Pells Consulting

ABN 74 978 620 434
Phone: 02 4381 2125
Fax: 02 4381 2126
49 Lakeside Drive
MacMasters Beach NSW 2251
www.pellsconsulting.com.au

MEMORANDUM

THIRLMERE LAKES – ADDENDUM 2 TO REPORT OF OCTOBER 2011

TO: FILE

FROM PHILIP PELLS

OUR REF: P053.M6

DATE: 30 January 2012

1. INTRODUCTION

If the reader of this memorandum is not reasonably familiar with the nature of coal, the physics of coal seam gas, and the process of gas outbursts during mining, then it is suggested that she or he read the material in Appendix A.

Tahmoor Colliery mines the Bulli Seam at a depth of about 400m to 450m, and from commencement of production in the early 1980s had to deal with frequent gas outbursts. About 10 explosive outbursts occurred every year, always during cutting the coal, and almost always associated with faults and dykes. These explosive ejections ranged from a wheelbarrow load of coal to many tons. This was taken as part and parcel of working at Tahmoor, and also, it should be noted, elsewhere in the Bulli Seam (Harvey and Singh, 1998).

In 1985 the operator of a Continuous Miner, Michael Penny, was killed by the explosive outburst of 330 tons of coal and about 3500 cubic metres of gas. Thereafter, in an attempt to protect the operators, Continuous Miners were encapsulated and provided with independent air supplies.

As summarised by Wynne (2002): *"In the 1880s, the general strategy for addressing these risks was that outbursts were 'inevitable' and so most effort went into protection against their consequences. By the 1990s this approach was no longer acceptable and there was a major redirection of effort towards the prevention of outbursts"*

2. GAS DRAINAGE TO PREVENT OUTBURSTS

The change in strategy at Tahmoor, from protection against consequences to prevention of outbursts, came about through the work of Dr Ripu Lama, then at the CSIRO (Vutukuri, 2002). Lama's finding was that, if sufficient gas is removed from the coal, to predefined limits, then outbursts would not occur. These limits were expressed in Threshold Limit Value graphs, such as the one reproduced in Figure 1 (Black and Aziz, 2008). The limits may change according to the area of the mine, according to coal type, the presence of dykes and faults, and depth below the surface.

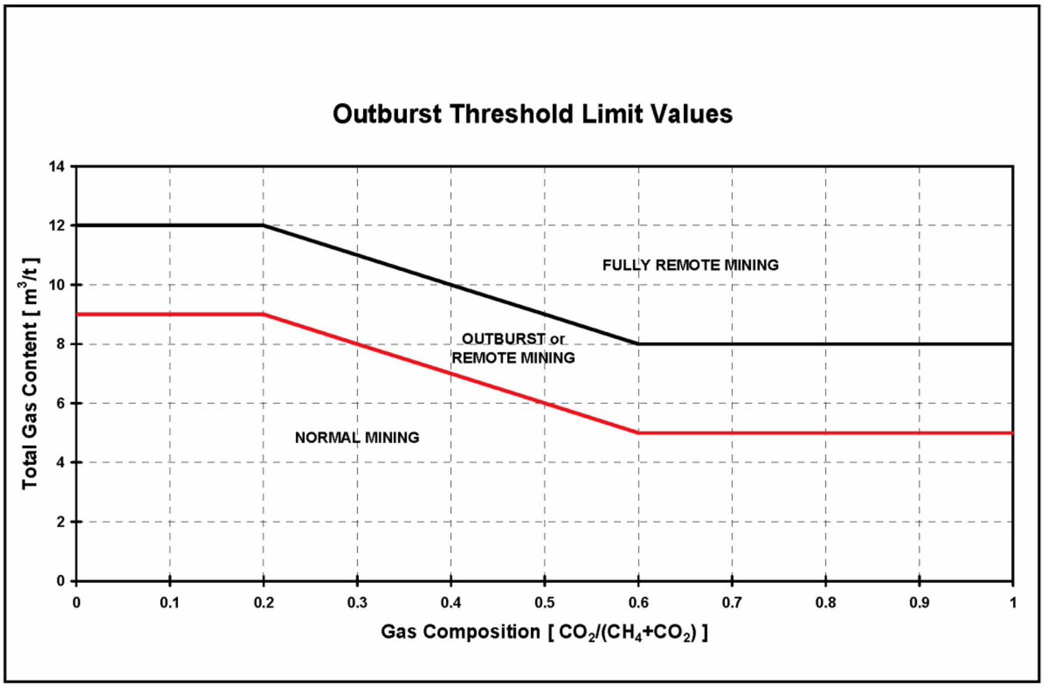

Figure 1: Typical outburst Threshold Limit Value (TLV) graph

It should be noted that the coal seam gas in the area of Tahmoor Colliery, adjacent to the Thirlmere lakes, is dominantly carbon dioxide (CO_2). The typical ratio was about 60% CO_2 to 40% methane. In the current area of mining to the NE the methane proportion is higher.

Initially the in-seam drainage boreholes were drilled by traditional rotary methods, but directional control of holes was difficult, and lengths were limited. Nowadays the holes are drilled using, steerable, downhole percussive motors; so called directional drilling, see Figures 2a and 2b.

