Outburst Risk Determination

ACARP Project C23014

Overseas Data

- Russia
  - Regulations
  - Review of major factors and summary
- China
  - Regulations
  - Review of procedures
  - Case studies
- Turkey
  - Case studies

Overseas Data

- Literature Review
  - Great Britain
  - Japan
  - New Zealand
  - Other European experience
  - Mechanisms – extensive review

Review of Outburst Types Worldwide

- Related to geological structure in almost all cases but with some notable exceptions
- Largest risk is seam entry from stone drivage particularly from the footwall of inclined seams
- Risk increases with coal rank
- Highest risk is in dry seams

Australian Data Set

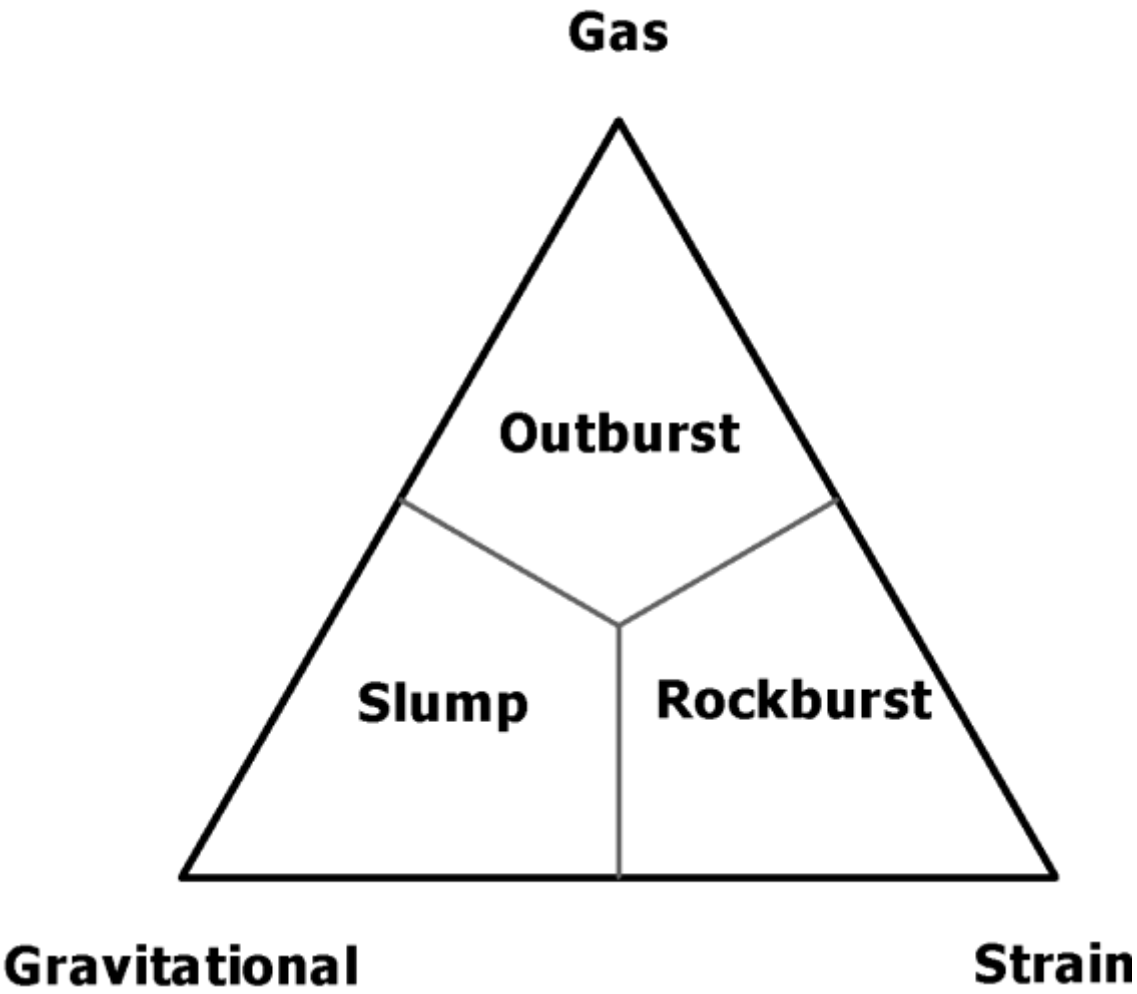
- Appin Colliery - all data associated with current mining areas. Data includes outbursts induced by remote mining methods and examination of cores
- Tahmoor Colliery – examination of cores
- Anglo---- Data from central Queensland operations including DRI index and outburst description from Central Colliery – limited core examination but some other physical testing
- Leichhardt Colliery – Historical data set
- Collinsville area – Historical data set
- Literature review including West Cliff and Tahmoor Collieries

What is an outburst?

- A failure of the coal and rock that occurs with fragmentation

FRAGMENTING FAILURE

- Energy release to propel that material
- Clearance of the material at the failing face by gas



Failure definition by energy release

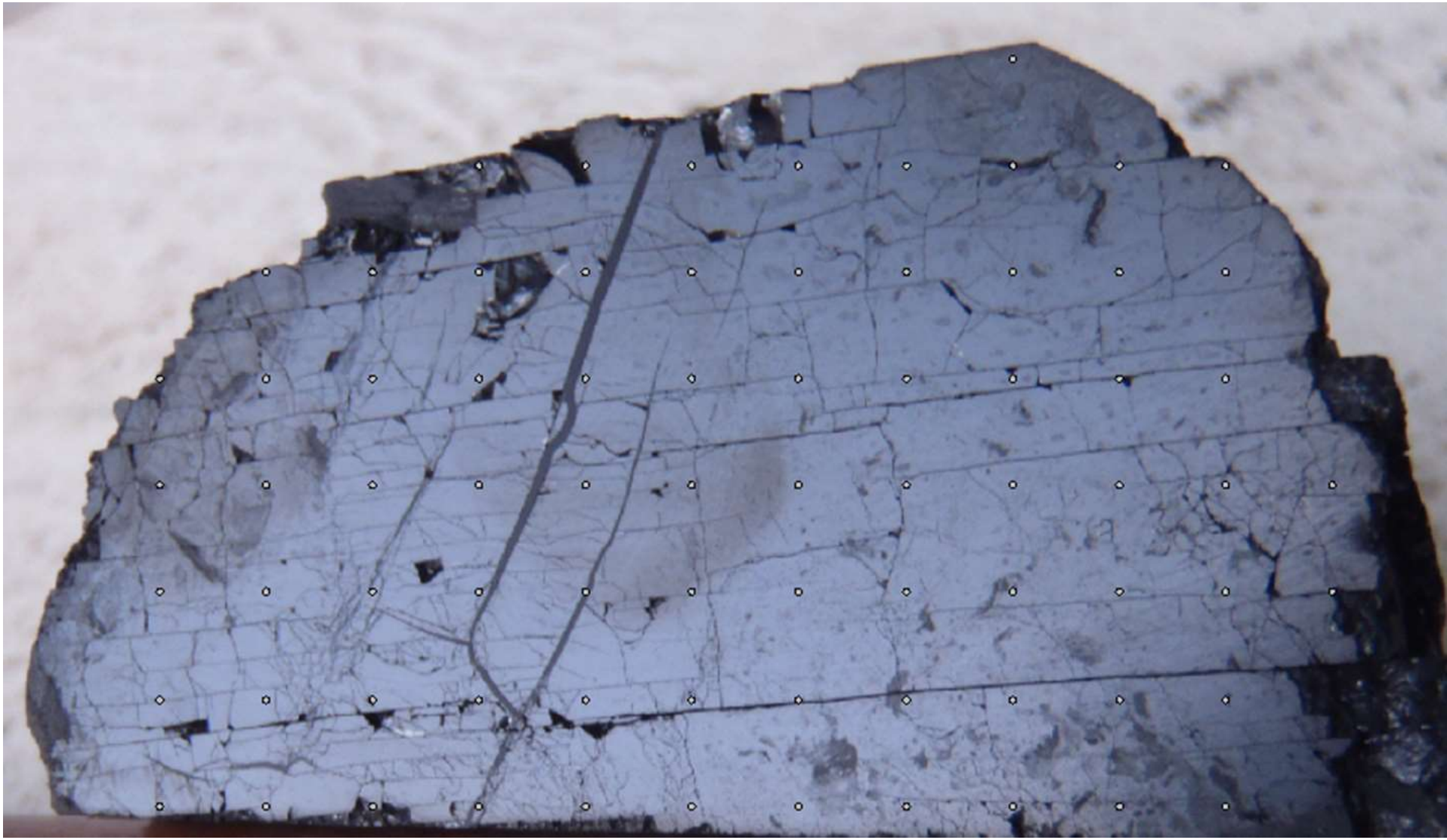
Why do some coals outburst while others do not?

- Permeability – if the coal is permeable it is unlikely to have high gas pressures near the face
- Some very gassy coals do not outburst and can be mined at 12-15 m3/tonne.
- Russians and Chinese make use of this to mine a non outbursting (amenable) seam in a sequence and thus stress relieve those seams around it.

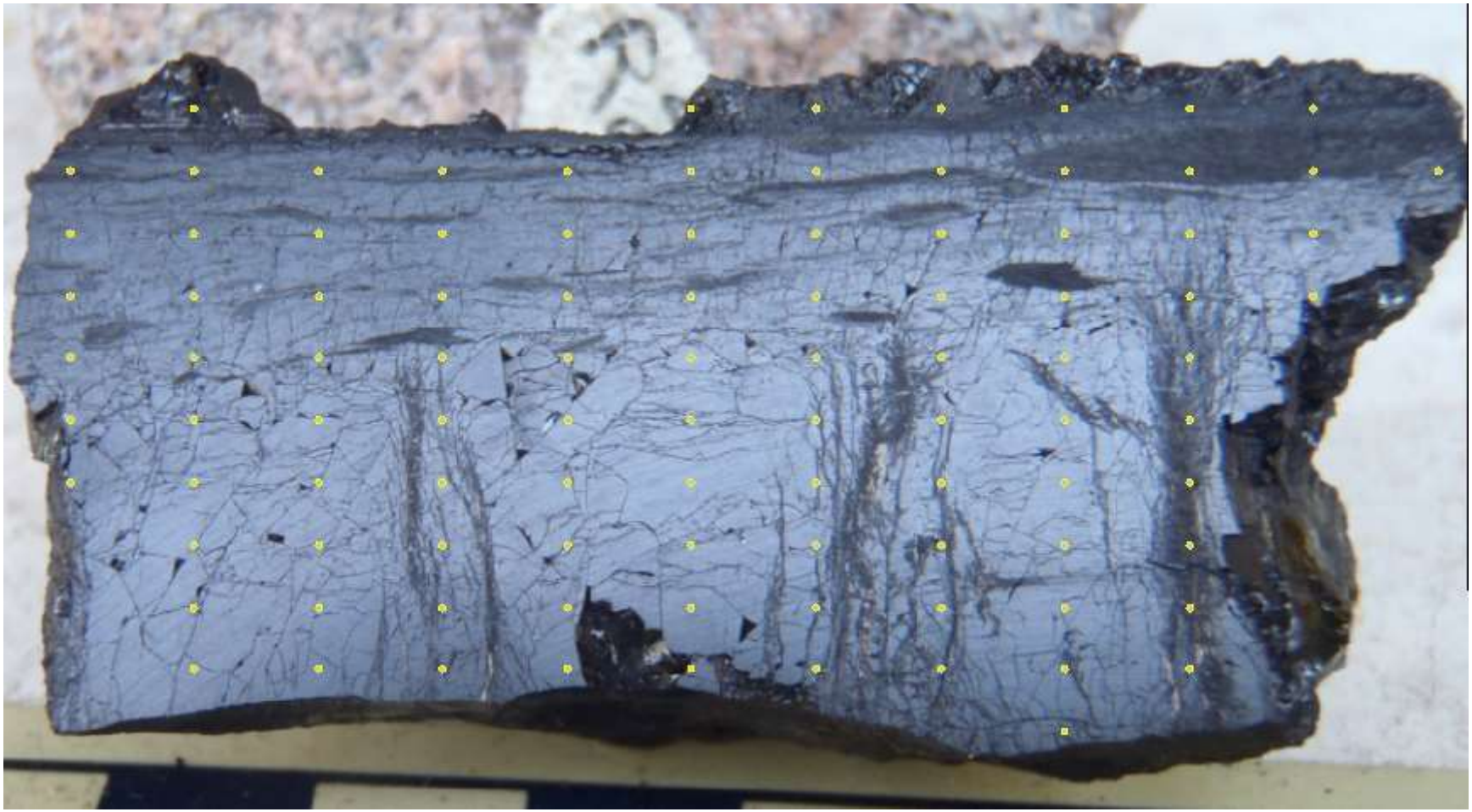
What is failure?

