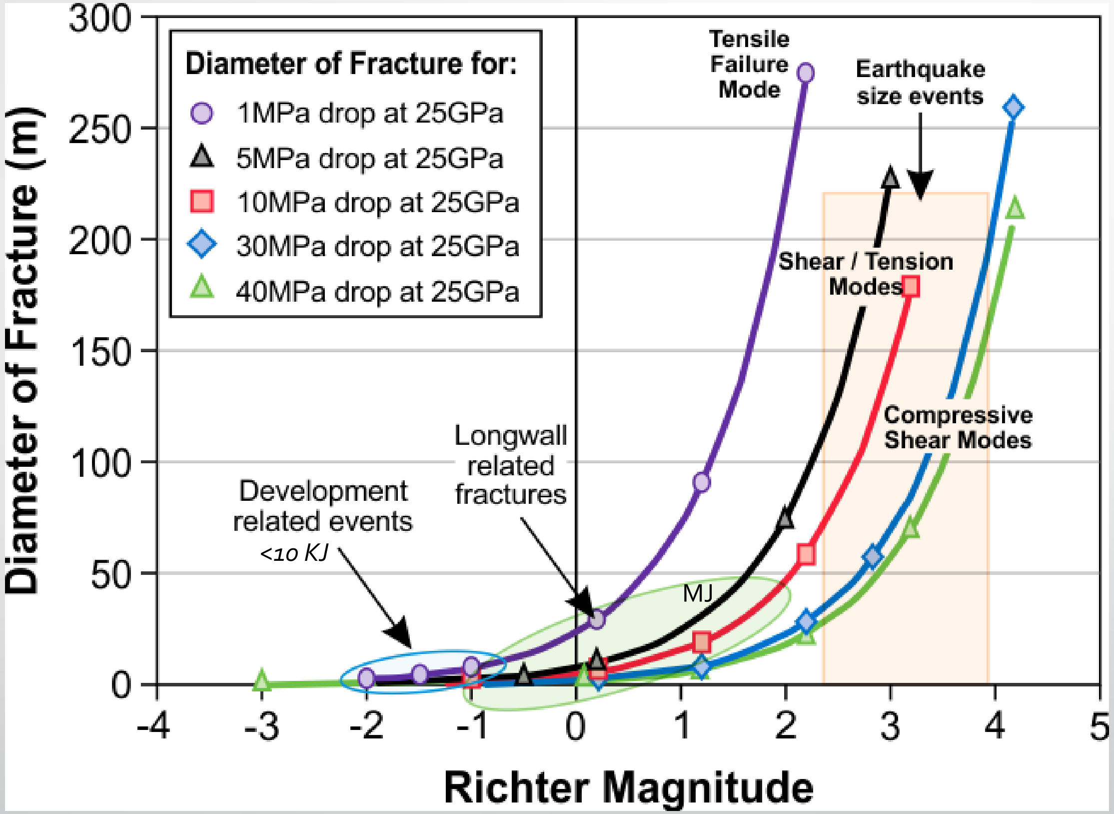


Seismic events indicating rock fracture



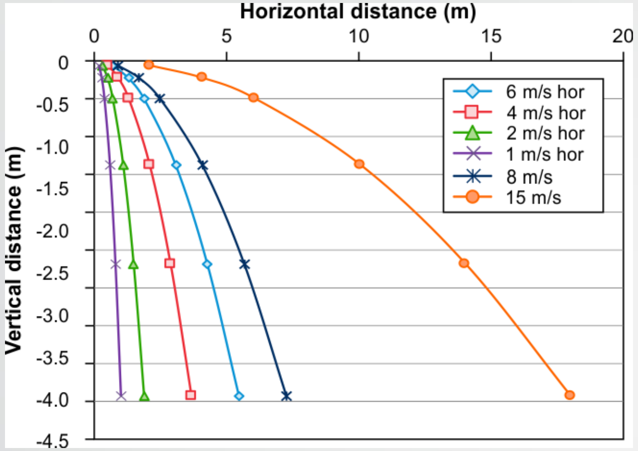
Small scale vibration from rock failure

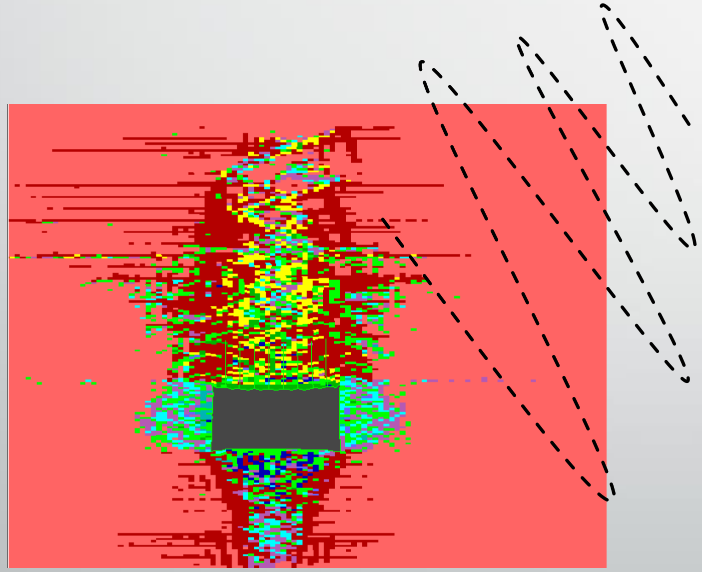
Seismic Energy

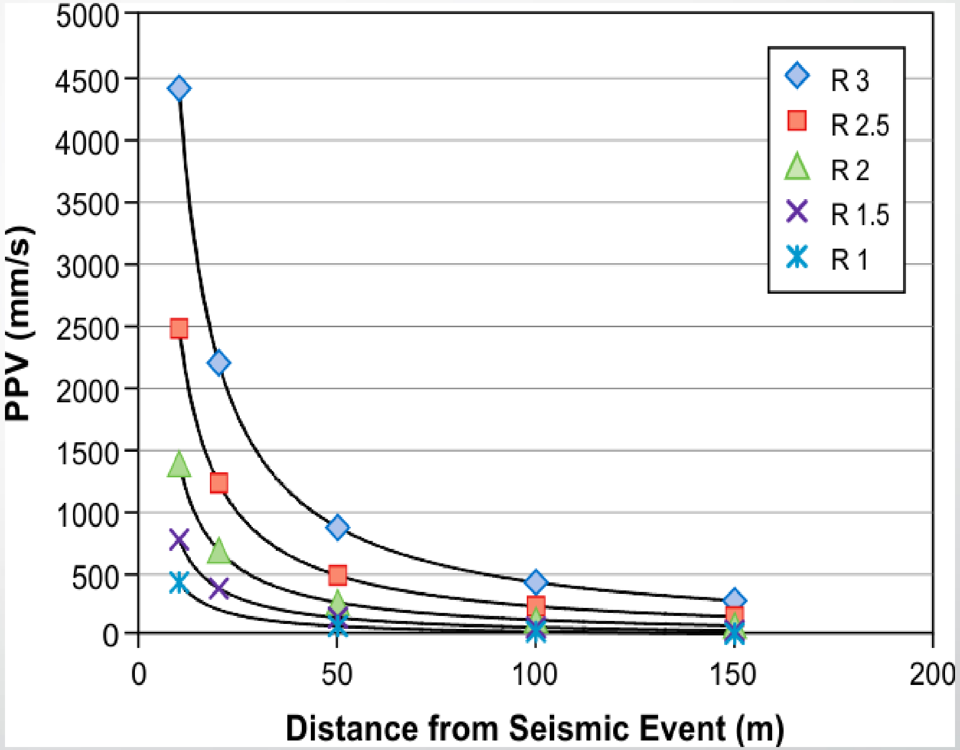


Scale of energy is typically reported as Richter Magnitude. A function of stress drop and surface area of the fracture surface

Energy / vibration reduces rapidly from source



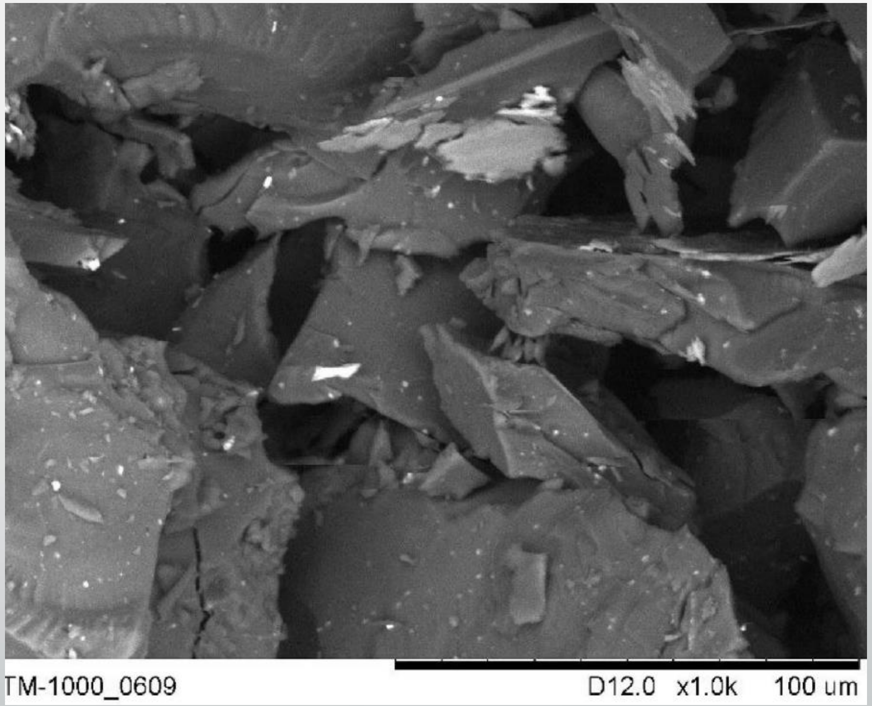