Borehole lengths in excess of a kilometre are possible, the boreholes can be steered, and the positions can be controlled to within a metre of design position (Lunarzewski, 2001). Hole spacings are designed so that gas depressurization occurs in all the coal that is to be mined

Figure 2a: Directional drill bit and motor

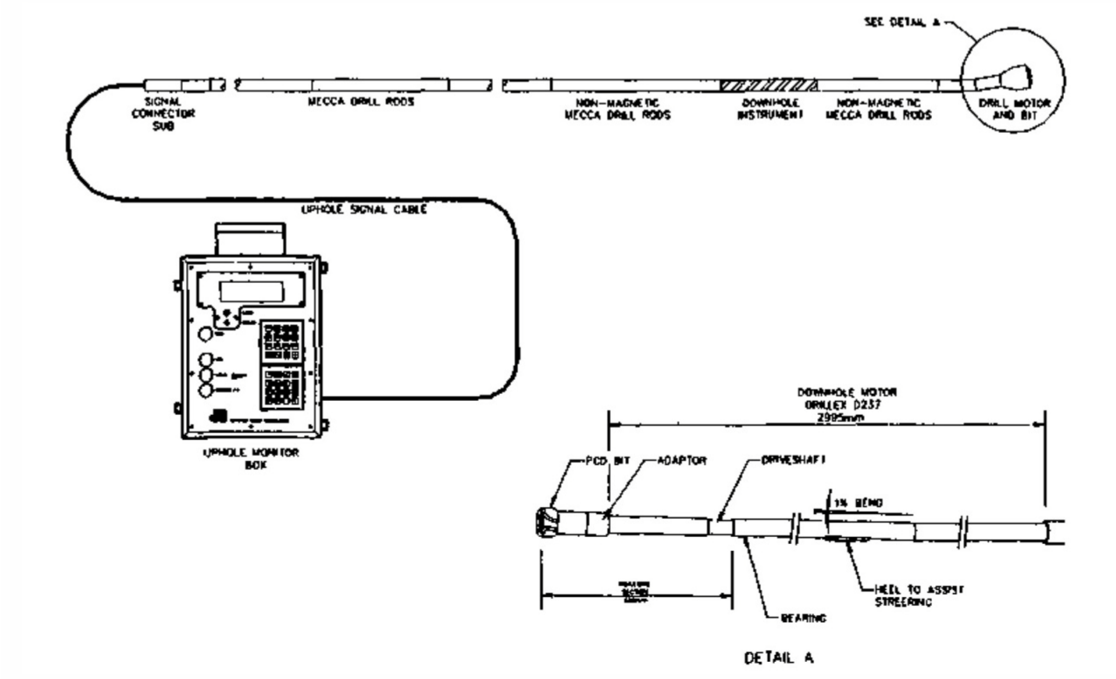

Figure 2b Directional drilling motor and equipment (Thomson, 1998)

Regardless of the method used to drill the boreholes, the method of depressurization is essentially the same. The entry points (collar) are fitted with tubes sealed in the drilled hole (called standpipes, even though they are near horizontal), and a vacuum is applied to the borehole. This facilitates diffusion of adsorbed gas, first into the cleats in the coal and hence, to the borehole and into the mine ventilation system, or a reticulation system. Drainage from each hole, under vacuum usually continues between 3 months and 6 months.

There is often a wide range in the effectiveness of the drainage holes, even in one area of a mine, primarily due to subtle changes in geological conditions and the nature of the coal (Black and Aziz, 2008).

A key point to note is that groundwater within the fractures in the coal, whether natural cleats or induced fractures, has to be depressurized, and effectively removed, before gas diffusion from within the coal becomes effective.

3. DEVELOPMENT OF GAS DRAINAGE AT TAHMOOR

Figure 3 shows the layout of Tahmoor Colliery as of mid 2010.

