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Enhancement of coal seam gas by N2 injection - a laboratory study

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Enhancement of coal seam gas by N2 injection - a laboratory study

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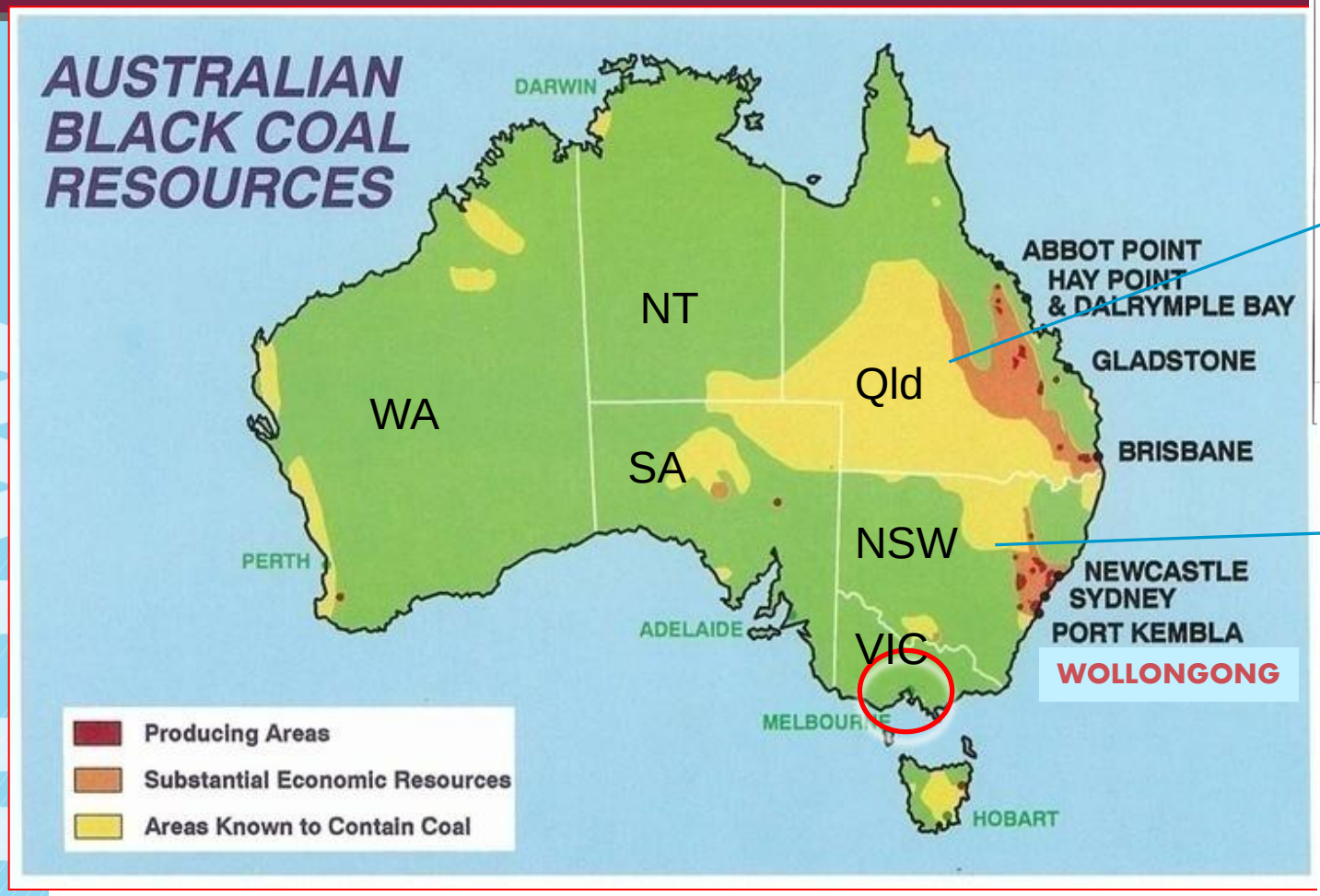
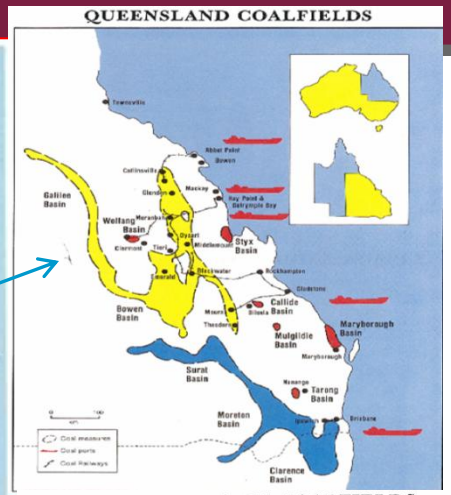
Enhancement of Coal Seam Gas by N_2 Injection- *A laboratory study*

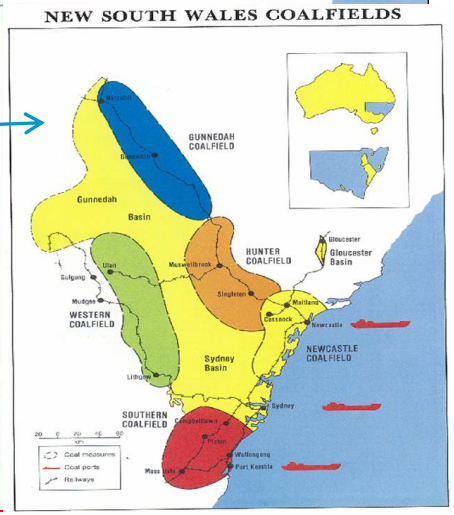
Naj Aziz

Raul Florentin, Lei Zhang, Ting Ren and Dennis Black

School of Civil, Mining and Environmental Engineering
University of Wollongong Australia





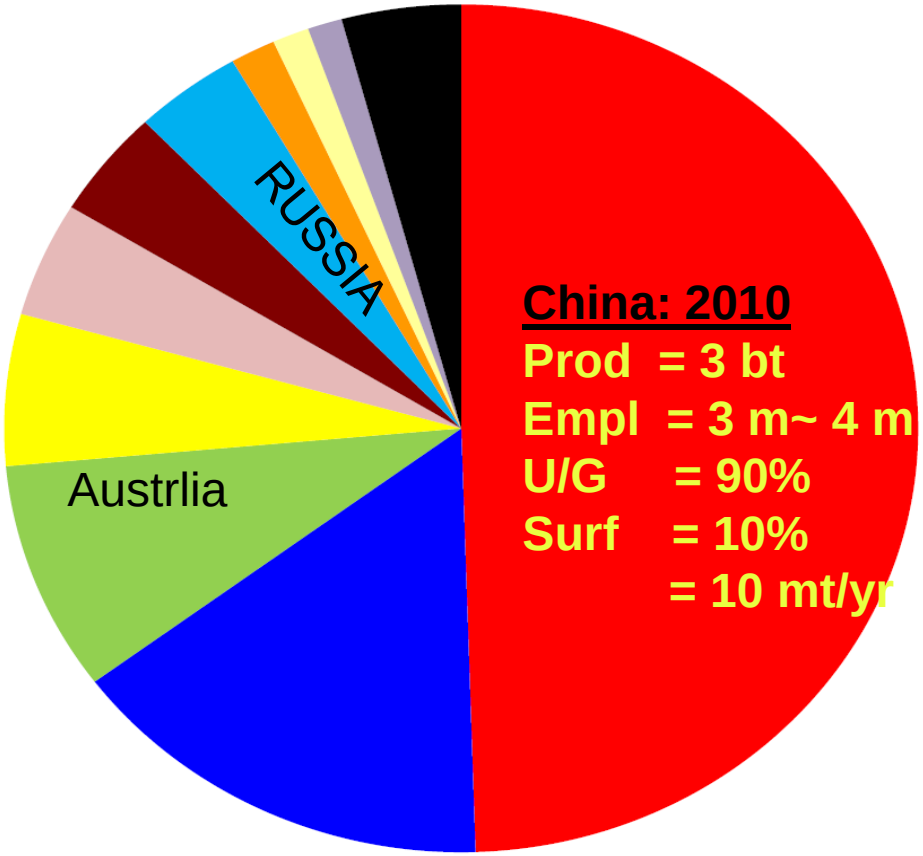


Recoverable economic **demonstrated** resources of black coal: **73.2 bt**
Recoverable **inferred** resources: **125.160 bt.**

Brown Coal: > 68 bt mainly in Vic. and small quantity in SA

World Coal Production 2010

2012



PR China 49.5%	46.5%
USA 15.3%	11.7%
India 8.8%	7.7%
Australia 5.8%	5.5%
Indonesia 4.4%	4.9%
South Africa 4.1%	3.3%
Russia 3.8%	4.5%
Kazakstan 1.6%	1.5%
Poland 1.3%	1.8%
Colombia 1.2%	1.1%
Other 4.2%	

- Australia is 4th largest producer of black coal, after China, USA & India.
- 5th largest producer of brown coal, after Germany, Russia, Turkey and USA.
- Brown Coal Output: 68 Mt in 2010 (Vic and S/A)

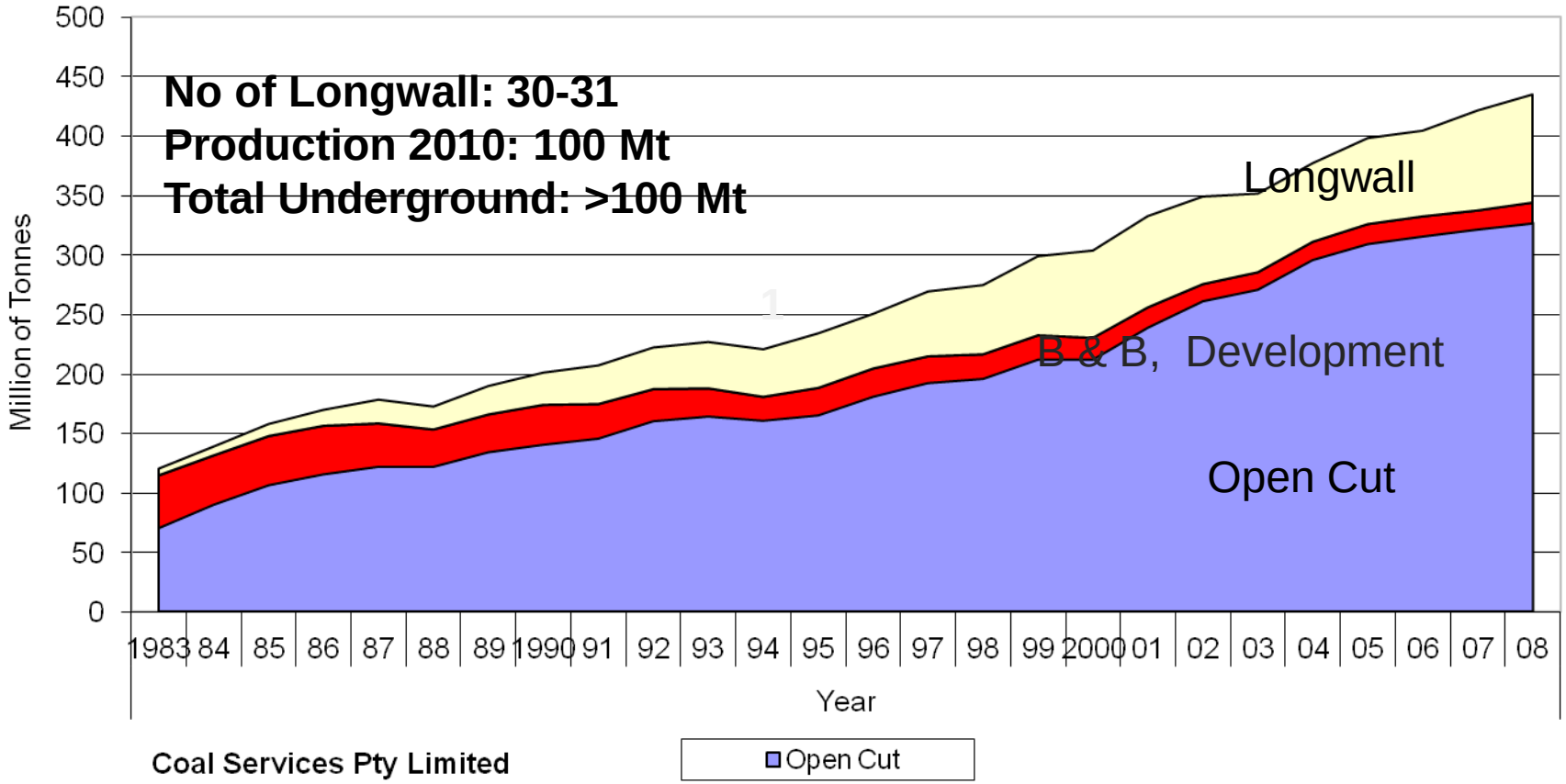
Australian Black Coal Mines Statistics 2011

