Coal Mine Outburst

Mechanisms, Thresholds and Prediction Techniques

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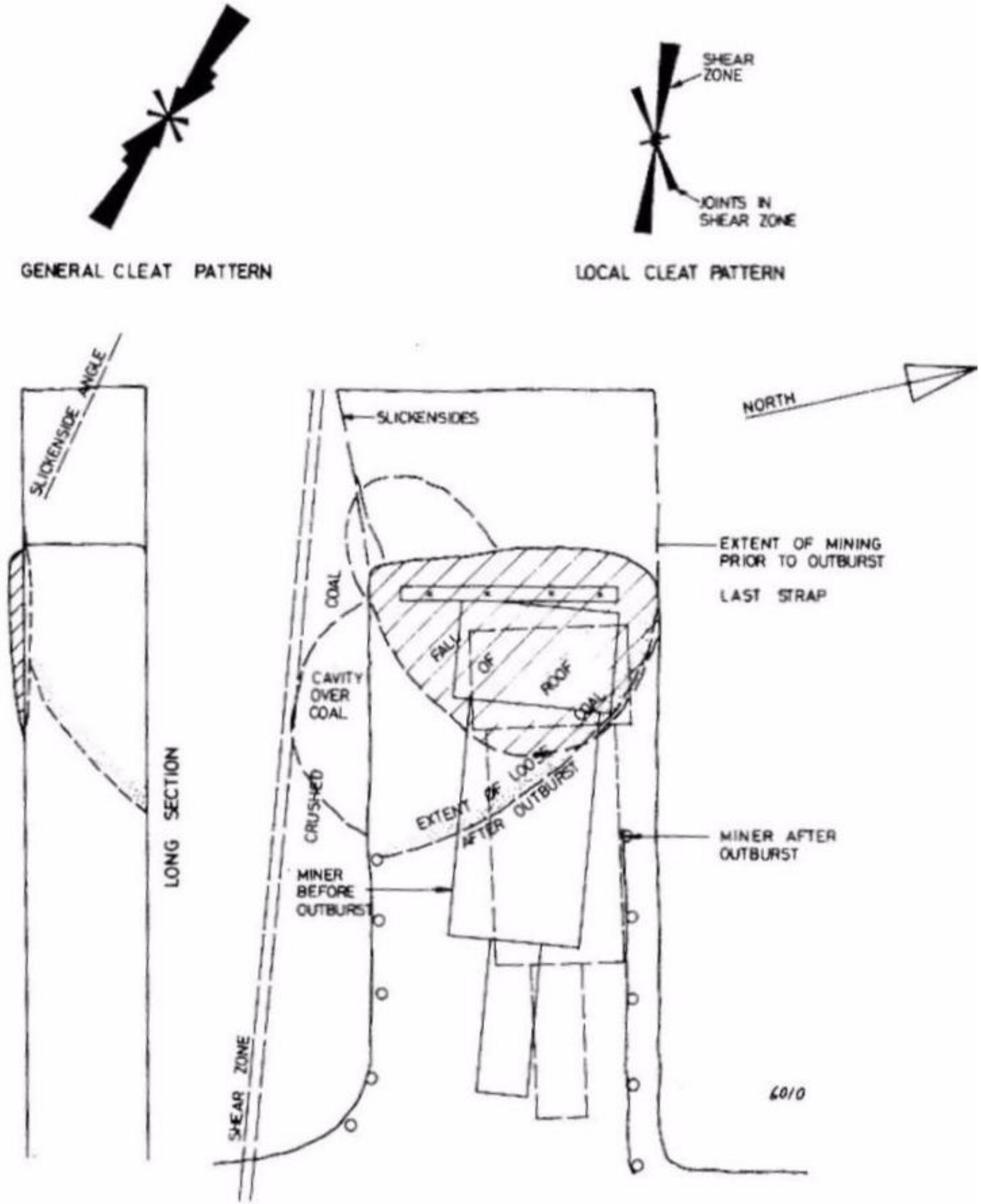
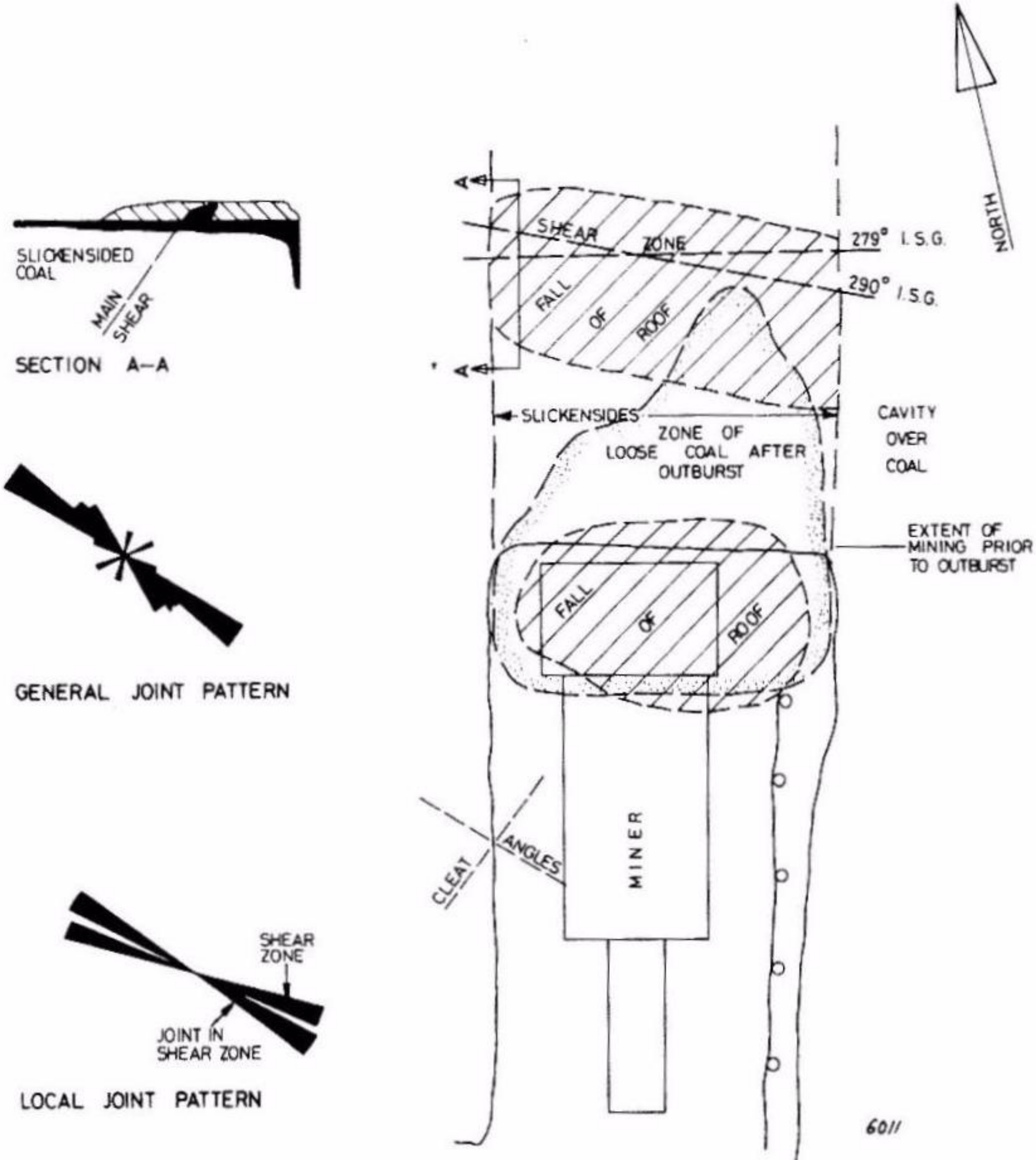
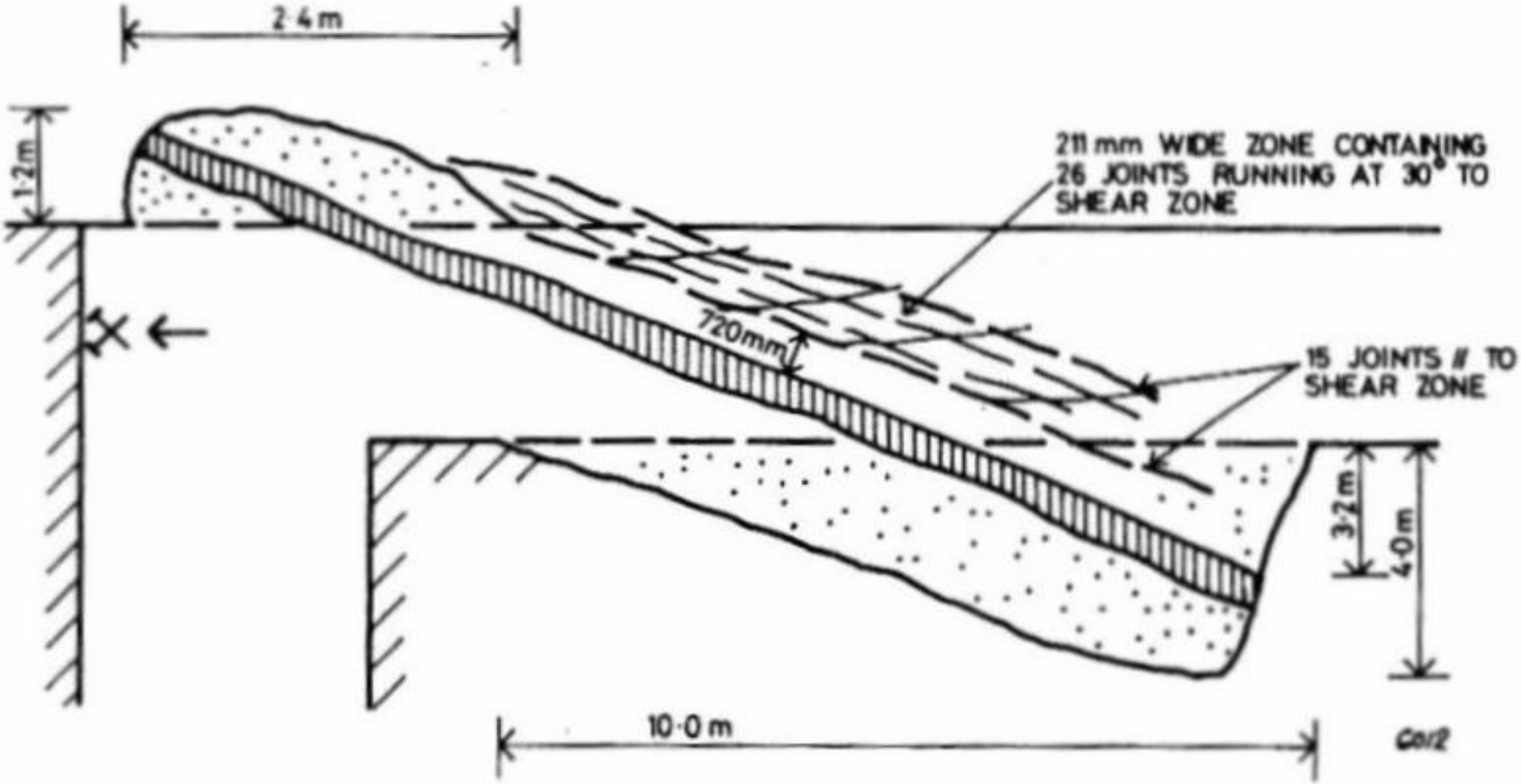
Westcliff Colliery
Outburst Illustration 1
(Marshall et al)

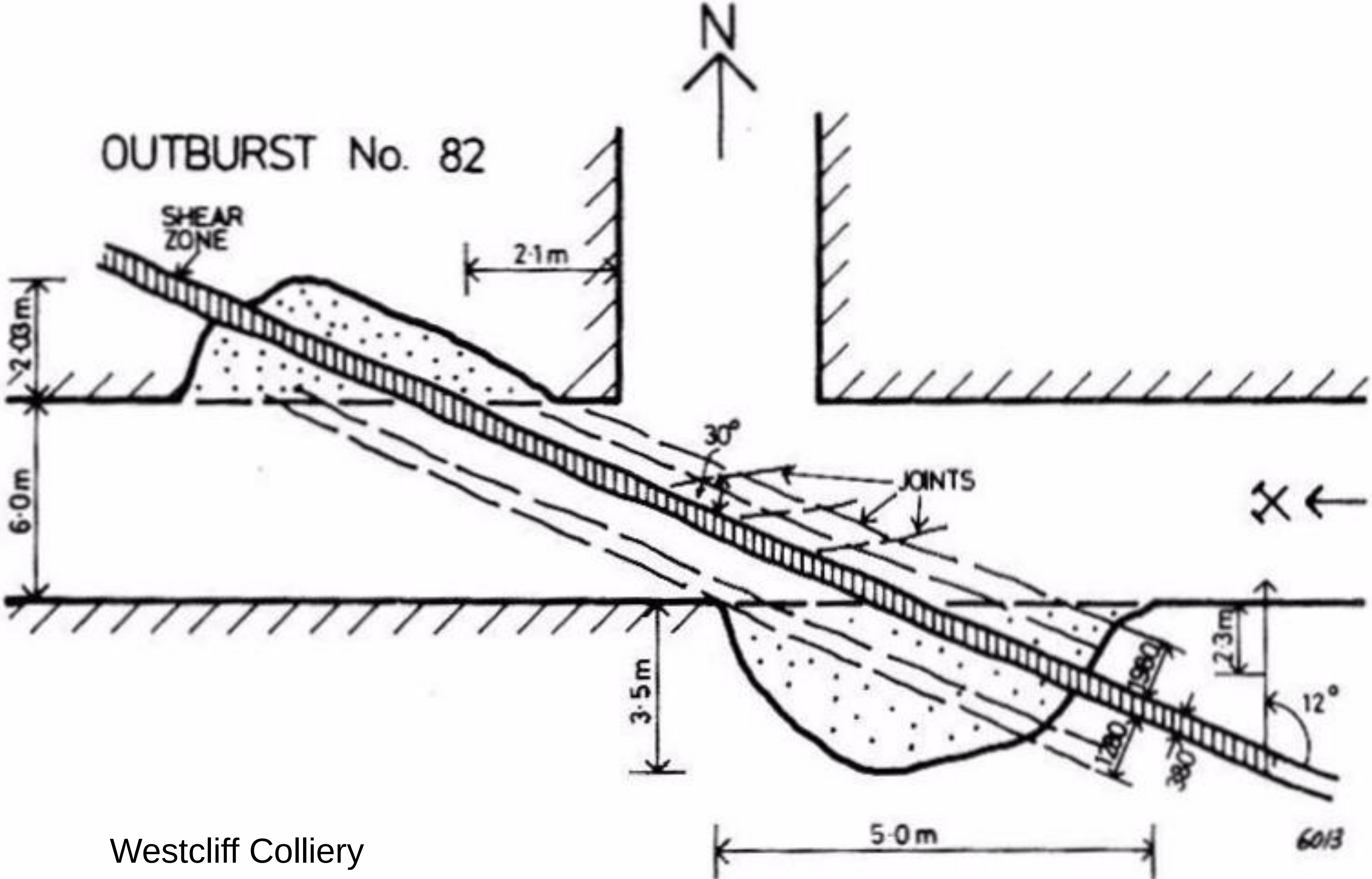


Westcliff Colliery Outburst Illustration 2 (Marshall et al)