Events need to be located relatively close . Longwall caving and fault activation most likely factors. Amplification in broken ground to be investigated further

Gas Energy

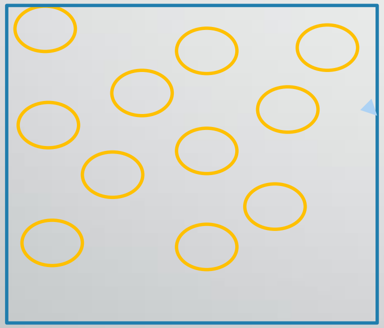
- Energy of expansion of compressed gas within the coal (rock).
- Gas within the pore volume and adsorbed onto surface area of coal micro fabric



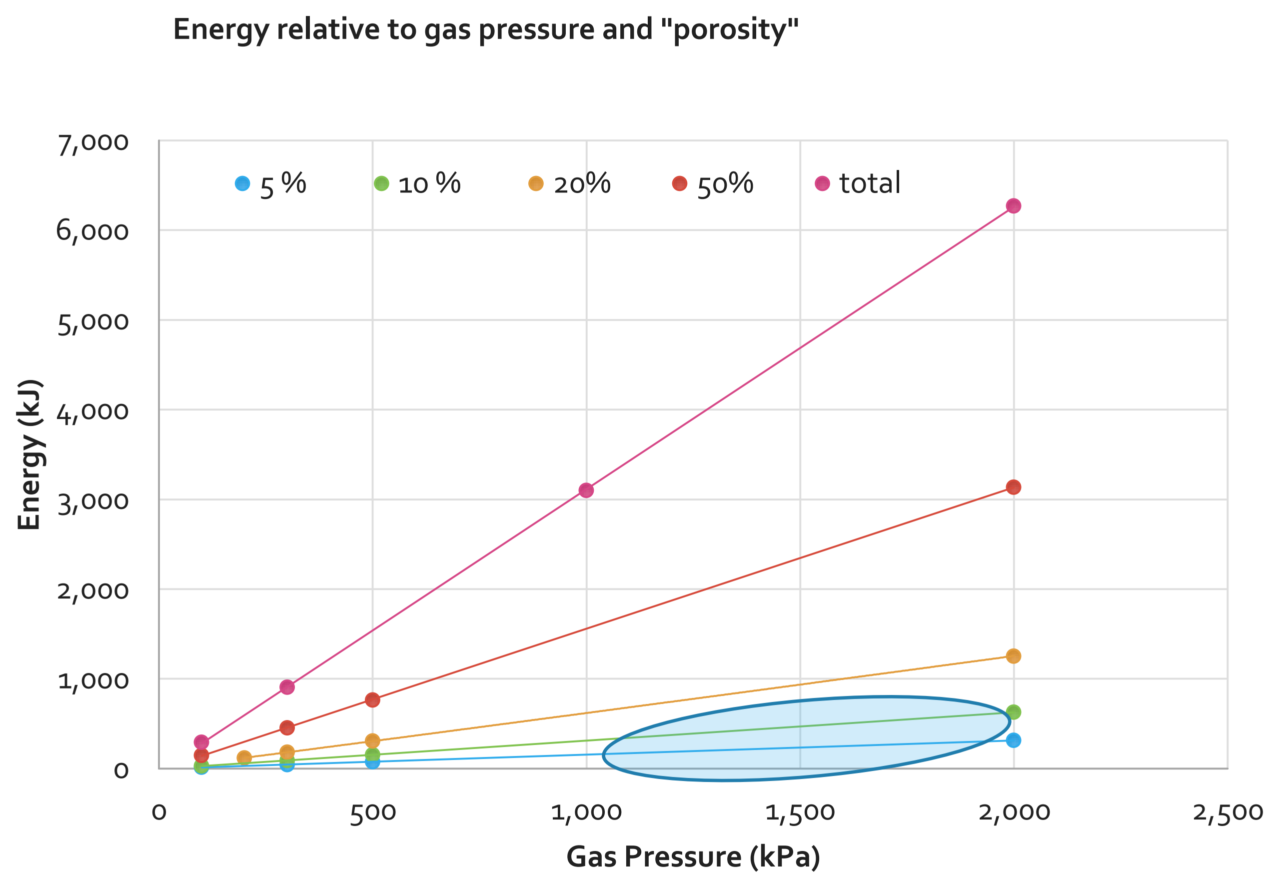
Energy created by rapid expansion from pore volume and desorption from surface area caused by micro / macro fracture of coal structure