	No of Mines		Production (Mt)		Methods of Mining (Mt)				Employment			Productivity Saleable Tonnes /man year		
			Raw	Sale	Raw		Saleable		Average No					
State	OC	UG			OC	UG	OC	UG	OC	UG	Tot	OC	UG	Tot
Qld	41	11	256	195	215	41.4	166	29	14 486	3 623	18 109	12 675	14 640	12 955
NSW	31	29	184	140	122	62	90	50	8 582	8 697	17 279	14 430	7 250	10 825
Tas	2	2	0.62	0.42	0.21	0.41	0.15	0.26	25	82	107	9 980	5 070	6 085
SA	1	-	3.8	3.8	3.8	-	3.8	-	222		222	17 220	-	17 220
WA	2	-	6.6	6.6	6.6	-	6.6	-	749		749	650		8 650
Aust	77	42	451	347	347	104	266	80	24 064	12 402	36 466	13 155	9 060	11 920
	(119)				(451)		(347)		36 466			11 920		

- **Almost 98% of black coal is sourced from Queensland & NSW**.
- Australia produces and exports both metallurgical (COKING) and thermal (STEAMING) coal in almost equal proportions.

Queensland produces the majority of Australia's metallurgical (coking) coal, **New South Wales** produces predominantly thermal (steaming) coal.

AUSTRALIAN RAW COAL PRODUCTION BY METHOD OF MINING



Coal Services Pty Limited

U/G Mining by Longwall Mining

Currently there are around 30 longwall operations in Australia. 45% of the longwall mines require regular gas drainage to manage coal seam gas emissions within the mine.

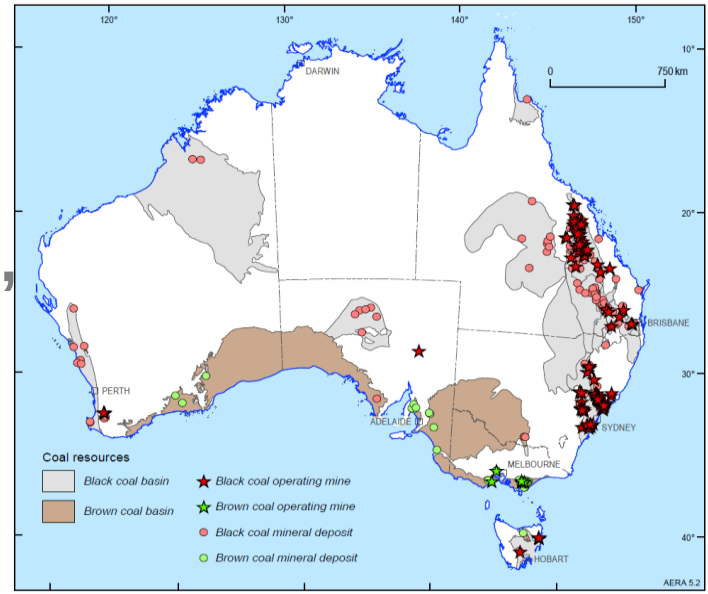
Coal seam gas represents potentially a significant risk to the safety and productivity of underground mines.

Queensland Mines

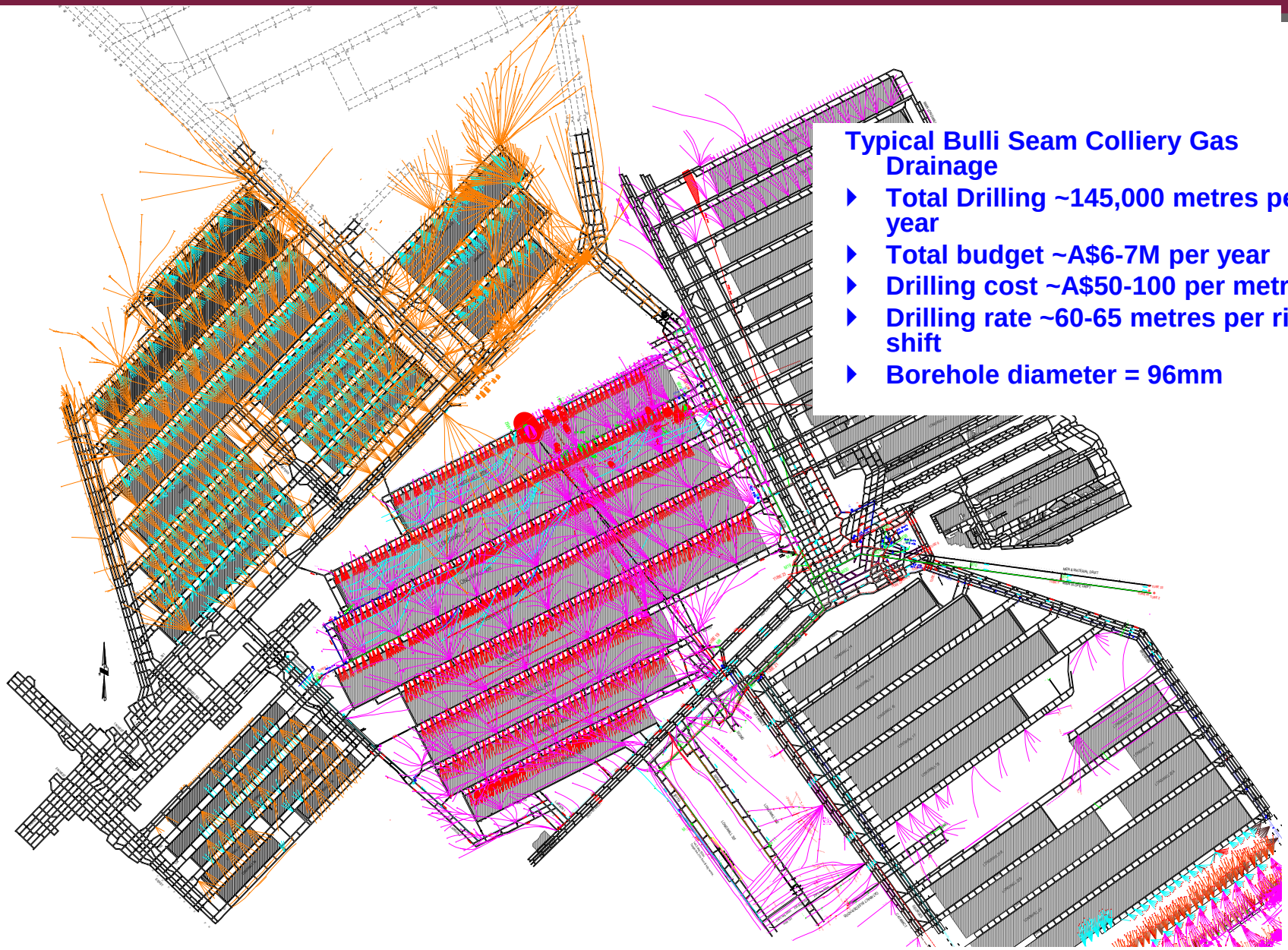
- Grasstree,
- North Goonyella,
- Moranbah North,
- Oaky No.1,
- Oaky North
- Newlands
- Carborough Downs

New South Wales Mines

- Appin,
- Integra
- Mandalong,
- Metropolitan,
- Beltana,
- Tahmoor,
- West Cliff,
- Whitehaven.



Intensive Underground Gas Drainage Drilling



Typical Bulli Seam Colliery Gas Drainage

- **Total Drilling ~145,000 metres per year**
- **Total budget ~A$6-7M per year**
- **Drilling cost ~A$50-100 per metre**
- **Drilling rate ~60-65 metres per rig shift**
- **Borehole diameter = 96mm**

Outbursts in Australian coal mines

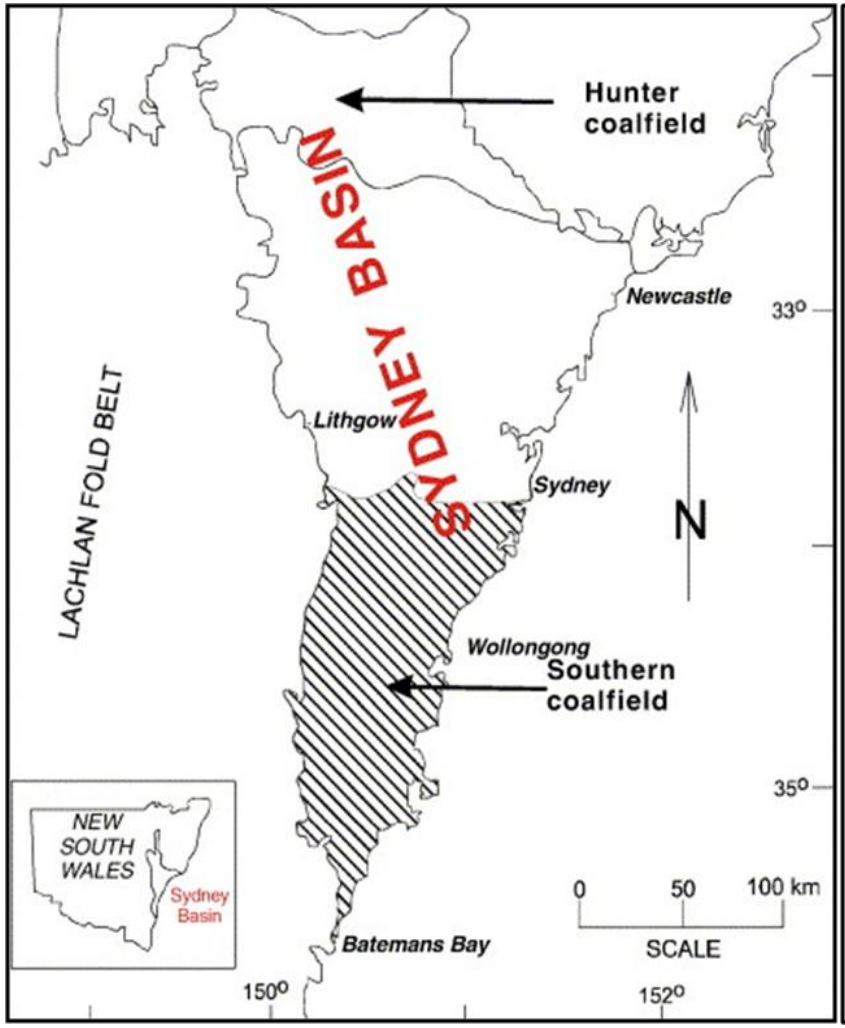
Colliery	Date	Seam	Basin	Depth (m)	No of O/B	No. Killed	Gas	Ejected coal size (t)	Work Place
Metropolitan*	1895-pres.	Bulli	Sydney	425	154 (tot)	-	CO_2 Mainly with CH_4	200	Pick
Metropolitan	1896	Bulli	Sydney	425		3	Firedamp		Single shot
Metropolitan	1926	Bulli	Sydney	400		2	Black damp	140	undercutting
Metropolitan	1954	Bulli	Sydney	425		2	CO_2	90	Undercutting
Metropolitan	1961	Bulli	Sydney	425			CO_2 +CH_4	300	Induced shotfiring
North Bulli	1911	Bulli	Sydney	370			CH_4	1	Pick-delayed
Coal Cliff	1961	Bulli	Sydney	450			CO_2+CH_4	2	Cont Miner
Corrimal	1967	Bulli	Sydney	400	4		CO_2 +CH_4	50	Cont Miner
Appin	1966	Bulli	Sydney	520			CH_4	60	Cont Miner
Bulli	1972	Bulli	Sydney	380			CH_4	100	Cont Miner
West Cliff	1977-93	Bulli	Sydney	460	253		CH_4	4-300	Cont Miner
Collinsville	1954-1978		Bowen	220	19		CO_2	400	
C.C.C.P	1978		Bowen	280				25	Cont Miner
Leichardt	1975		Bowen	370			CH_4	500	Cont Miner
Tahmoor	1985	Bulli	Sydney		90*	1	CO_2		Cont Miner *Since 1981
South Bulli	1991	Bulli	Sydney			3	CO_2	300	Development
West Cliff	1994	Bulli	Sydney			1	CH_4		Development
Central	2001	German Ck	Bowen	400	1			60-80	Development
Brimestone /Oakdale	1992-1995	Bulli	Sydney		2		CH_4 +CO_2	10	Development
Kemira	1980-1	Bulli	Sydney		2		CH_4	6-100	Development
Tower	1981 - 2000	Bulli	Sydney		19		CH_4	1-80	Development *Since 1981
Appin	2010	Bulli	Sydney		3		CH_4 +CO_2		Development