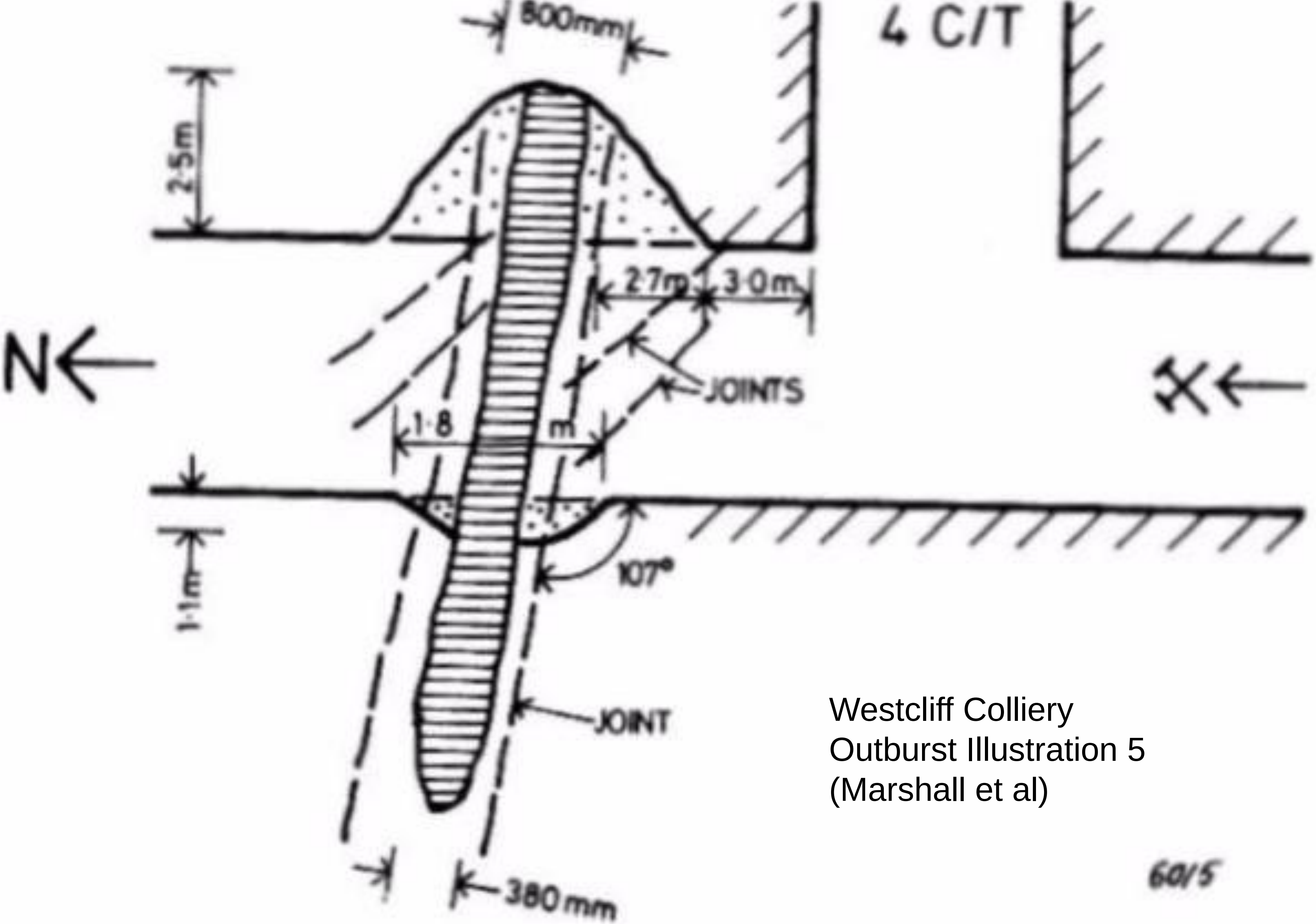




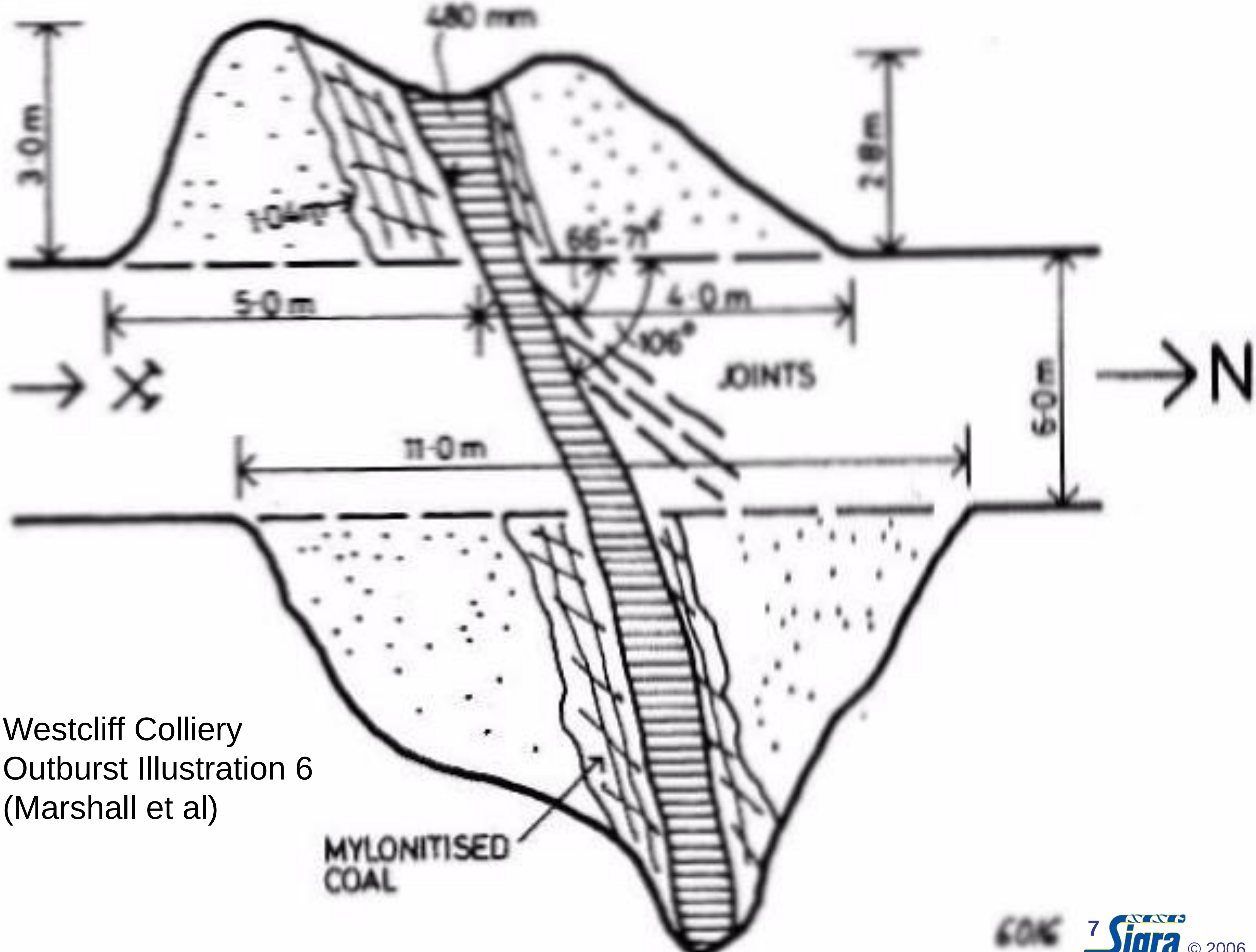
Westcliff Colliery
Outburst Illustration 3
(Marshall et al)



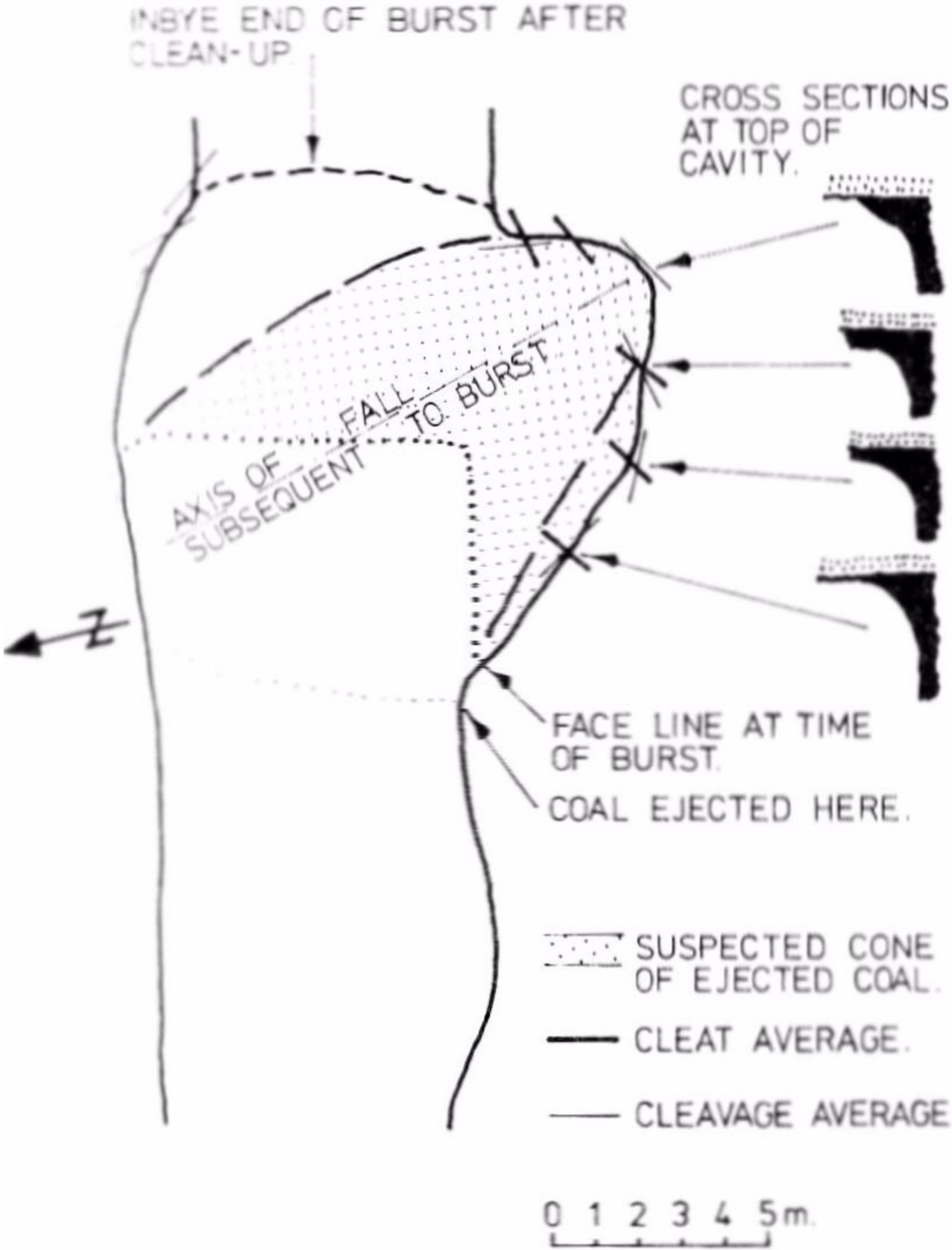
Westcliff Colliery
Outburst Illustration 4
(Marshall et al)



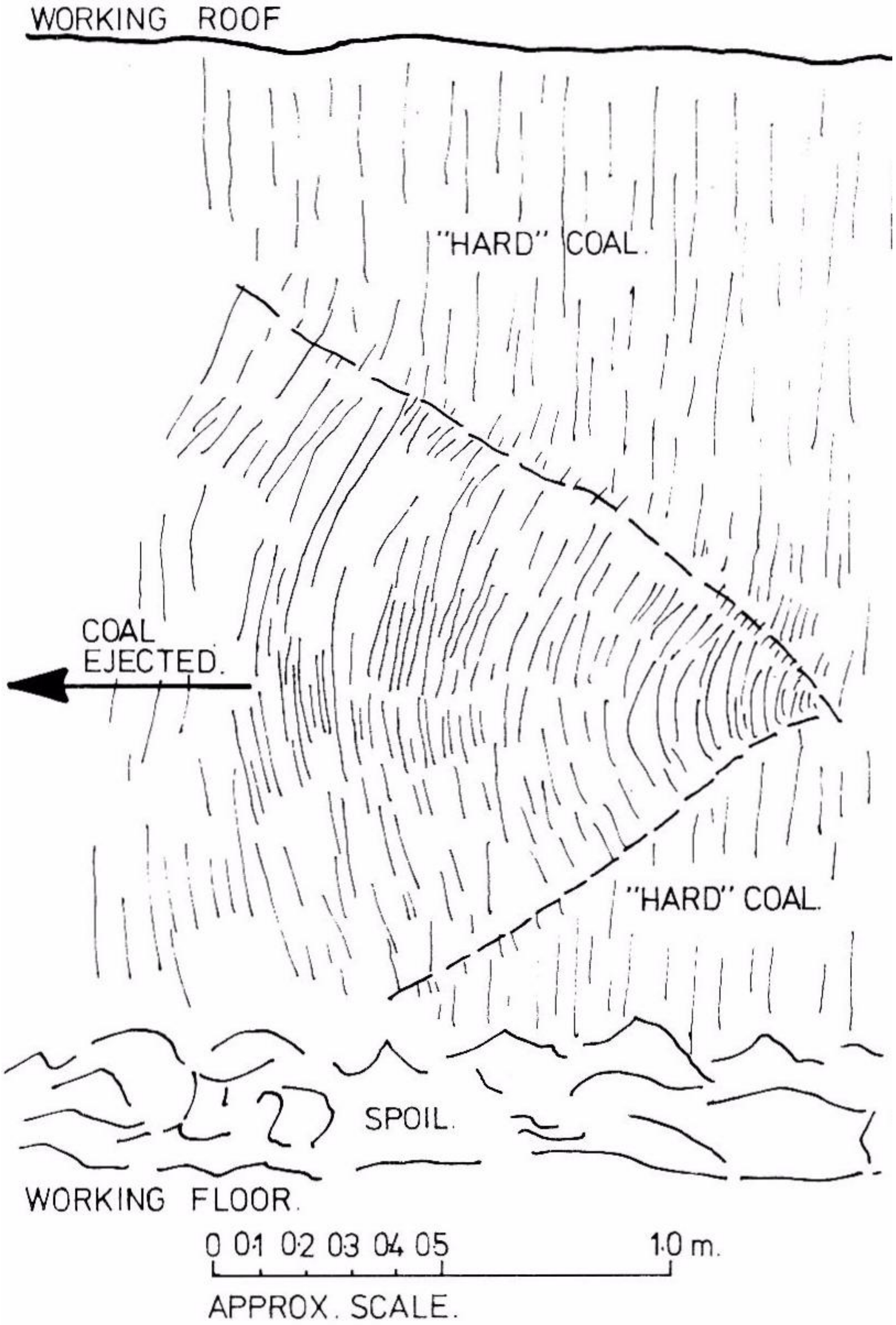
Westcliff Colliery
Outburst Illustration 5
(Marshall et al)