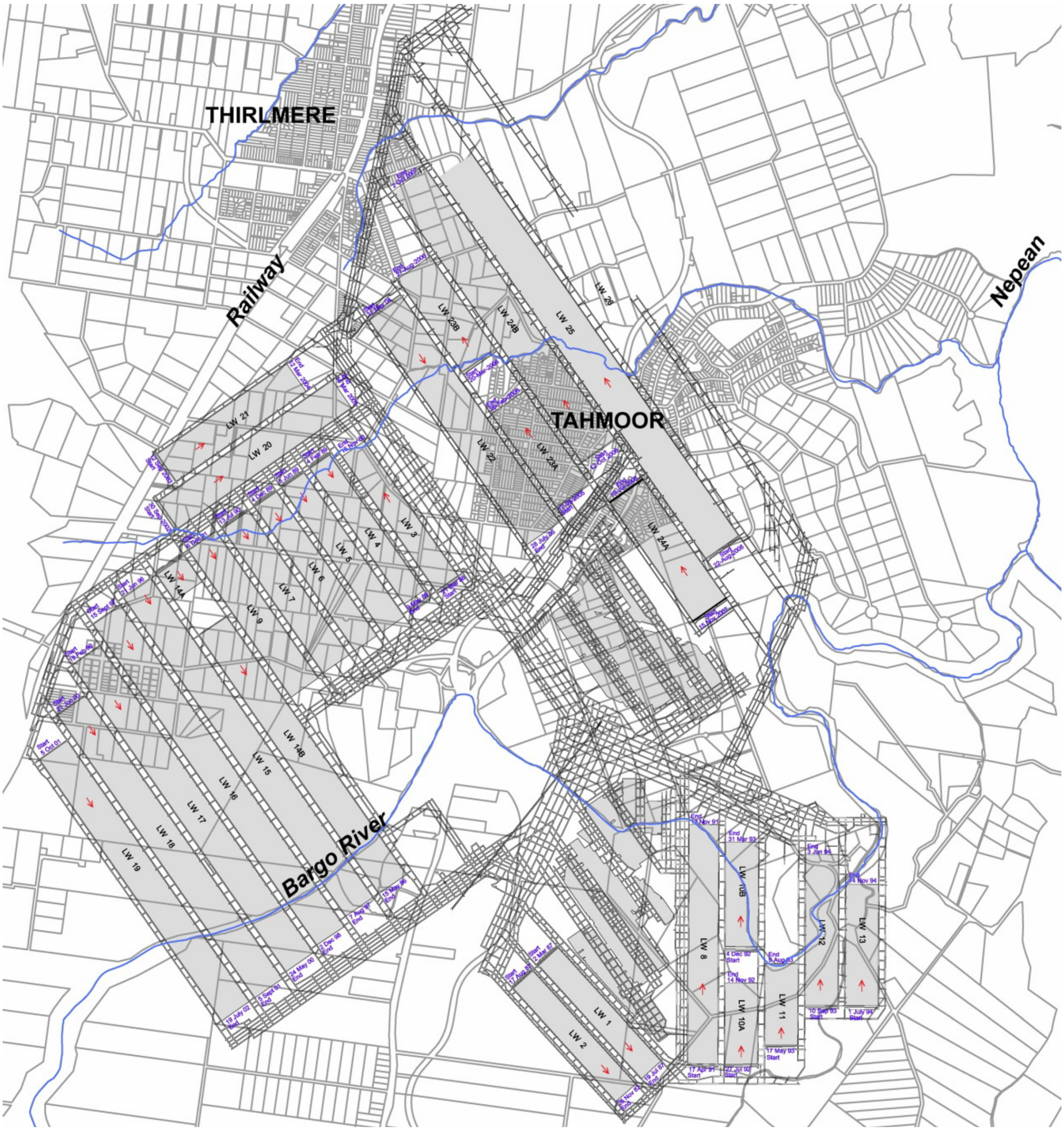

Figure 3 Layout of Tahmoor Colliery

Figure 4 shows the part of the mine closest to the Thirlmere lakes, about 400m above Bulli Seam level. The closest longwall is about 800m in away from Lake Couridjah.

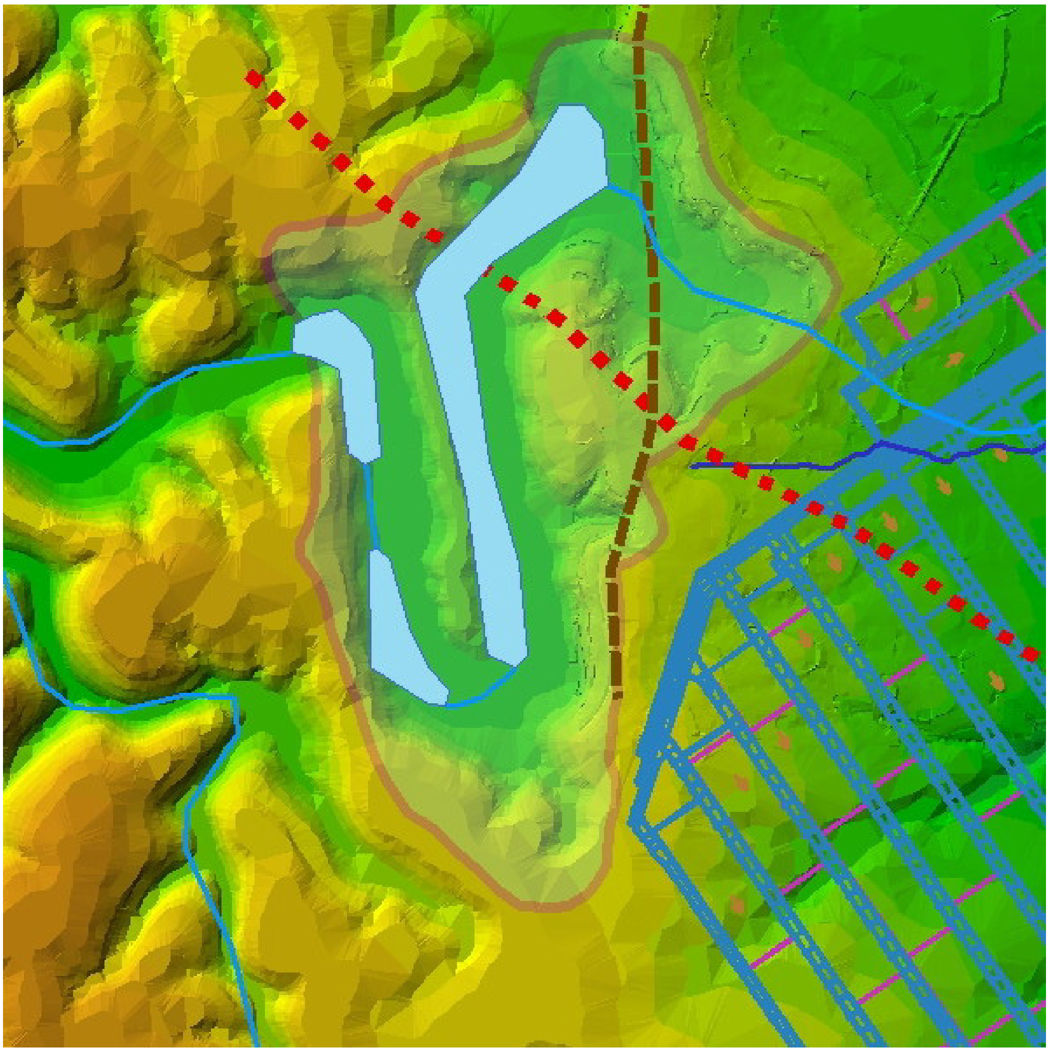

Figure 4: Proximity of Longwalls 14 to 21 to Thirlmere lakes

The longwalls closest to the lakes are the NW –SE trending set comprising Longwall 14 to Longwall 19, and the two at right angles to this set, namely Longwall 20 and Longwall 21 (see Figure 5, below).