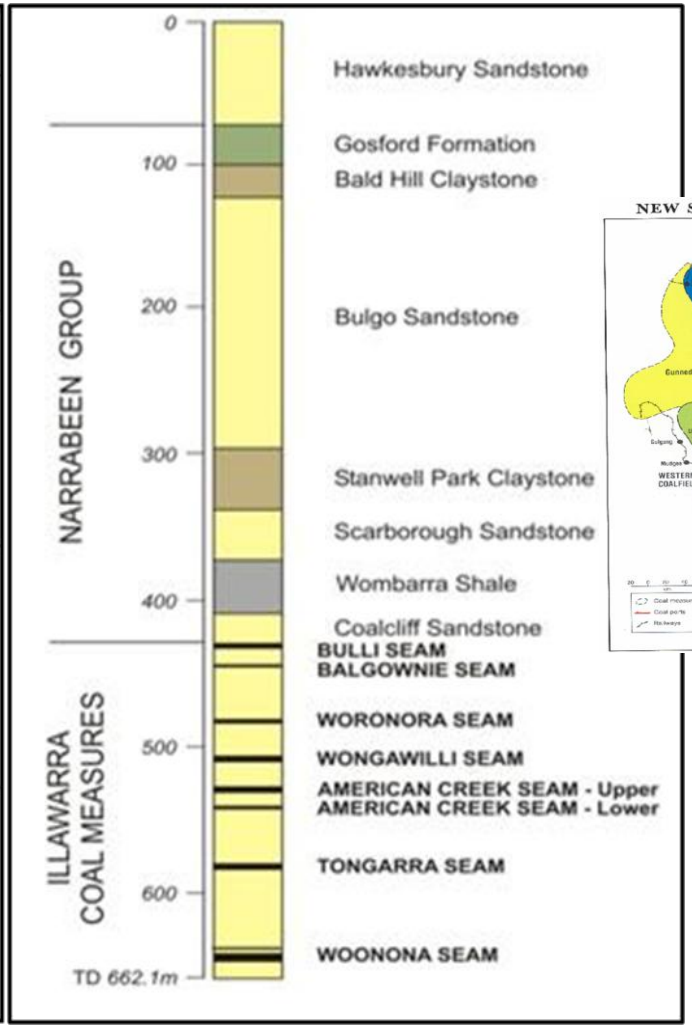
* Total Number of outbursts > 730

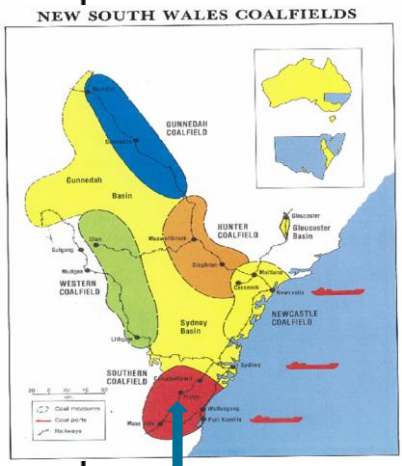
No of O/B since 1895 > 730

Problem: Coal seams with difficult to drain sections

- **Some sections of some coal seams are difficult to drain of gas.**
- **Bulli seam, Illawarra Coal Measure formation, Sydney Basin**





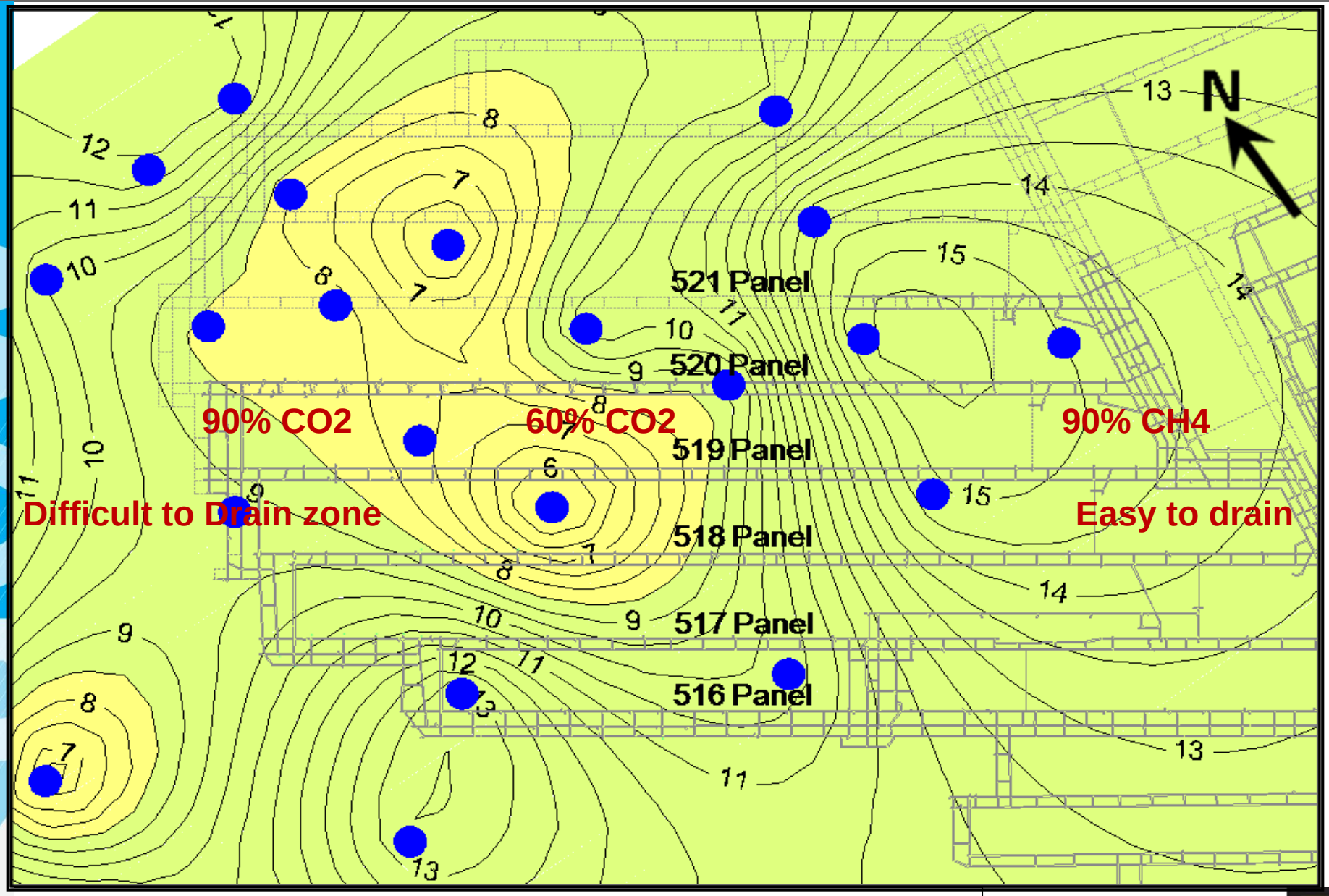


Bulli Seam

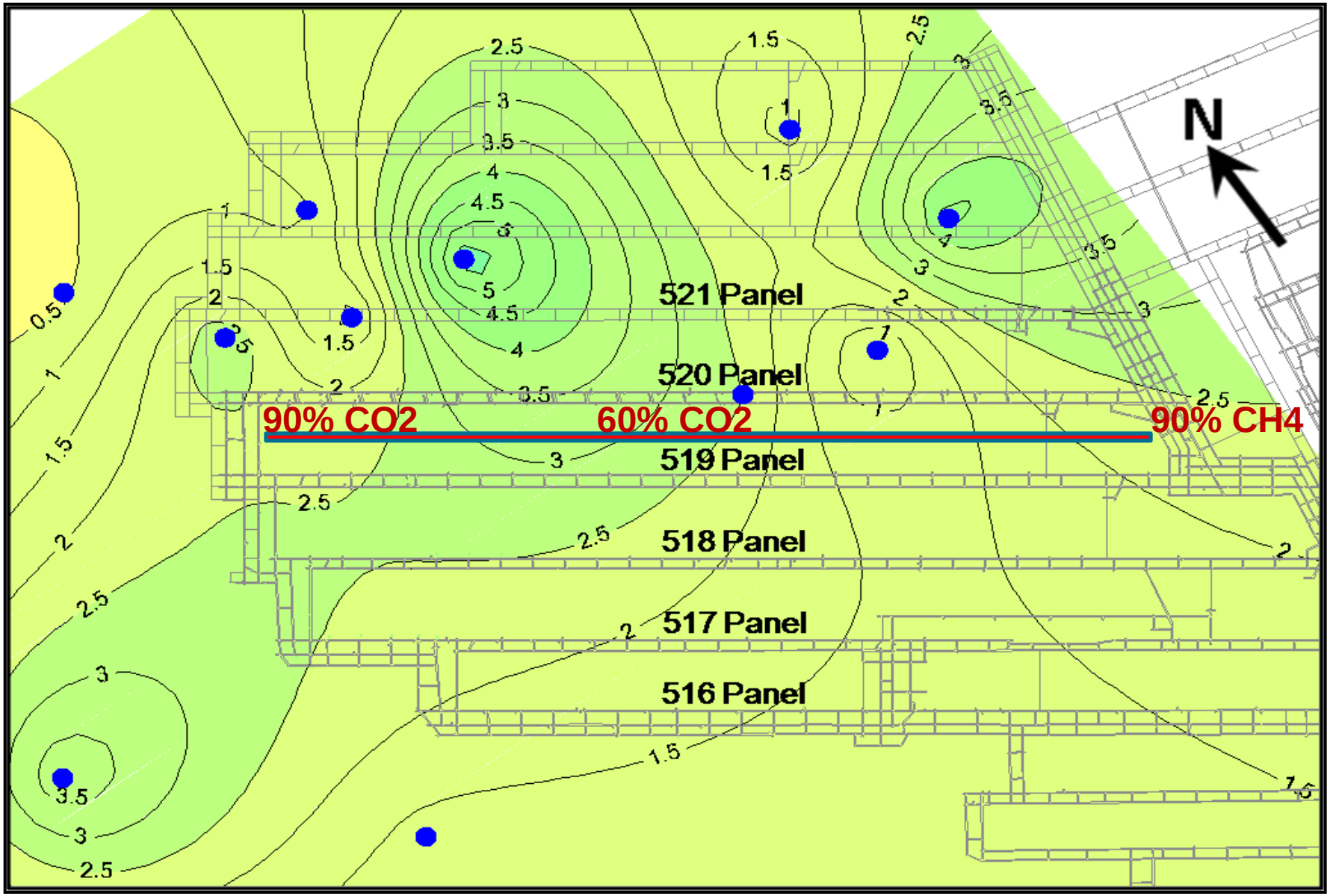
Bulli Seam Coal property Values

Coal Property	Minimum	Maximum
$CH_4/(CH_4+CO_2)$ (%)	6.5	97.8
Gas Content (m^3/t)	5.2	15.7
Permeability (mD)	0.05	6.0
Seam Thickness (m)	2.3	3.2
Ash Content (%)	9.4	14.8
Moisture Content (%)	0.7	1.3
Vitrinite Reflectance ($R_{V(max)}$)	1.23	1.36
Vitrinite (%)	28.9	54.5
Inertinite (%)	45.5	71.1
Mineral Matter (%)	1.8	5.8
Volatile Matter (%)	19.7	25.3

