# Risk Minimisation in Longwall Operations in Massive Goaf Conditions Using Microseismic and Hydraulic Fracturing Techniques

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## ABSTRACT

Moonee Colliery operates a longwall extraction system in the Great Northern seam of the Newcastle Coal Measures, approximately 100km north of Sydney, NSW.

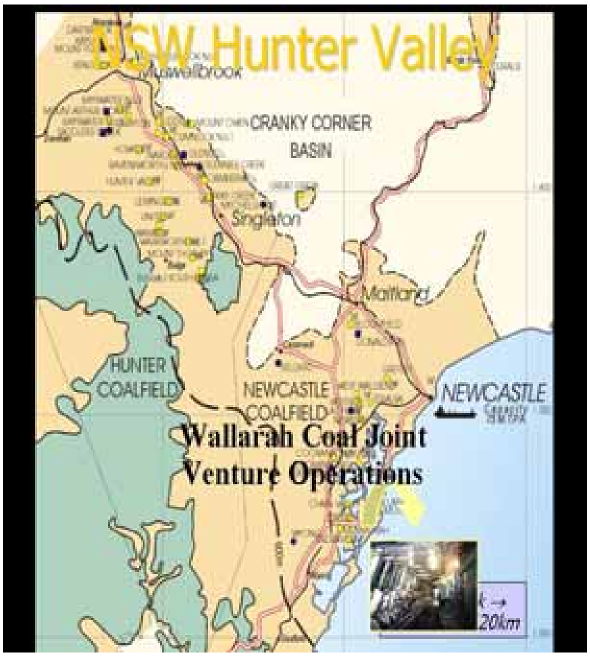
In the initial mine area of longwall blocks1-4a, the Great Northern seam is overlain by a massive conglomerate approximately 35m in thickness at an average depth of cover of 130m.

Unanticipated sudden, blocky caving of this material has produced windblasts with associated velocities of 100m/sec and over-pressures of 35kPa. Although these events have not resulted in fatality, the potential safety risk to face personnel was such that the mine was threatened with closure.

The development of a Windblast Management Plan to minimise the exposure to windblasts, a Micro-seismic Management Plan to predict caving events, and the use of hydraulic fracturing to generate caving on demand, have all contributed to the saviour of the mine. Prior to the introduction of hydraulic fracturing, falls were highly variable and ranged in goaf area from $2000m^2$ to $30,000m^2$ with an average of around $7,000m^2$. Hydraulic fracturing has introduced consistent and far less variable falls, planned as averaging around $5000m^2$ and all accompanied by microseismic warning. Moonee Colliery is believed to be the only operation in the world using real-time microseismic warning and using hydrofracturing as a day-to-day operational process. These processes have enabled it to return to financial viability in an environment of strict procedural control, whilst ongoing efforts are made to optimise and enhance these systems. Moonee's story is a case study of the successful application of research and development work to the economics of a mine.

## INTRODUCTION

Moonee Colliery is a coal mining operation in the Newcastle coalfields of New South Wales located in the Catherine Hill Bay Area which is approximately 100km north of Sydney (see fig. 1).



It commenced mining shortly after World War II mining the Wallarah Seam, initially for domestic markets and later for export. It was initially a bord and pillar operation and when the reserves of the Wallarah seam were exhausted the mine moved into the underlying Great Northern Seam. This was uneconomic prior to the introduction of the longwall, principally due to the claystone which forms the immediate roof below the massive conglomerate strata. The mine was put on care and maintenance for a number of years in the 1990's and was subsequently reopened as a longwall operation with the first longwall block commencing in November 1997. The mine is currently operated as part of the Wallarah Coal Joint Venture which is a joint venture between Billiton Coal Australia Limited and the Japanese Trading House Nissho Iwai. Current production level of the mine is around 1.5 million tonnes per annum with a workforce of approximately 110.

Moonee Colliery operates a 90m wide DBT longwall face, the equipment on which is listed in Table 1. It is a very narrow face due to both the reserve constraints that exist at the mine and the original design to minimise surface subsidence.