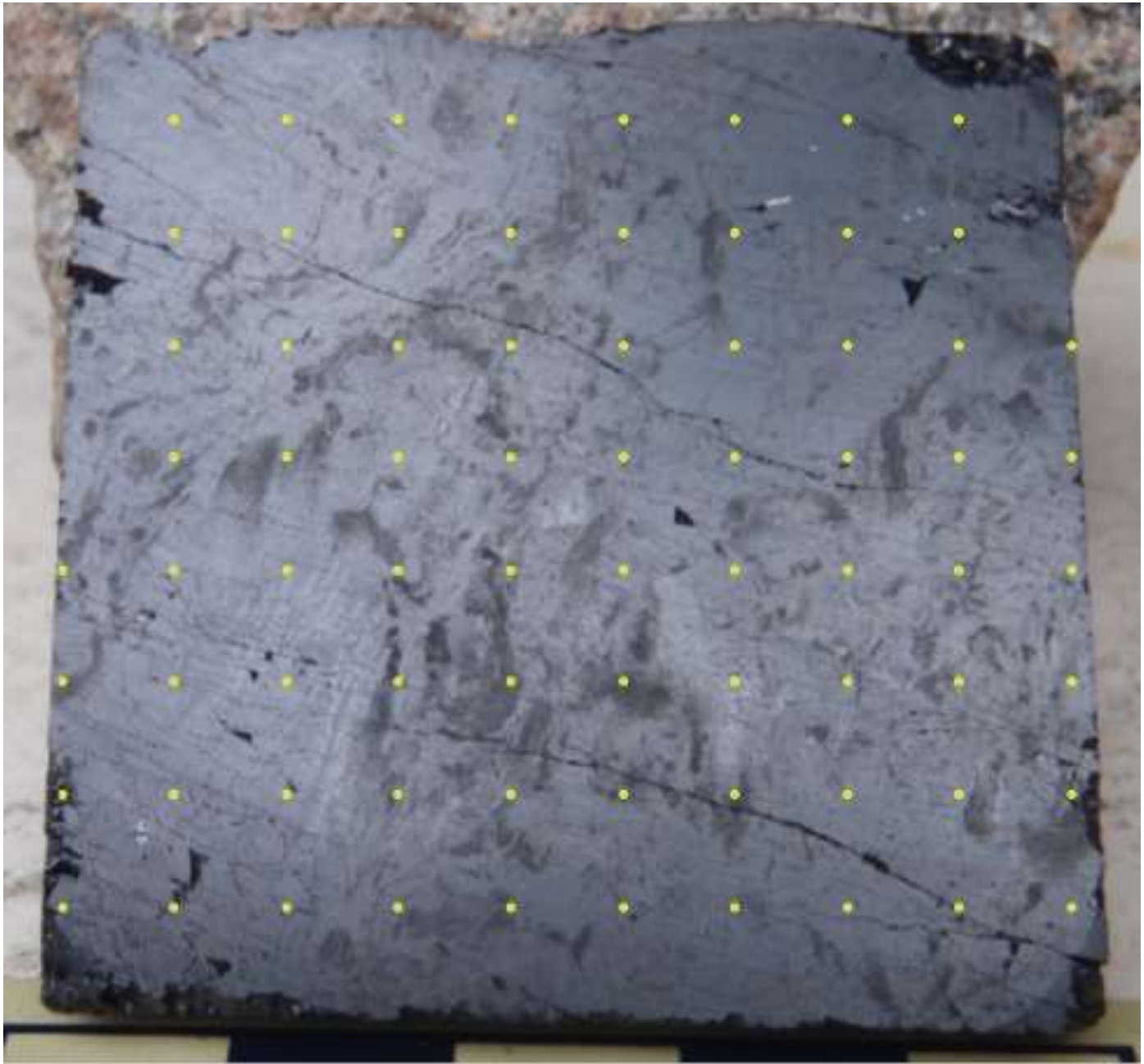
- Failure is a breakage of the coal. This is caused by shear or tensile stress exceeding the material (cohesive) and frictional strength
- Frictional strength is dependent on effective stress
- Effective stress is the total stress normal to a (failure) surface - fluid pressure x the fractional area of the surface it acts upon.
- If we have sheared coal this is easy to understand – high surface area
- What is the area that fluid pressure can act upon in a solid coal? This is dependent on coal structure. Therefore what is the structure in a solid coal?

How do we quantify existing discontinuities?