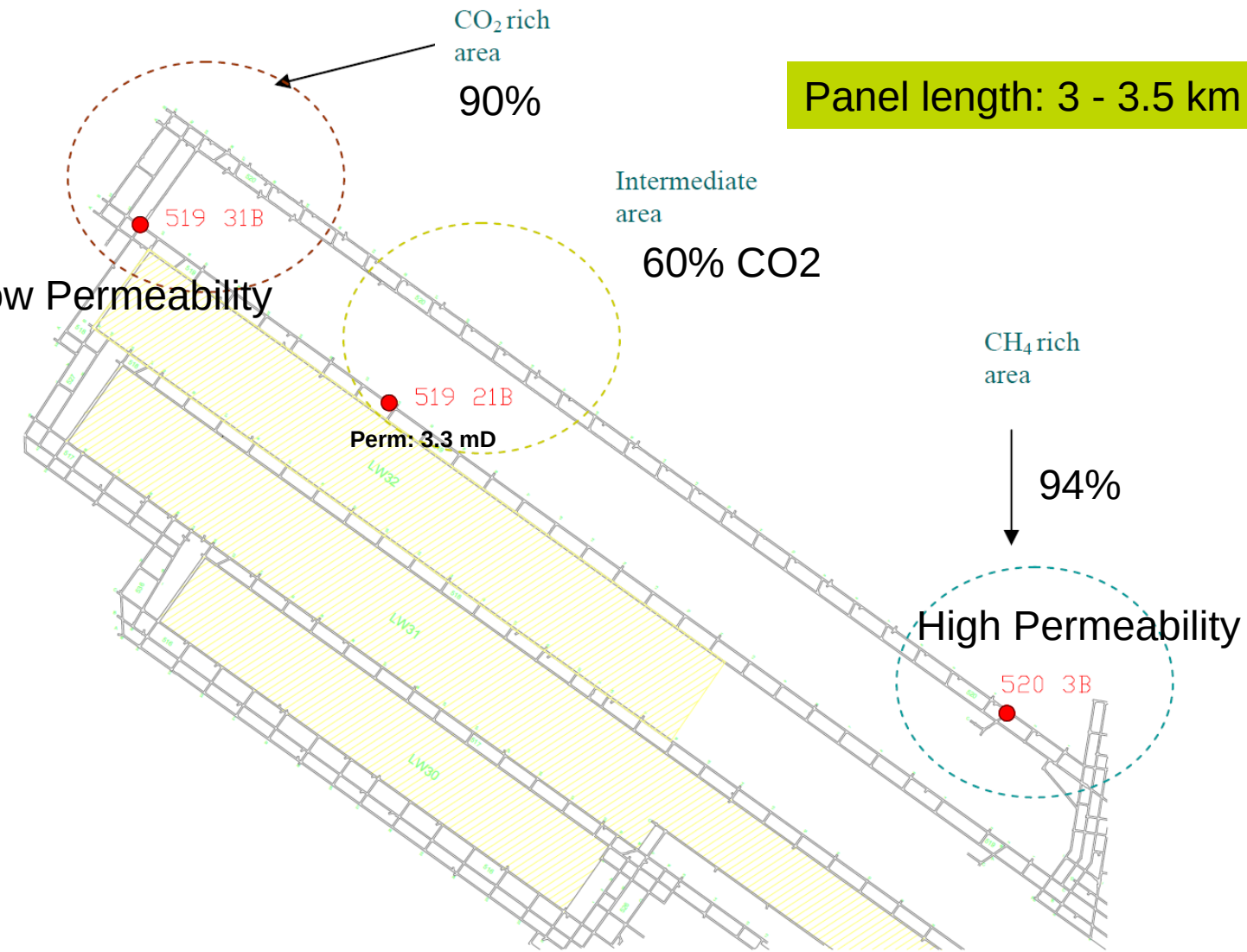
Gas content contours relative to mine workings



Permeability contours (mD) relative to mine workings



Panel length: 3 - 3.5 km



Solution

N_2 injection and recovery of the inherent gases;

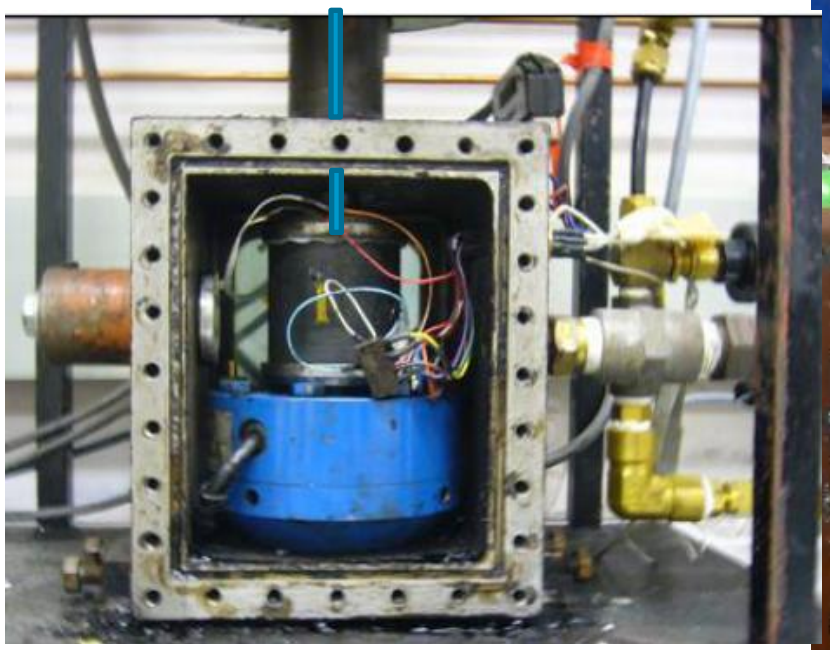
Seam Gas:

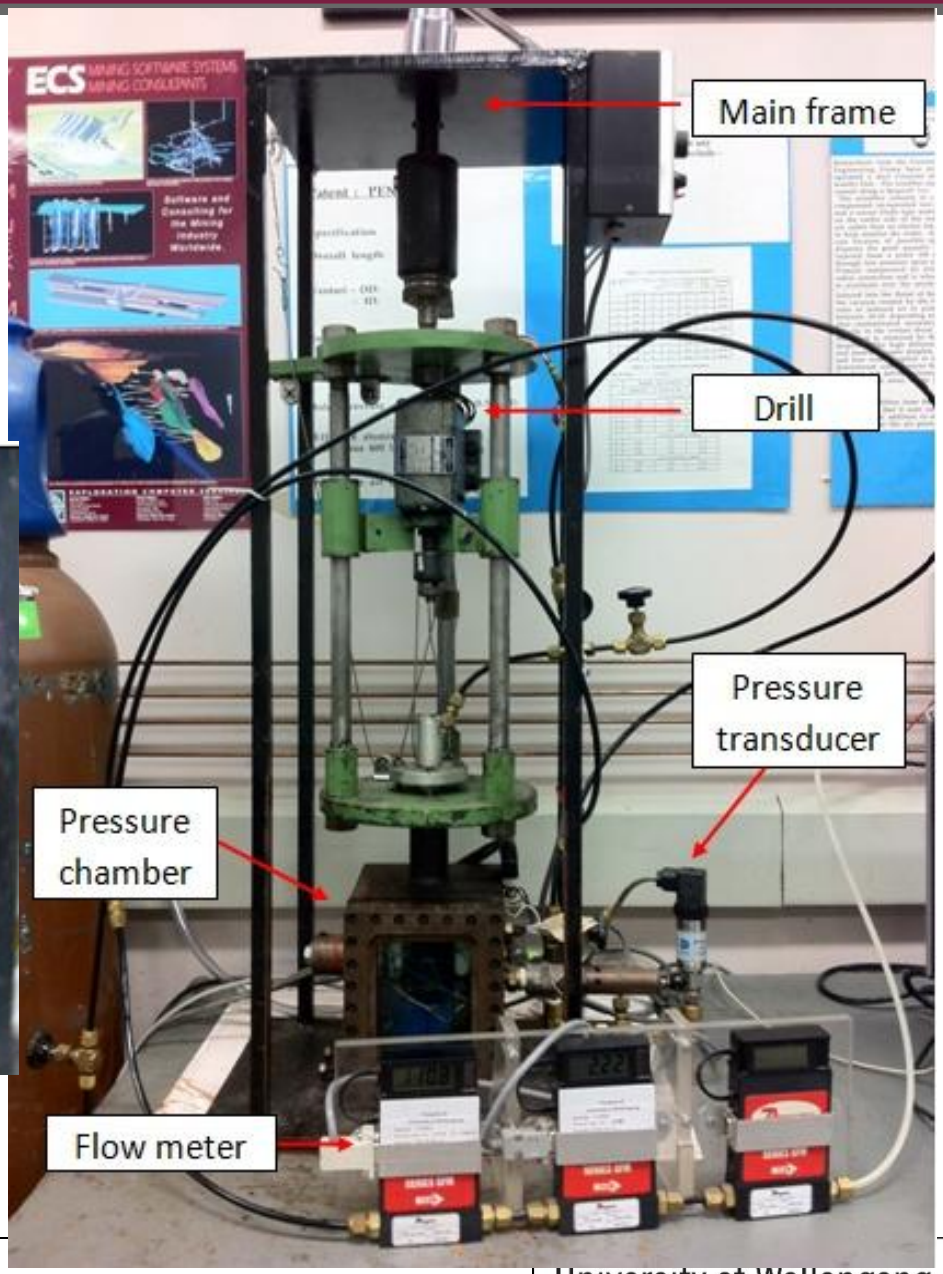
- **CO_2 or**
- **CH_4 or**
- **CH_4 / CO_2**