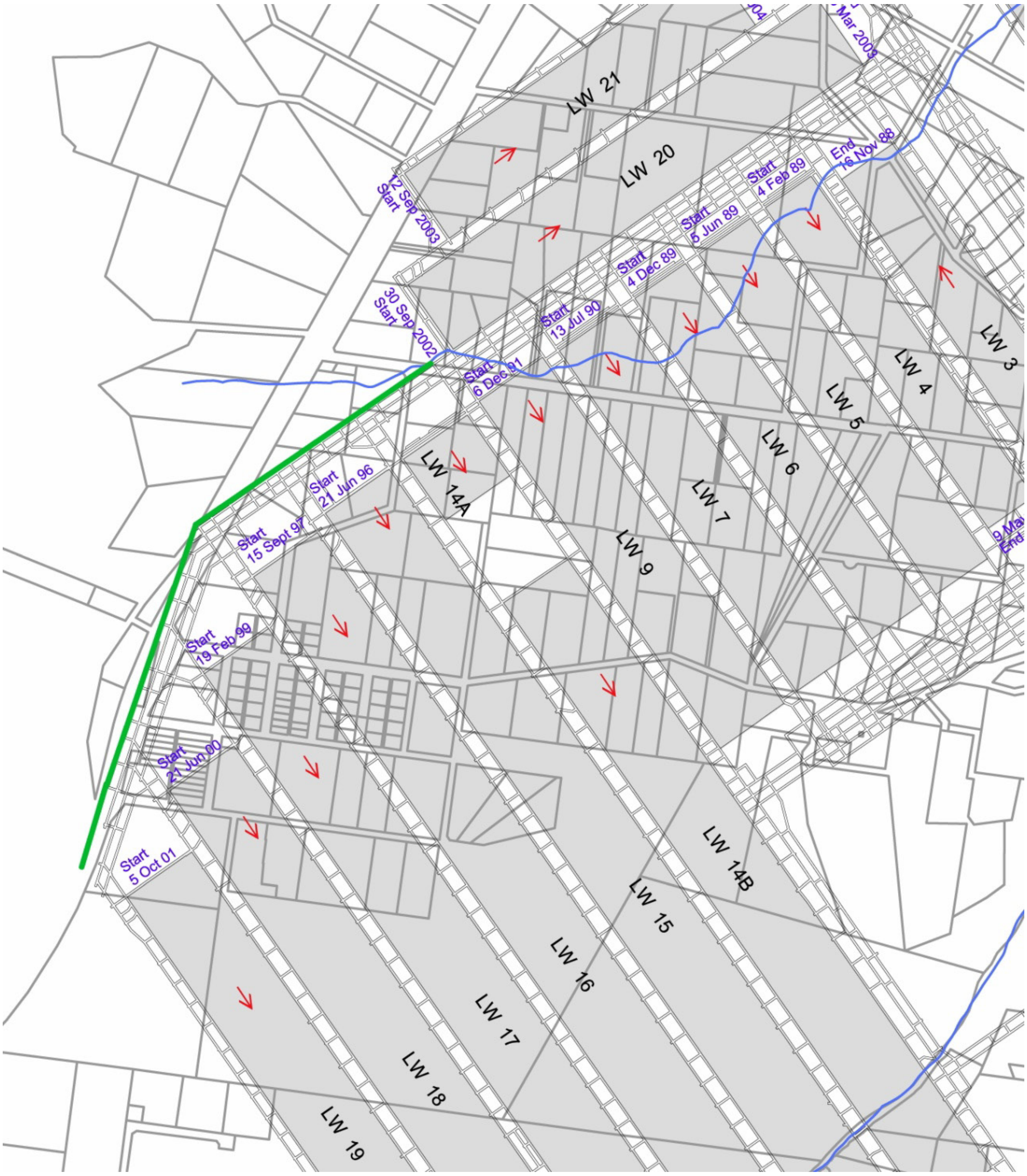

Figure 5 Details of Longwalls 14 to 21

The dates of mining of these longwalls are:

- LW 14A and 14B – started late 1994, completed 15 May 1996
- LW 15 – started 21 June 1996
- LW16 – started 15 September 1997
- LW17 – started 19 February 1999
- LW18 – started 21 June 2000
- LW 19 – started 5 October 2001
- LW 20 – started 30 September 2002
- LW21 – started 12 September 2003, terminated 29 March 2004 due to many roof falls that damaged the 16 year old longwall equipment.

Figures 6a and 6b show geological structures at seam level in the vicinity of the longwalls listed above. These structures are discussed in some detail in Section 3.3 of the Pells Consulting report of October 2011