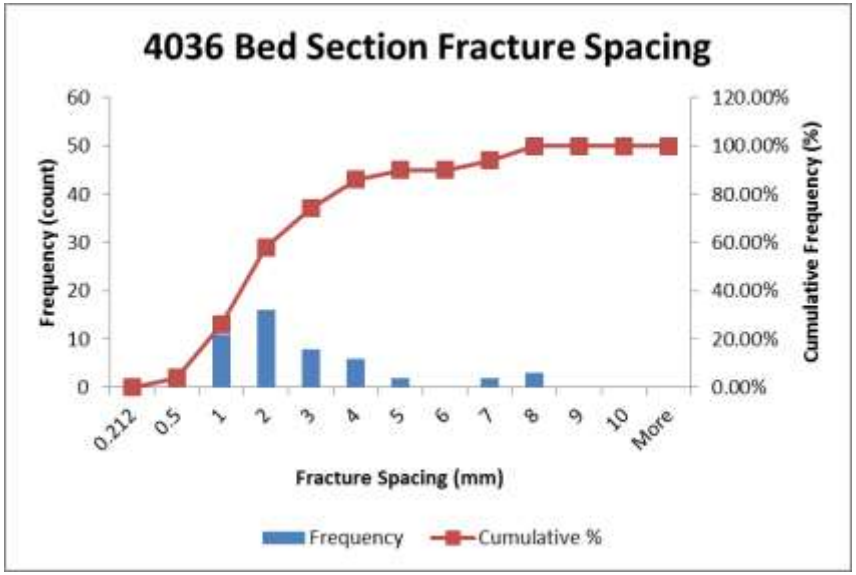


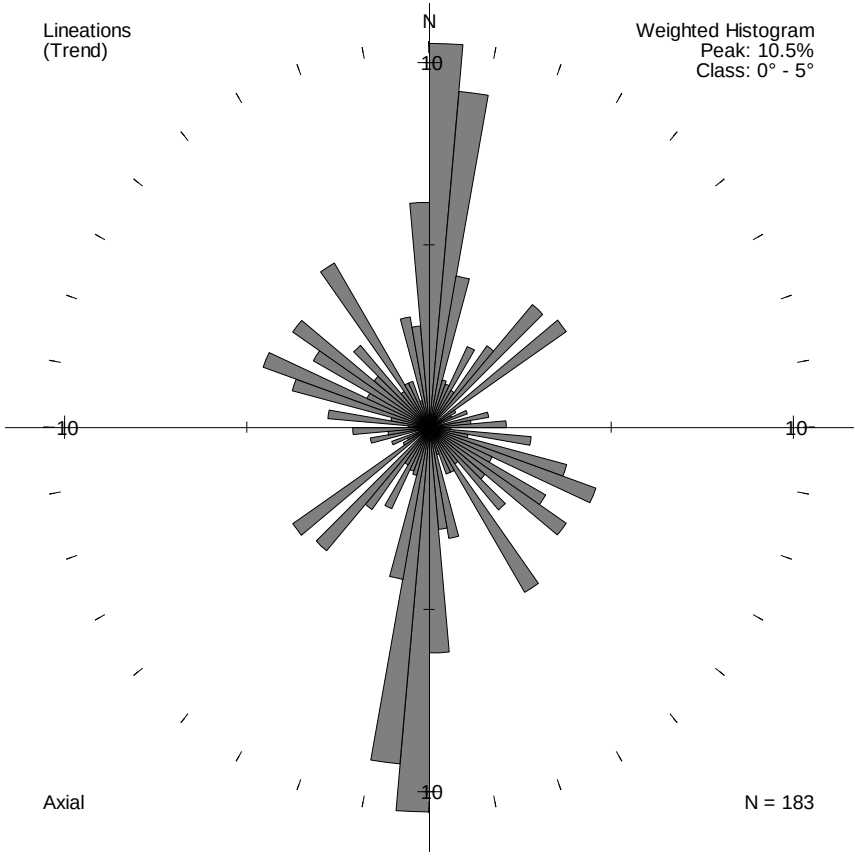
Cross section exploration core

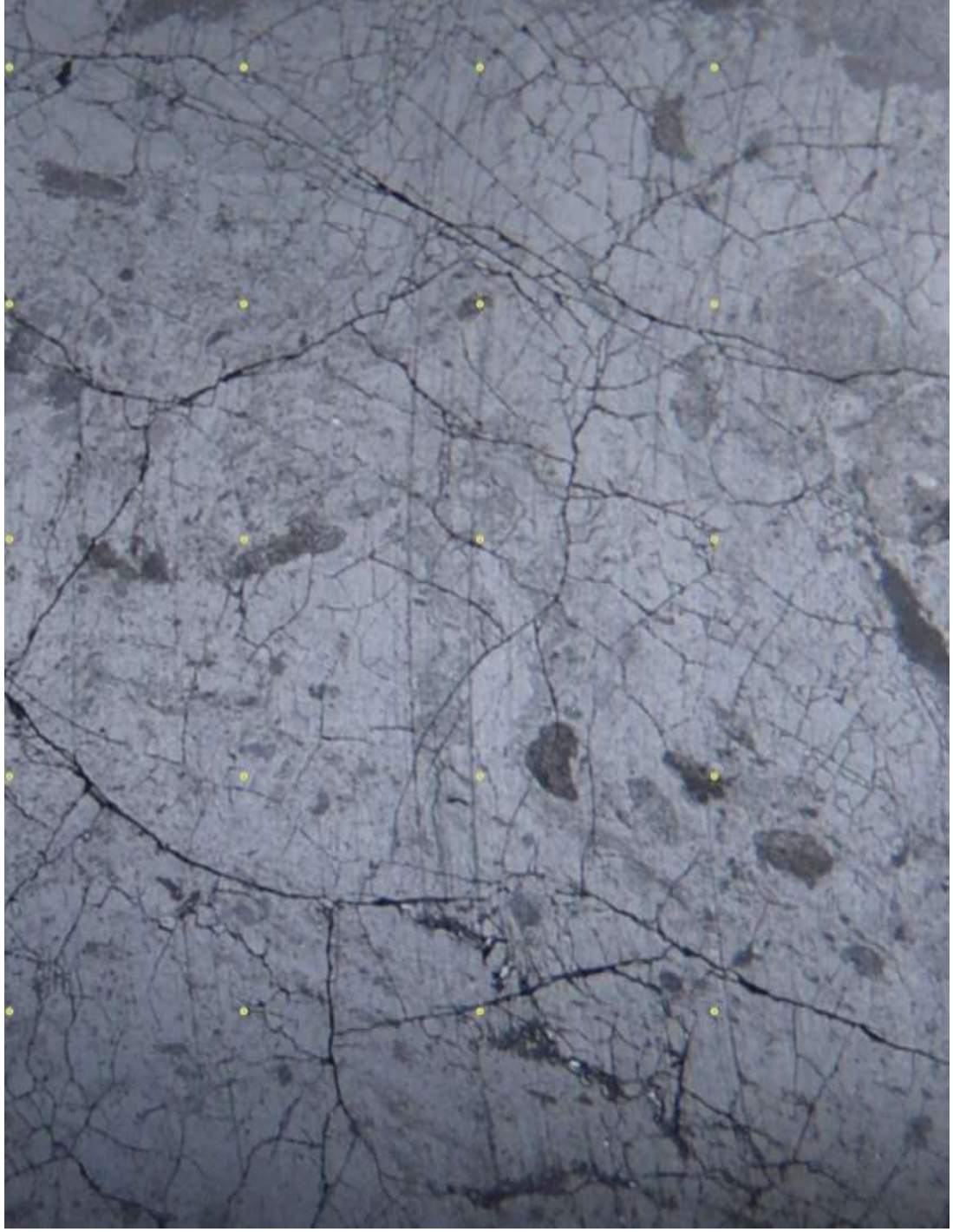




Quantification







Shallow water oxidising conditions

Deeper water reducing conditions

Very shallow water oxidising
Evidence of particle movement

Oscillating water level and conditions

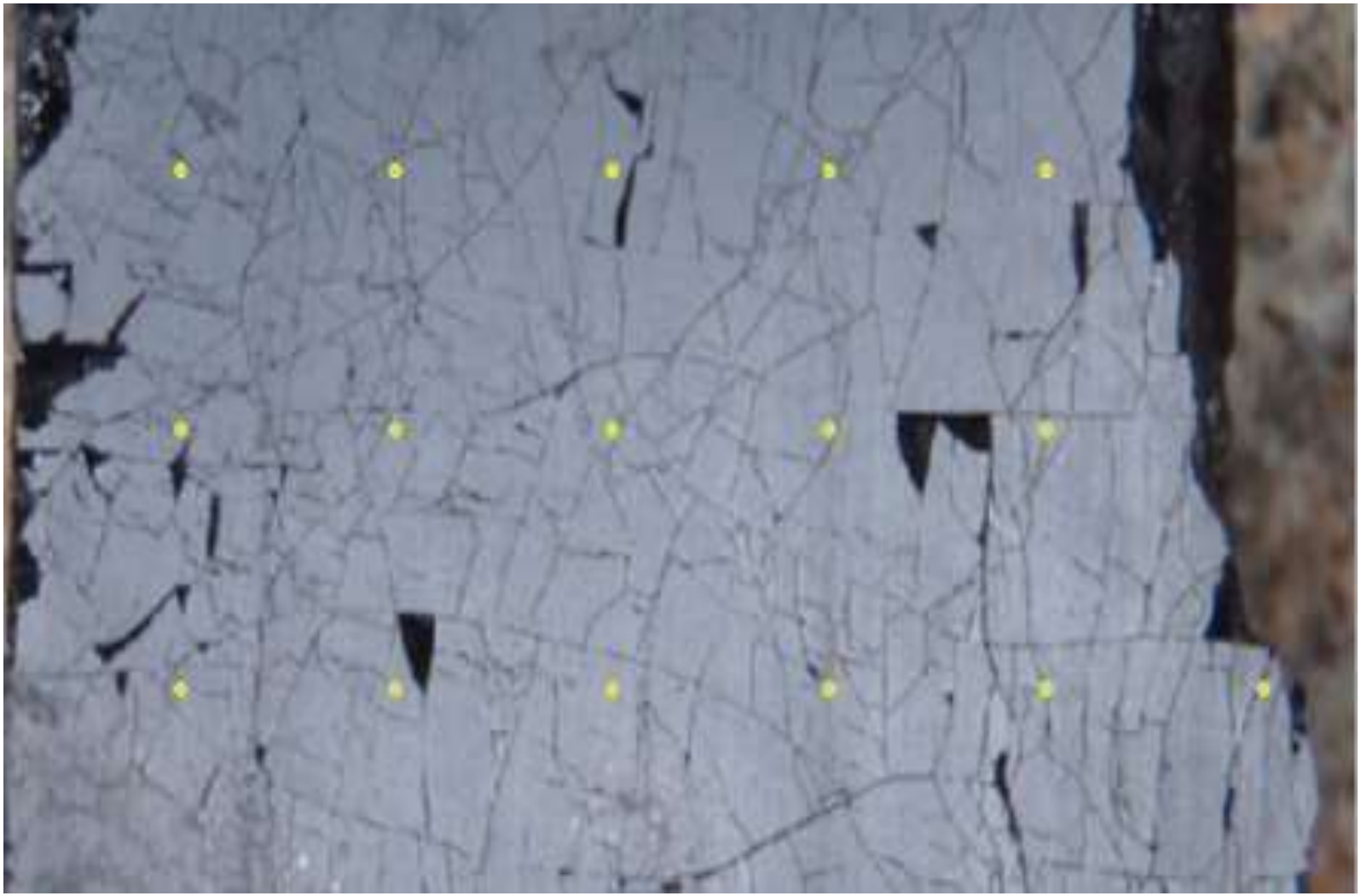
· Inertite

· Vitrite high density of fractures

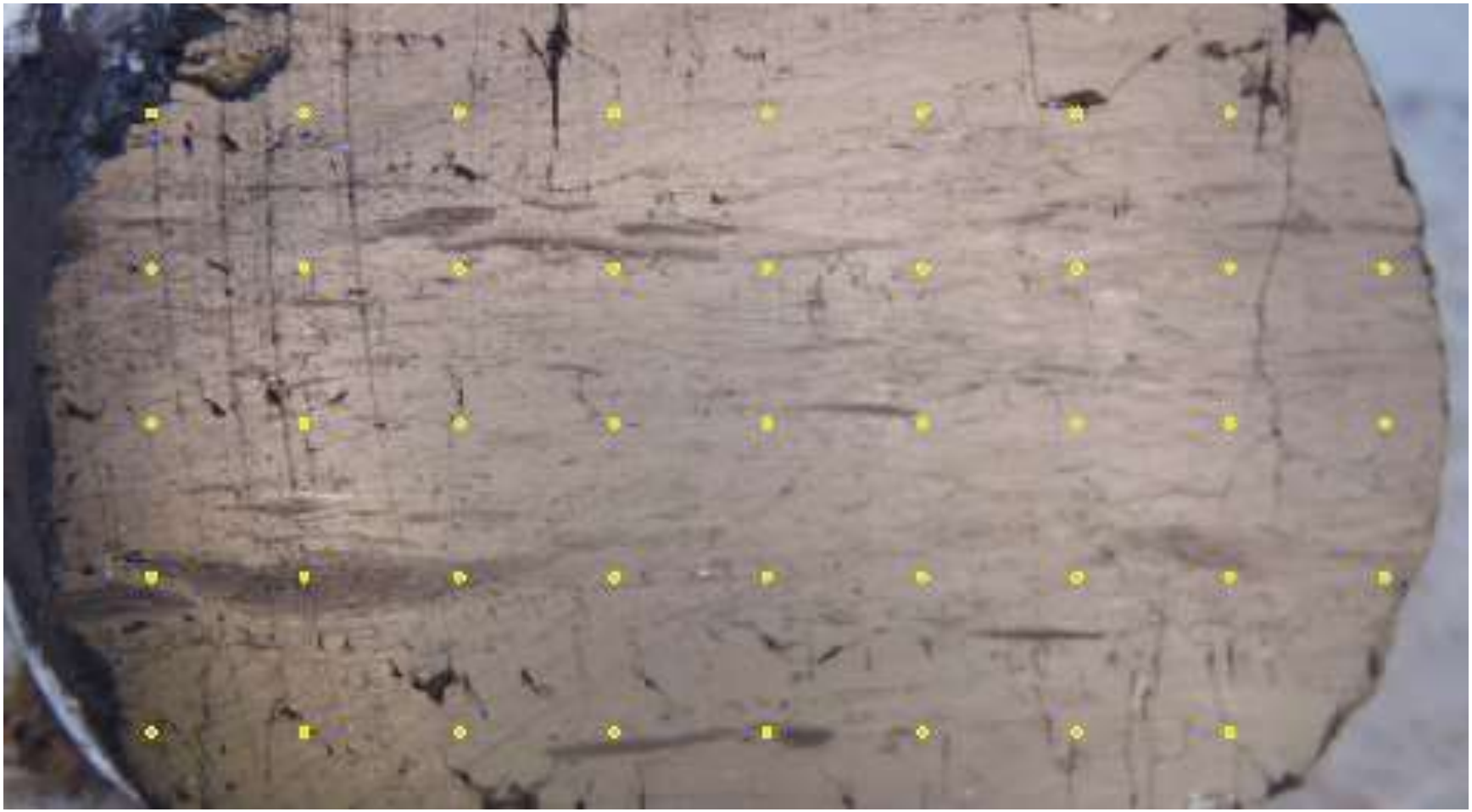
Inertite with cellular structure
(Note penetration by major structure)

· Clarite (banded coal)

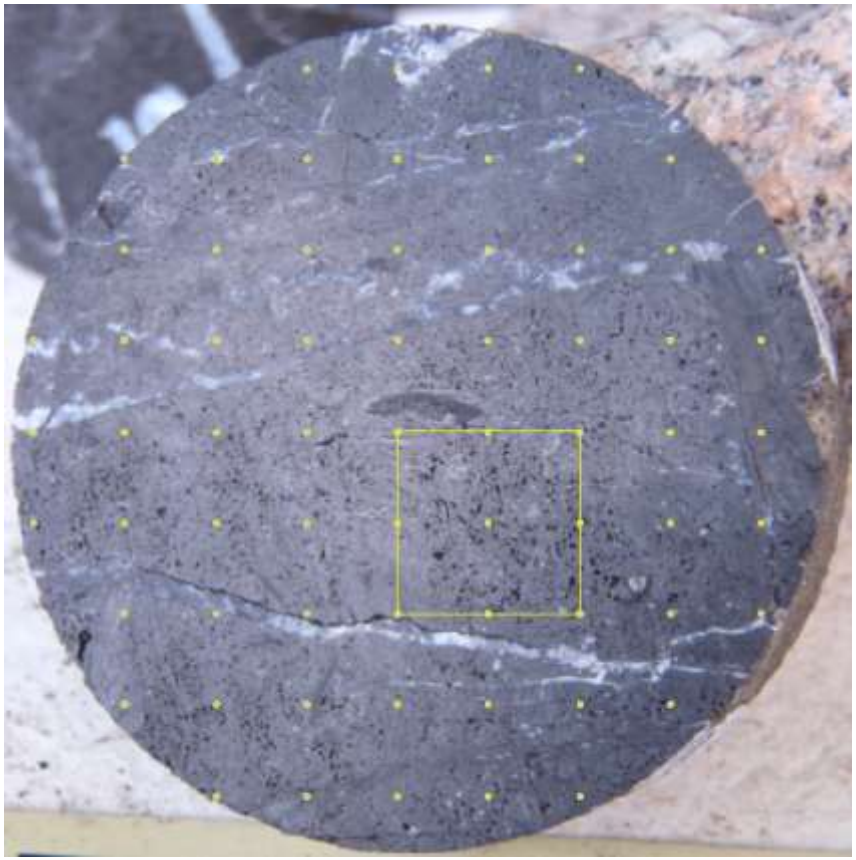
(Shorter fractures tend to terminate on inertite)