- **Laboratory study**

Investigation of Hard-to-drain – N2 Injection Study

MFORR



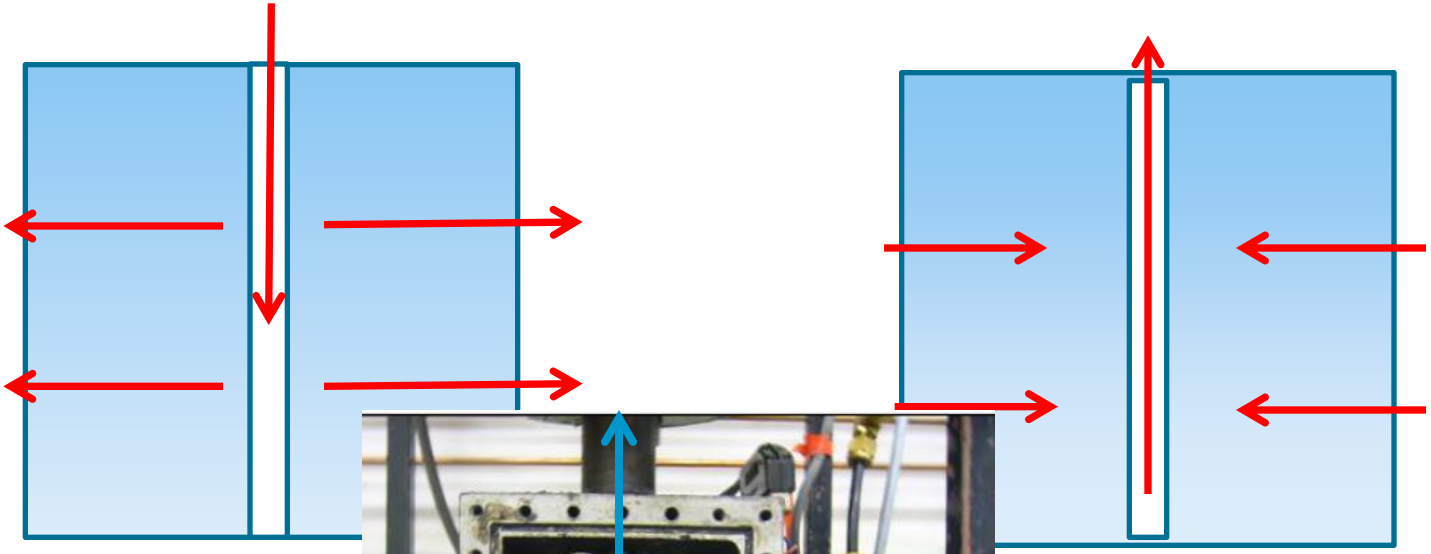


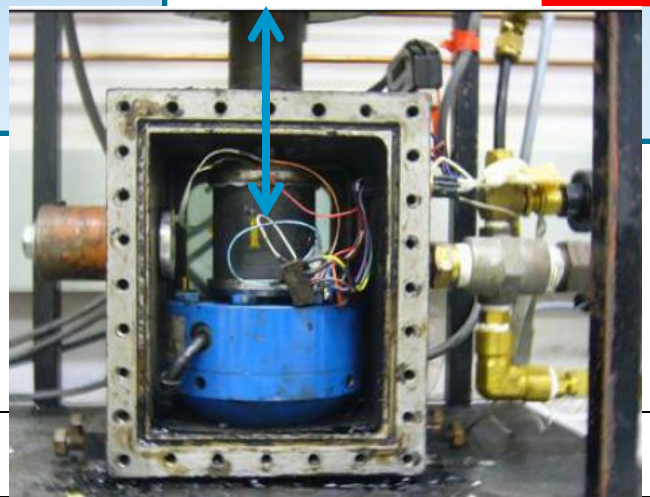
Laboratory Experimental study - N2 Injection

Nitrogen Injection methods

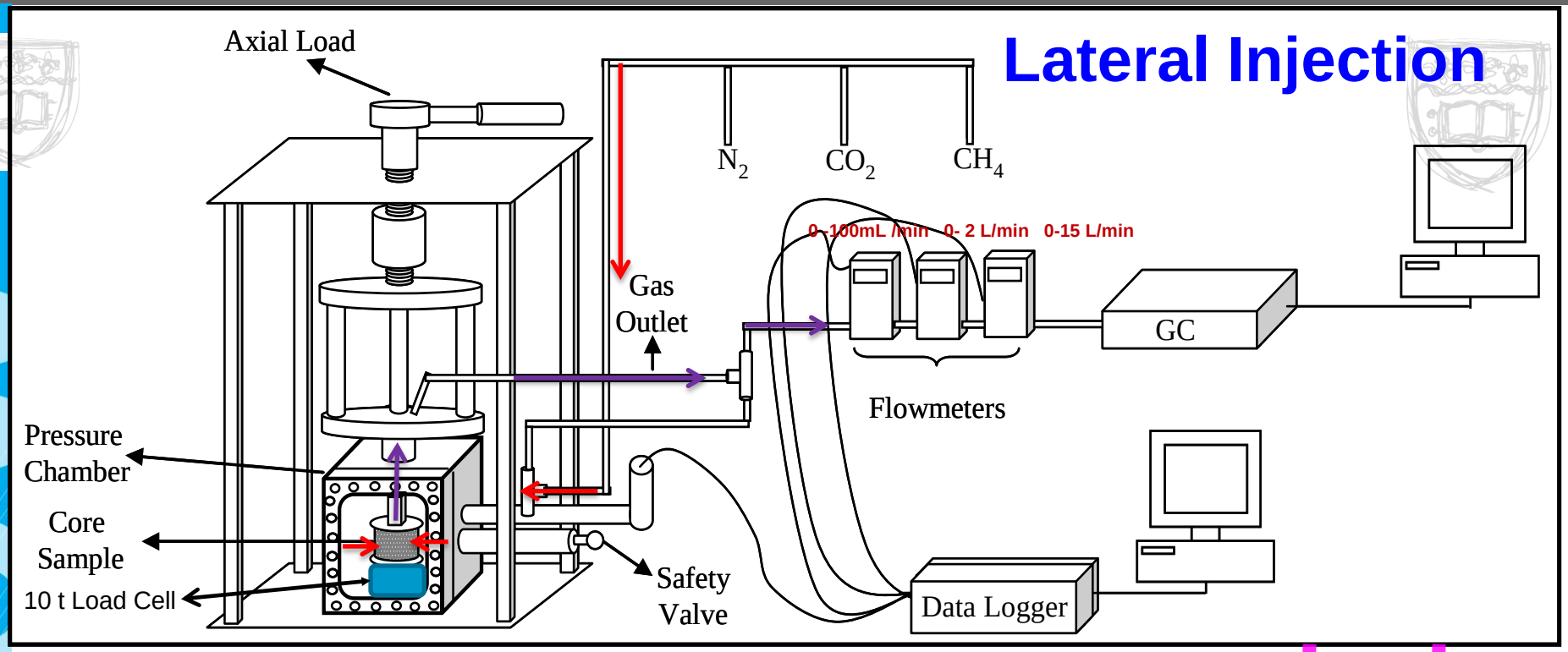
Axial N2 Charge (Reverse/Direct)

Lateral N2 Charge (Indirect)

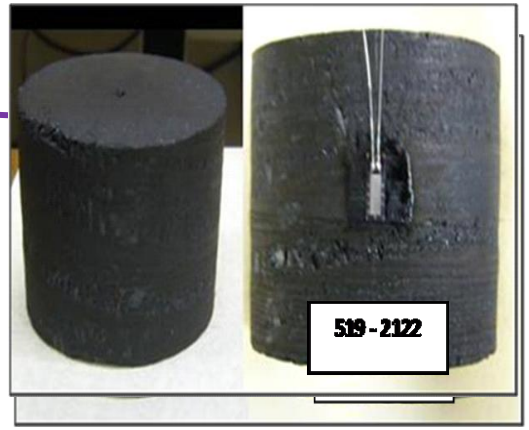


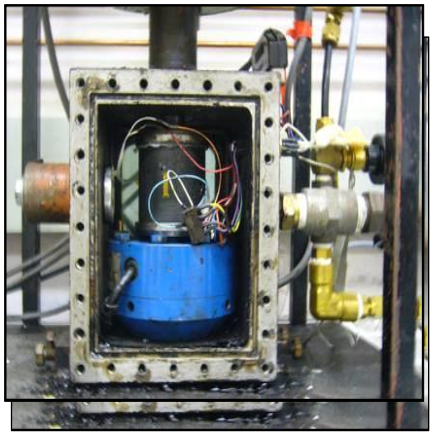


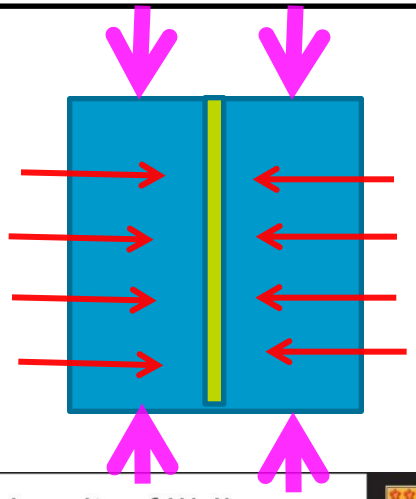
Triaxial permeability apparatus and MFORR