Porosity

Gas within pore volume



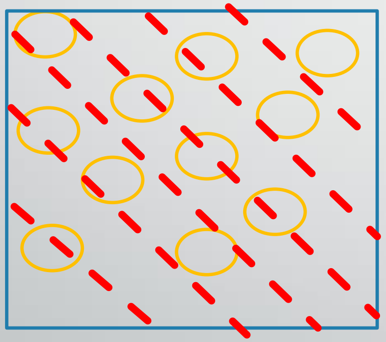
630 kJ @ 2MPa



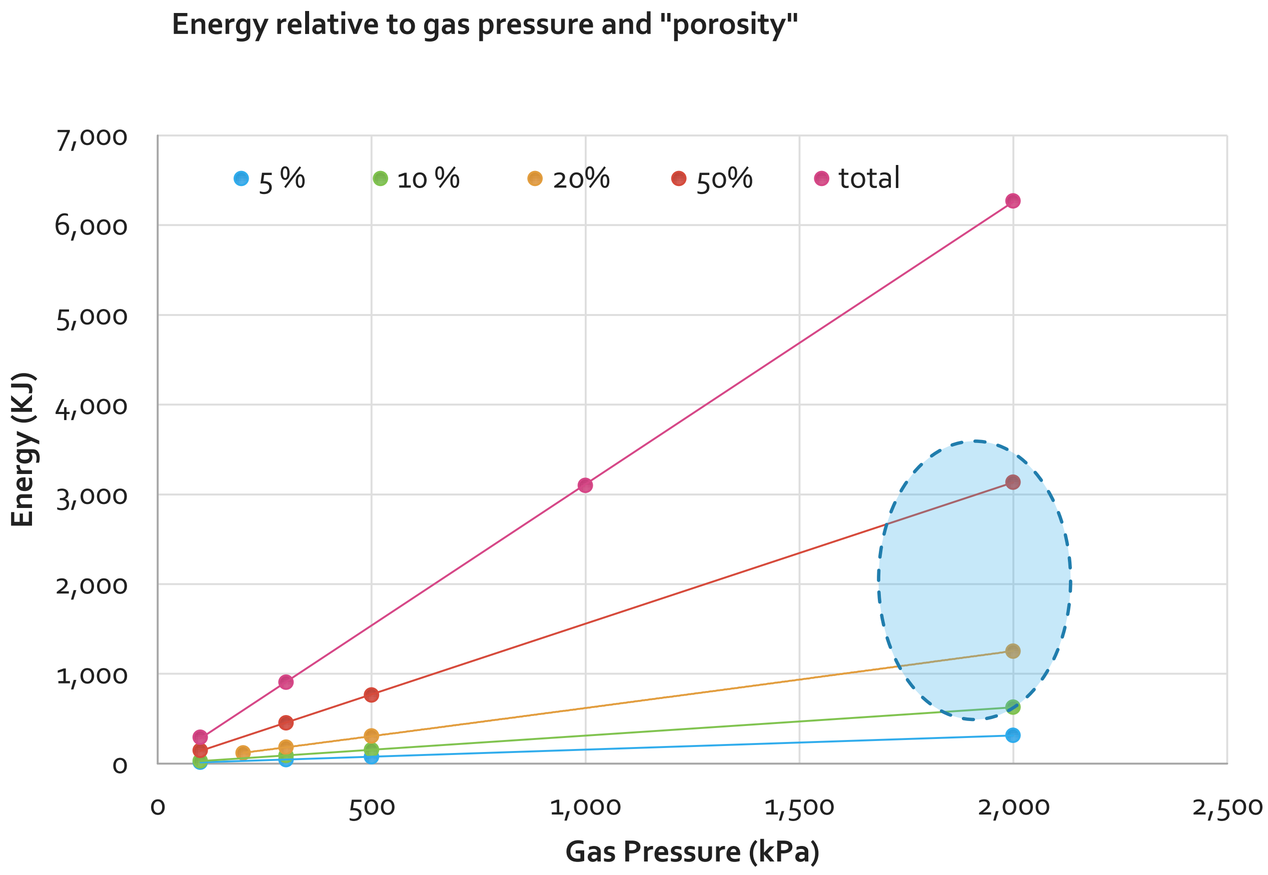
Energy created by rapid expansion from pore volume and desorption from surface area caused by micro / macro fracture of coal structure