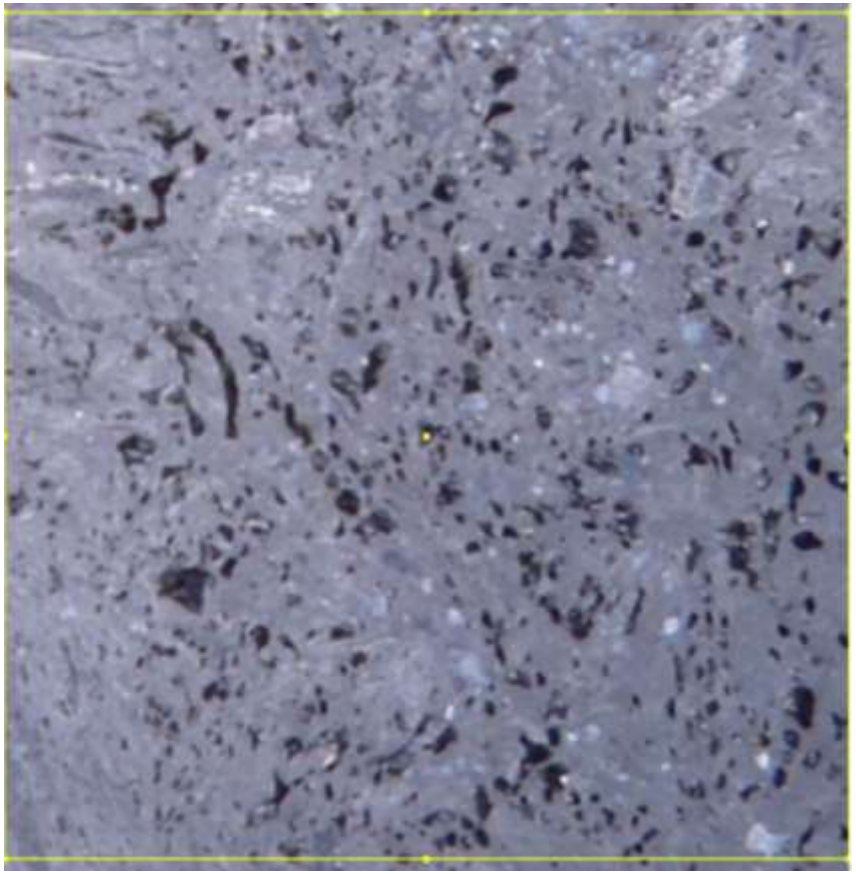


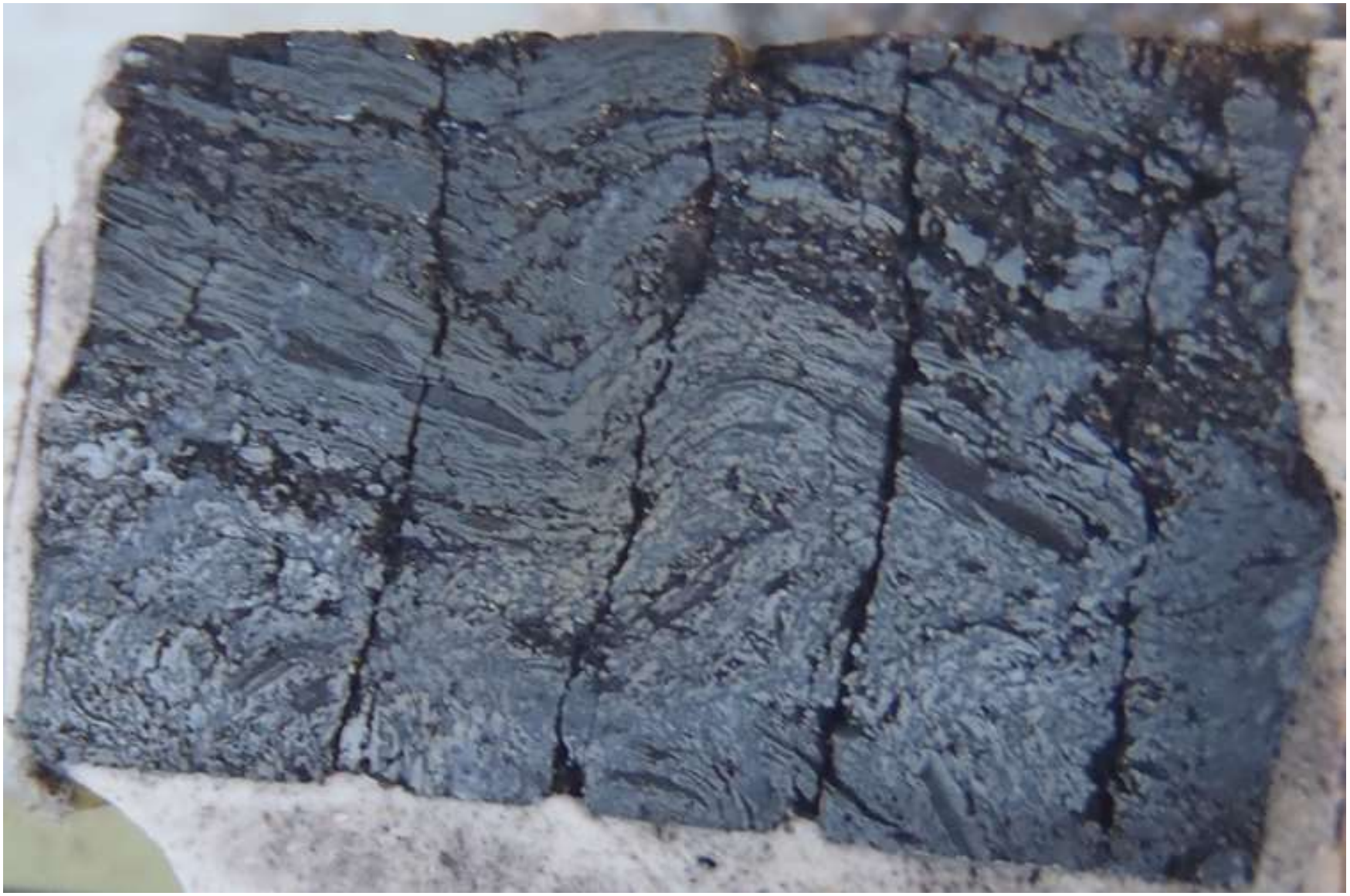
Dull coal



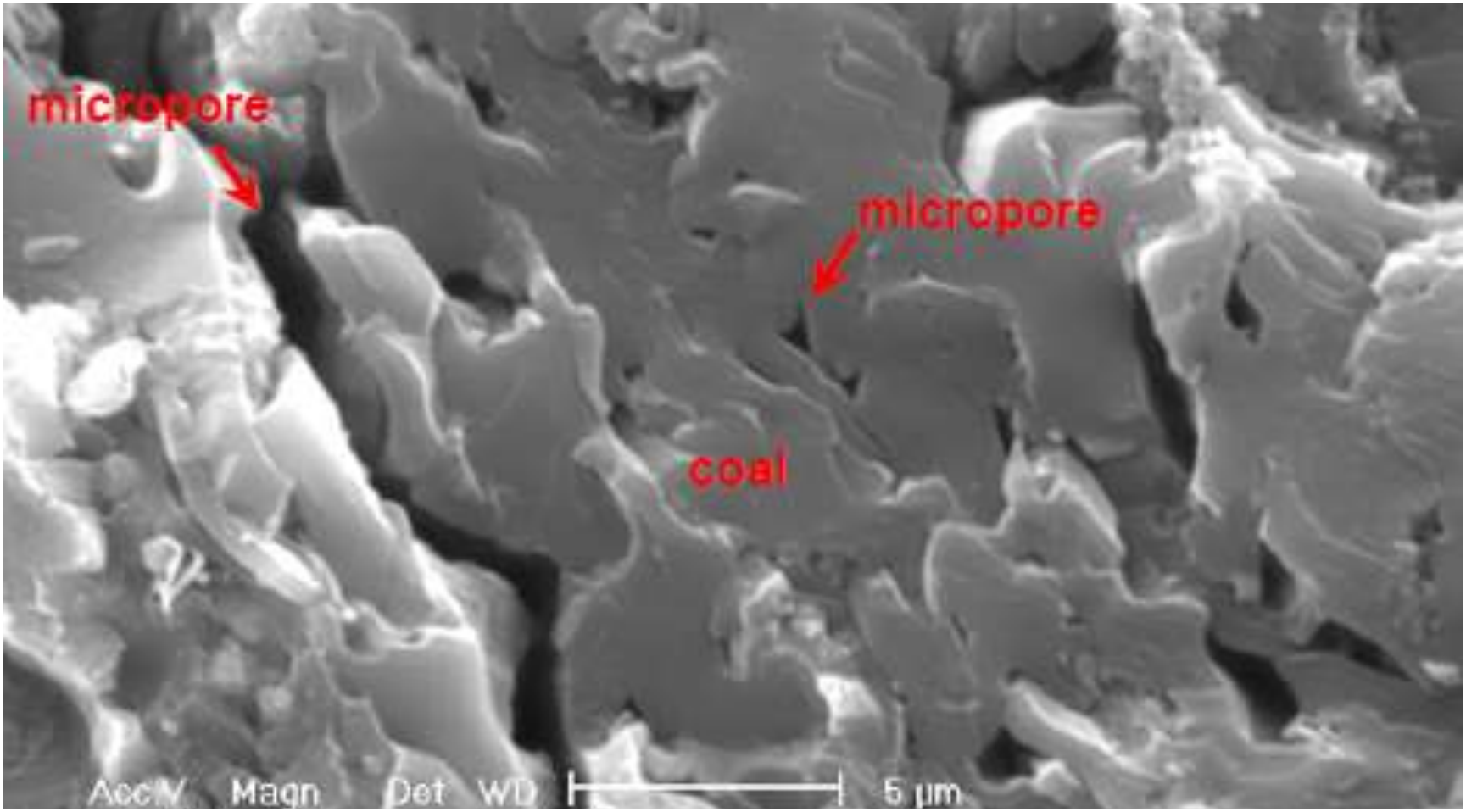
Cinder







SEM of high rank coal

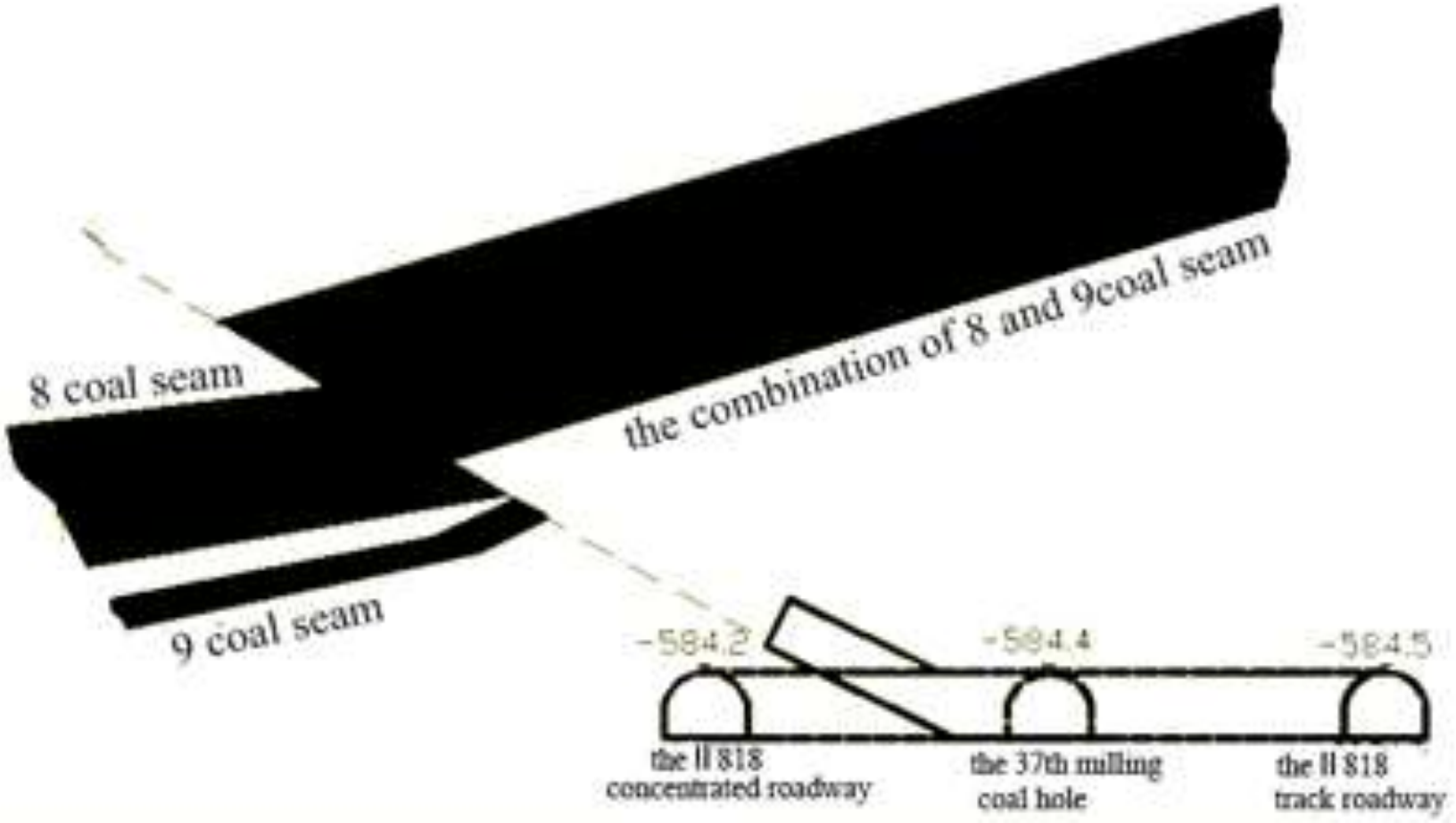


Real Outburst Cases

- Entry through stone into a faulted area

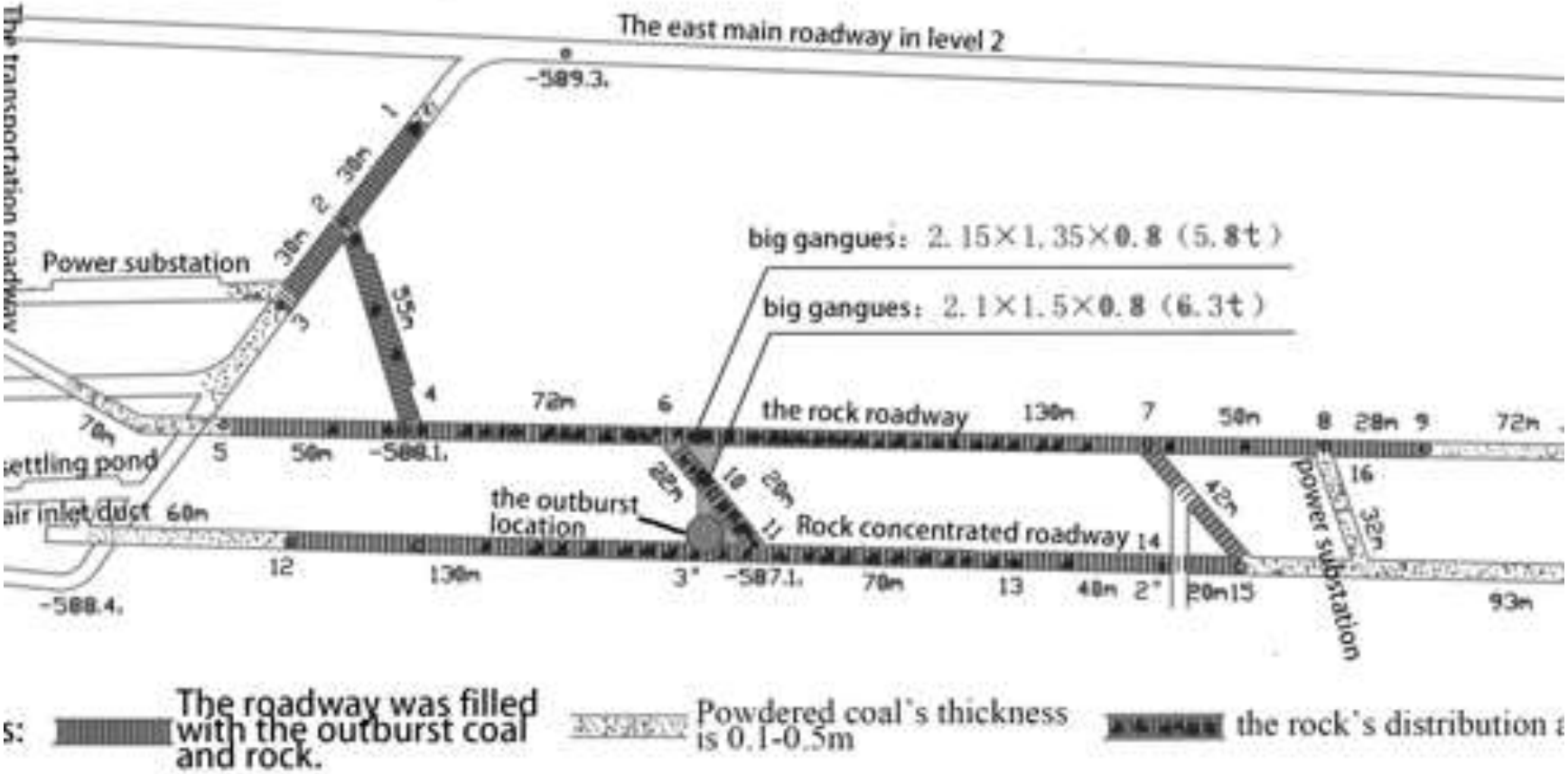
  Luling Mine, Anhui Province, China, 2002
- Borehole outburst – D6 Seam, Lenina Mine, Karaganda Basin, Kazakhstan, 2008
- Rib outburst, Pervomayskaya, 2005
- Solid coal outbursts- Leichhardt Colliery, Blackwater, Central Queensland, 1974-1982