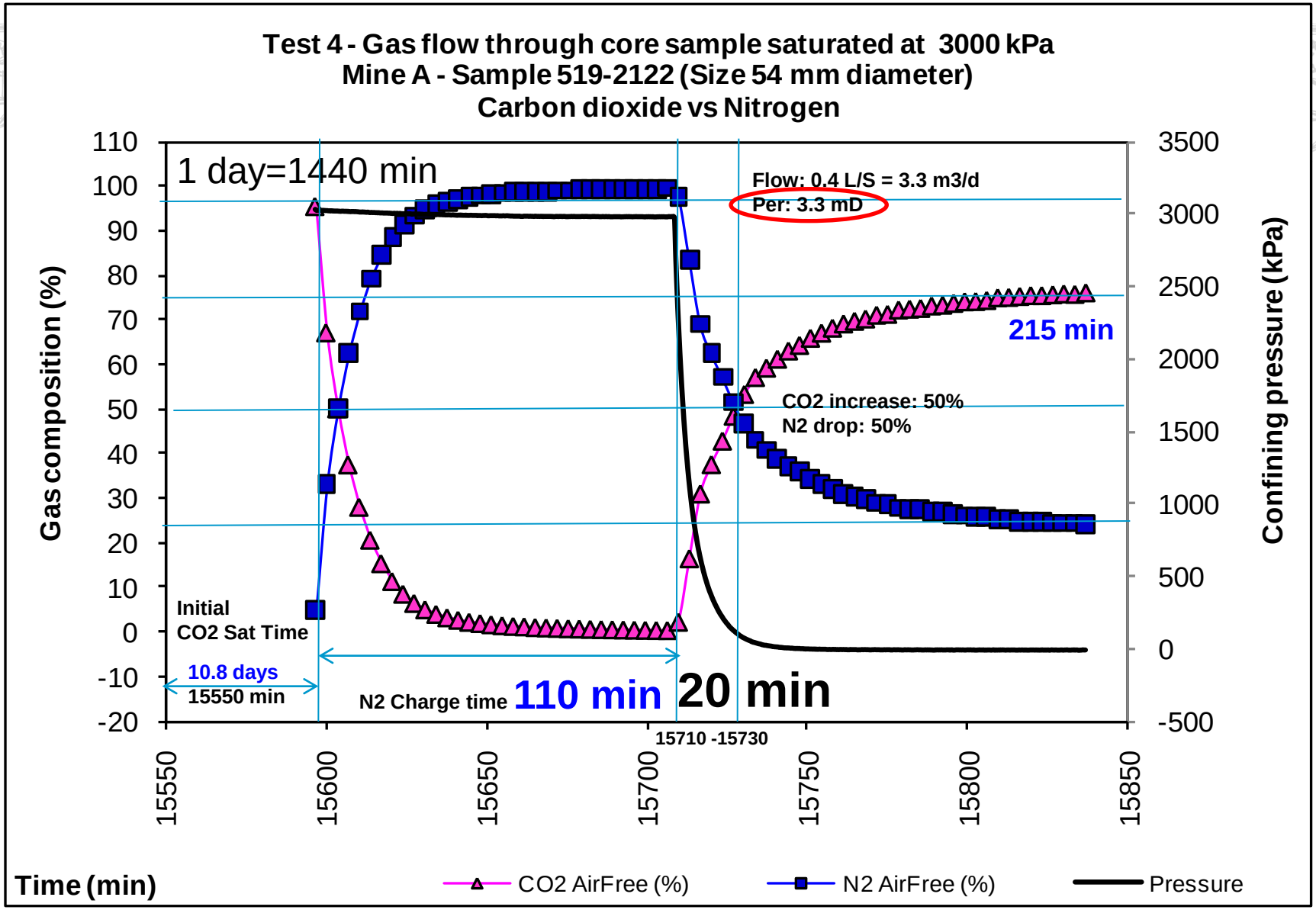


Hole Dia: 2.0 mm

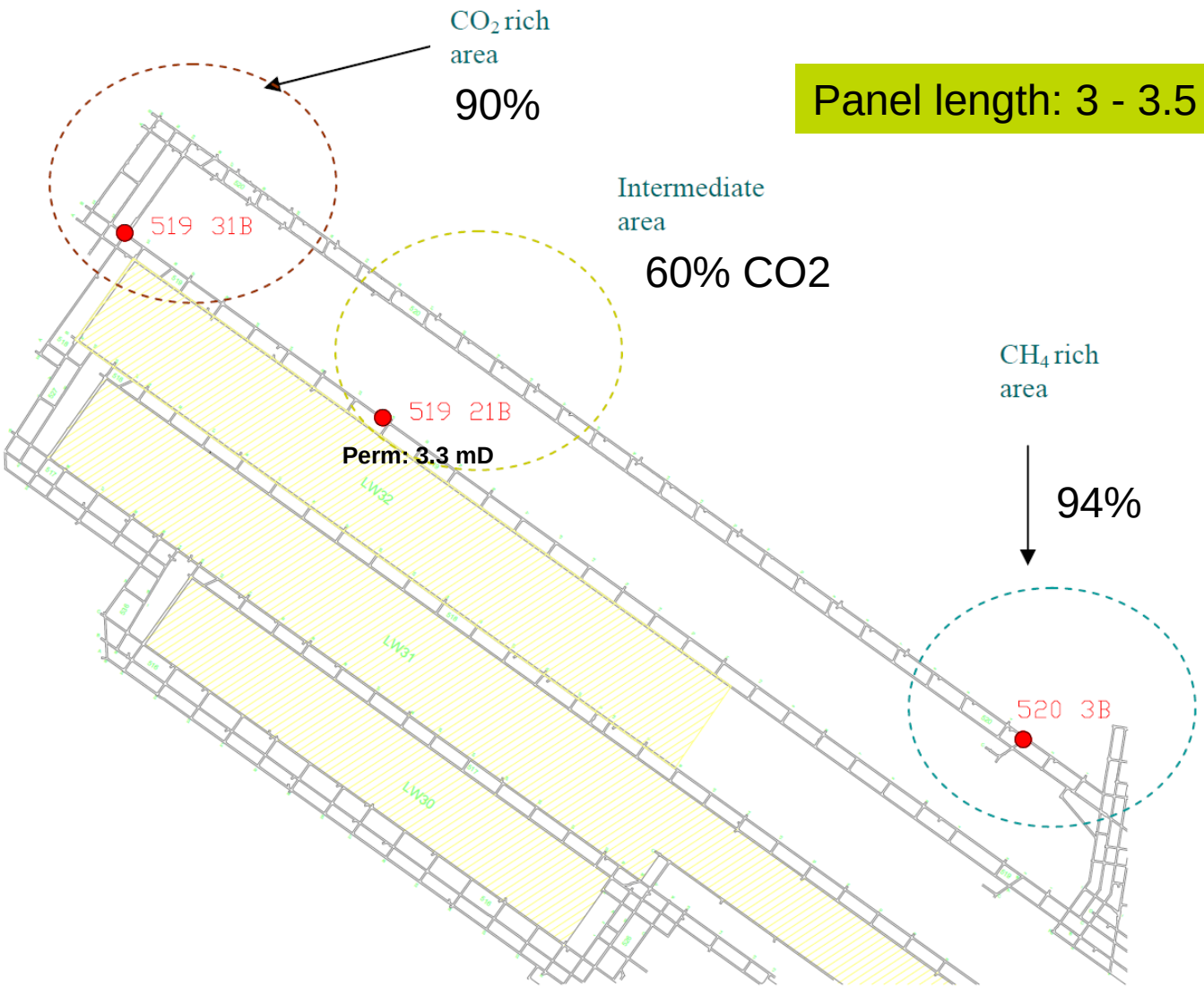




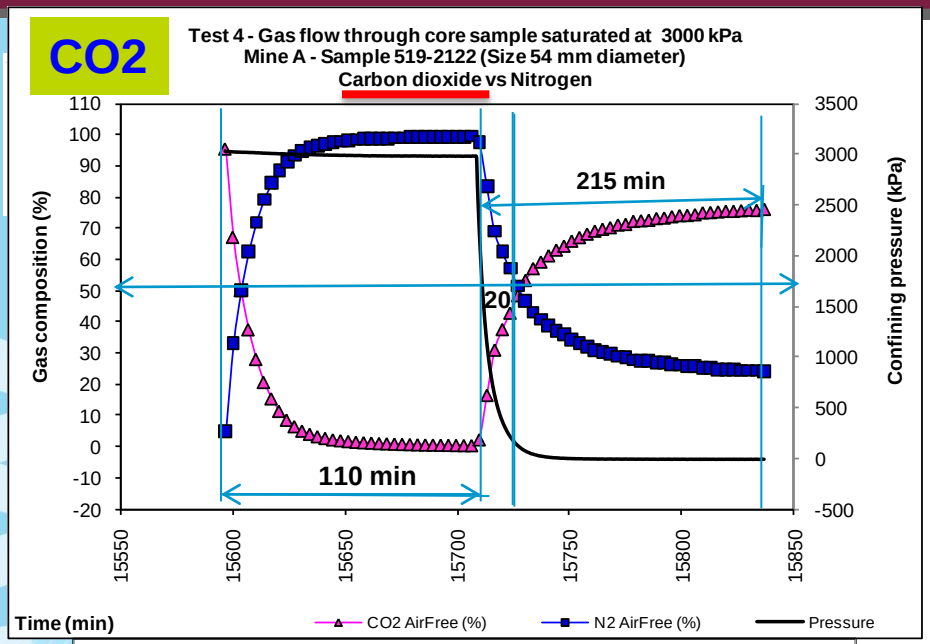


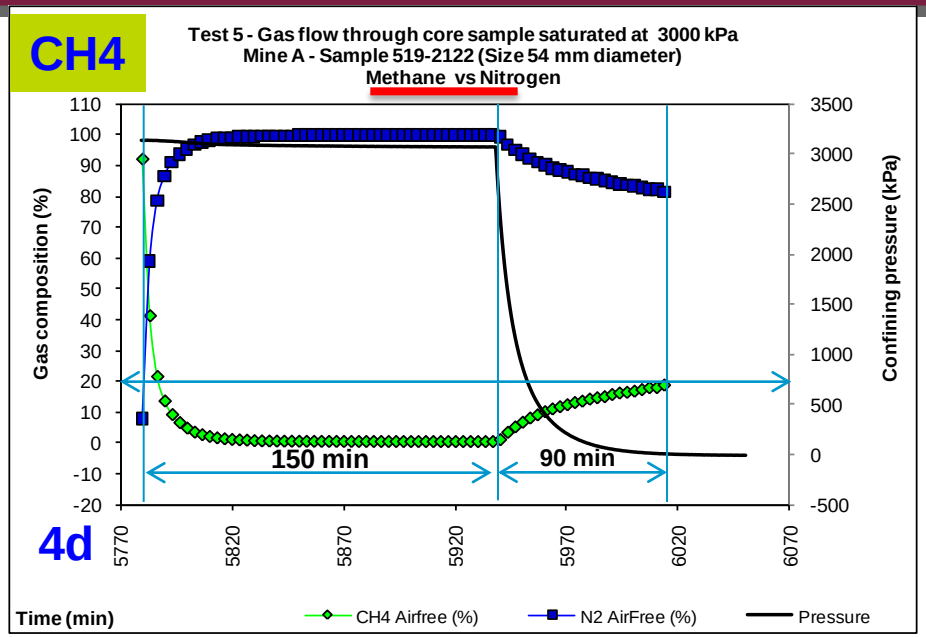

Test 4 - Gas flow through core sample saturated at 3000 kPa
Mine A - Sample 519-2122 (Size 54 mm diameter)
Carbon dioxide vs Nitrogen
1 day=1440 min
Flow: 0.4 L/S = 3.3 m3/d
Per: 3.3 mD
215 min
CO2 increase: 50%
N2 drop: 50%
Initial
CO2 Sat Time
10.8 days
15550 min
N2 Charge time
110 min
20 min
15710 -15730
Gas composition (%)
Confining pressure (kPa)
Time (min)
CO2 AirFree (%)
N2 AirFree (%)
Pressure

Panel length: 3 - 3.5 km



CH4 and CO2 Recovery by N2 Injection





CO2: Saturation Time =10.8 days

0-50%: 20 min.

Hence 50% composition point occur at 15 730 min (10.9 days)

@ 3200 kPa the Maximum CO2 flowing through the sample = 0.04 l/sec (3.3 m3/d) with Cleat permeability of 0.5-1.5 mD

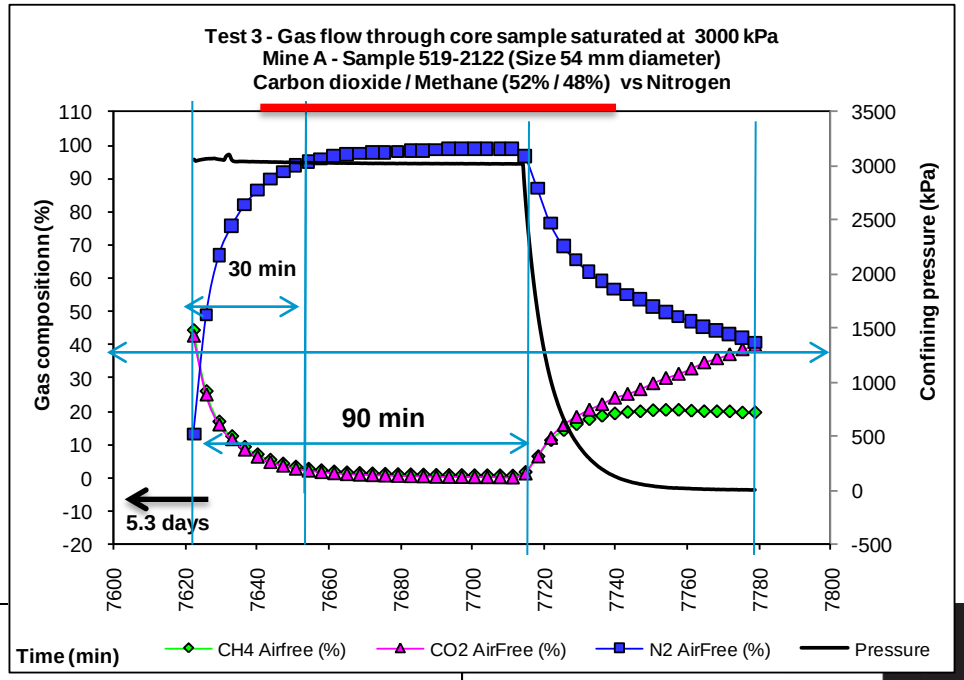
CH4: Full saturation= 5760 min (4d)