Porosity + fracture

Gas within pore volume

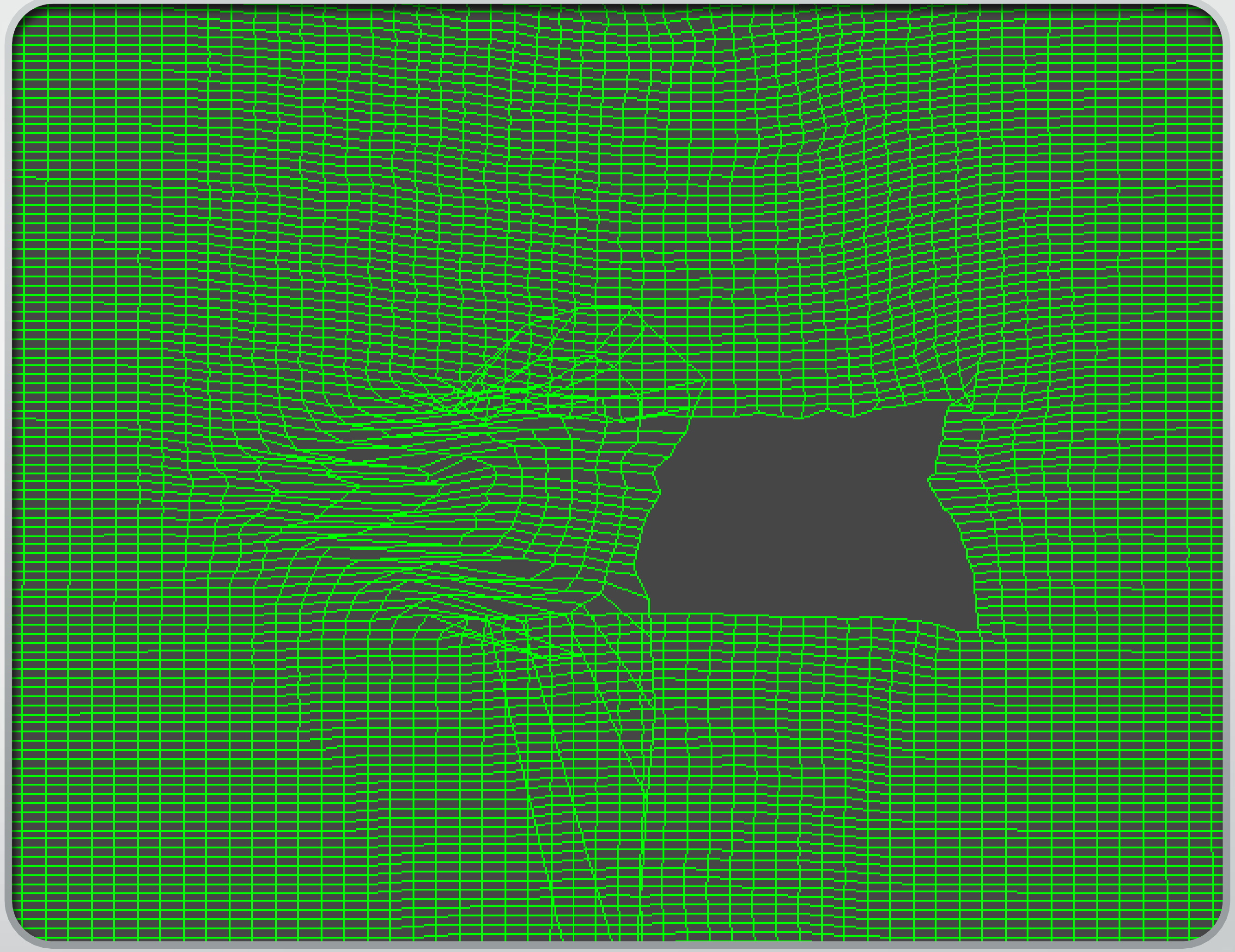


3000 kJ ?? @ 2 MPa

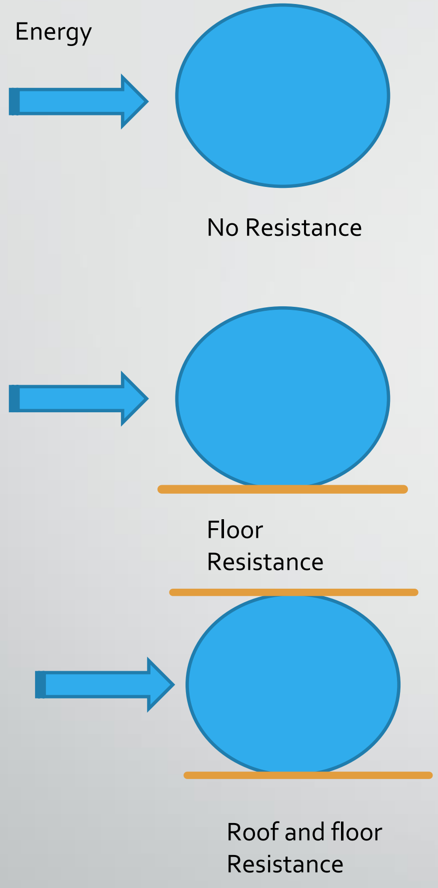


How much energy is required

- Resistance to movement must be overcome
- Resistance includes confinement, in-situ strength , reinforcement