Luling mine China, 7 April, 2002



8 730 tonne coal 930 000 m^3 CH_4

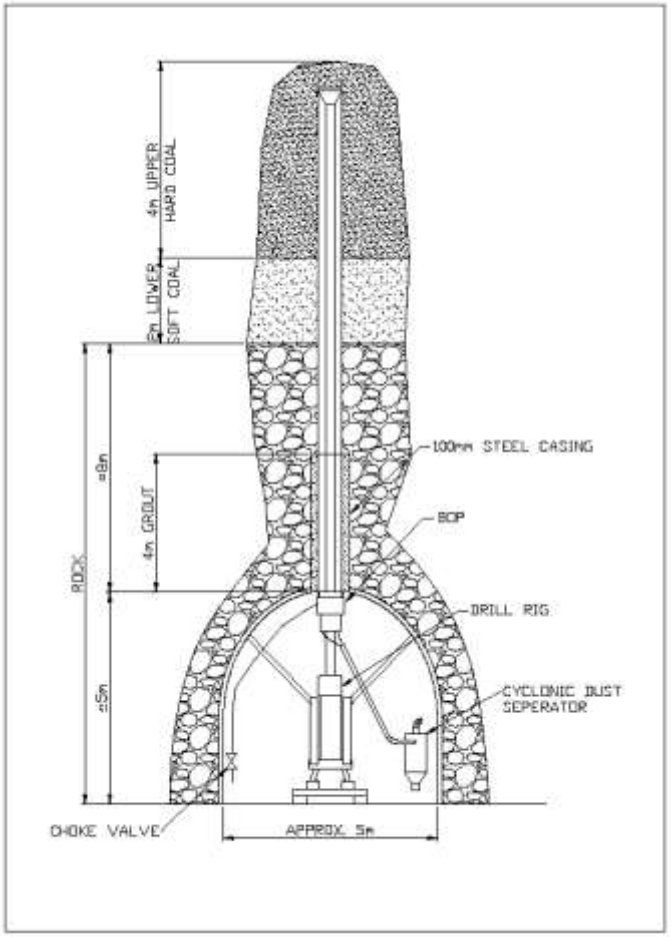
shotfiring



Lenina Mine, Kazakhstan
6 m seam has 1.5 m of fine gouge coal in base
45% <0.1 mm diameter

8 m^3 coal
26% + CH_4

Reversed ventilation
2 Fatalities on later incident

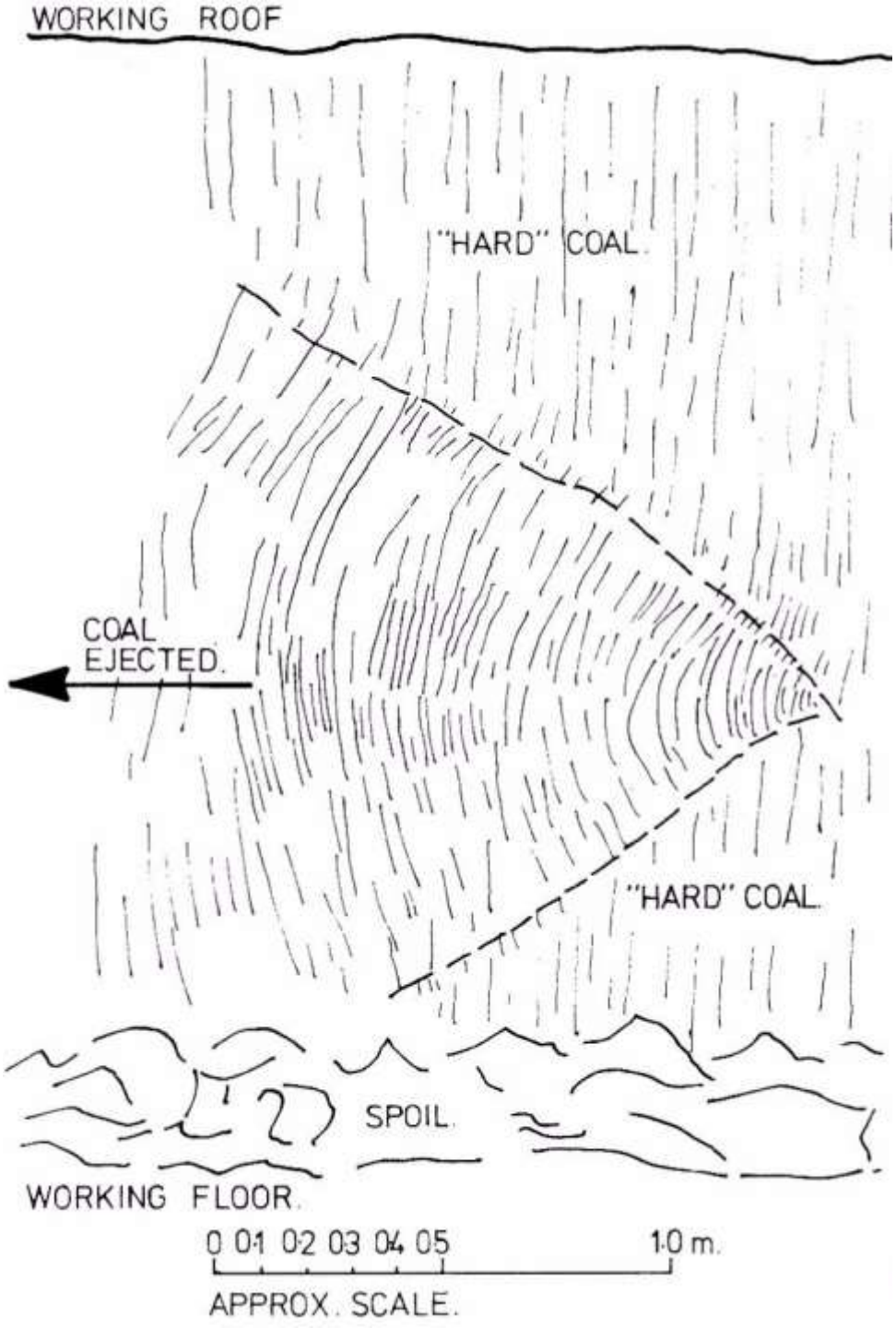


Rib outburst Pervomayska Mine

- Single entry development by road header with gathering arm loader
- Outburst occurred 15 m behind face blocking entry
- Several shifts after mining
- 2 Fatalities

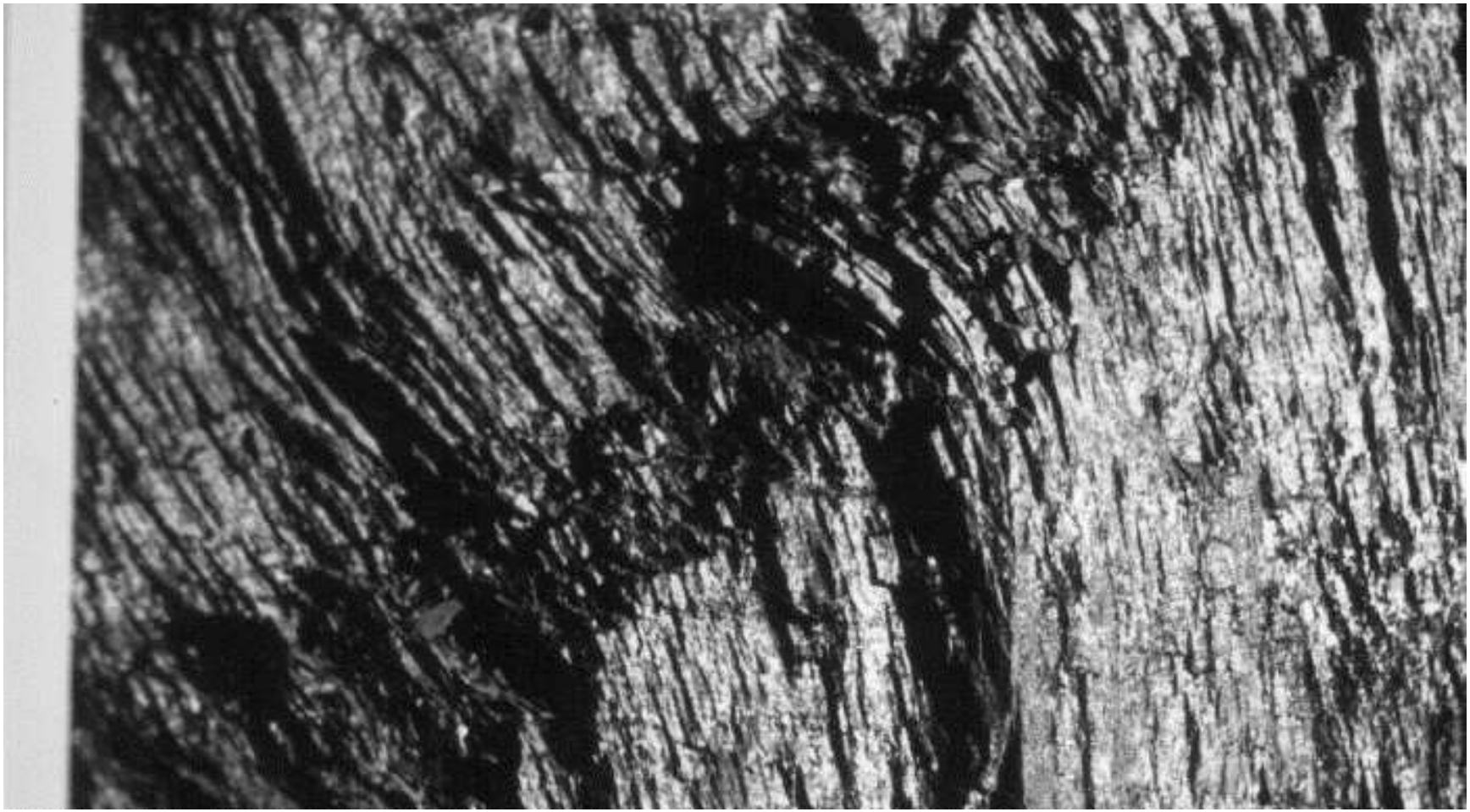
Solid Coal Outbursts – Leichhardt

- Typically 30 tonnes but major event was 350 tonnes
- Failure occurred perpendicular to well defined cleat structure and induced cleavage
- Failure took place at > 2.4 MPa seam gas pressure
- Ribside hardened before the outburst

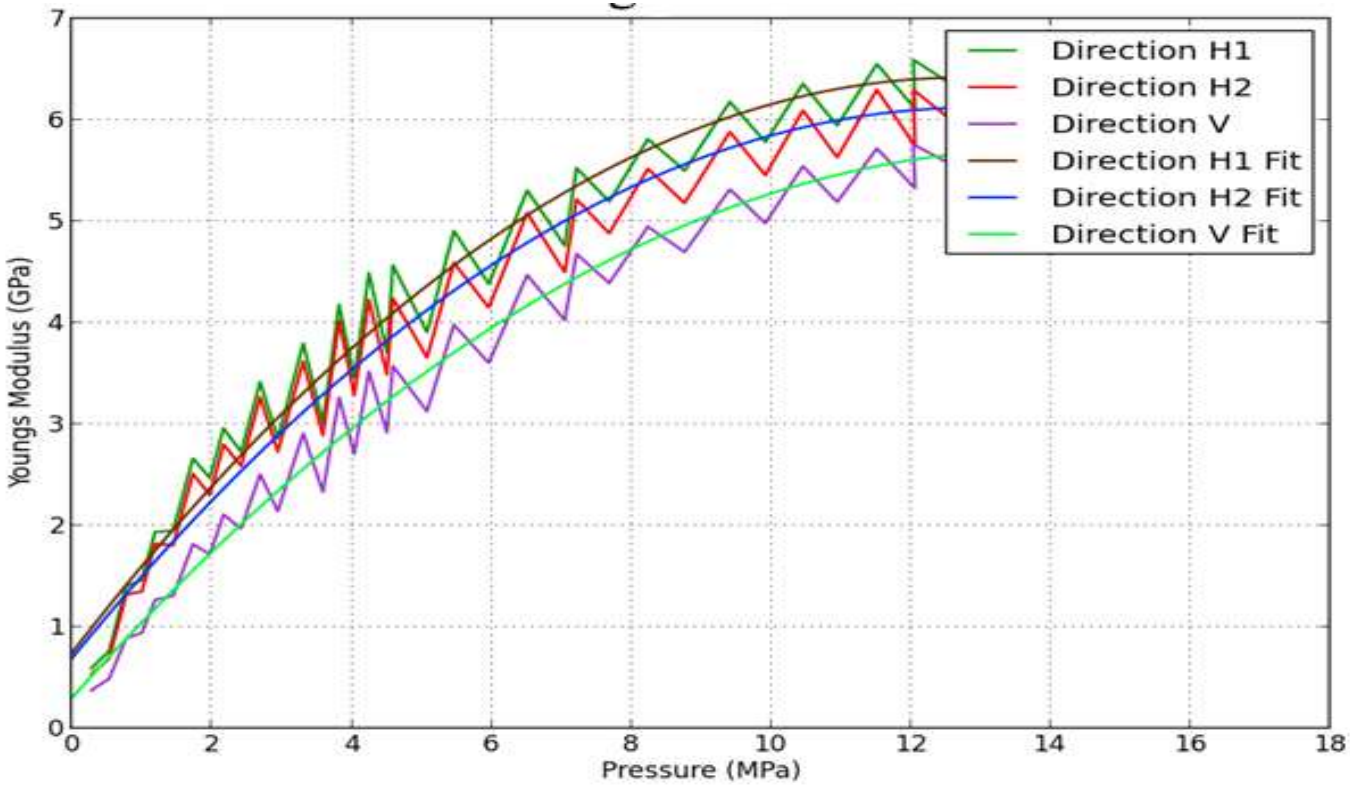


Leichhardt Colliery
Outburst Cavity – Induced Cleavage Planes

Photo of Induced Cleavage



Rib hardening due to stress-strain behaviour of coal



What can you measure to determine if a coal will outburst?