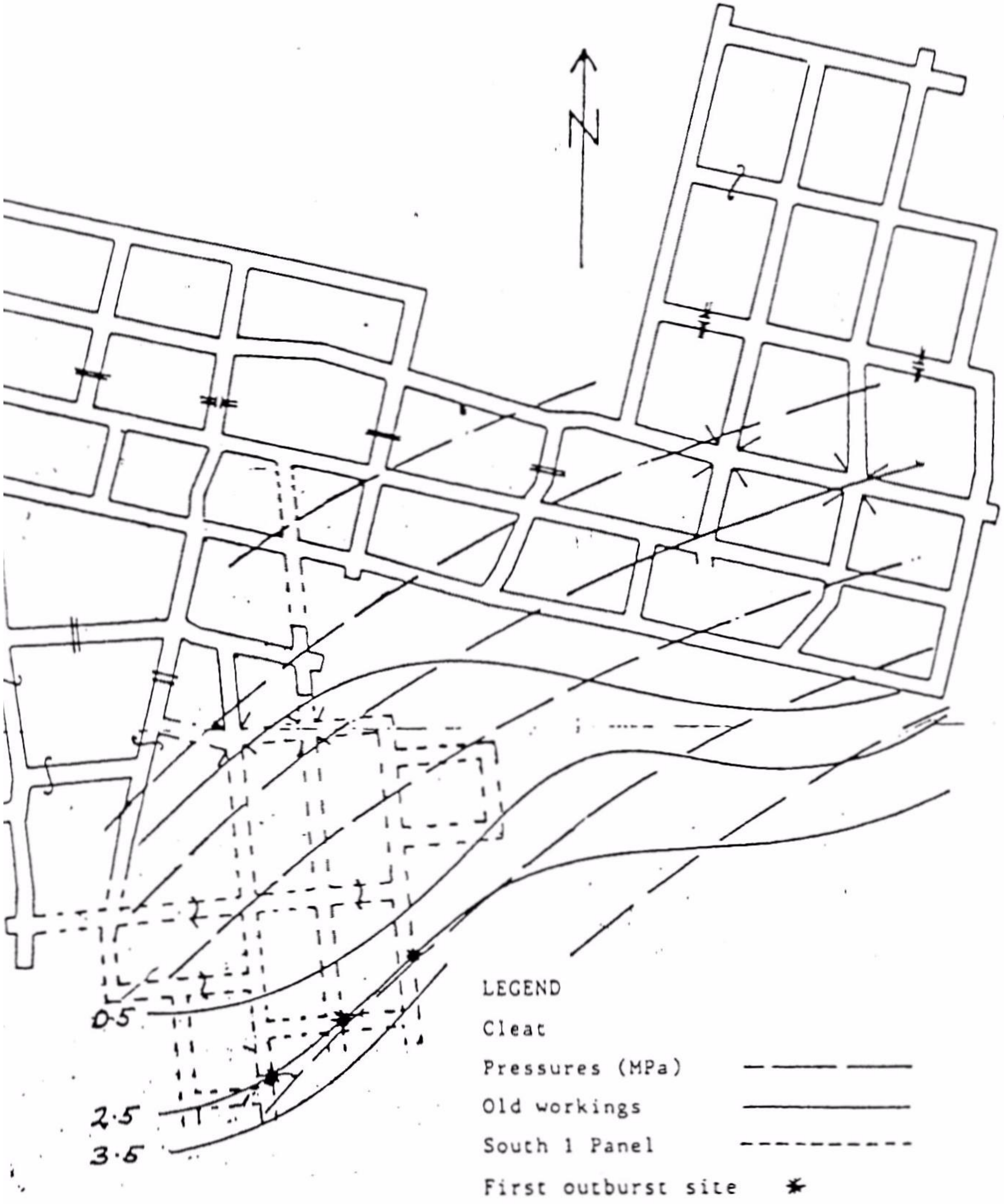
Westcliff Colliery
Outburst Illustration 6
(Marshall et al)



Leichhardt Colliery
Outburst Illustration,
(Moore and Hanes, 1980)

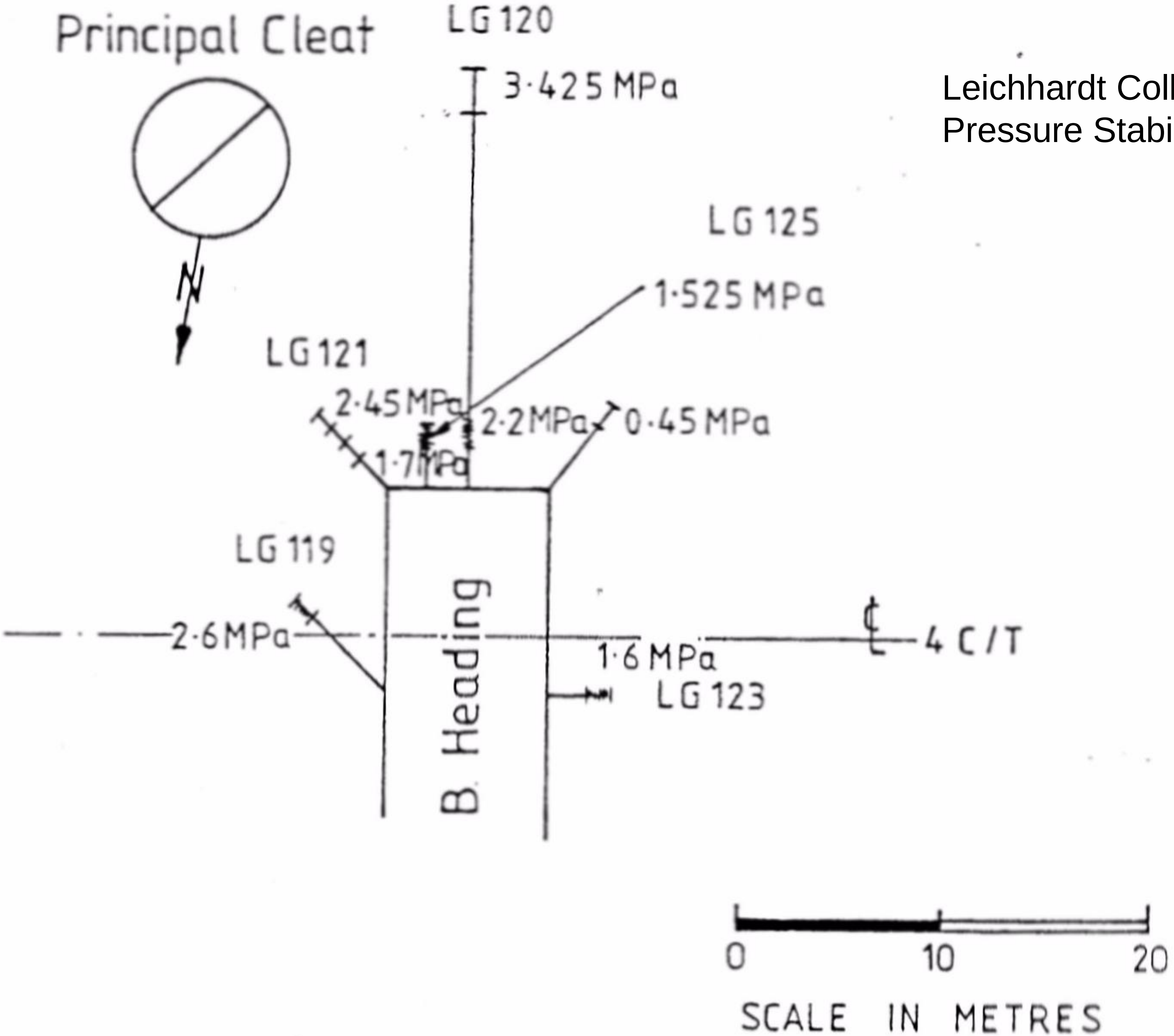


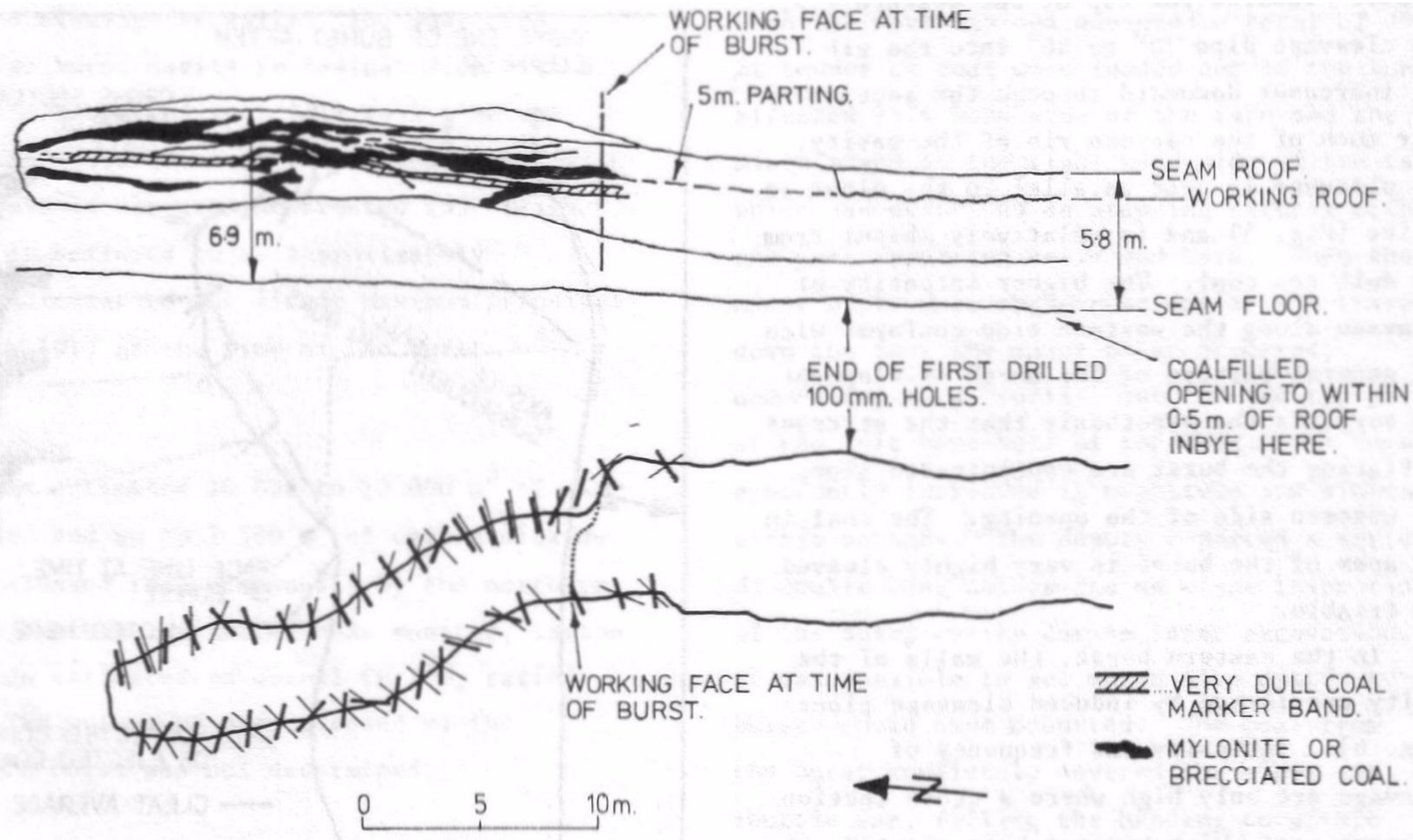
Leichhardt Colliery
Outburst Cavity – Induced
Cleavage Planes