Burst velocity dependent on resistance and energy



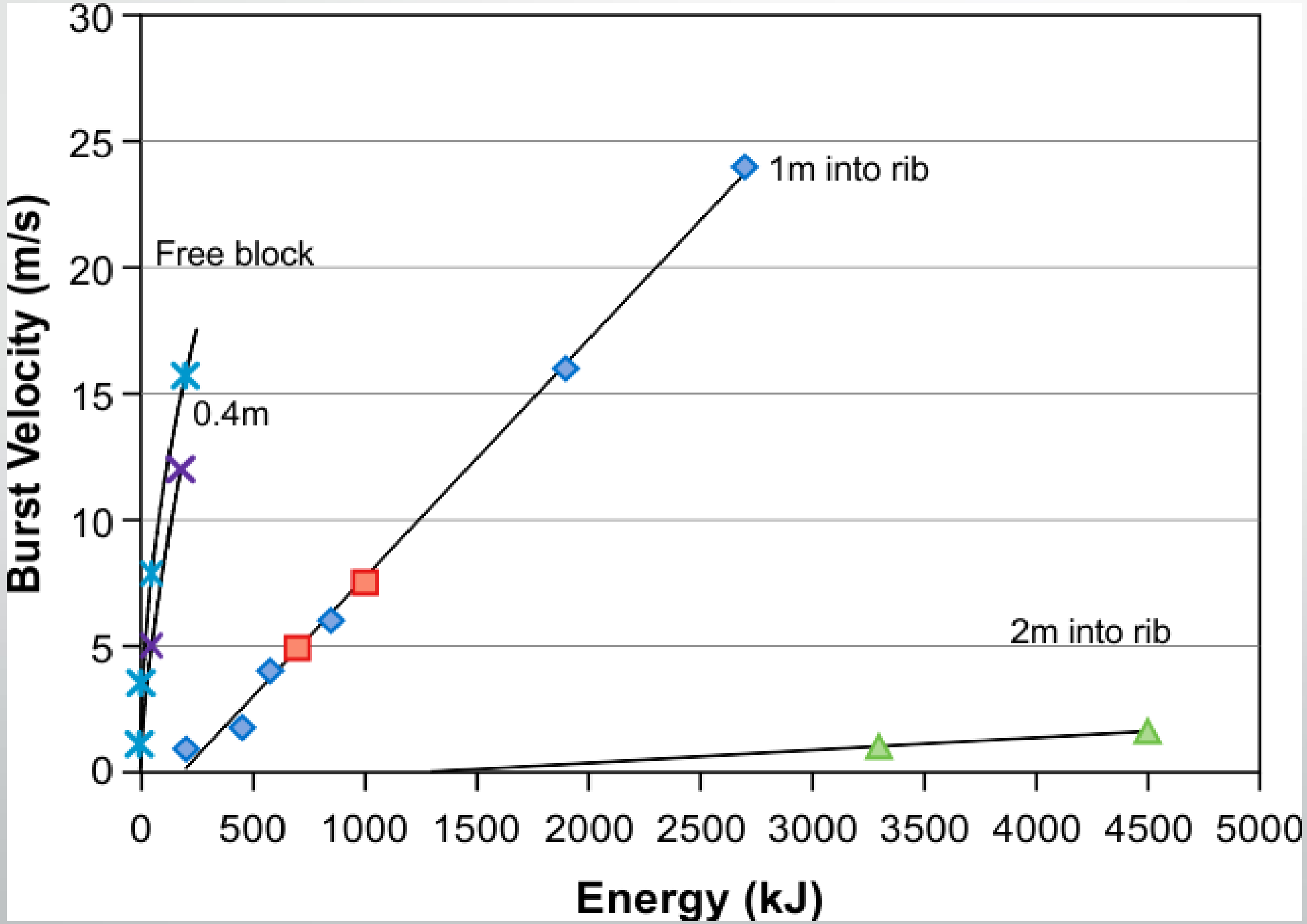
$$\text{Velocity} = \sqrt{2 * \frac{(Energy - Resistance)}{mass}}$$

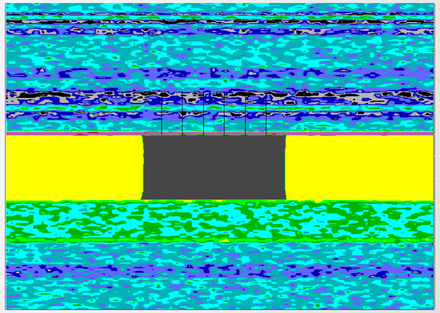
Options.

1. Unconstrained ribside (no resistance)
2. Moderate confinement (floor and clay band)
3. Full confinement (floor and roof)

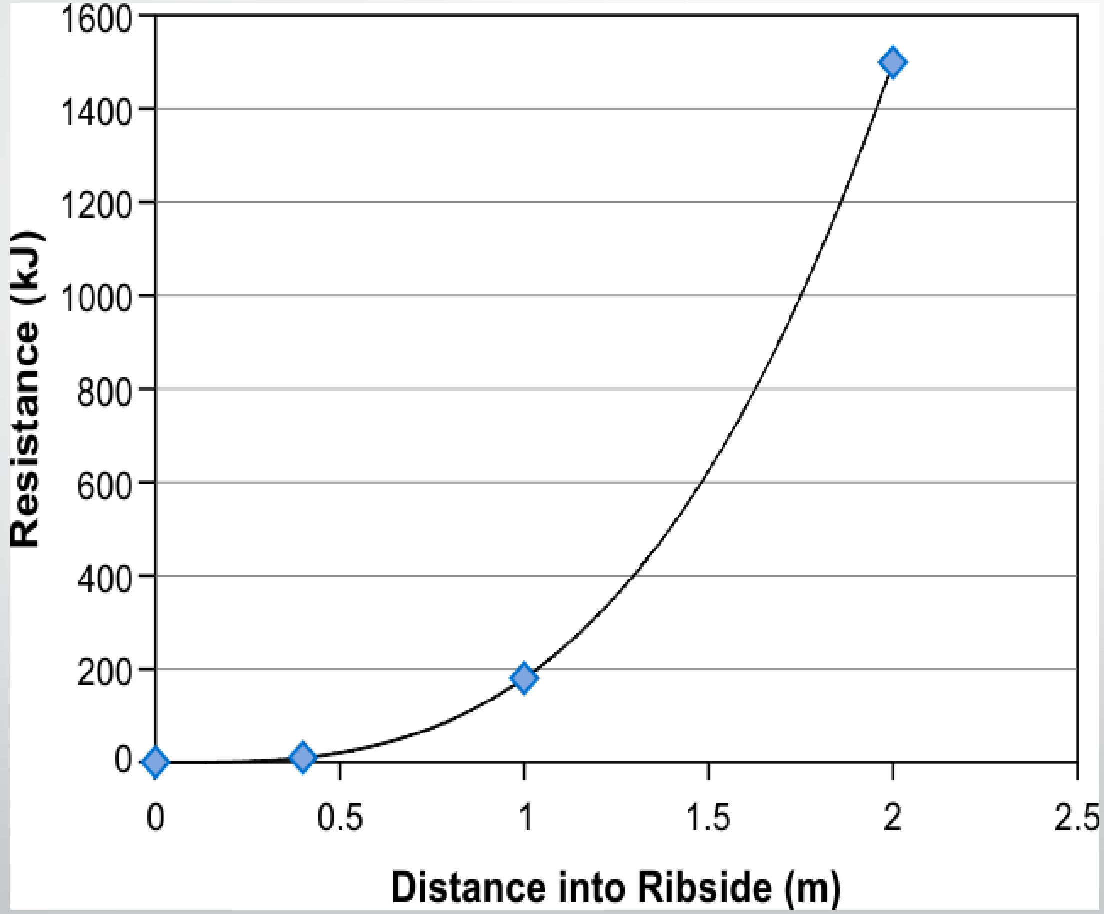
Note. Different seams will have different energy thresholds