Figure 6a: Overall geological structures; green dots show gas outburst locations

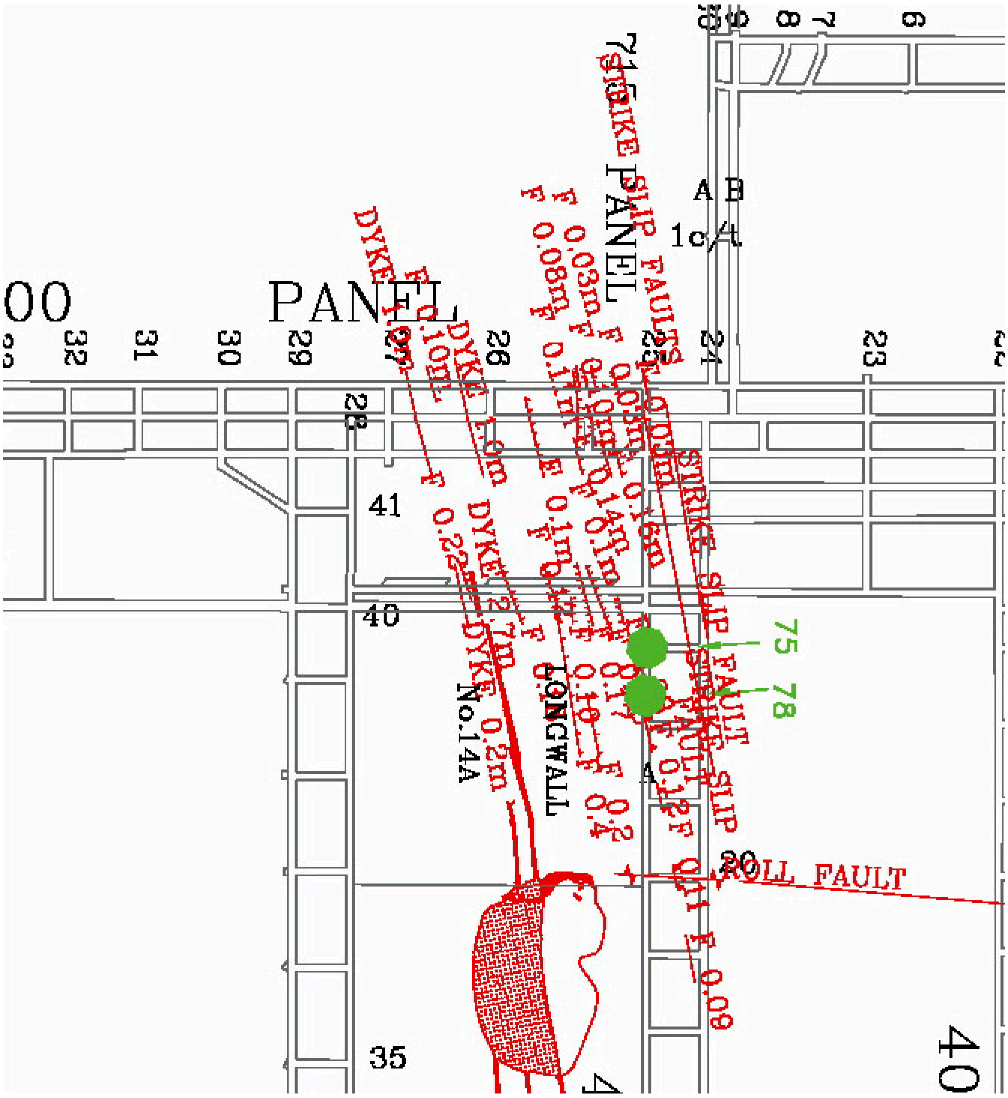

Figure 6b: Detail of Fault T1

Figures 7a shows the in-seam gas drainage holes drilled for the longwalls listed above, taken from Wynne (2002). Details in the vicinity of fault T1 are given in Figure 7b