Table 1: **Moonee Colliery Longwall Face Equipment**

| | |
|---|---|
| **Width:** | **90m Block Lengths: 1900m** |
| **Supports:**<br>**Yield:** | **53 x 2 leg DBT Shields range 2.5-4.1m**<br>**860 tonne** |
| **Shearer: 881kW** | **Long-Airdox Electra 1000DERDS with 2.0m dia drums** |
| **Cutting height:** | **3.1m unidirectional 0.75m web** |
| **AFC:** | **DBT 932mm PF4/30mm twin in-board chain**<br>**Speed 1.27m/s, Power 350kW single end** |

The immediate roof over much of the mine consists of a finely grained claystone which was predicted to fall behind the supports and the roof above the claystone which consists of around 40 metres of massive conglomerate was predicted to either span for the full width or to result in very shallow sporadic goaf falls. The principles stress direction is horizontal and sub-parallel with the face line direction. However trouble appeared from the first goaf fall which occurred after a retreat of approximately 200 metres and resulted in a massive windblast (fortunately on a weekend) in January 1998. Windblast destroyed many ventilation appliances in the longwall area, blew down some 10 rows of water barriers in the panel, and projected items like computer keypads in the maingate some 30 metres outbye. The next subsequent falls were much smaller events and there was a hope at that point that the goaf would continue to fall behind the supports and follow the longwall as it retreated. However the fifth goaf fall in the panel, which occurred at 10am on Thursday 22 January 1998, resulted in a windblast which knocked over and injured 6 of 19 crew who were present engaged on regular maintenance. It also destroyed several ventilation appliances. The injuries to the personnel were relatively minor in physical nature with the worst injury being a broken rib but the psychological damage done to the mine personnel as a result was extensive. The publicity received by the organisation was extensive and very negative as shown by the headlines in the only Sydney afternoon newspaper (fig. 2). This was the first of a number of windblast crises that the mine faced in the next 12 months before the event which resulted in the trial of hydrofracturing.

THE Daily Telegraph

SYDNEY, Thursday, January 22, 1998 Weather: Showers, 26 degrees Phone 9288 3000 80 cents*

FREE INSIDE TODAY

Australia Day colour magazine

Daily Telegraph – YOUR SYDNEY FESTIVAL NEWSPAPER

MINE BLAST

17 men injured in shaft explosion

By TREVOR SEYMOUR
Police Reporter

UP TO 17 workers have been injured, two seriously, after a huge blast rocked a coal mine today.

Figure 2: Sydney Daily Telegraph January 22 1998

## GEOLOGICAL SETTING OF MOONEE COLLIERY

A generalised stratigraphic sequence of the uppermost subgroup of the Newcastle Coal Measures, the Moon Island Beach Sub-Group, together with the immediately overlying Munmorah Conglomerate Formation of the Narrabeen group is given in Figure 3. Constituent components include coal, conglomerate, sandstone, shale and rocks of pyroclastic origin which are of variable grain size up to coarse and are termed ‘tuff’. Moon island Beach Sub-Group includes 3 major Coal Members – the Fassifern, Great Northern and Wallarah seams all of which are currently worked at various mines throughout the locality.