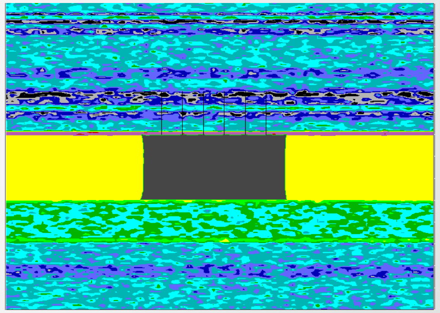
Burst velocity – resistance relationship





Resistance to be overcome in the rib

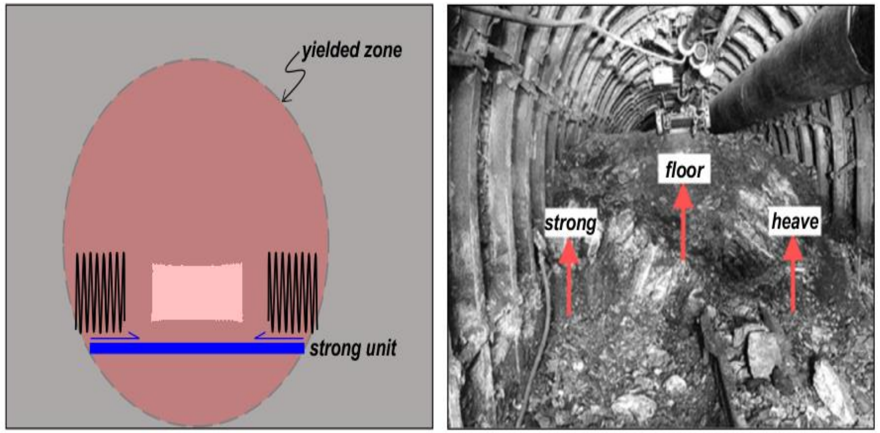




Gives an estimate of the volume of burst relative to energy

Note. i. Relationship is geology –stress dependent
ii. Ribside fractured to 2.5m

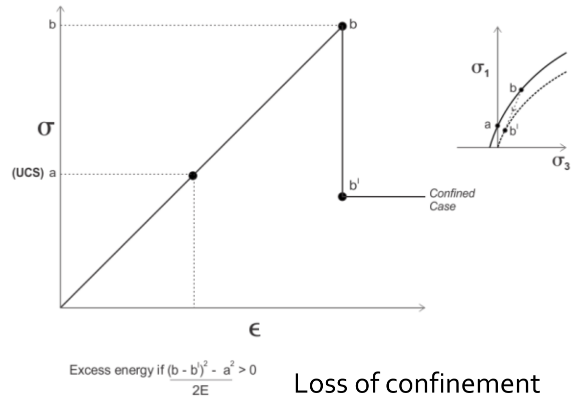
Summary of energy available during development driveage



If a unit surrounded by failed and softened strata fails rapidly then energy can be provided by the surrounding yielded ground >500Kj m^{-3} is possible.

The energy available to contribute to a burst = $\Delta\sigma^2 \times \left(\frac{1}{E_r} - \frac{1}{E_c}\right)$

Energy form during Development	Mechanism	Energy Magnitude (KJ)	Comments
Strain			
	Rock fracture about a roadway	< 5/m^3	Stiffness of surrounding ground high
	Fracture of coal	< 10/m^3	Stiffness of surrounding ground high
	Slip on bedding	< 16/m roadway (5MPa stress drop along 2m length coal/stone contact)	Limited depth into ribside. conservative estimate
	Loss of confinement in Australia	typically low	Unlikely unless locally elevated stress
	Loss of confinement in yielded rib (deep European / Chinese mines)	> 400 /m^3 (see example in text)	Commonly associated with extraction
	Pillar failure	NA	Not relevant with pillar geometries used in Australia



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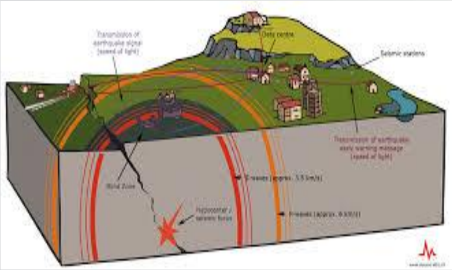
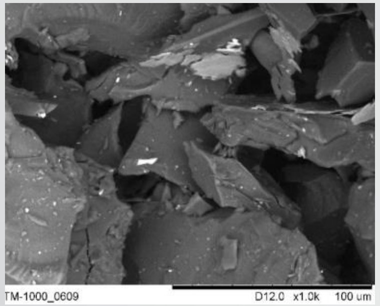
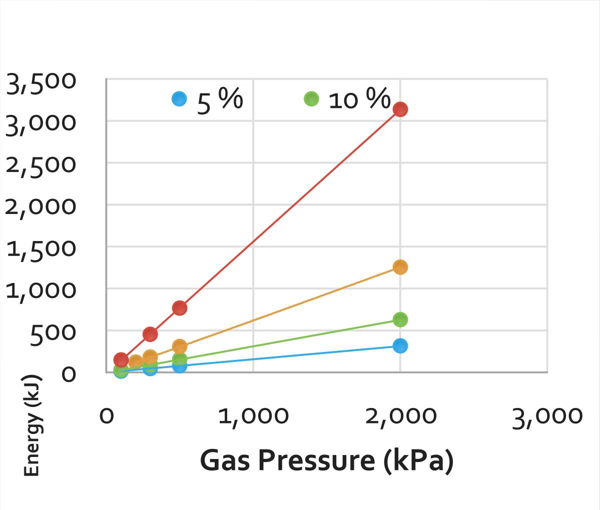