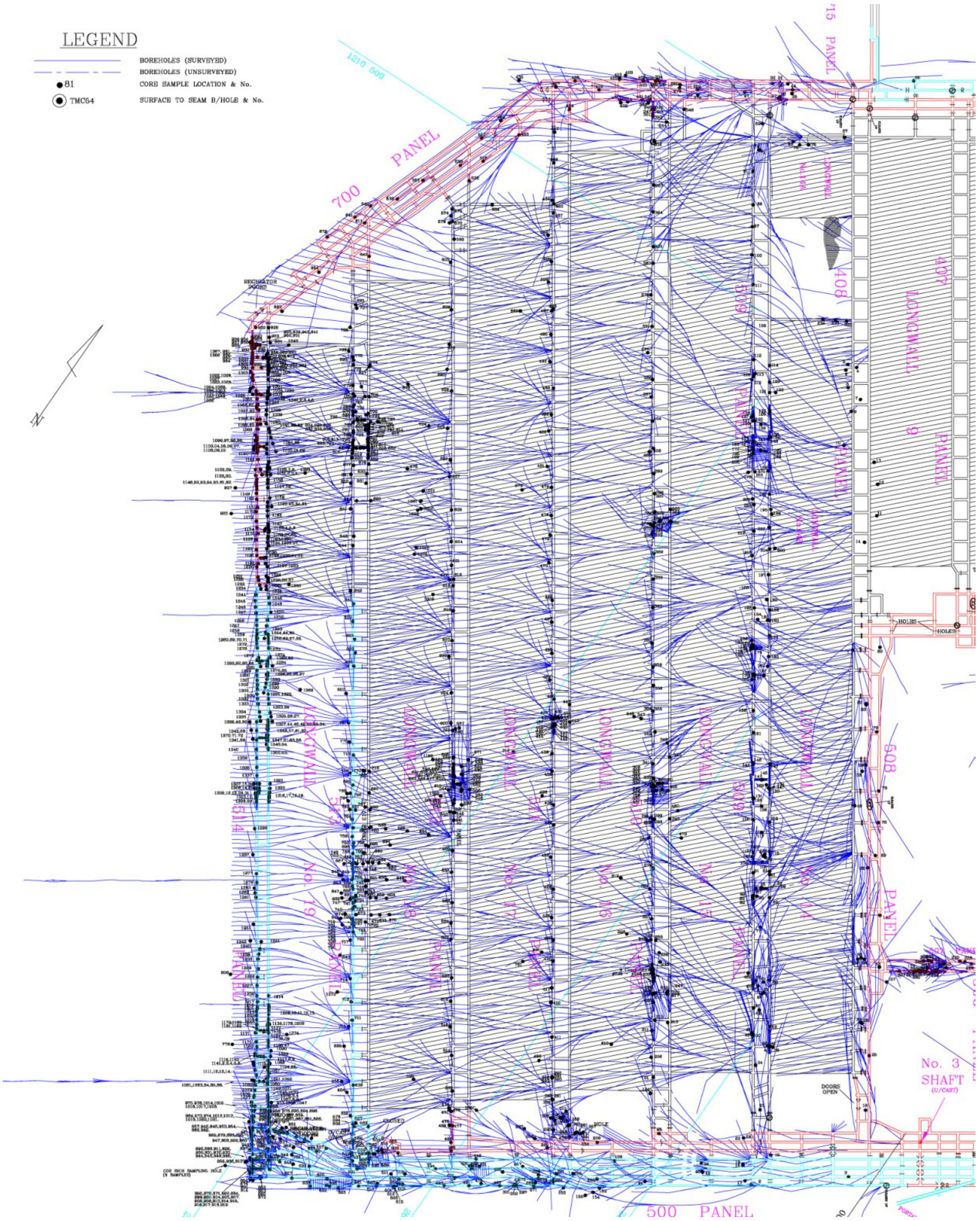

Figure 7a: In-seam gas drainage Longwalls 14 to 19

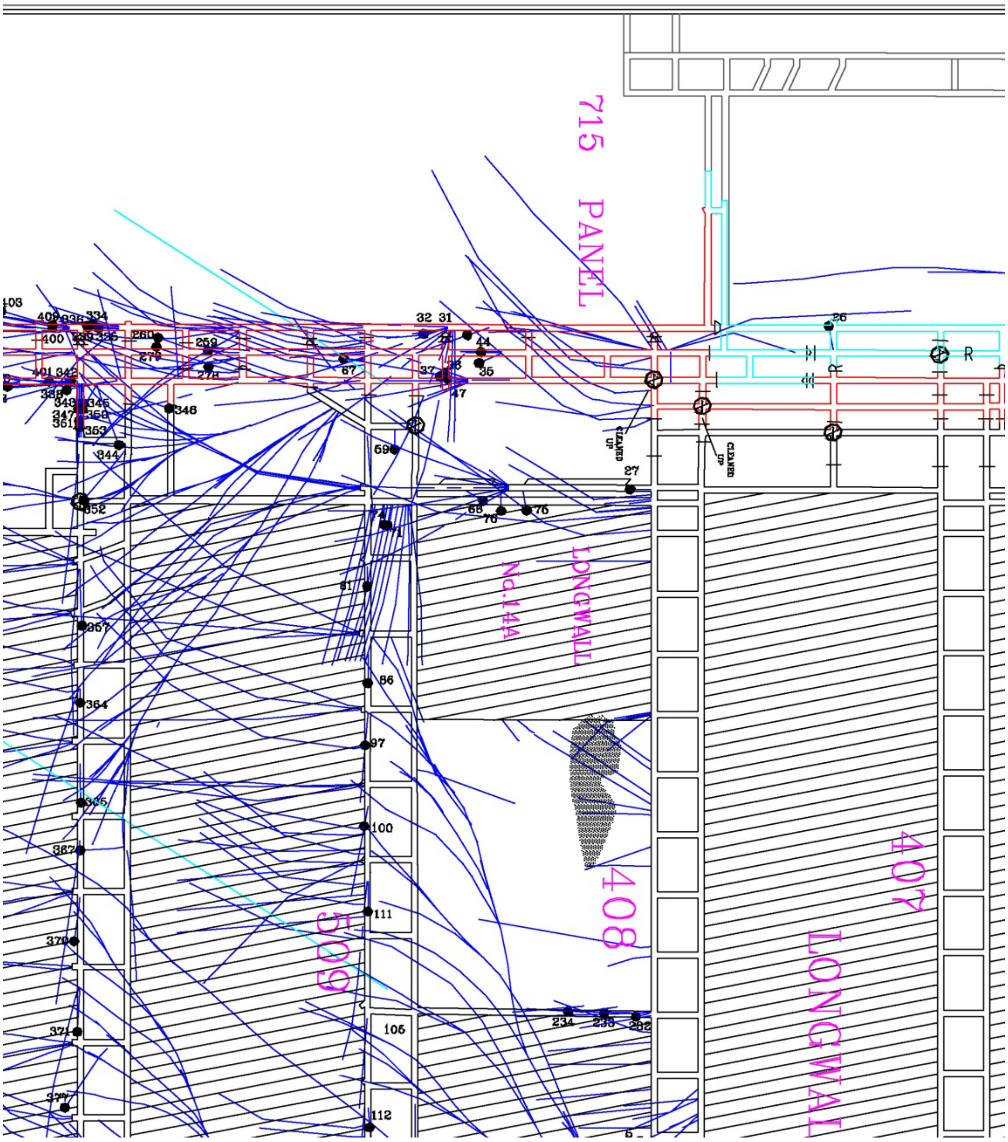

Figure 7b: Drainage holes at start area of Longwall 14A in vicinity of faults and dykes shown in Figure 7b

In regards to Figure 7, Wynne notes the following:

"*The progressive improvement in drilling techniques is well illustrated in Fig 1* (Fig 8, herein). *It can be seen that in 1994 (right hand side of diagram), some areas were overdrilled, whilst others were underdrilled and thus drainage was less than optimum. By 2001 (left hand side), the patterns are very evenly spaced, giving almost perfect coverage of the areas to be drained"*

Comparison of Figure 7b with Figure 6b shows that, as would be expected from the history of gas outbursts at faults and dykes, there was some concentration of the gas drainage holes in the vicinity of the NW-SE strike slip fault, termed T1 in our October 2011 report. In particular, gas drainage holes targeted this fault beyond, and to the west of the workings; towards the Thirlmere Lakes.