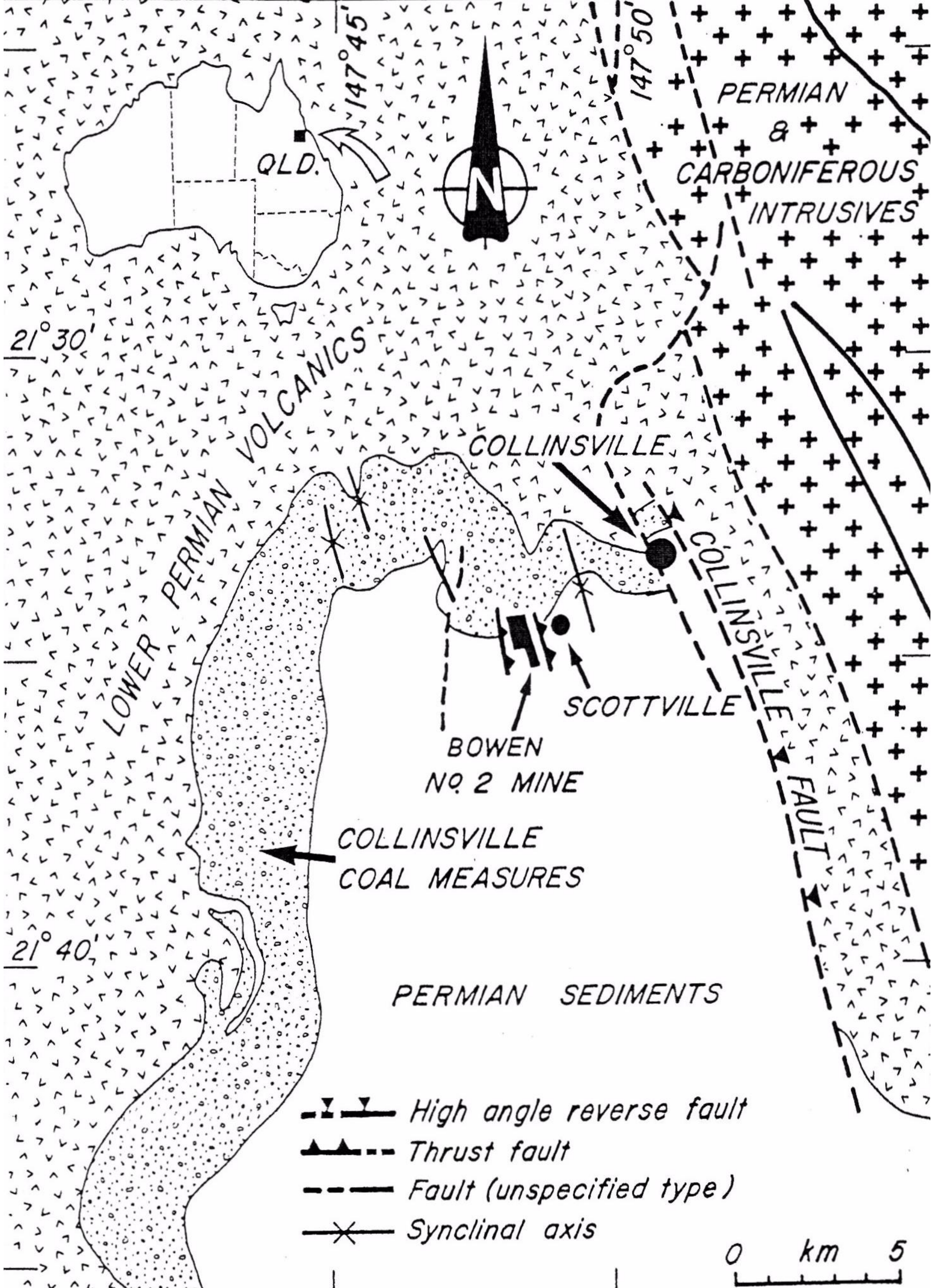
Leichhardt Colliery Outburst – Cleat Line Pressures

Leichhardt Colliery – Cleat Pressure Stabilisation

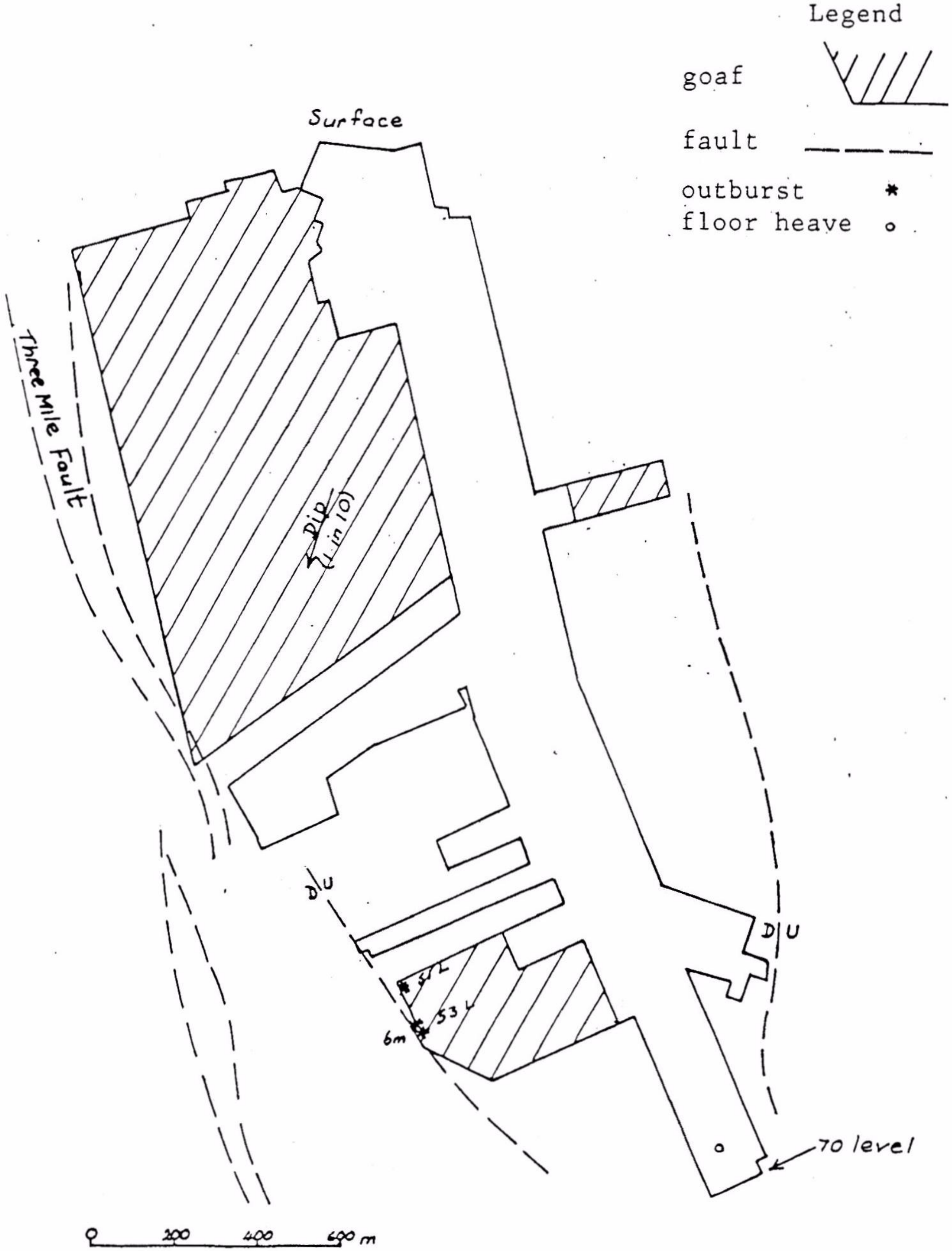




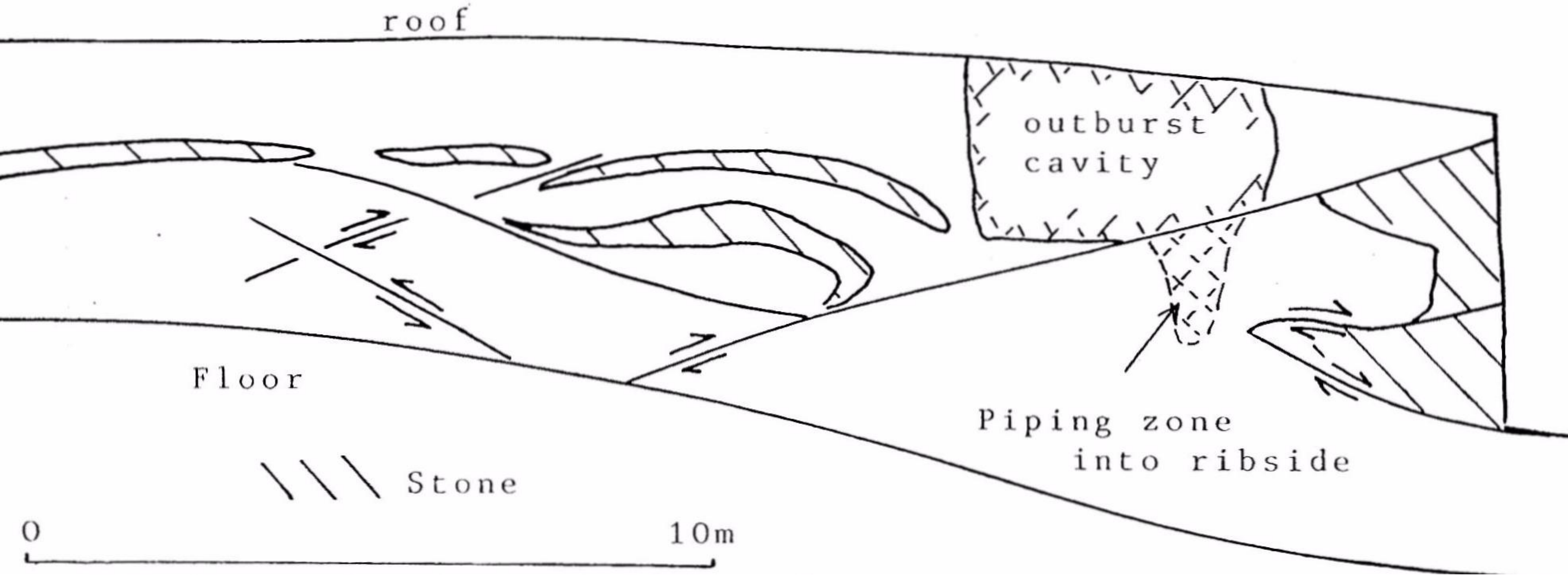
Leichhardt Colliery
December 1978 Outburst
Cavity



Geological Setting of Bowen No. 2 Mine, Shepherd et al (1980)



Bowen No. 2 Mine, Collinsville Faults, Outburst and Floor Heave Sites

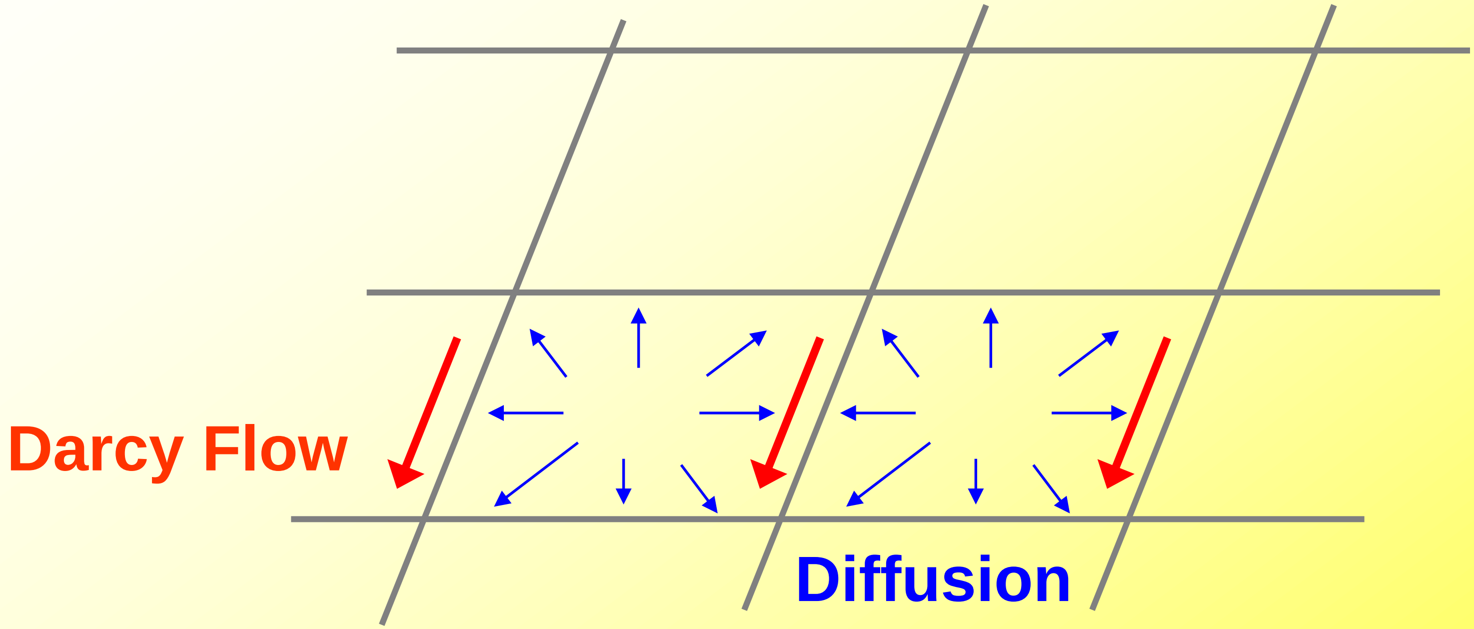


Collinsville No. 2 Mine

Sketch of 53 ½ Level outburst in the six metre throw thrust fault.

View of southern ribside.