Energy form during Development	Mechanism	Energy Magnitude (KJ)	Comments
Seismic			
	Rock fracture	< 10/m^3	
	Fracture of coal	<100/m^3	Typically a “gradual” process. Not dynamic
	Bedding plane shear (stick slip mechanism)	<25/m roadway (5MPa stress drop along 2m length)	Typically not dynamic unless an undulating cohesive contact.
	Fault slip on existing plane	< 1 /m^2 (assume 1MPa cohesion)	Pre-existing rupture surface. Conservative estimate.
	Fault rupture or extension	Unlikely to cause fresh rupture of rock in development	May have fresh rupture in an active tectonic zone

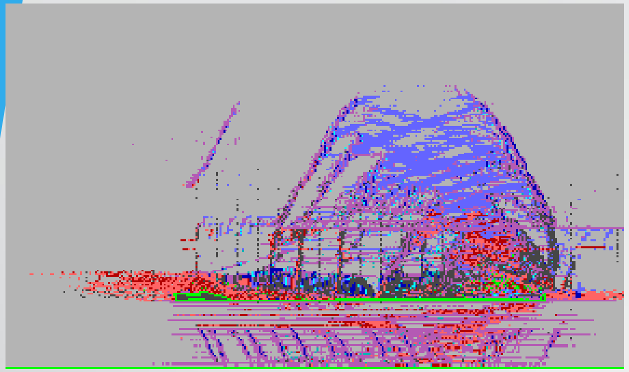
Summary of energy available during development driveage

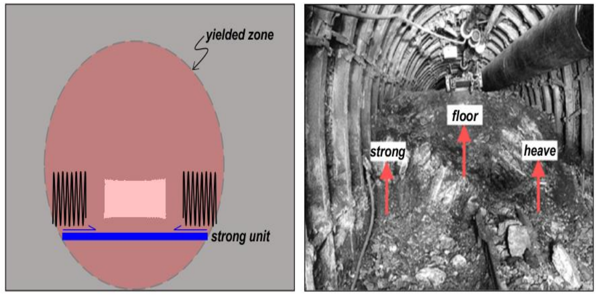




Energy form during Development	Mechanism	Energy Magnitude (KJ)	Comments
Gas			
	Pore volume	60-700/m^3 (see Figure 22)	Function of pore volume and gas pressure
	Rapid diffusion	> 2000 /m^3	1-2MPa pressure

Summary of energy available during extraction





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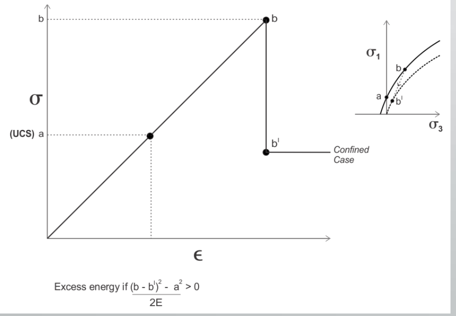
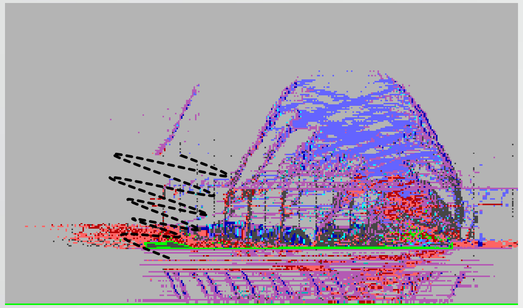
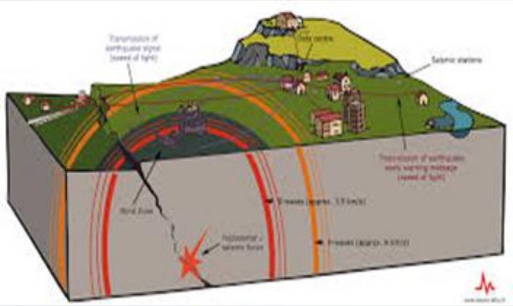


Energy form during extraction	Mechanism	Energy Magnitude (KJ)	Comments
Strain			
	Failure of large massive units	Little excess energy	Energy radiated as seismic energy
	Normal abutment fractures	Little excess energy	Energy radiated as seismic energy
	Isolated pillars (excess energy from overburden)	➢ 2000/m^2	Typically not used in Australia
	Loss of confinement in intact coal zones	< 100/m^3 (based on 2MPa confinement and 35MPa vertical)	Damaging if associated with loss in rib resistance
	Loss of confinement in yield zones	250/m^3 (10MPa excess stress in yield zone see example in text)	Requires particular geology to occur
	Dynamic Failure and movement of large massive units ahead of the face (excess energy from overburden)	Moderate to Large …Depends on site conditions. Not common in Australia	Overload face coal due to lower stiffness in overburden

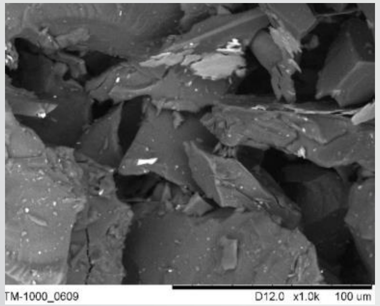
Summary of energy available during extraction





Energy form during extraction	Mechanism	Energy Magnitude (KJ)	Comments
Seismic			
	Failure of large caving units	➢ 2000	Large rupture events
	Normal abutment fractures	< 90/m^3 for individual fractures	Fractures about the roof and floor
	Fault reactivation	< 1/m^2 fault plane activated (1MPa cohesion)	No additional rupture
	Fault extension	< 13/m^2 of new rupture surface Can be very large	Assume 5MPa cohesion and 1GPa shear modulus (conservative)

Summary of energy available during extraction



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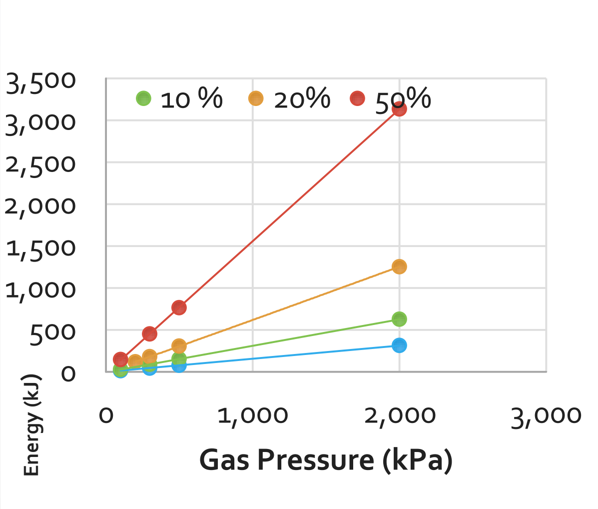
	Rapid diffusion	> 2000 /m³	1-2MPa pressure