Finally, it should be noted that in January 2002 adverse impacts on the Bargo River were recorded above the area of Longwall 14 to Longwall 18. There was fracturing of rock shelves in the river bed and drainage of some shallow pools. It is reported that the river was drained directly above Longwall 18 and the length of drainage extended for some distance beyond Longwall 14 (MSEC 2006)

The mine discharge records show (see Fig 4.4 in October 2011 report) the following.

- During the extraction of Longwalls 14A through to Longwall 17 the daily discharge was remarkably consistent, at about 2.8 ML per day.
- In mid-2001, during the time of extraction of Longwall 18, it climbed to about 5.5ML per day before dropping back.
- Then in mid-2002, at the end of Longwall 19, it increased to 8.0ML per day before dropping to ~5ML per day, or less,
- In early 2003, at the time of mining Longwall 20 it increased to over 11ML per day, but this tapered off during Longwall 20 extraction, back to ~5ML per day.

Unfortunately, while there seems to be a linkage between mine inflows and the development of particular longwalls, we have been unable to obtain details of when mine inflows occurred.

4. IMPLICATIONS TO WATER LEVELS OF THE THIRLMERE LAKES

In our report of October 2011 the results of our hydrological and groundwater analyses led us to form the hypothesis that the mining at Tahmoor Colliery had resulted in some loss of water to, and an increase in seepage from, the Thirlmere Lakes.

At the time of writing that report we did not have the details of the in-seam coal seam gas depressurisation that accompanied the longwall mining of Longwall 14 to Longwall 21.

It is a reasonable postulation that the gas depressurisation under vacuum, and the prior removal of groundwater associated with that depressurisation, would have exacerbated the mechanisms that we postulated.

P. J. N Pells
FTSE, BSc(Eng), MSc, DSc, FIEAust MASCE

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APPENDIX A
NOTES ON COAL STRUCTURE, COAL SEAM GAS AND GAS OUTBURSTS

1. COAL STRUCTURE

"Rocks are composed of minerals, coal is composed of Macerals. However, minerals often have reasonably well defined chemical and physical characteristics; Macerals cannot quite be put into such neat boxes" (Fazeli, University Teheran)
Macerals are the remains of plants and degraded plant materials. Not only is the type of plant important, but how it was modified during the process of coal formation (the terrible word, *coalification*) is important to coal structure. Spores, pollens and resins typically do not degrade as rapidly as leaves and roots. A fallen log may in part degrade in a swamp to be gel-like, while the remainder may retain the original cellular structure.

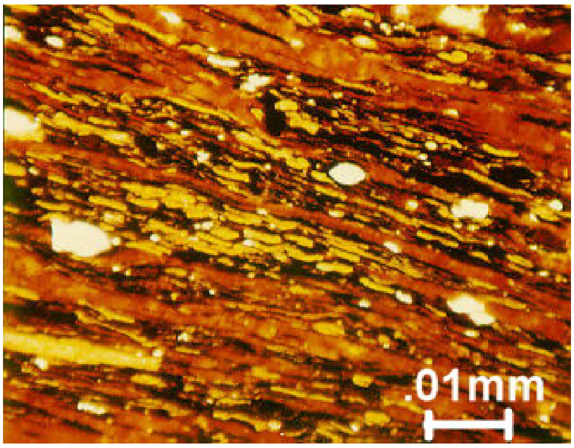

Figure 1

Surprisingly, under a microscope, and with white light, a thin section of coal is predominantly red. The yellow blebs in the above photo are coalified spores, orange squiggles are coalified plant cuticles ('skin') and the red material is the remains of woody tissue.

Where things get interesting in respect to gas, is that coal is full of very very tiny pores. So under a scanning electron microscope, at a very much smaller scale that the thin section shown above, coal may look as shown below.

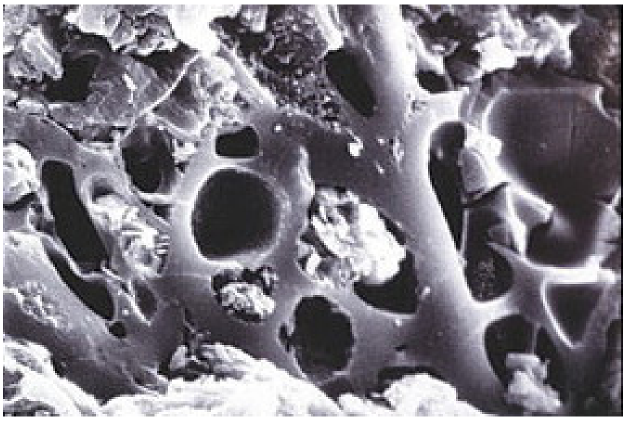

Figure 2; SEM photograph by Satya Harpani

Three sizes of pores are used in analysing gas retention in coal (Faiz et al, 1992). These are:

- Macro-pores : greater than 50 nanometres (a nanometre is .000001mm[1])
- Meso-pores : 2 to 50 nanometres
- Micro-pores : less than 2 nanometres (a methane molecule is .33 nanometres)

The total porosity of Australian coals is typically between about 4% and 8% of which macro-pores account for less than 25% (Faiz et al, 1992).

Extraordinarily, the micro-pores in coal may create internal surfaces exceeding 100 square metres per gram of coal (Puri et al, 1988).

2 GAS AND WATER RETENTION IN COAL

Gas

The natural gas found in coal is understood to have originated during the formation of the coal. It is estimated that during formation of 1 tonne of coal some 1500m^3 of gas is produced (Remmer et al, 1986). So the coal is both the source and the reservoir.

It should be noted that while methane is usually the dominant gas, there are places in the Southern Coalfields of NSW, including Tahmoor, where the CO_2 component is high.