Fundamental Parameters – unique value of a property that is not influenced by other parameters or by the method of measurement (theoretically at least)

eg – pressure, flow rate, stress, gas content

Index Values – involve a measurement by a specific test method that is influence by a number of fundamental parameters

eg – Hargraves' emission value, DRI, toughness

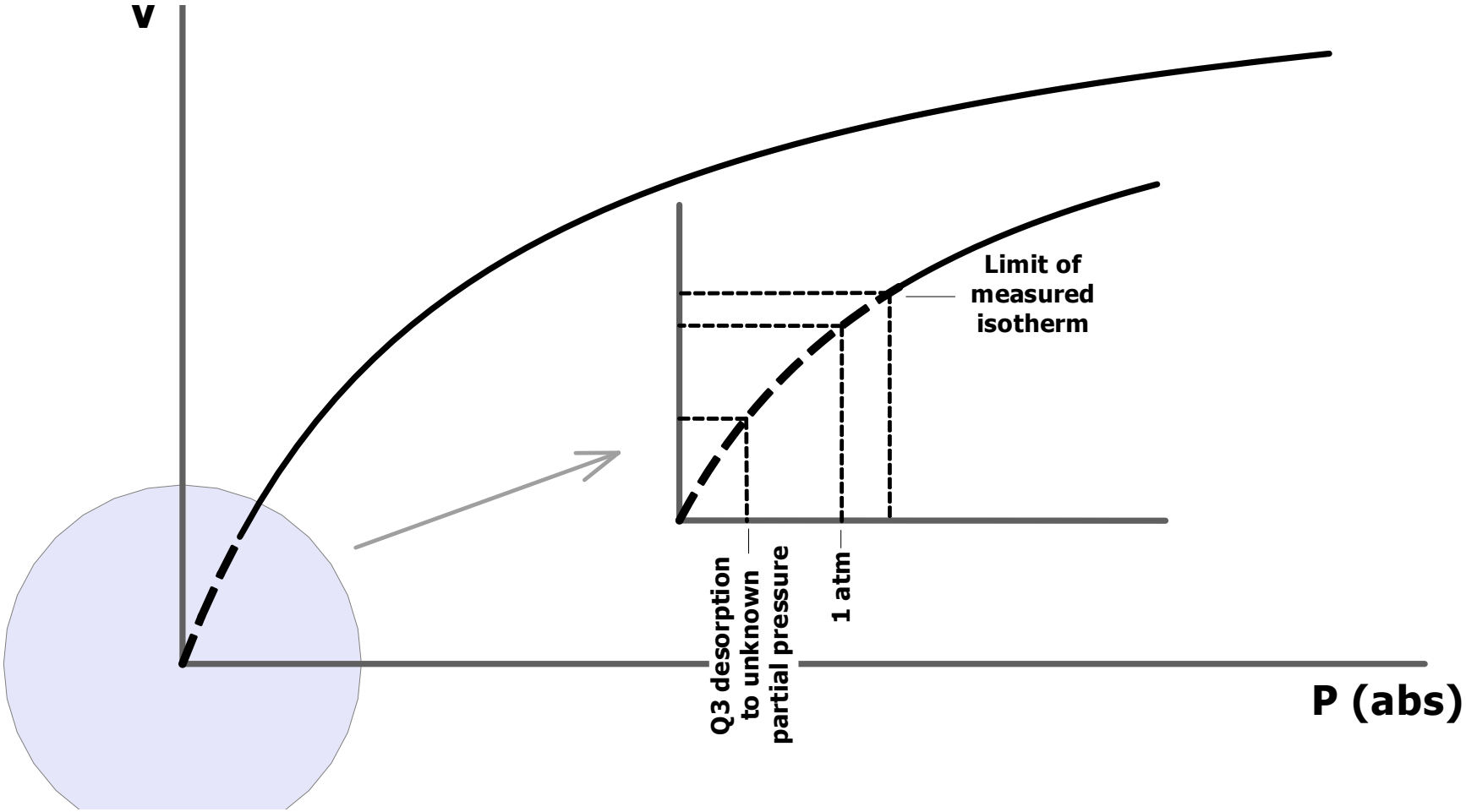
Fundamental Parameters

- Pressure – a simple measurement but one that will fail to a lower pressure
- Gas content – will fail to lower gas content
- Diffusion coefficient – derived from measurement of desorption rate and particle size – derived from measurement of total gas content, desorption rate and particle size
- Stress – physically difficult to measure
- Mechanical properties of coal – difficult to measure, E & ν
- Permeability – highly variable

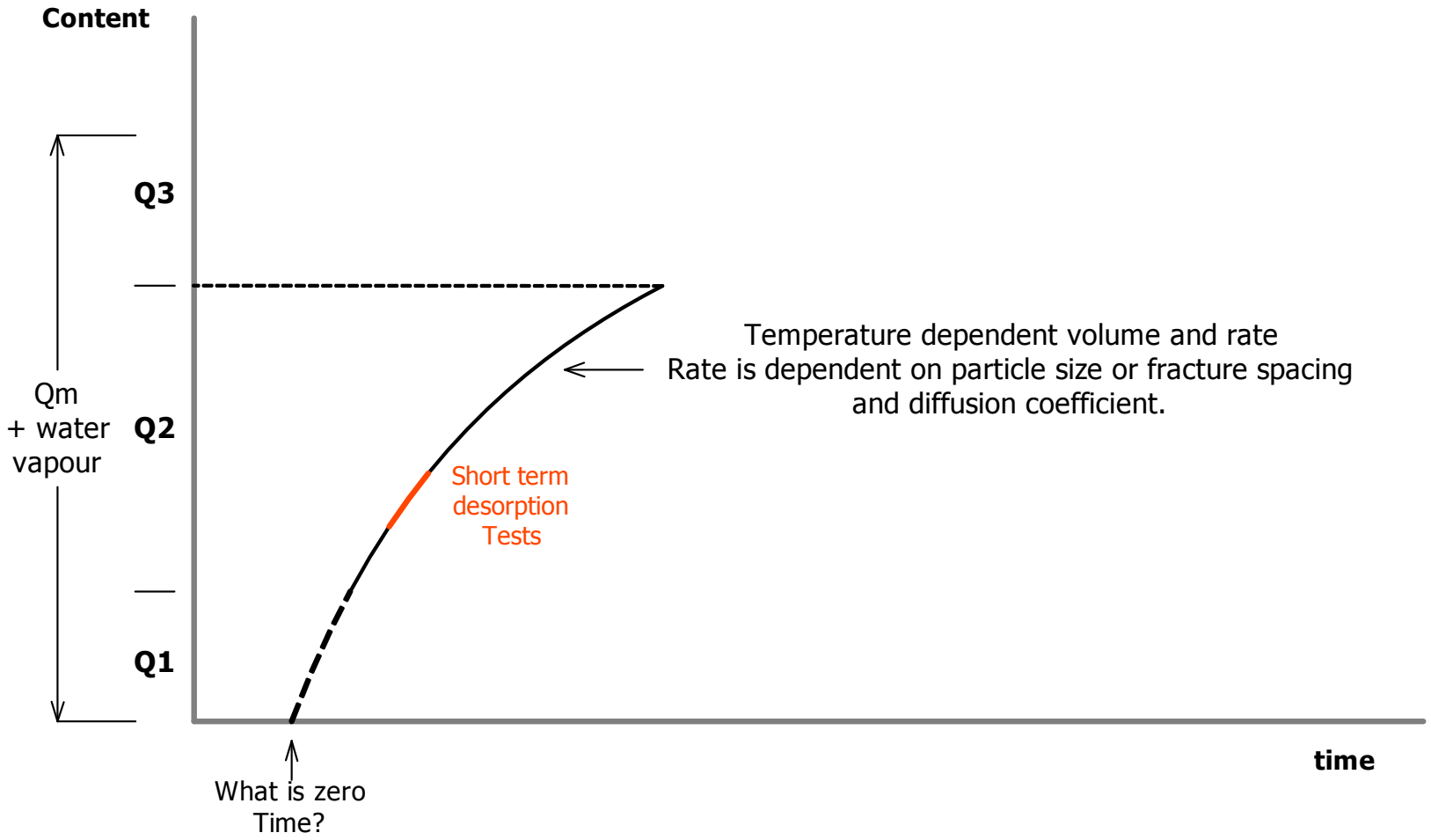
How accurate is gas content?

- Problems with straight line regression of early time - any small segment of a curve is straight!
- When does desorption start?- not all at once.
- What is the partial pressure of seam gas at the end of the desorption process?
- What is the water vapour volume component?
- Base gas content measurement from atmospheric pressure.

Isotherm Facts



Desorption Facts



Index Tests

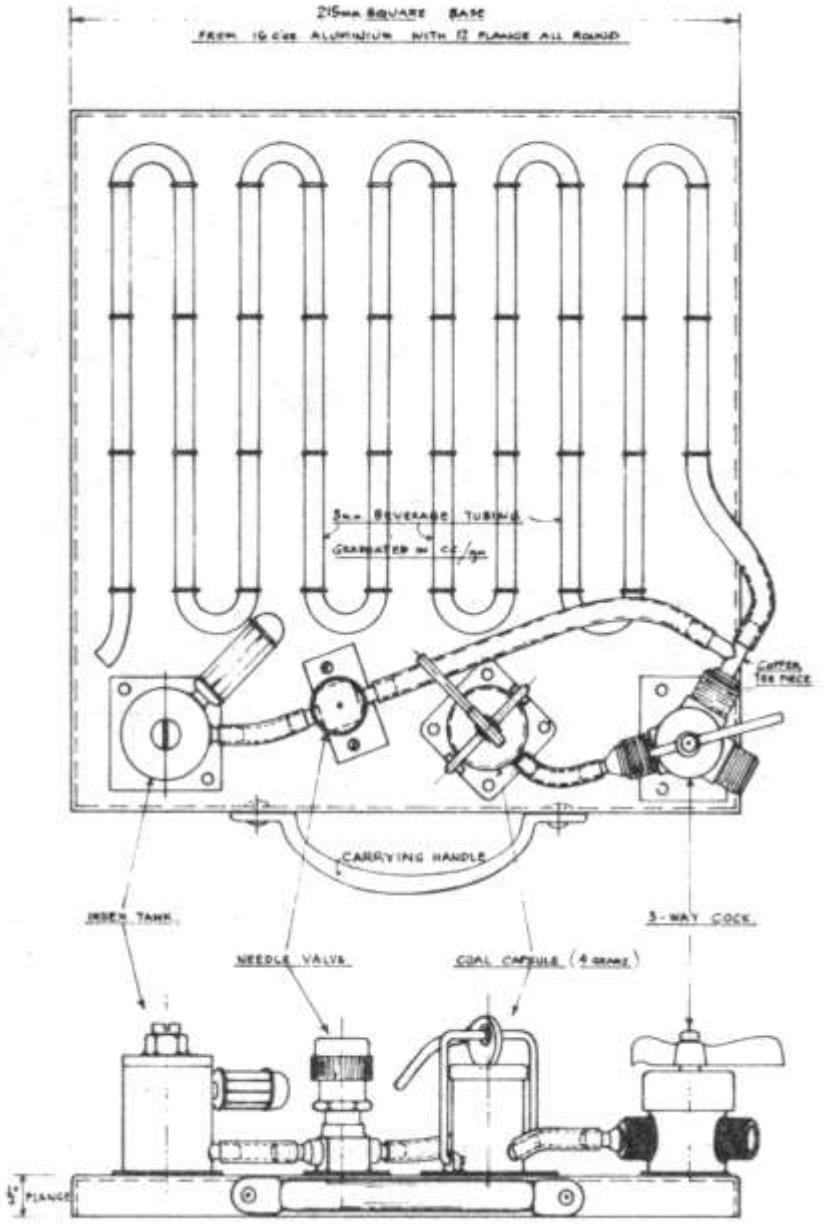
- Whole string of desorption based test
  - Hargraves' emission index
  - Chinese drilling cuttings gas desorption index (CDCDI) Parameters Δh2 and K1
  - DRI, IDR30, D_A
- Adsorption tests
  - ΔP
- Toughness tests
  - Toughness tests
    - Protodyakanov hammer
    - Q index gun

Desorption Process and Measurements

- Tests that only measure a short interval of time in the desorption curve provide only that measurement – without context