Flow @ 3200 kPa = 0.04 l/sec (3.3 m3/d) with cleat permeability of 2.5 mD

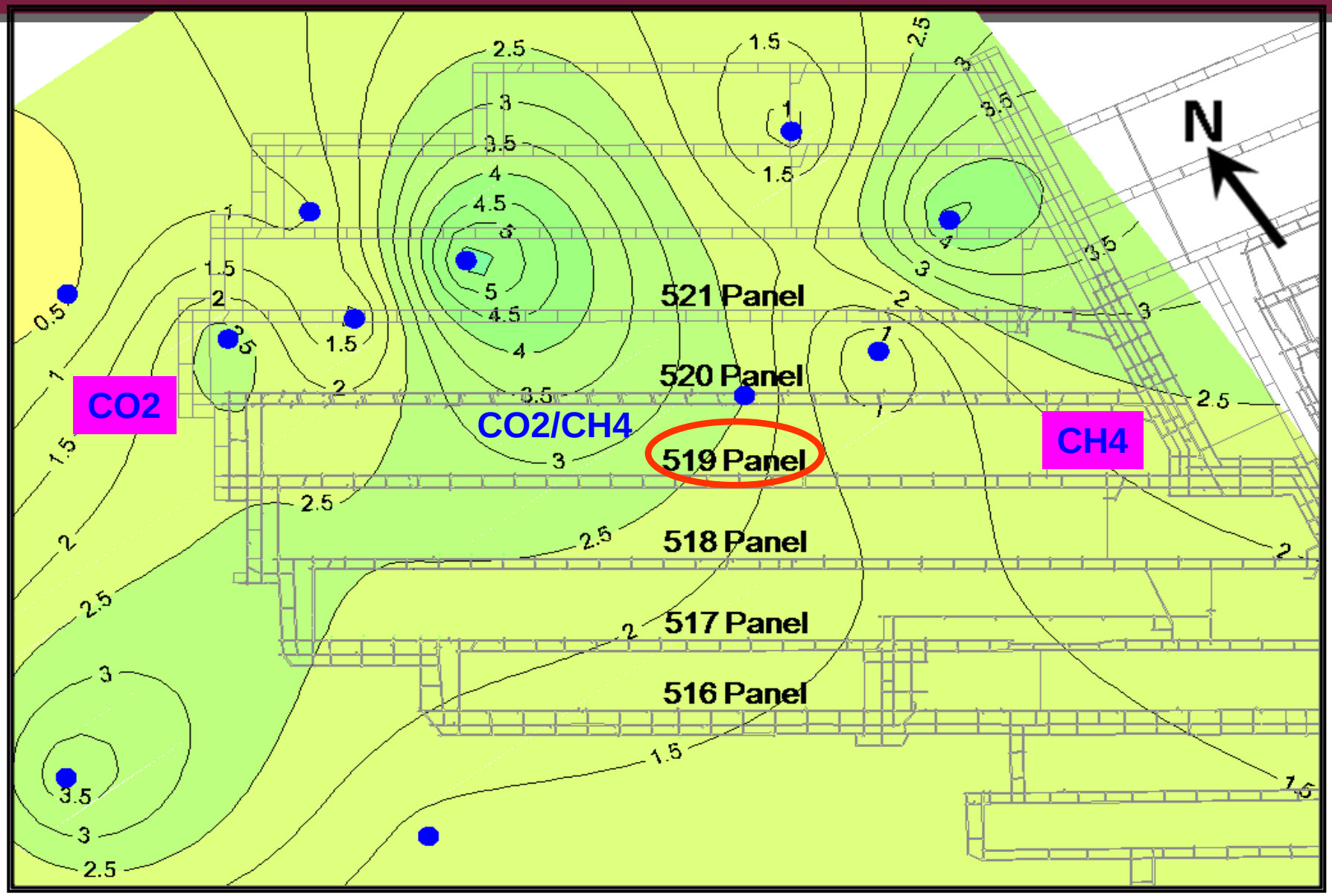
CH4 drainage improvement = 20 % after 90 min

CO2/CH4: Initial Saturation Time = 7630 min (5.3 days)

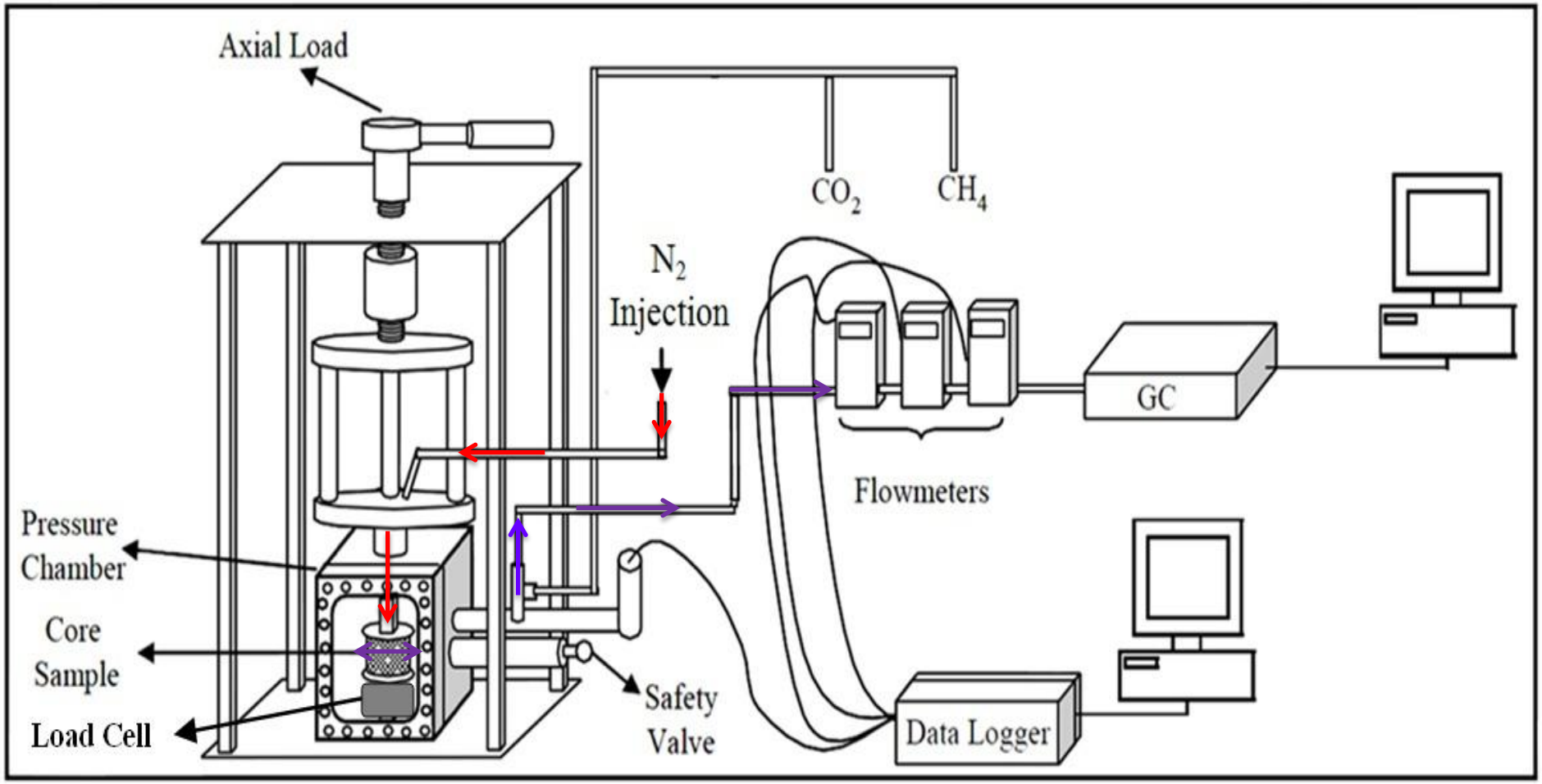
Time for full N2 Charge at zero reduction of CO2 /CH4= 30 min



Permeability contours (mD) relative to mine workings and measurement locations

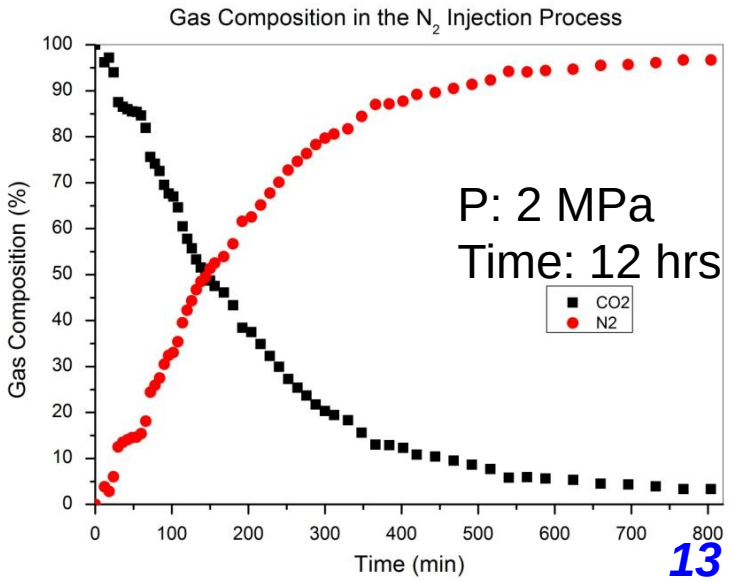


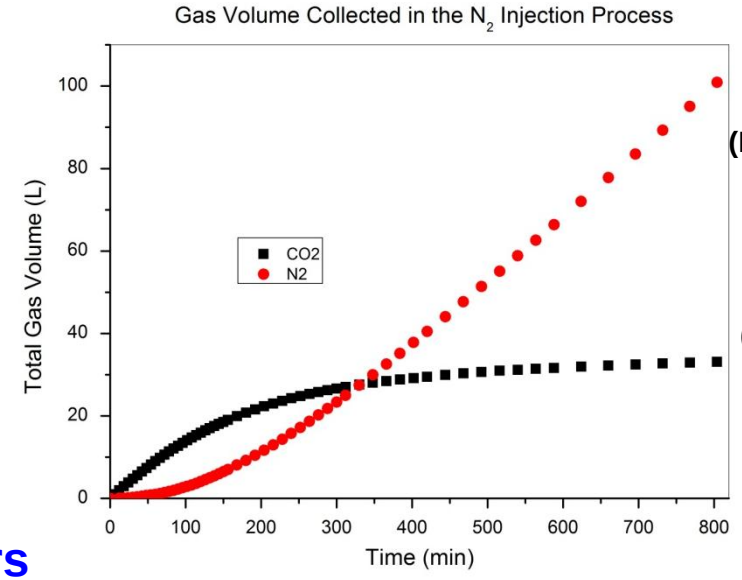
Axial /Reverse /Direct Injection Method



1. Seal gas chamber and evacuate to near zero pressure
2. Load the coal sample axially to 750 kg Force (3 MPa pressure)
3. Charge the cell with CO2 and monitor . Maintain gas sorption equilibrium at 2 MPa.
4. Charge N2
5. Release permeated gas out of the gas chamber at every 6 min to pas through flowmeters and to GC for gas composition analysis

N2 Reverse Flushing (CO2 Flushing)



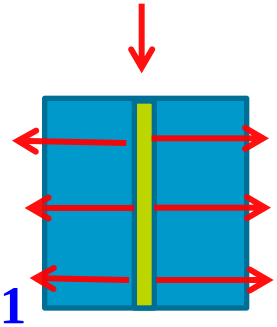


N2=101 L
(N2 Consumed)

CO2 = 33 L
(CO2 Liberated)