The ability of coal to hold large quantities of gas, despite the low porosity, arises from the fact that the natural gas is adsorbed on the walls of the pores at near-liquid density.

Faiz et all (1992) note that, while there are three modes of gas retention in coal (sorbed molecules, free gas in micro and macro-pores, and gas dissolved in groundwater), more than 90% of the gas is held by sorbtion[2]

Water

Water is stored in the natural fractures in coal, called cleats. It is not stored in the pores.

3 EXTRACTION OF GAS FROM COAL

It is through the cleat system that the pores in the matrix of coal are connected to a borehole drilled in a coal seam[3]. This is well illustrated by Figure 3, modified from King (1990).

A gas extraction borehole drilled into the coal seam will first typically produce water contained in the cleat network, and a small amount of gas. As the cleats are depressurised, and dewatered, the ‘reservoir’ pressure near the borehole is reduced. This releases some gas from surfaces in the coal. The gas migrates from the pores into the cleats, and as water saturation in the cleats drops, there is an increase in the

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[1] The angstrom unit is a tenth of a nanometre. A CO_2 molecule is 3.3 angstrom, or 0.33 nanometre; a methane molecule is 3.6 angstrom

[2] The word ‘sorbtion’ is a generic tern that includes Adsorbtion, Absorbtion and Ion-exchange

[3] Additional open fractures can be created by hydrofracturing; these being essential in gas extraction from shale rocks.

ability of the gas to flow in preference to water: the relative permeability to gas increases.

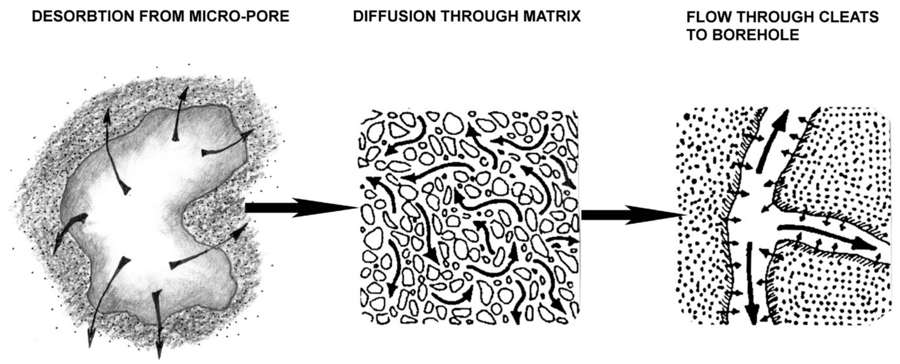

Figure 3: The chemo-physics of gas extraction from coal (after King, 1990)

4. GAS OUTBURSTS

Creating of an excavation into the Bulli Seam at a depth of, say, 450m, forms a depressurised void at close to atmospheric pressure (~100kilopascal). However, the groundwater and gas pressures in the coal would be in excess of 4000kilopascal. The excavation is analogous to the borehole described in Section 3, above. Gas will flow to the opening.

If the coal is homogenous, the pressure distribution will change with time in a manner computed numerically by Zhu et al (2007), and reproduced in Figure 4.

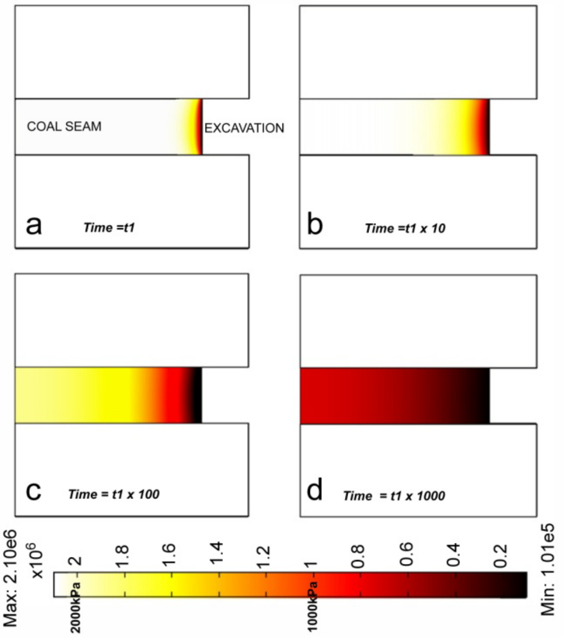

Fig 4: Numerical modelling of gas pressures (Zhu et al, 2007)

If the coal has the strength to resist pore pressure differential pressures such as illustrated in Figure 4 all will be well. However, if it does not, the may be small outbursts. Where matters get messy are if there are low permeability geological features (dykes, fault gouge, ‘tight’ coal) that act as barriers to depressurisation, somewhere not too far behind the coal face. Then all hell can break loose.

For example:

On 24 July 1991, three men) Craig John Broughton, Robert Kelvin Coltman and Leigh Ronald Pearce) were killed by the outburst of coal and gas at the South Bulli Colliery.
The outburst in ’B’ Heading if W12 Panel ejected an estimated 300 tonnes of coal and 6000m^3 of gas (predominantly CO_2) into the working area. This occurred with sufficient force to dislodge the ventilation ducting, losing the auxiliary fan ventilation, slew the shuttle car sideways, and had sufficient force to blow open the inbye ventilation doors causing a short circuit in the ventilation. The Continuous Miner driver was buried, (with his machine) *to his neck with outburst material and it is believed died instantaneously from the effects of carbon dioxide. The shuttle car was being driven away from the Continuous Miner at the time of the outburst and from the injuries sustained by the driver it would appear he was thrown out of the driver’s compartment by the force of the outburst, It would appear that the third miner killed, died attempting to assist the car driver, and was overcome by the gas.* (Harvey & Singh, 1998)