: **Coal Burst Mechanism and Likelihood in Australia**

Phenomenon	Development operations	Extraction operations	Energy source	Comment
Pillar failure	unlikely	unlikely	Stored strain	Largely engineered out in Australia
Strong contacts to coal	Unlikely	Possible	Stored strain or seismic	required Loss of confinement mechanism
Faults (continuous)	Unlikely (slumps and low level ejection possible)	Possible	Seismic	Uncommon unless associated with fault extension at the periphery
Fault Termination zones	Unlikely but possible Slumps and low level ejection possible	possible	Seismic	Associated with fault extension
Dykes, mylonite zones and faults	possible	Possible	Gas	Undrained pockets of high gas content coal together with high fracture density and enhanced porosity
Massive units eg sandstone	Most unlikely	Possible	Seismic	Dynamic caving of thick units close to the face
Undrained coal	possible	possible	Gas/stored strain	Associated with macro and micro mining induced fracturing of coal in high stress areas

Burst risk based on energy and mechanisms

We are getting much closer to having a quantifiable risk approach.

Combined energy sources may be additive

Prediction and definition of key aspects is still challenge

i. Definition of structural properties and location

ii. Location of isolated gas sources

Sites will have different threshold (resistance) values based on geology

Sites will have different combinations of factors to consider

Research is ongoing sponsored by mining companies and ACARP

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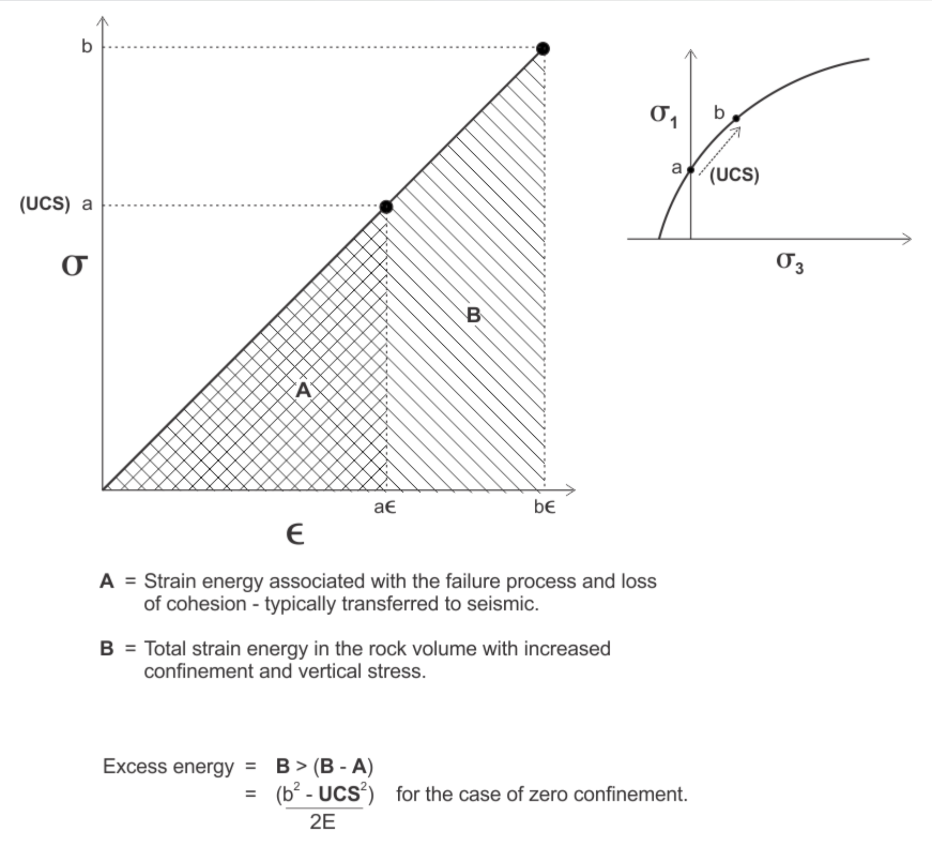
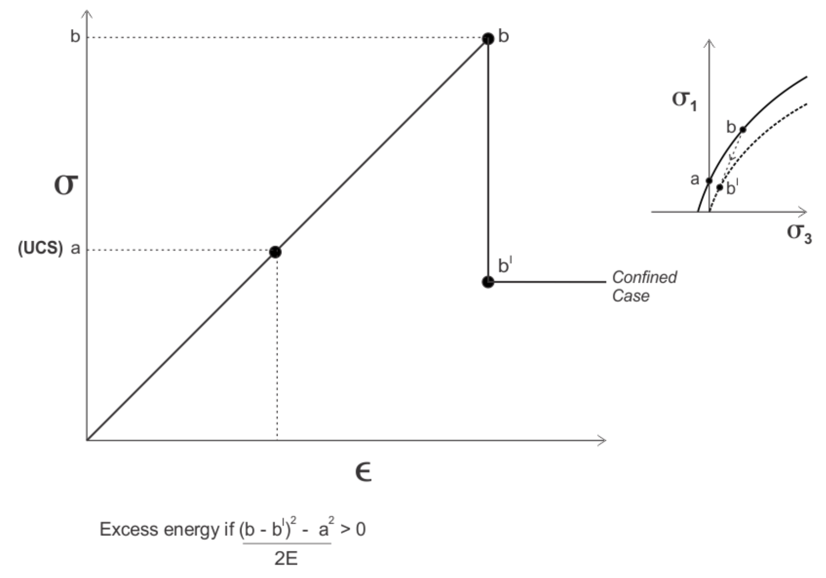
With Reference to Energy Considerations.

Winton Gale SCT Operations


b
(UCS) a
σ
A
B
aϵ
bϵ
ϵ
σ1
σ3
b
a
(UCS)
A = Strain energy associated with the failure process and loss of cohesion - typically transferred to seismic.
B = Total strain energy in the rock volume with increased confinement and vertical stress.
Excess energy = B > (B - A)
= (b² - UCS²) / 2E for the case of zero confinement.


b
b
(UCS) a
σ
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Confined Case
ϵ
σ1
σ3
b
a
b'
Excess energy if (b - b')² - a² > 0 / 2E