Gas Flow In Coal



Darcy Flow

$$V = -\frac{k}{\mu} . \frac{dp}{dx}$$

Diffusion

$$F = -D\frac{dC}{dx}$$

Strain Energy Per Unit Volume of a Biaxially Stressed Coal Face

Strain energy per unit volume of a biaxially stressed coal face is as shown in equation (1). This is simply the integral of stress and strain.

$$W_d = \frac{1}{2}\varepsilon_r \sigma_r = \frac{1}{2}\sigma_r^{\ 2}\left(\frac{1-\nu}{E}\right) \qquad (1)$$

Where:

W_d = energy elastically stored per unit volume under biaxial states conditions
σ_r = uniform radial stress field
ν = Poisson’s ratio
E = Young’s modulus

Strain Energy Due to Elastic Wall Contraction

The coal surrounding the failing cylinder may also impart energy to the core by elastic release. This energy is given in equation (2).

$$\frac{W_r}{Vol} = 2\sigma_r^{\,2}\left(\frac{1-\nu^2}{E}\right) \qquad (2)$$

Where:

W_r = Energy due to elastic wall contraction on unloading
Vol = Volume of cylindrical hole
σ_r = radial stress
ν = Poisson's ratio
E = Young's modulus

Potential Energy from Adiabatic Expansion of Gas

Equation (3) describes the potential energy available from adiabatic expansion of gas.

$$W = \frac{P_1 V_1^{\gamma}}{(\gamma - 1)} V_1^{(1-\gamma)} \left(1 - \left(\frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}} \right) \qquad (3)$$

Where:

W = work performed

P_1 = initial pressure

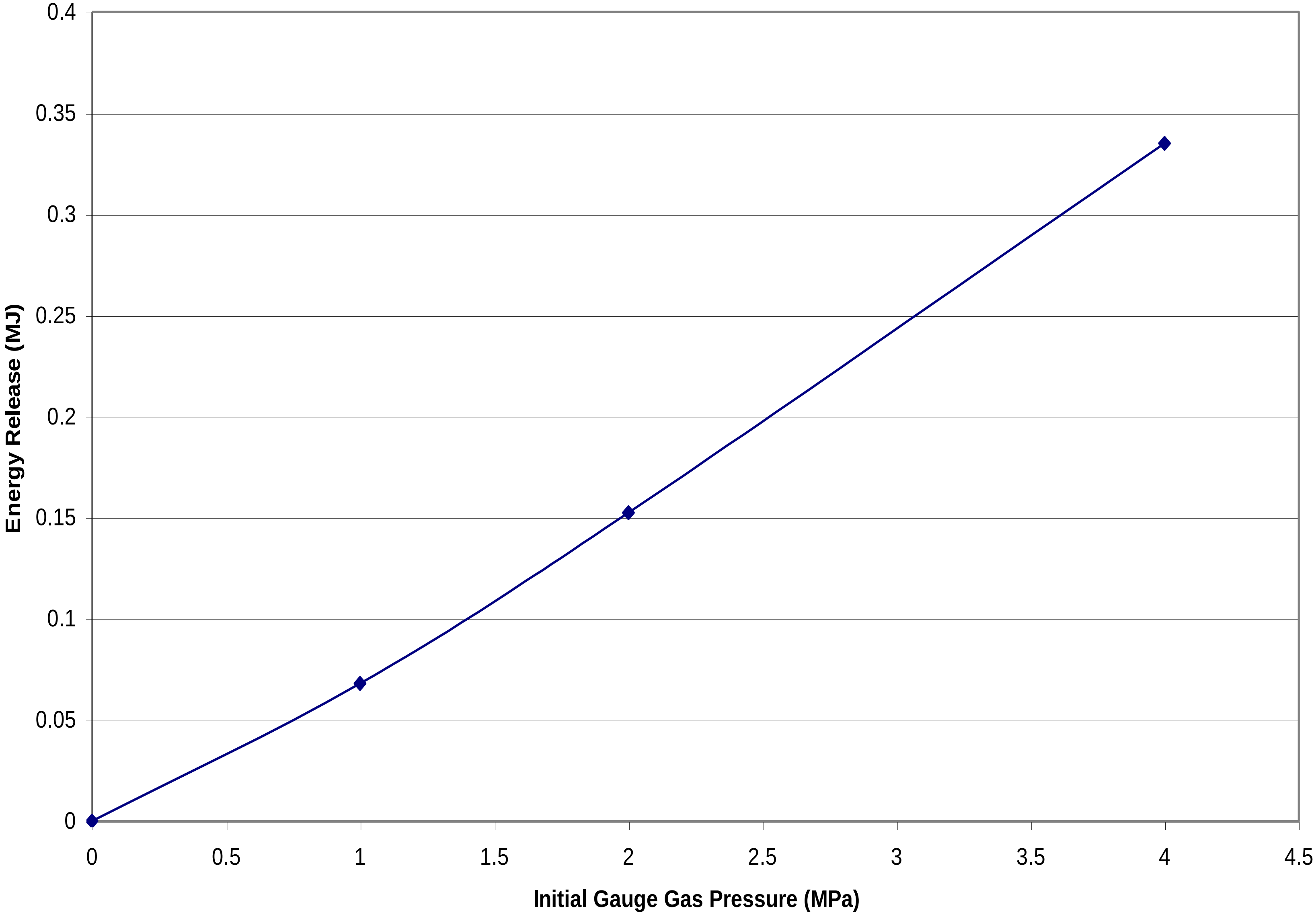
P_2 = final pressure

V_1 = initial volume

V_2 = final volume

γ = ratio of specific heats $\frac{C_p}{C_v}$

Adiabatic Energy Release on Expansion of 0.05 cu.m of Methane



Energy available from 50 litres of gas expanding adiabatically to atmospheric pressure.
Note 50 litres per cubic metre corresponds to a porosity of 0.05% in one cubic metre.

Energy from Expanding Gas

The energy available from expanding gas is by definition the integral of pressure with volume change. Mathematically this concept may be expressed in equation (4).

$$W = \int_{V1}^{V2} P \delta V \qquad (4)$$

The energy available from gas being diffused out of a coal particle assumes that the gas comes out at a pressure and then expands to do work. The particle must be able to deliver this gas at a pressure and the gas must be able to expand. As the volume diffused is time dependent then the power of the expanding gas is dependent on time.

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Desorption from a Cylinder

The equation (5) describes desorption from a cylinder with a uniform initial concentration.

$$\frac{M_t}{M_\infty} = 1 - \sum_{n=1}^{\infty} \frac{4}{JOR_i^2} e^{\left(-D\left(\frac{JOR_i}{a}\right)^2 t\right)} \qquad (5)$$

where $\frac{M_t}{M_\infty}$ is the ratio of desorbed gas over the total gas that may be released

JOR_i are the roots of a Bessell function of the first kind for the equation $J_O(a\alpha_n) = 0$

D is the diffusion coefficient

t is time

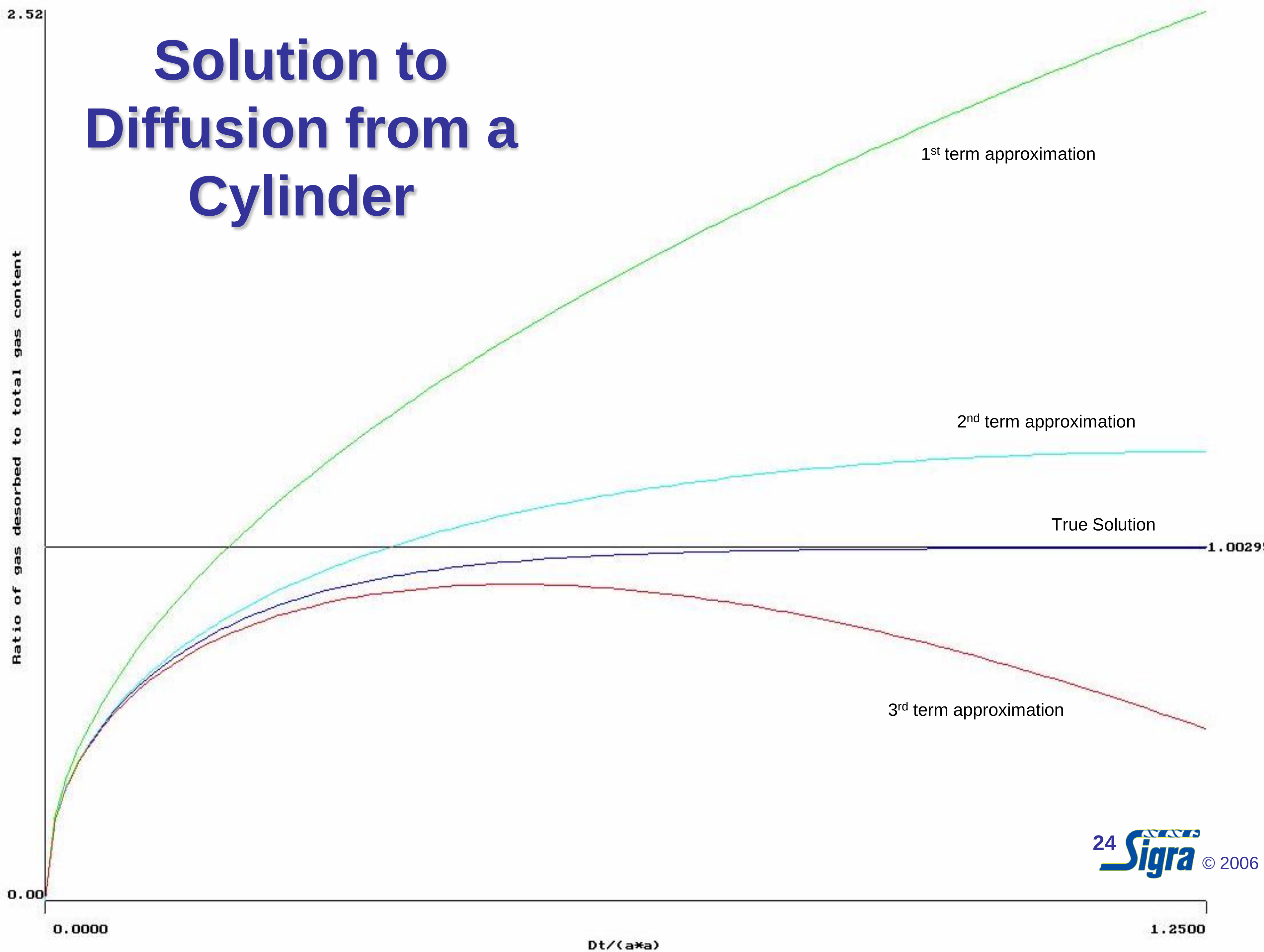
a is the radius of the cylinder

Desorption from a Cylinder

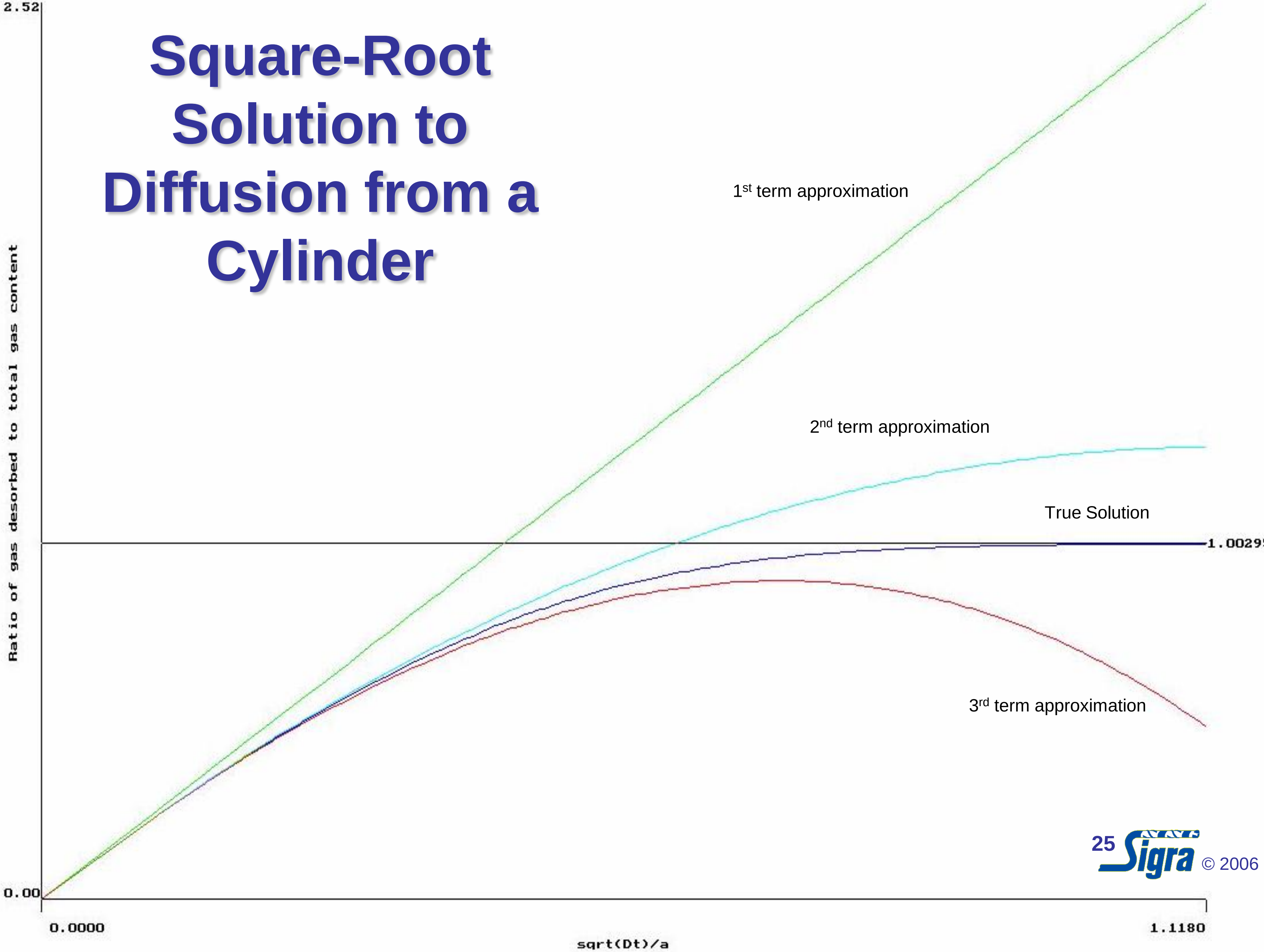
For small values of *Dt/a2* equation (5) may be approximated to equation (6):

$$\frac{M_t}{M_\infty} = \frac{4}{\sqrt{\pi}}\left(\frac{Dt}{a^2}\right)^{\frac{1}{2}} - \frac{Dt}{a^2} - \frac{1}{3\sqrt{\pi}}\left(\frac{Dt}{a^2}\right)^{\frac{3}{2}} + \ldots \quad (6)$$