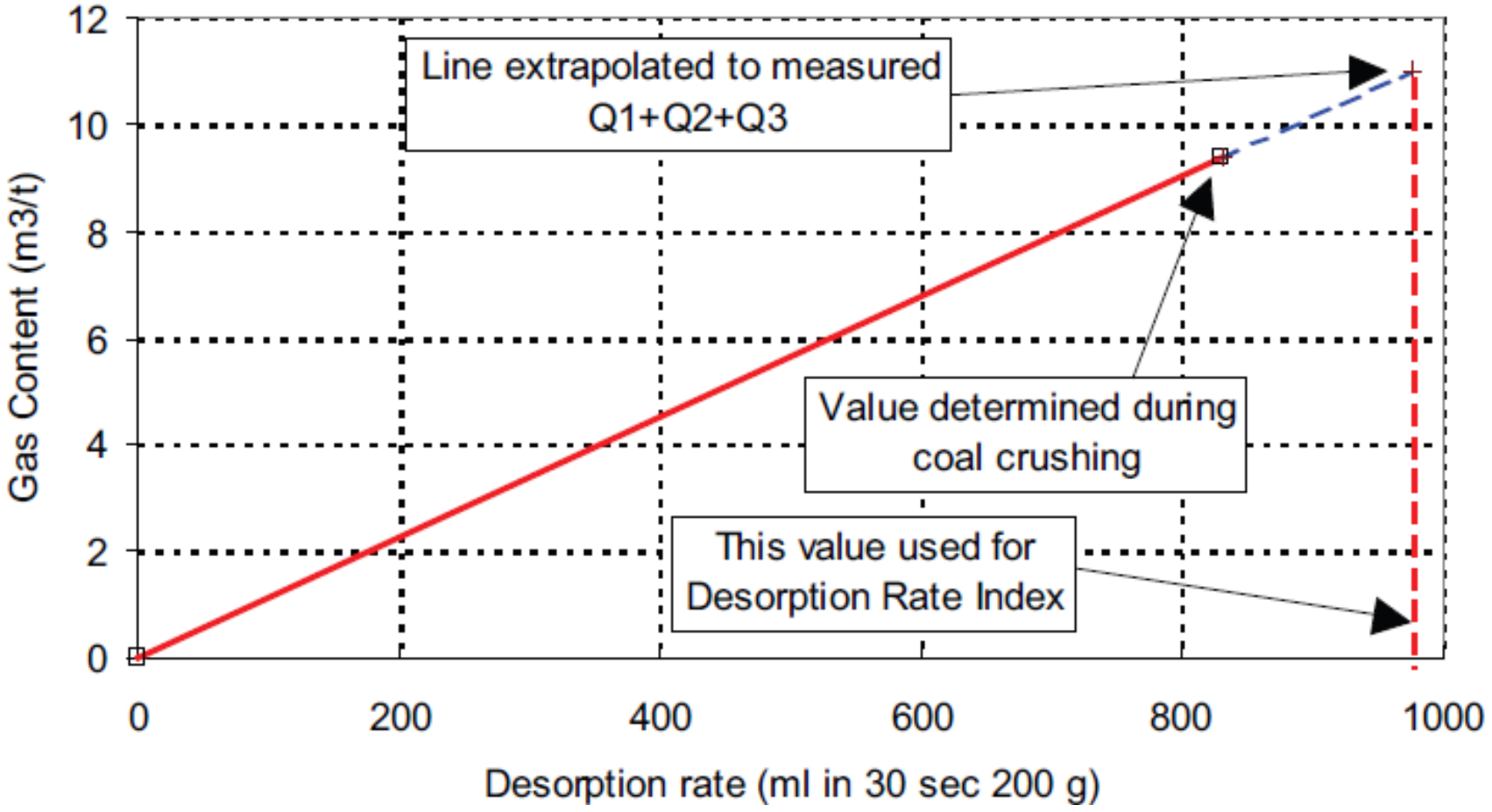
- In combination with total gas content AND a particle sizing they provide an indication of the diffusion coefficient

Hargraves' Emission Meter

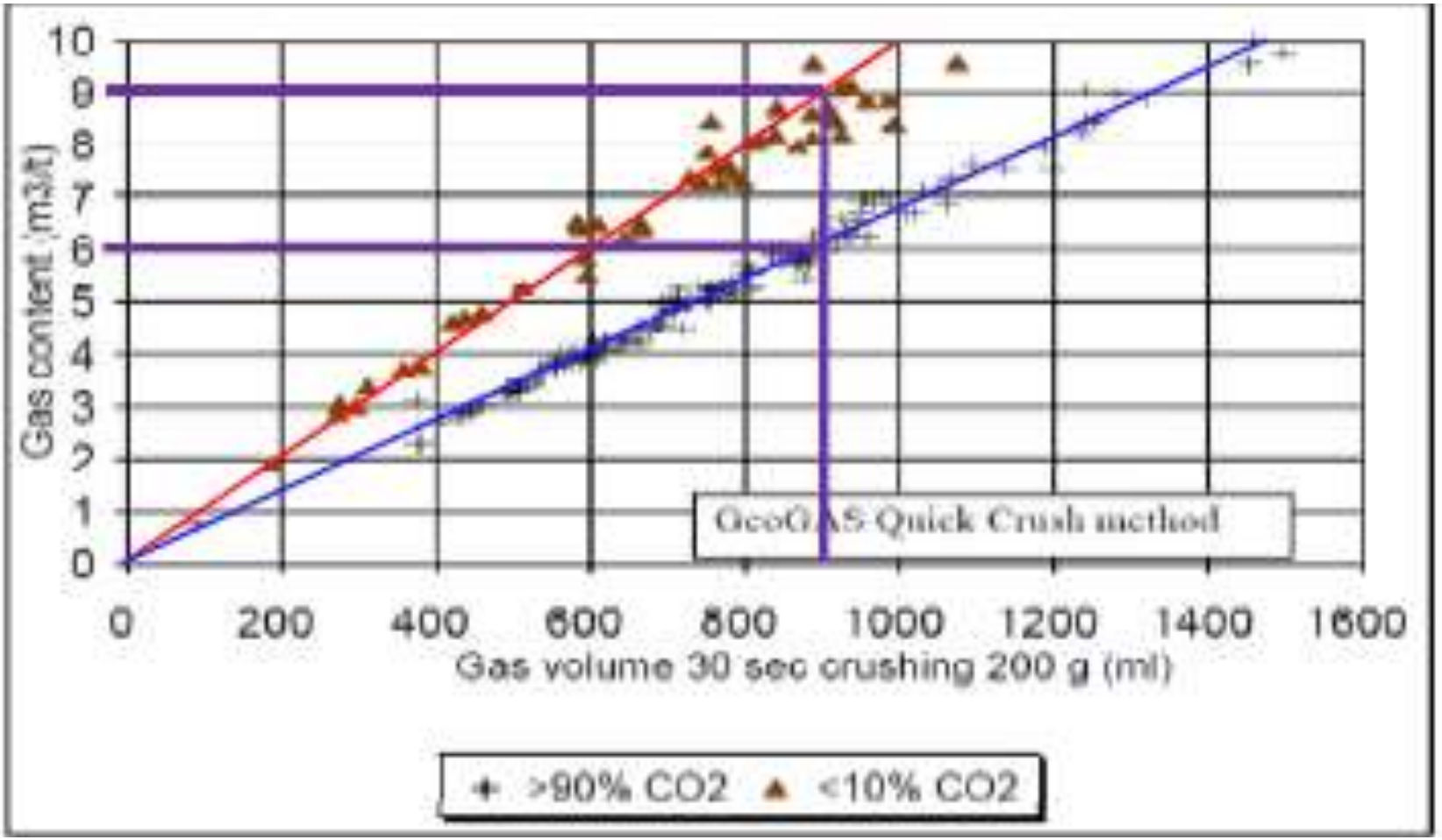


Chinese Desorbometer

DRI Logic - 1


Line extrapolated to measured Q1+Q2+Q3
Value determined during coal crushing
This value used for Desorption Rate Index
Gas Content (m3/t)
Desorption rate (ml in 30 sec 200 g)
0
2
4
6
8
10
12
0
200
400
600
800
1000

DRI Logic - 2


Gas content (m3/t)
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
Gas volume 30 sec crushing 200 g (ml)
GeoGAS Quick Crush method
>90% CO2
<10% CO2

Apparent DRI Logic

- There is a relationship between the 30 second gas release on crushing and the gas content.

  Of course this is the case – but what is the relationship?
- That because there is an established relationship between the total gas content and the crushed gas release in the 30 seconds it is possible to extrapolate the 30 second crush value to represent the full gas content. This is a highly dubious assumption dependent on the process before and during crushing!
- That because the 900 value of DRI corresponds to the Bulli seam outburst thresholds of 6 and 9 m^3/t (the correlation here is extraordinary!) that this value should define a new outburst threshold called DRI 900.
- That these thresholds should then apply to any other seam!

Toughness Measurements

- The strength of coal is difficult to measure
- The toughness is even harder to determine
- Therefore index tests are used in ex-Soviet and Chinese mines.

Proto-
dyakanov
drop hammer
f index value

Russian penetrometer gun
Used multiple times in each ‘bench’ q index value

Energy Release

- Strain energy in the rock and coal
- Energy due to adiabatic expansion of gas in pore space
- Energy due to diffusion into pressurised void space – followed by expansion of the void

Fundamentals of outbursting

- Outbursting occurs as FRAGMENTING FAILURE with an accompanying energy release
- Typically the energy comes from energy stored in
  - Elastic strain 1 % to 10 %
  - Fluid (gas) in pore space 7 % to 50 %
  - Gas desorbing into pore space 50 % to 90 %
  - Energy release may exceed 3 MJ/m^3 in fine gouge
  - Any potential energy exceeding 0.1 MJ/m^3 is serious.
- Energy is absorbed during breakage and by loss of gas expansion energy (leaky piston effect)

Pressure or Gas Content?

- Gas pressure forms part of the effective stress equation that leads to the failure

$$\sigma'_n = \sigma_n - \alpha P$$

- Gas content is linked to gas pressure through the sorption isotherm
- Gas content in combination with pressure and diffusion coefficient equates to available energy through desorption.

Methane vs Carbon Dioxide

- Methane will be at a higher gas pressure for a given gas content and will therefore be more likely to promote failure
- Carbon dioxide will be at a lower pressure for a given gas content and is less likely to promote failure
- The diffusion coefficient of carbon dioxide is less than that for methane and therefore the energy release form a CO_2 outburst will be less than that from a CH_4 one for a given gas content.

The importance of clearing the face

- One of the most important aspects of an outburst is the function of gas in clearing the face of gas.
- The confining stress is removed progressively thus leading to further face failure

Review of methods to assess outburst risk worldwide

- Gas content
  - Russia 10 m^3/t (daf) in some locations
  - China 8 m^3/t if they can measure it
- Gas Pressure
  - Russia 1.0 MPa (dependent on seam)
  - China 0.74 MPa (Enforced)
- Main Indices
  - ΔP initial gas recovery rate for coal
  - f hardness coefficient
  - q strength meter (penetrometer) reading
  - S volume of cuttings from intersecting boreholes

Combined parameter measurements

- Chinese
  - Equation takes into account depth (stress), gas pressure and Protodyakanov toughness index
- Russian
  - Equation takes into account Pressure and Protodyakanov toughness index