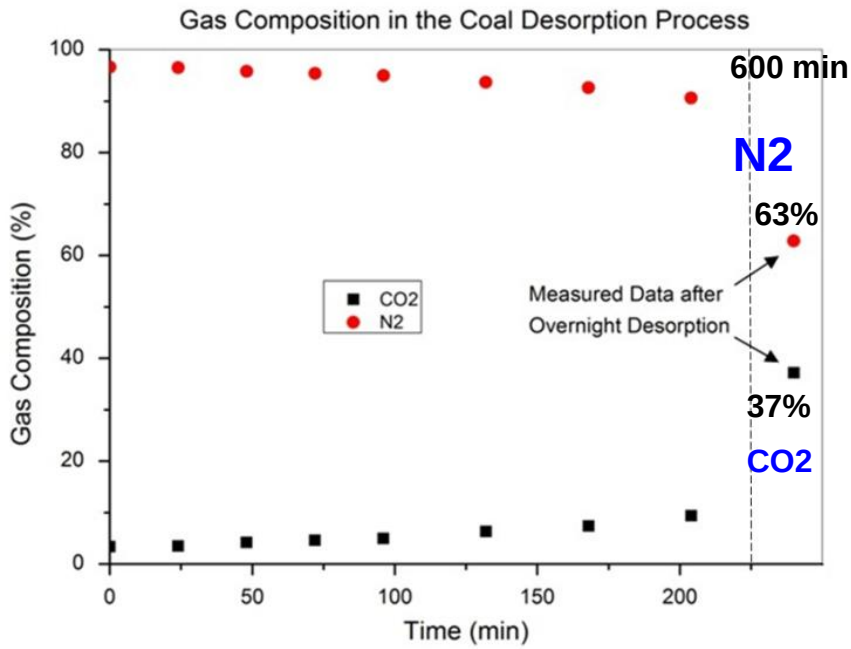
***13* hrs**

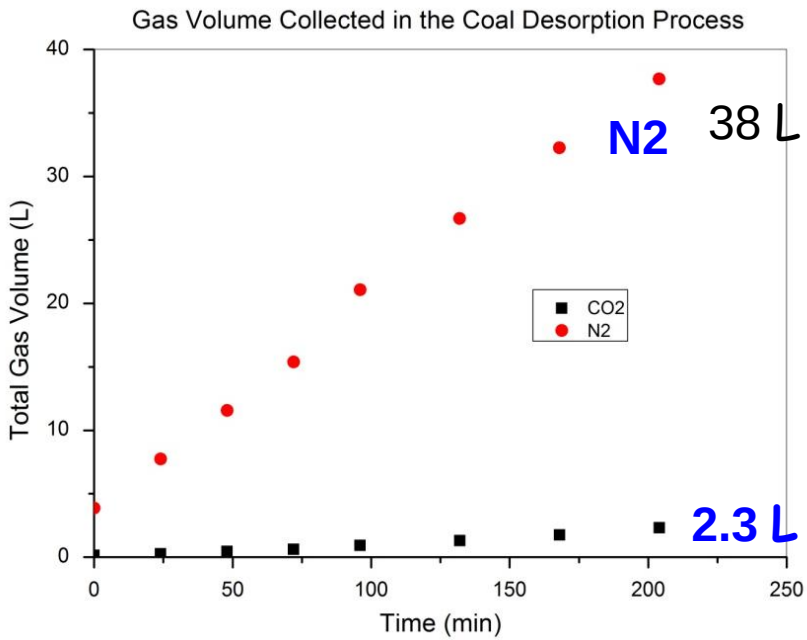
- During the N_2 flushing process, CO_2 composition of the chamber gradually decreased as N_2 composition increased. The whole flushing test took more than 13 hrs (800 min).
- Press. Gradient for gas collection = 50 kPa
- Time for 1.0 L gas collection: 10 sec.
- **N2** consumed during flushing: 101 L
- **CO_2** liberated: 33 L.



Ratio: 3:1

Desorption stage

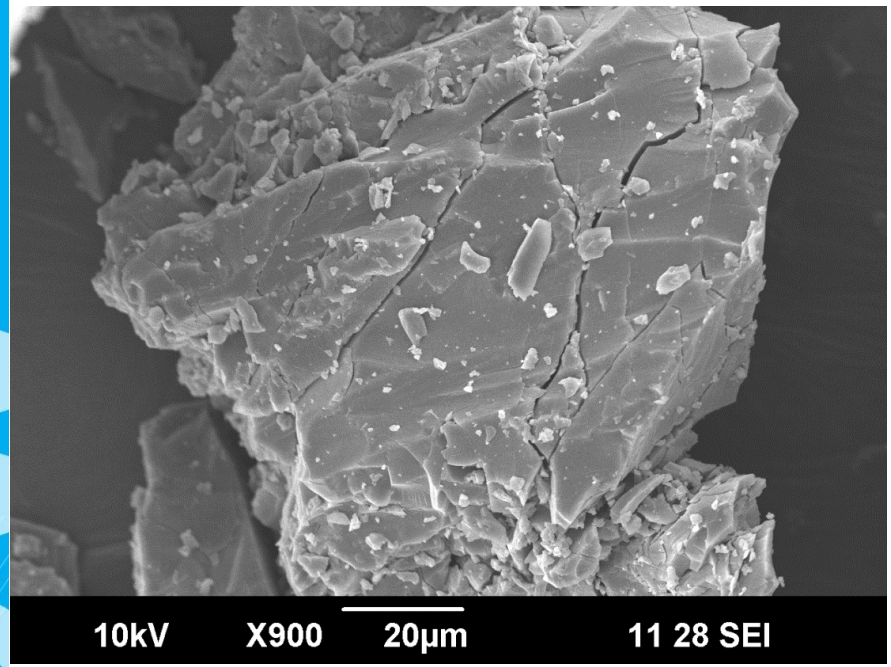




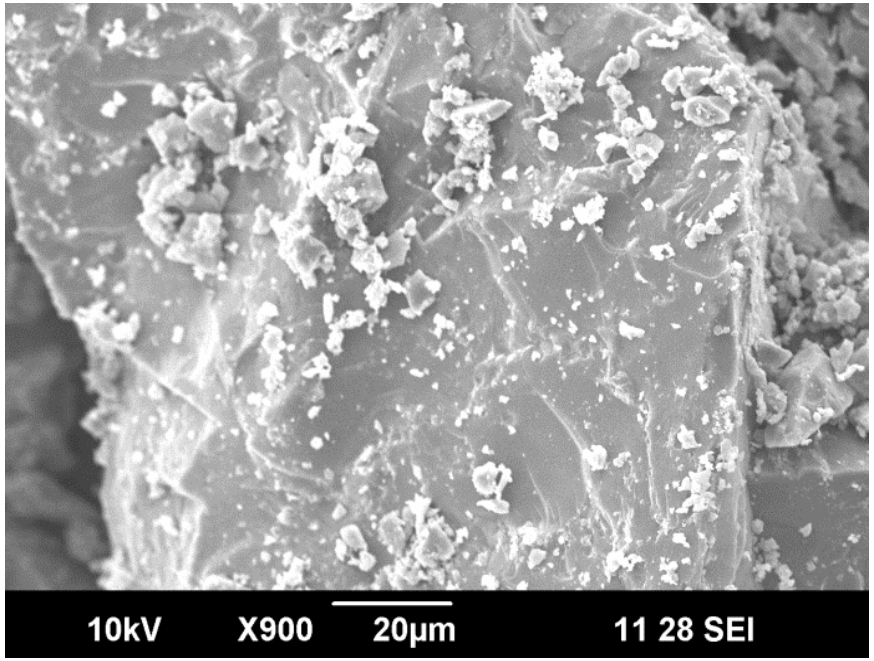
In the **desorption process**, CO_2 composition starts to increase from 3.4% to 9.4%, while **N_2** composition deceases from 96.6% to 90.6% over a period of around 3 hrs (200 min) time.

The collected gas volume of CO_2 and N_2 in the desorption process was 37.7 L of N_2 and 2.3 L of CO_2, a ratio **16.3 : 1**

Investigation of Hard-to-drain – SEM Test



Easy-to-drain sample



Hard-to-drain sample

The microstructures of the hard-to-drain coal samples appear to be less generated or fractured as compared with the easy-to-drain samples. This may explain another reason for the difficulty of draining gas from coal sections of Bulli seam in hard-to-drain area, where the coal structure is less fractured.

CONCLUSIONS

- **N_2** Injection is a viable method of gas recovery from coal particularly from hard to drain sections of coal seams
- Higher quantities of **N_2** gas is required to remove **CO_2** gas during both forced and reversed method of **N_2** injection
- Coal structure and permeability are important factors in the drainability of gas from coal.

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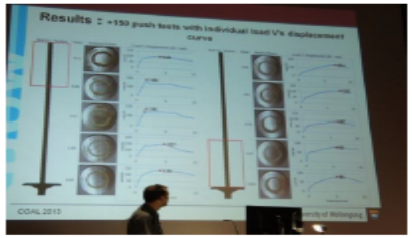

Coal 2015

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- Surface mining.
- Geology,
- Heading development,
- Mining methods; longwall, bord and pillar, top coal caving and hydraulic mining,
- Equipment and machinery performance or innovations,
- Ground control and strata management,
- Longwall and roof fall recovery,
- Instrumentation and monitoring,
- Rock bolting, cable bolting or other roof support techniques,
- Mine subsidence,
- Mine ventilation, mine gas drainage and outburst control,
- Mine fires and explosions,
- Mine flooding,
- Risk management,
- Mine management and mine contract,

We strongly encourage receiving papers from coal mine operations, as well as fundamental and applied coal mining research

Abstract submission	**August 28th, 2014**
Acceptance of the paper based on abstract	**September 15th, 2014**
Date of full paper submission	**November 27th, 2014**
Conference day	**February 11~13th, 2015**

Contact:

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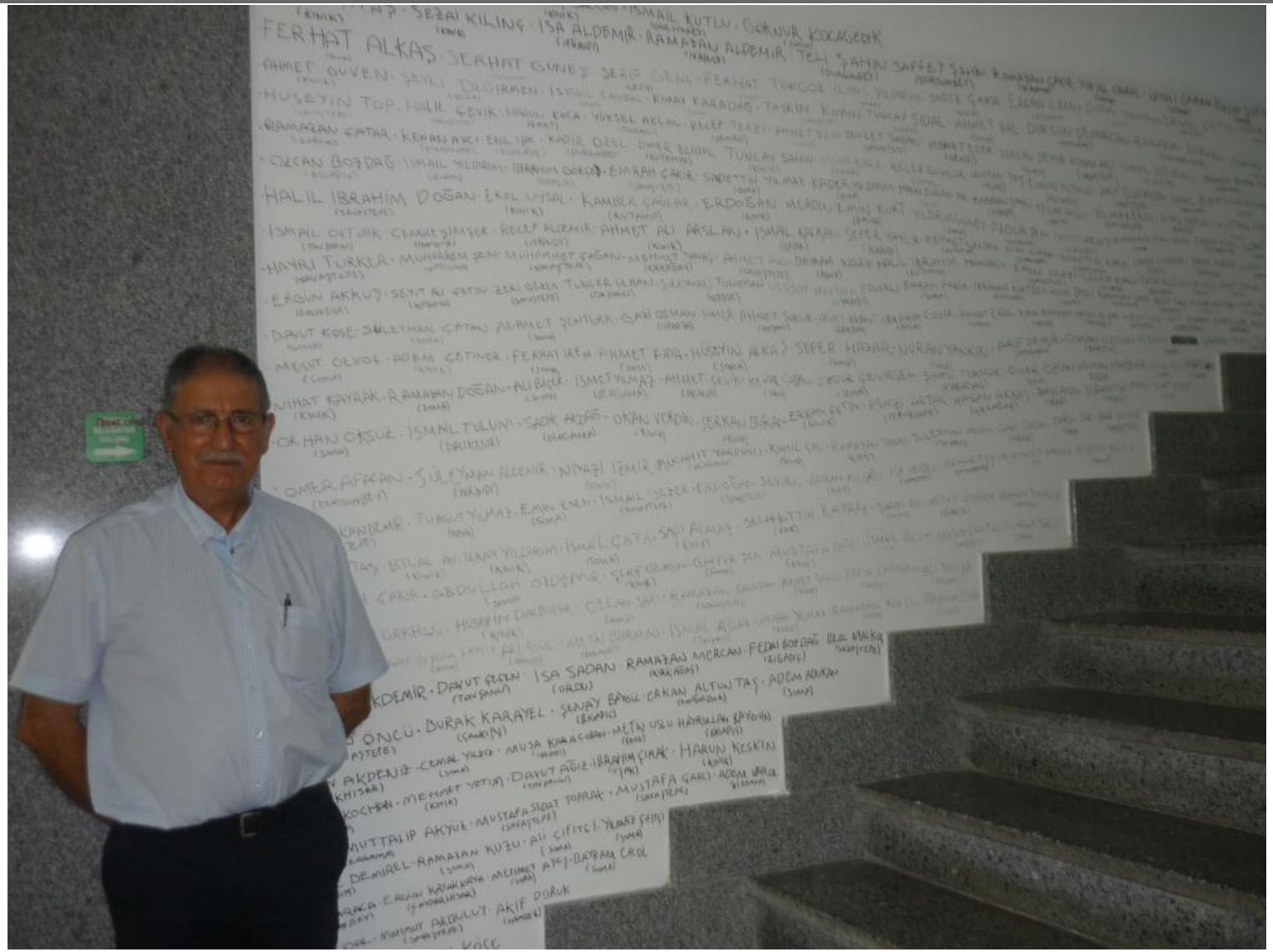
Soma Mine Accident, June 2014



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Thank You