Solution to Diffusion from a Cylinder



Square-Root Solution to Diffusion from a Cylinder

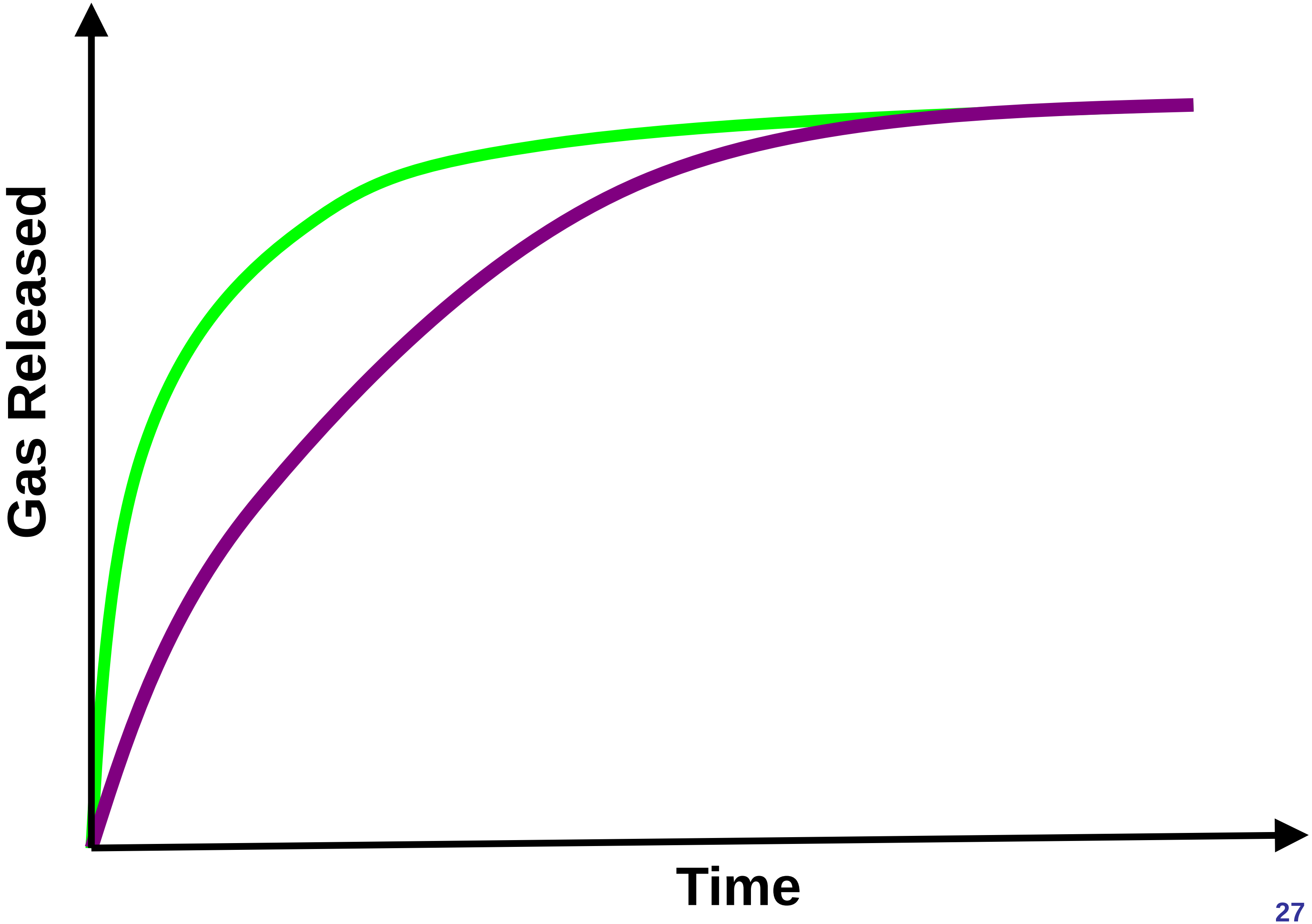


Evaluation of Dt/a^2 using Equation (6)

Evaluation of Dt/a^2 for 5% and 10% errors using the 1st, 2nd and 3rd term solutions of equation (6).

	1st term	2nd term	3rd term	% error
Dt/a^2	0.0125	0.265	0.4	5
Dt/a^2	0.050	0.40	0.625	10

Field Testing and Theoretical Diffusion Curves from a Cylinder



Diffusion Coefficients

Unfractured HQ Core (61 mm diameter)

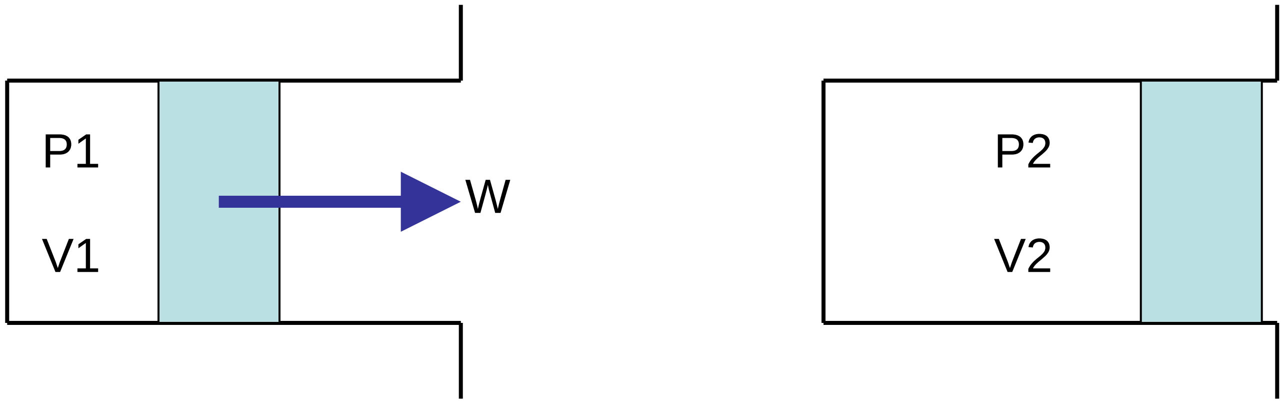
- Desorbs 10% of gas content in 20 minutes.
- $D = 5 \times 10^{-9}\ m^2/s$

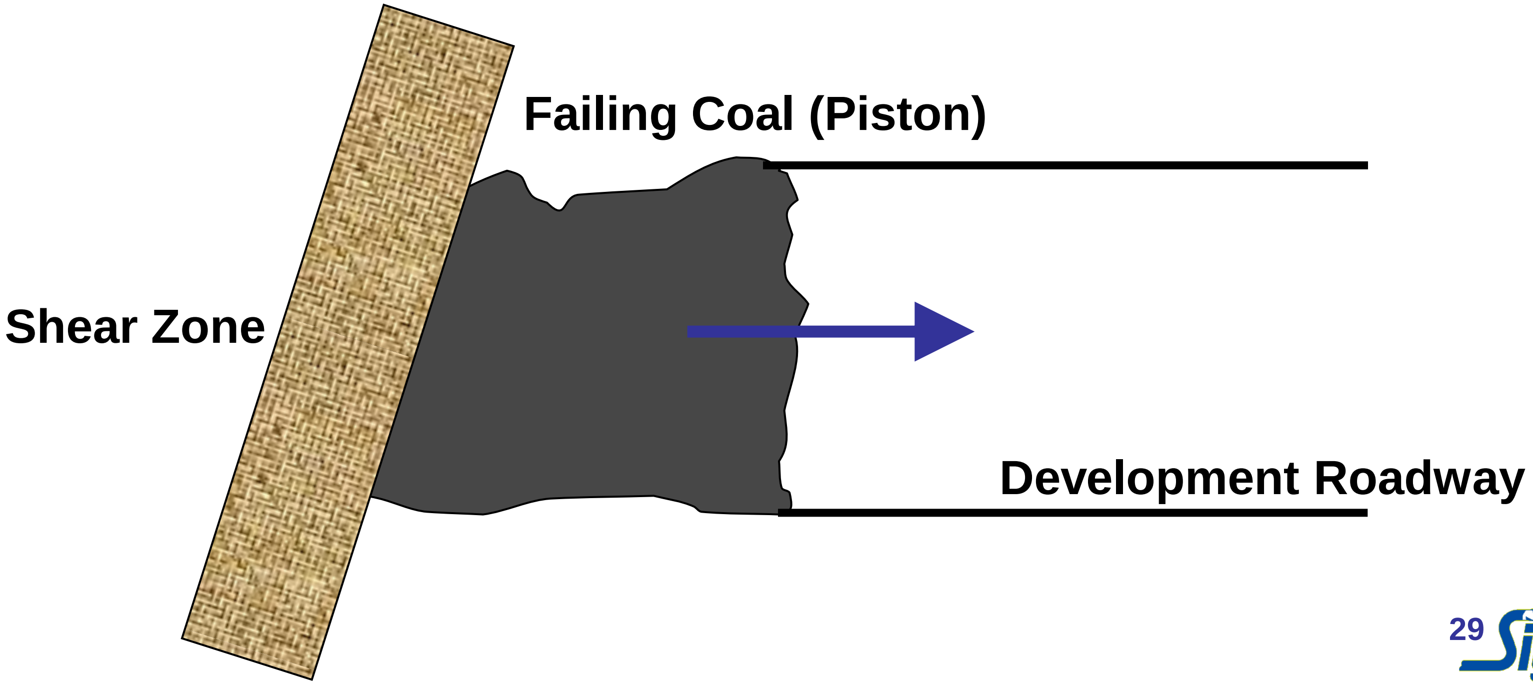
If the effective diameter = 20 mm

(due to fractures)

- $D = 6.5 \times 10^{-10}\ m^2/s$

Work Done by Adiabatically Expanding Gas on Hypothetical Piston





Diffusion from Particles

The diffusion of gas from spherical particles is described by Crank (1975) in equation (7) which may be reduced to equation (8) for small values of *Dt/a2*.

$$\frac{M_t}{M_\infty} = 1 - \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\, e^{\left(\frac{-Dn^2\pi^2 t}{a^2}\right)} \qquad (7)$$

$$\frac{M_t}{M_\infty} = 6\left(\frac{Dt}{a^2}\right)^{\frac{1}{2}}\left\{\pi^{-\frac{1}{2}} + 2\sum_{n=1}^{\infty} ierfc\,\frac{na}{\sqrt{Dt}}\right\} - 3\frac{Dt}{a^2} \qquad (8)$$

ierfc is the complimentary error function.

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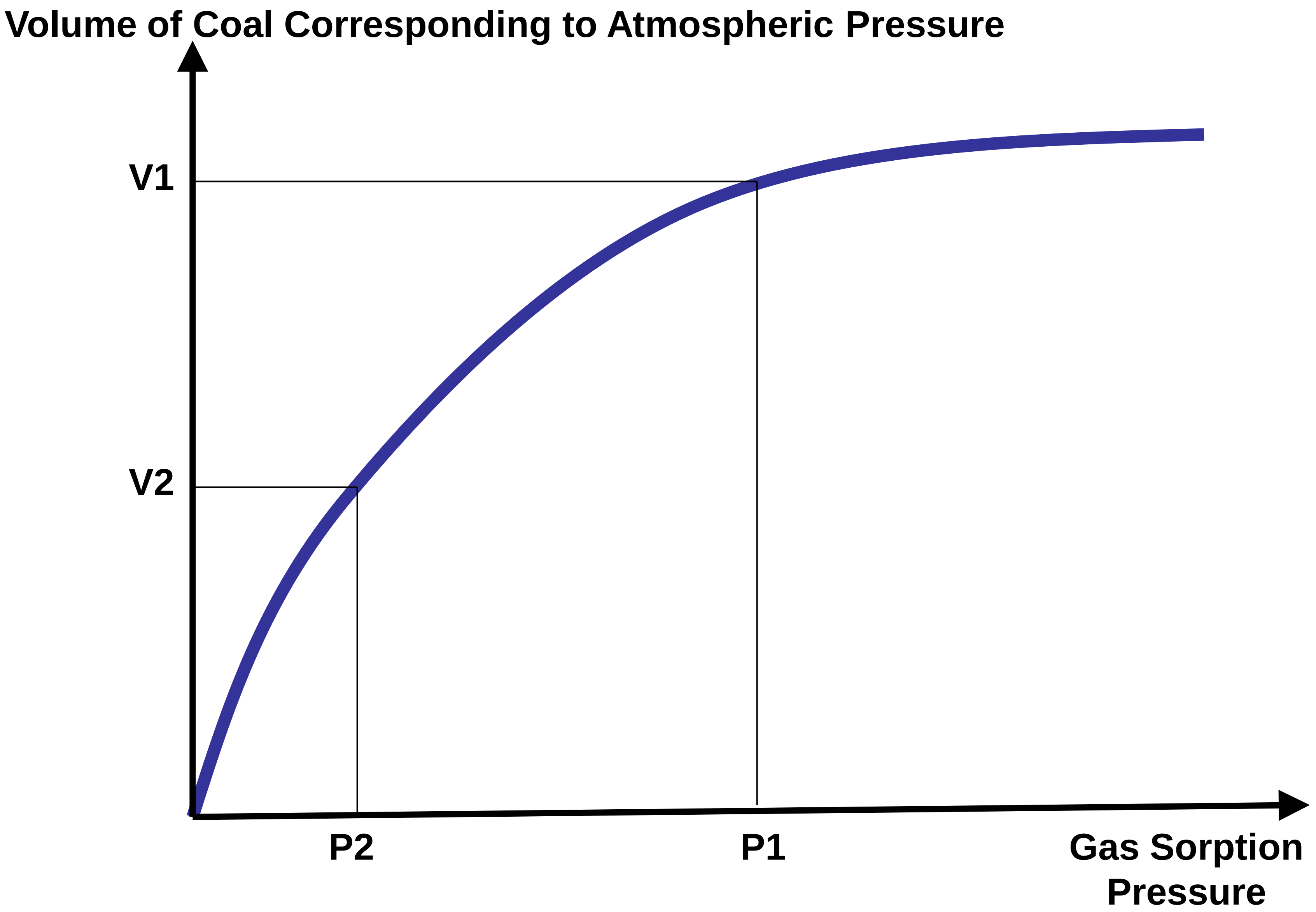
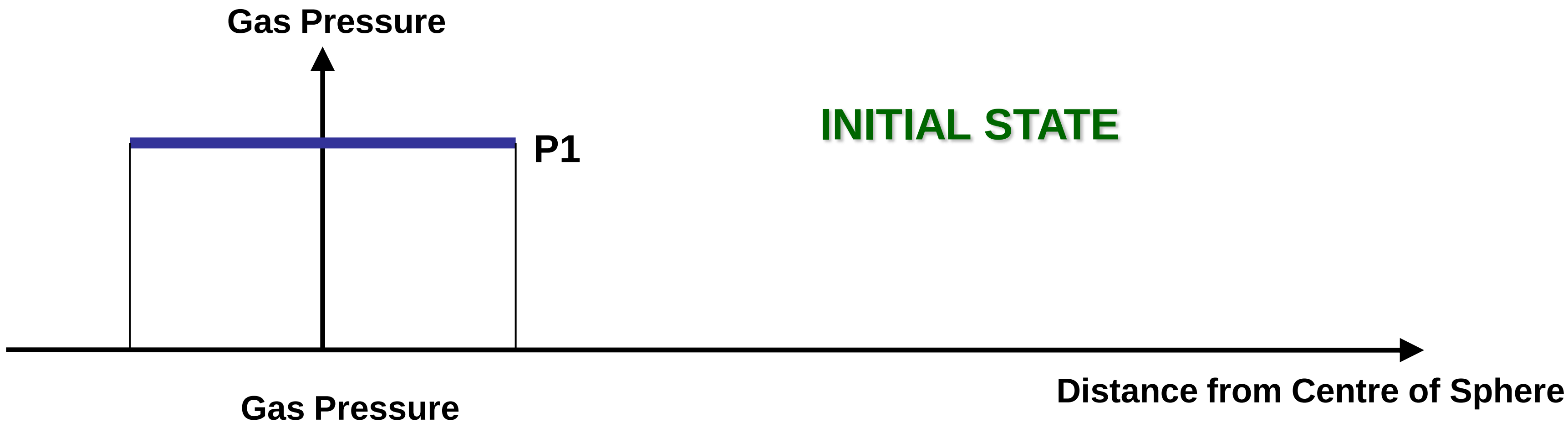
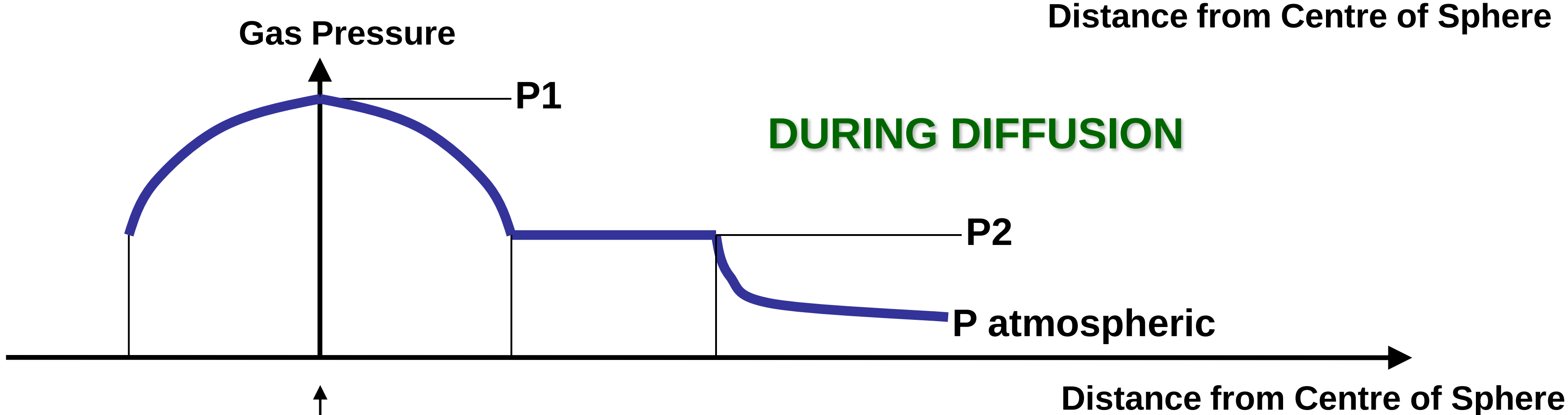
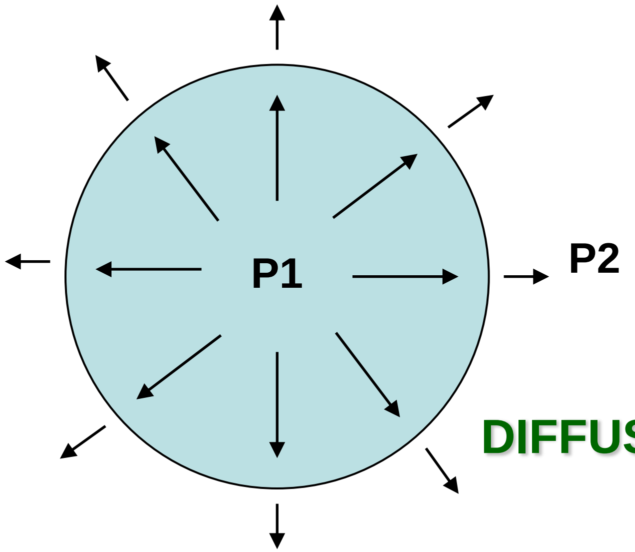
SORPTION ISOTHERM