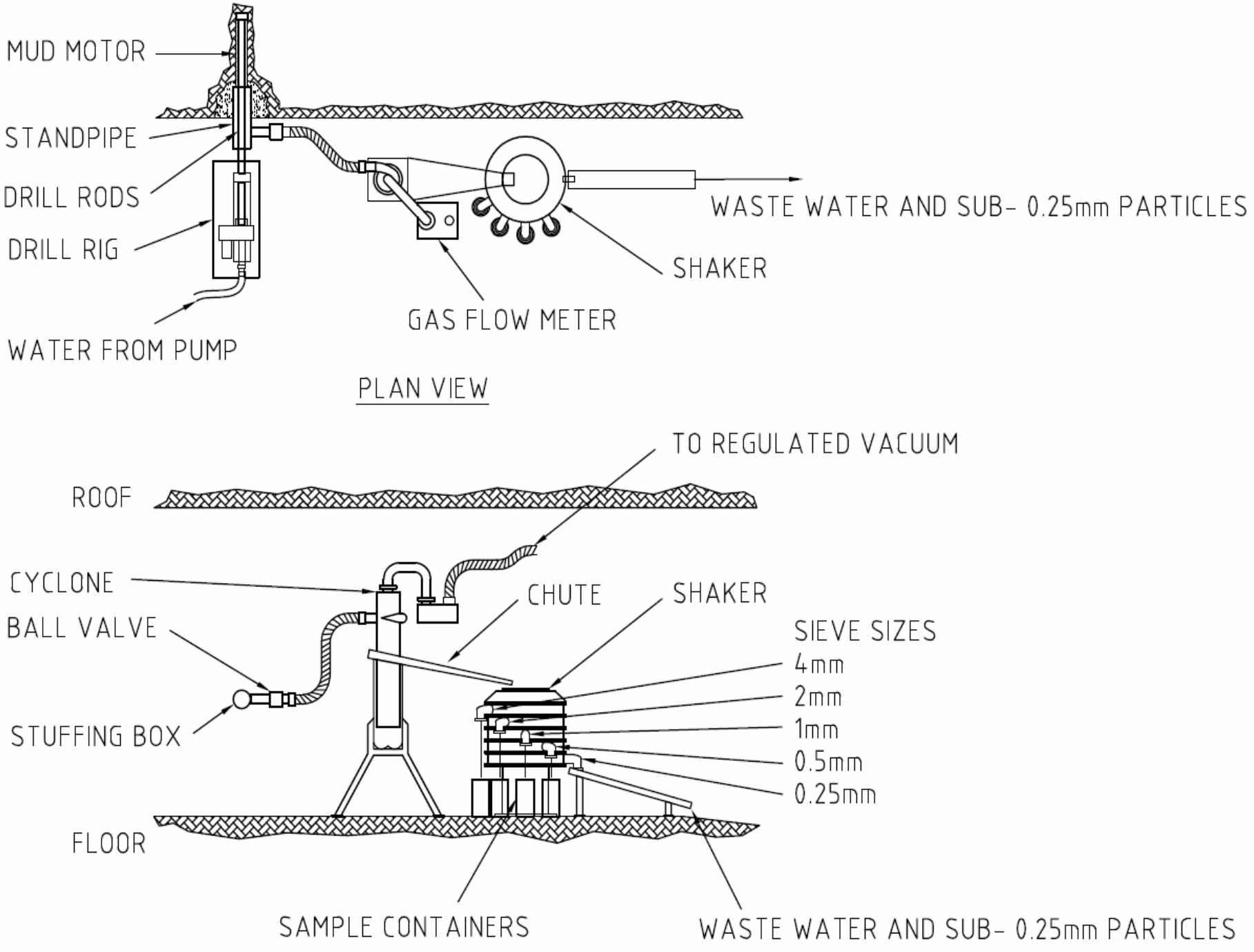
Measurement Solutions

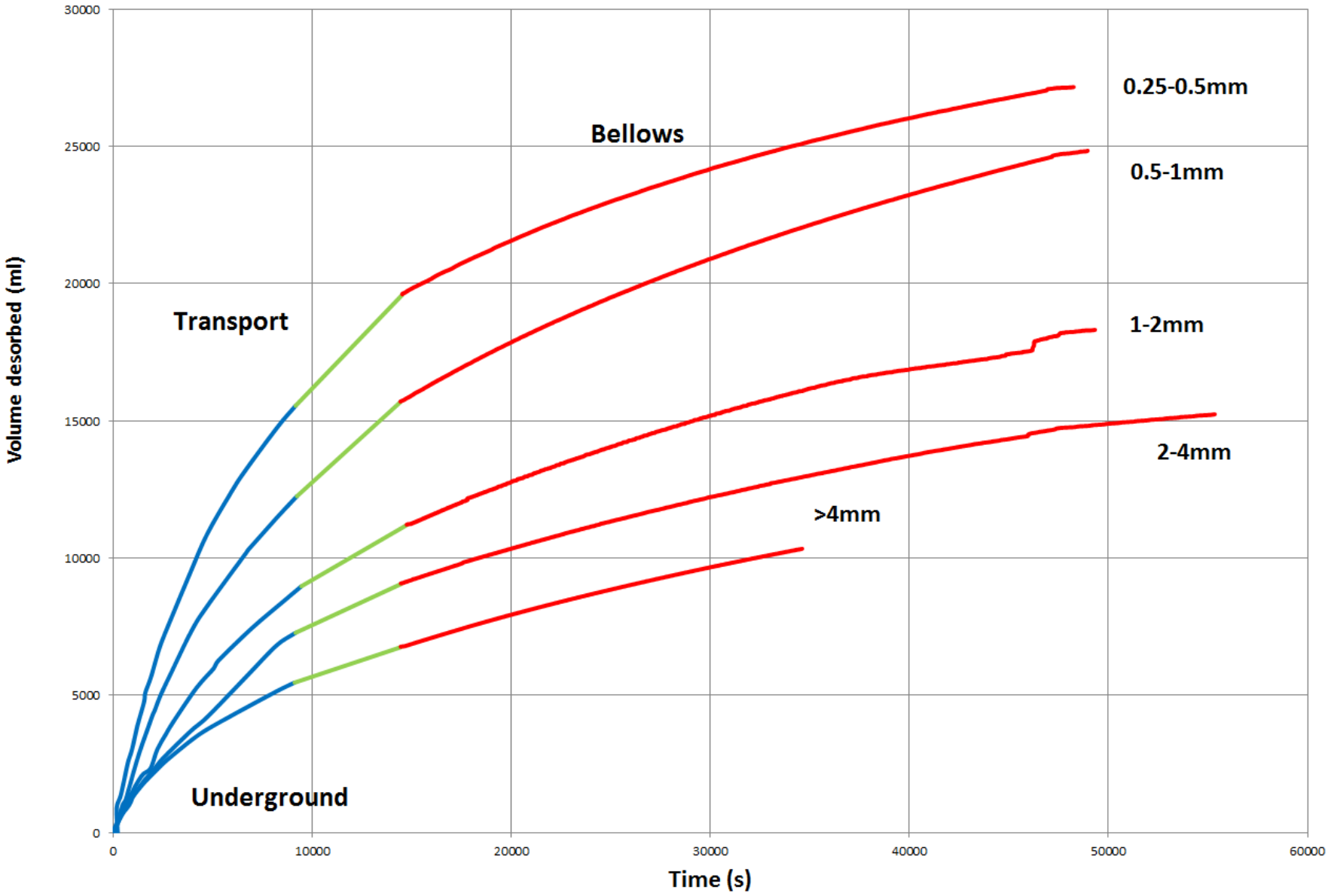
- Discrete measurements
  - Need to sort out
    - Gas content
    - Isotherm
    - Toughness
    - Diffusion coefficient

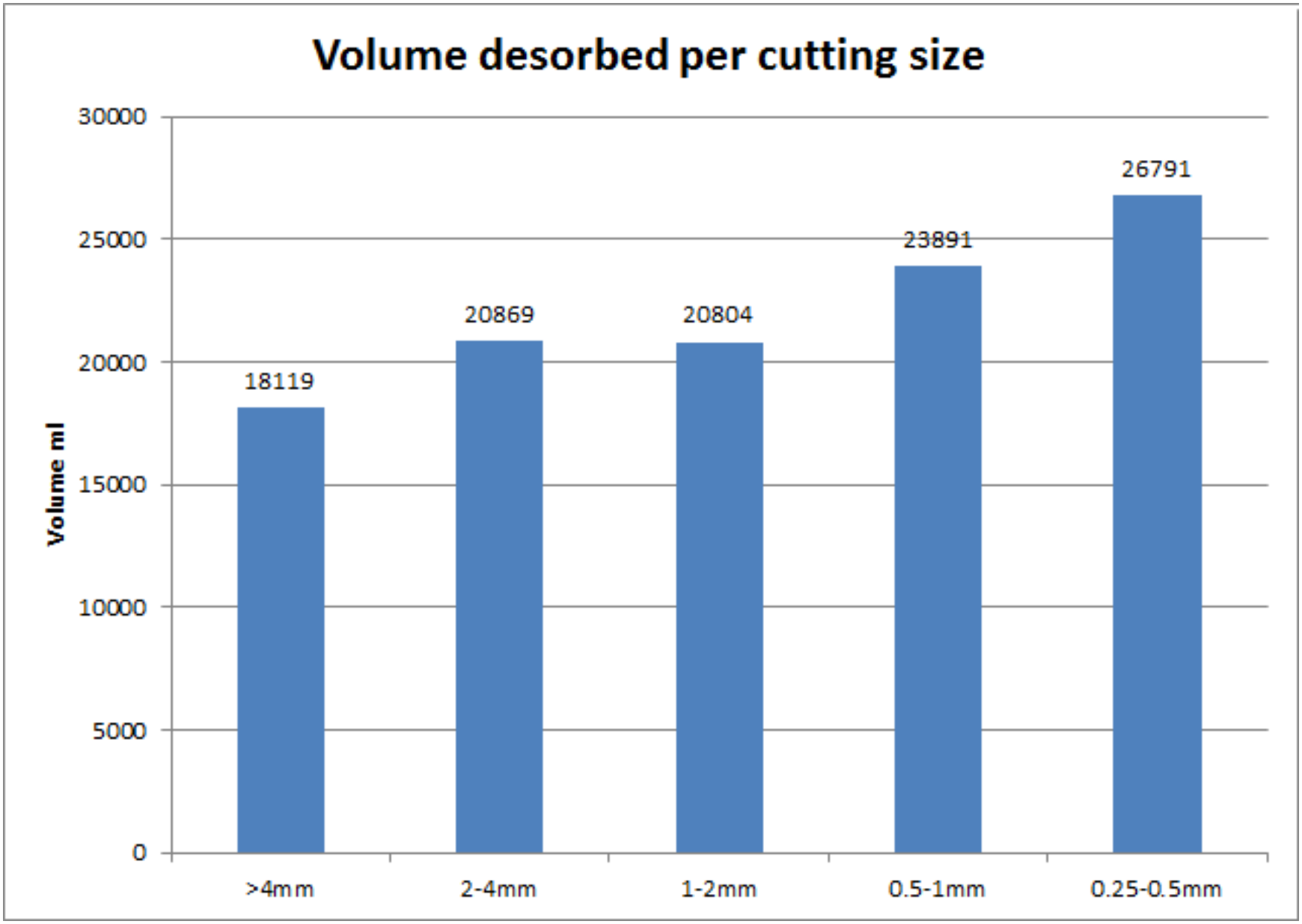
Fundamental Need

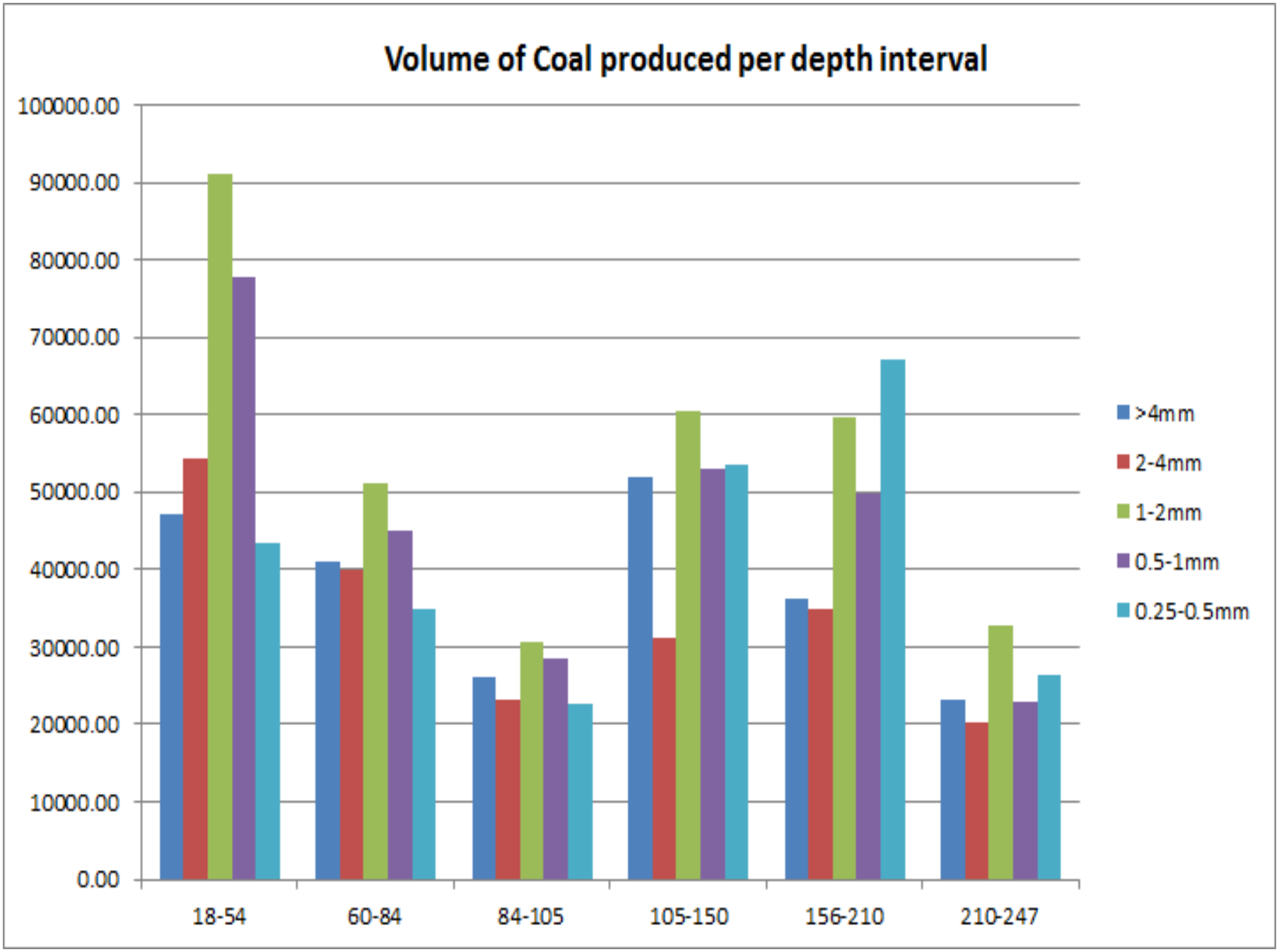
- To understand the nature of fragmentation of coals and effective stress within sheared and apparently solid coal
- Really need to look at coal structure in detail
- Need practical test “pop gun”?

Particle Disintegration Test – Pop Gun


MUD MOTOR
STANDPIPE
DRILL RODS
DRILL RIG
WATER FROM PUMP
GAS FLOW METER
SHAKER
WASTE WATER AND SUB- 0.25mm PARTICLES
PLAN VIEW
TO REGULATED VACUUM
ROOF
CYCLONE
BALL VALVE
STUFFING BOX
CHUTE
SHAKER
SIEVE SIZES
4mm
2mm
1mm
0.5mm
0.25mm
FLOOR
SAMPLE CONTAINERS
WASTE WATER AND SUB- 0.25mm PARTICLES


Volume desorbed per cuttings size (Sample 2: 150m)
Volume desorbed (ml)
30000
25000
20000
15000
10000
5000
0
0
10000
20000
30000
40000
50000
60000
Time (s)
Transport
Bellows
Underground
0.25-0.5mm
0.5-1mm
1-2mm
2-4mm
>4mm


Volume desorbed per cutting size
Volume ml
30000
25000
20000
15000
10000
5000
0
18119
20869
20804
23891
26791
>4mm
2-4mm
1-2mm
0.5-1mm
0.25-0.5mm


Volume of Coal produced per depth interval
100000.00
90000.00
80000.00
70000.00
60000.00
50000.00
40000.00
30000.00
20000.00
10000.00
0.00
18-54
60-84
84-105
105-150
156-210
210-247
>4mm
2-4mm
1-2mm
0.5-1mm
0.25-0.5mm

Acknowledgements

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