DIFFUSING SPHERE

Diffusion from coal particles initially at concentration to P1; to edge corresponding to P2.

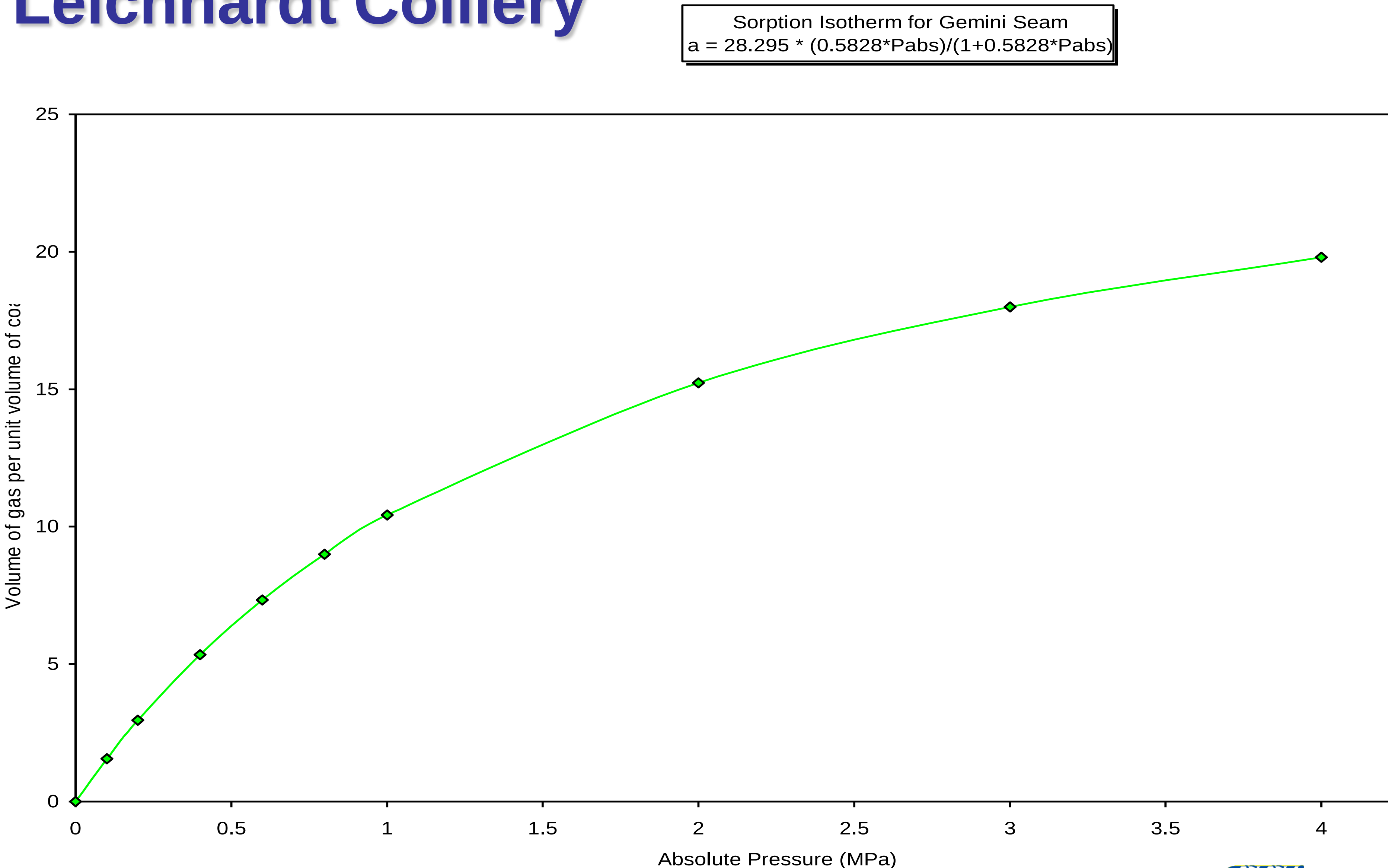
Adiabatic expansion from P2 to atmospheric pressure.

Adiabatic expansion = Potential to do work.

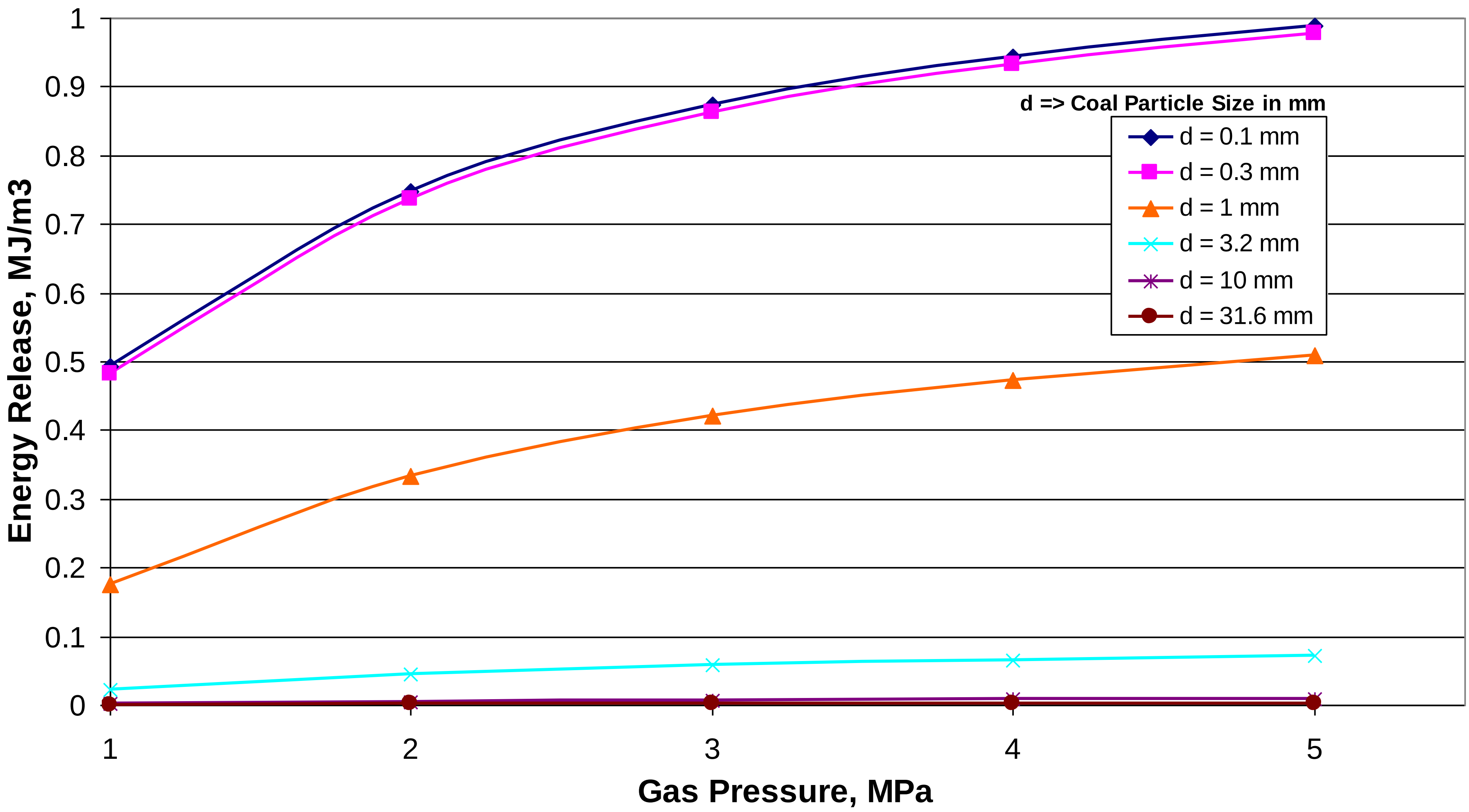
Coal Properties

Young's Modulus, E	2.0 GPa
Poisson's Ratio, v	0.3
Uniaxial Compressive Strength, UCS	12 MPa
Seam Stress	12 MPa
Seam Gas Pressure	4.0 MPa = 18.5 m^3/m^3 = 14.8 m^3/tonne
Seam Void Ratio (Porosity)	2%

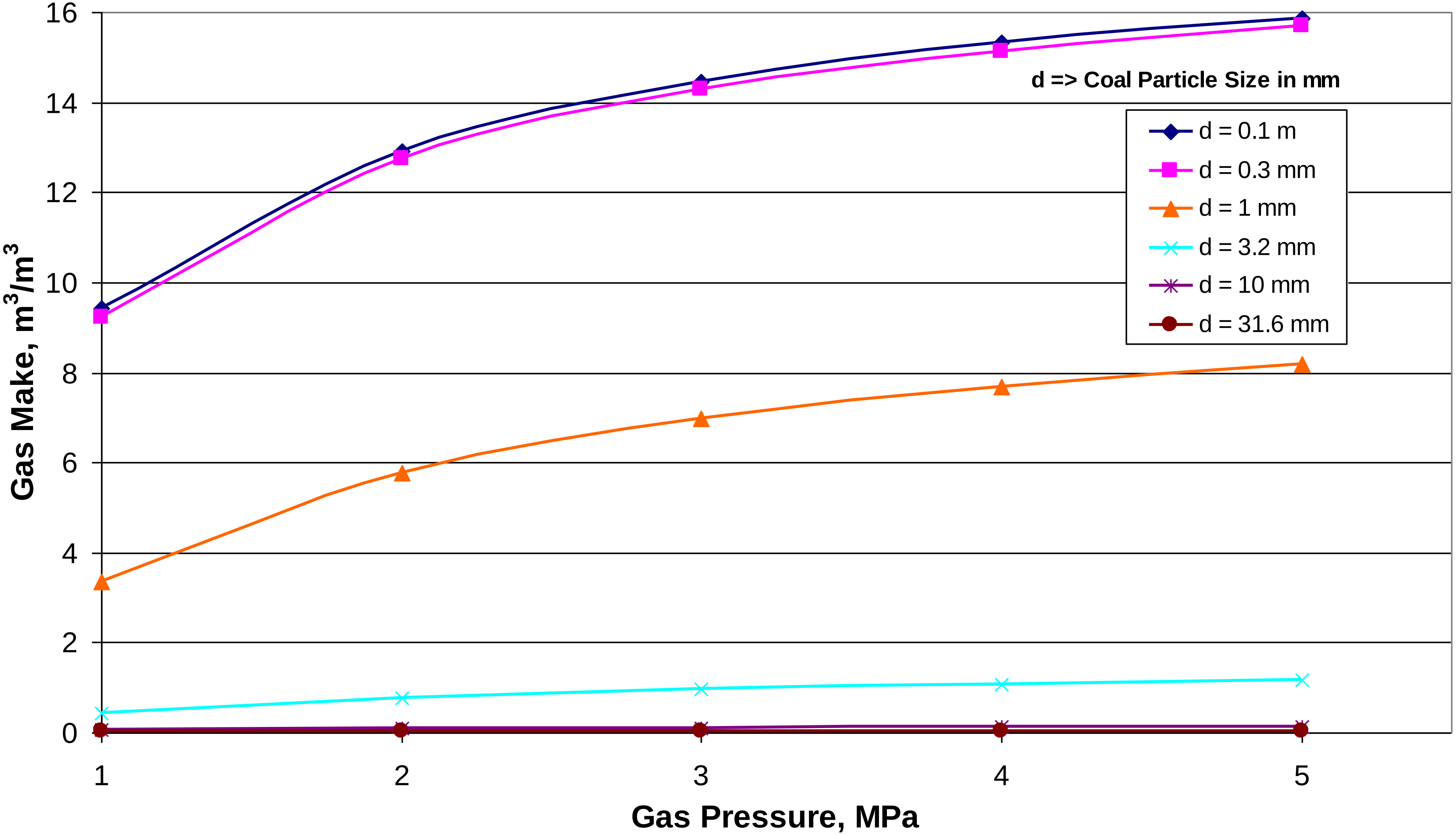
Sorption Isotherm for Gemini Seam, Leichhardt Colliery



Gas Energy Release, D = $1x10^{-8}$ m^2/s

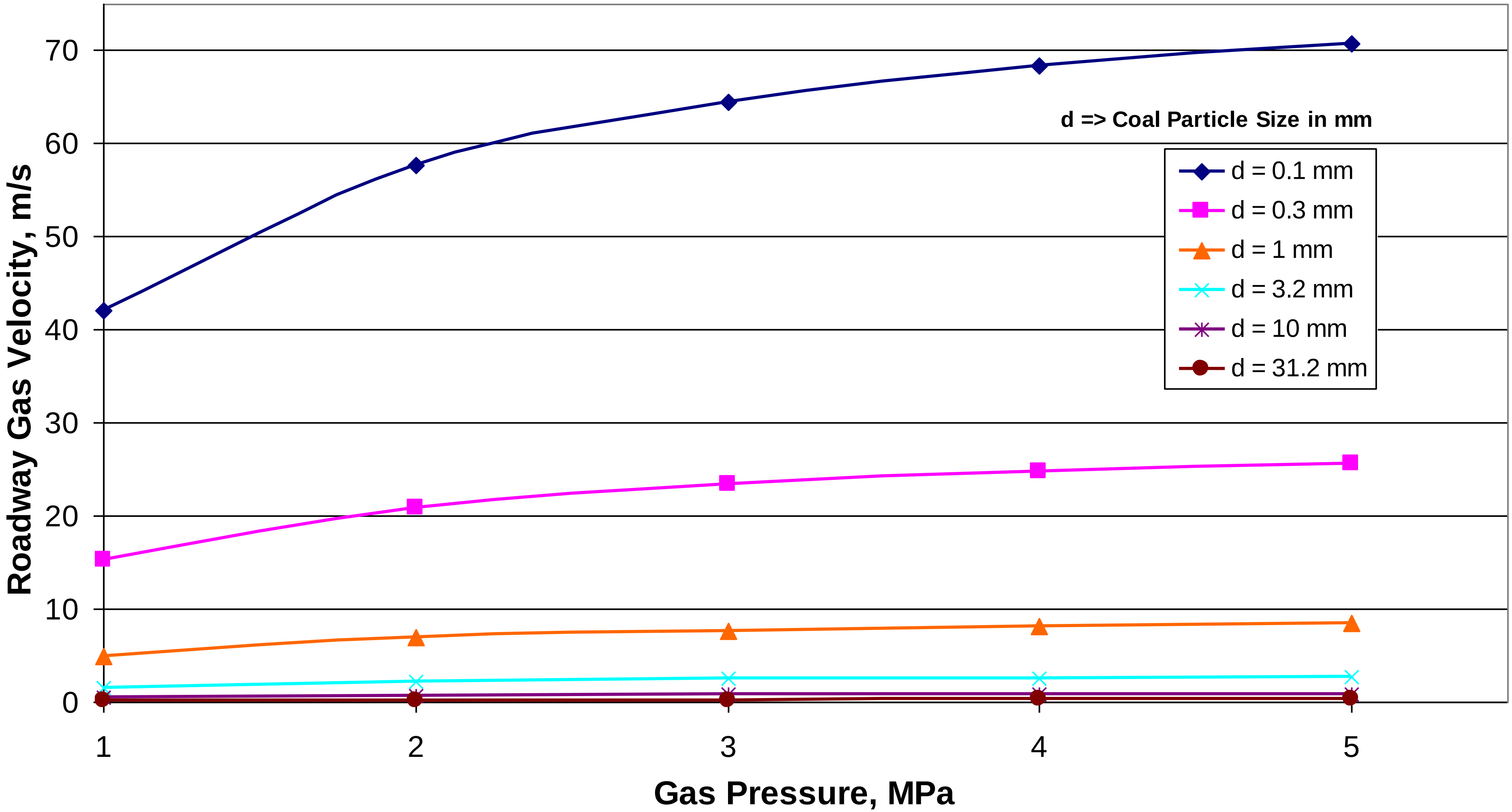


Gas Make, D = $1x10^{-8}$ m^2/s



Gas Velocity In Roadway of 12.5 m^2

$D = 1x10^{-8}\ m^2/s$



Important Energies

Maximum Strain Energy Release per m^3	0.16 MJ/m^3
Maximum Free Gas Strain Energy Release on Adiabatic Expansion	0.13 MJ/m^3

Energy From Diffusion, MJ/m^3		
	$D=1x10^{-8}$ m^2/s	**$D=1x10^{-10}$ m^2/s**
0.1 mm particles	**0.94**	**0.47**
1 mm particles	**0.47**	**0.009**
10 mm particles	**0.009**	**0.001**

TEST TECHIQUES

- Finding Structure
- Finding Properties
- Solid Coal Outburst

Finding Structure

- Coring
  - Core Loss => Concern
- Monitoring
  - Gas Release
  - Cuttings Volume
  - Cuttings Size
- Torque and Thrust Sub
- Structure Size Important

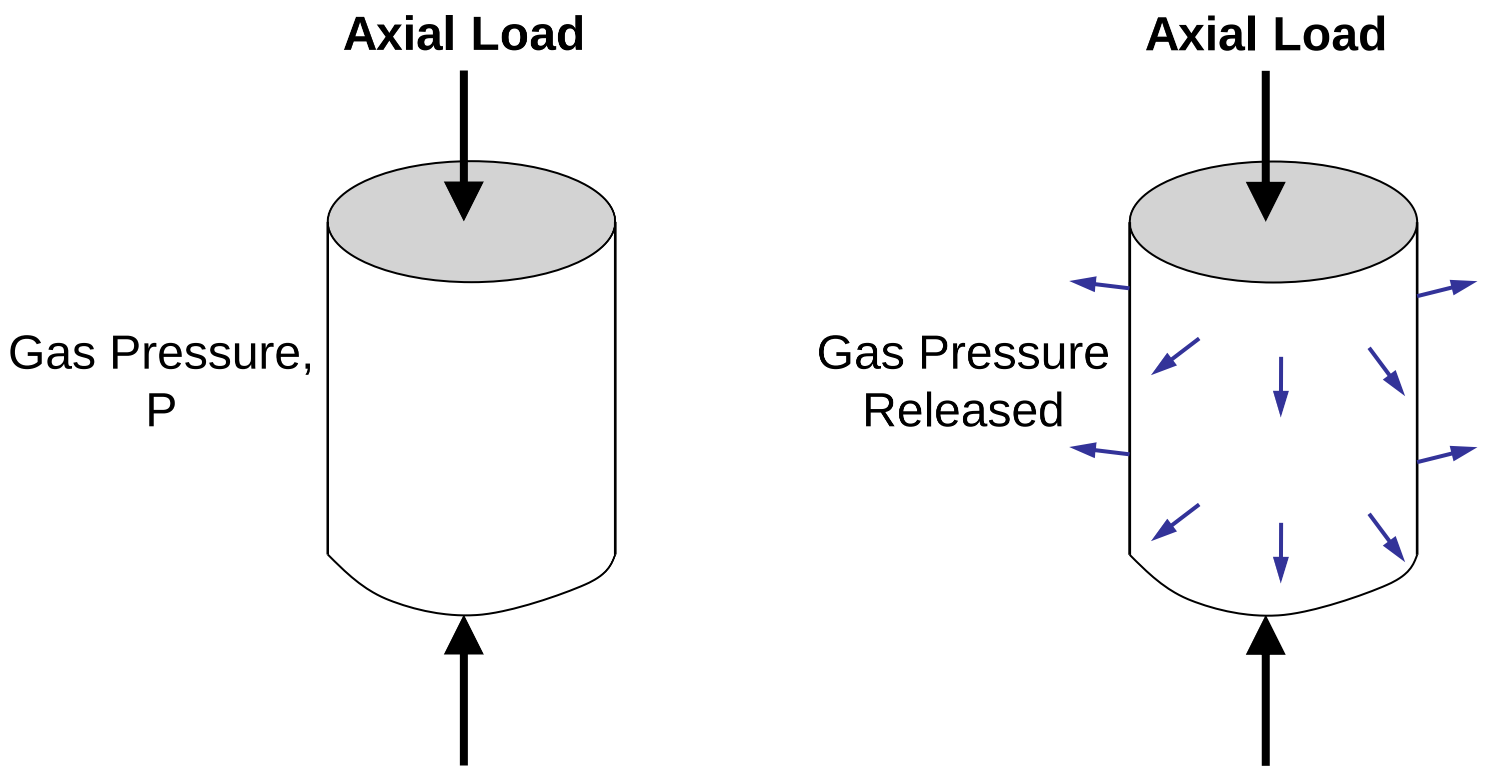
Finding Properties

- **Coring**
  - **Gas Content**
  - **Diffusion Coefficient (Conservative)**
- **Open Hole**
  - **Particle Size (Conservative)**
  - **Diffusion Coefficient (Particles may have degassed too much)**
  - **Use of Borehole Pressurisation Tool to get Undegassed Chips**
- **Pressure Sensing**

Solid Coal Outbursts

- **Will the Coal Fragment?**
- **Gas Pressure**
- **Stress**
- **Toughness**
  - **Measure of Energy to Propagate Fracture**
- **Core Test?**

Solid Coal Outbursts Test



Fully Gassed Core

Does the Core Fragment?

Hargraves Emission Meter

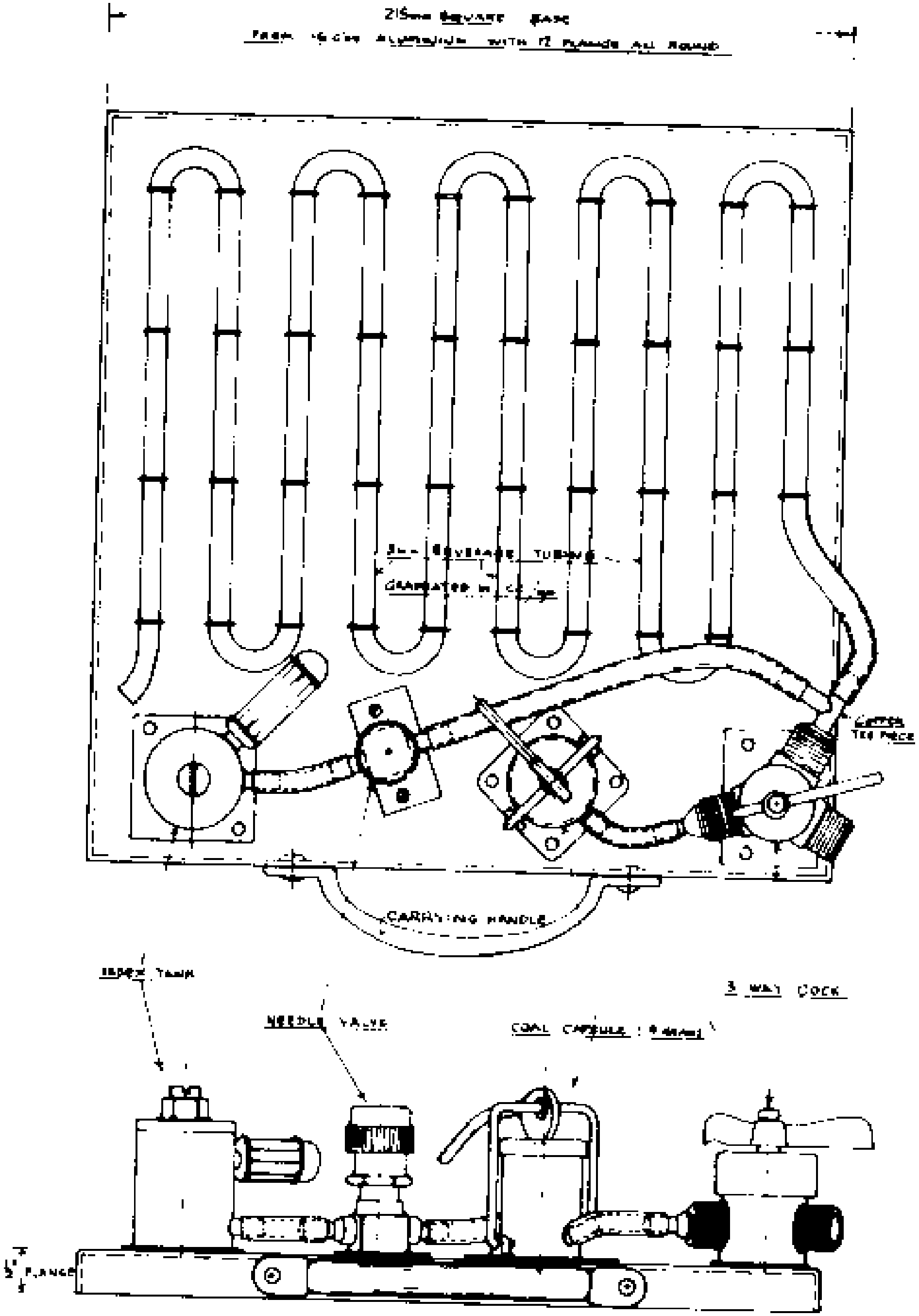


FIG 2 EMISSION VALUE METER

Thank You

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