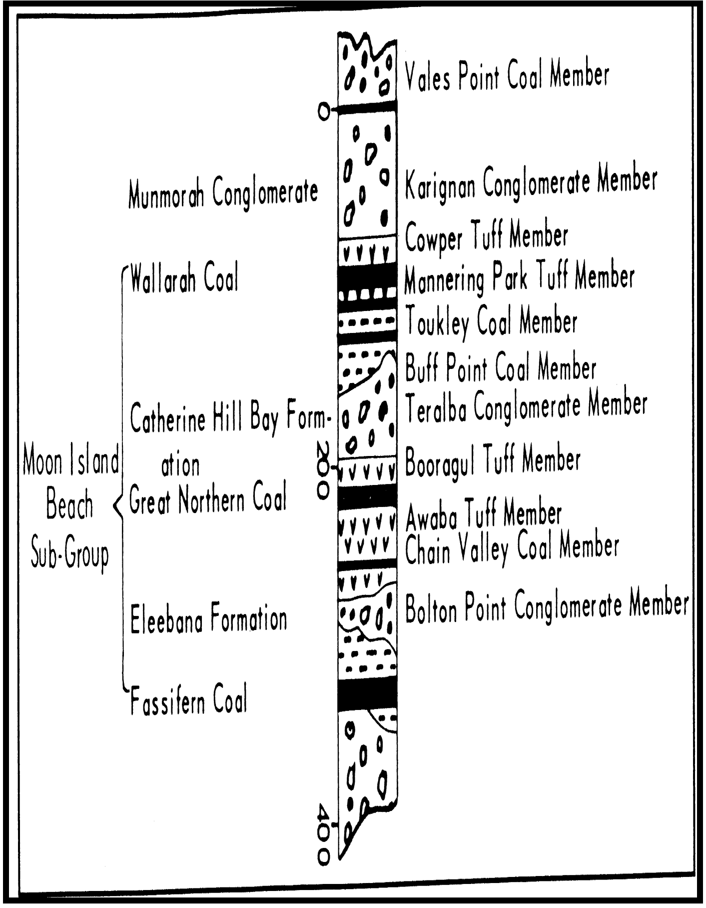


**Figure 3: Generalised Stratigraphic Sequence**
**(Fowler 2000 p.4)**

The Great Northern Seam worked at Moonee Colliery is a high volatile low sulfur medium ash thermal coal which is used for power generation. The seam is mined at Moonee at a height of around 3.1 metres of a total seam thickness of up to 4 metres. Overlying the Great Northern Seam coal is the Catherine Hill Bay formation. This ranges in thickness from zero, where the Great Northern Coal and Wallarah Coal merge, to over 60 metres. In the roof of Moonee Colliery the Booragul Tuff member forms the immediate roof of the working seam which is termed the ‘claystone' roof’. Above this immediate claystone roof is the Teralba Conglomerate which is up to 40 metres in thickness and composed of conglomerate, sandstone and some mudstone. Chert and quartzite pebbles predominate and are rounded and sub-rounded and generally less that 25mm in diameter but range up to 150mm. Bedding ranges from massive to well-bedded with generally extensive cross bedding. The compressive strength of the conglomerate averages around 45 Mpa and exhibits tensile strength around 8 MPA. Roof support requirements in the roadway development at Moonee Colliery dictate that sufficient roof coal is left to support the overlying claystone and at the same time leave up to 0.5m of coal in the floor to minimize the incidence of heave of the floor which contains bentonitic clays. Thus the working height in development is restricted to around 2.8m. The longwall itself cuts up to a height of around 3.3m leaving some 300mm of roof coal to temporarily support the claystone on the longwall face as it retreats.

## HISTORY OF WINDBLAST EVENTS ON LONGWALL 1 AND 2

No real definition of windblast existed from a quantitative view point and to this end it was decided that an event that registered more than 20m/s in any of the roadways underground would be used as a definition of windblast at Moonee Colliery. This definition roughly coincides with the maximum constant velocity against which a human being can remain upright. This is roughly equivalent to a Beaufort scale of 10 and is described as a strong gale with 10 metre waves and which could remove tiles from roofs of houses. The windblast monitoring system was specially developed to record air overpressures and velocities during windblasts by massive goaf falls. Its development was supported financially by a grant from the Australian Coal Association Research Program (ACARP)[1], together with substantial financial contribution from coal mining companies. Dr Chris Fowler of the University of New South Wales describes this in detail (1997). The equipment comprises a windblast data logger, four sensorpods and a hand held interface and is certified by the Department of Mineral Resources for use in hazardous locations in underground coal operations. The system monitors both velocity level and overpressure during a windblast event and is set at a minimum trigger level of 6m/s. A windblast normally comprises a rapid rise in absolute pressure which peaks and is then followed by a rapid negative pressure which is called a ‘suck back’. Dr Fowler’s work showed that the peak overpressure is always greater than the peak underpressure and therefore the peak velocity in the direction from the goaf away from the fall is always greater than the peak goaf ‘suck back’ velocity (Fowler, 2000 p.17). The intensity of the ‘suck back’ face can be almost as severe as the positive pressure phase. An example of the velocity/time graph during a windblast event is shown in Figure 4 and clearly shows the ‘suck back’ velocity which in this instance has occurred around 3 ½ seconds after the initial fall.

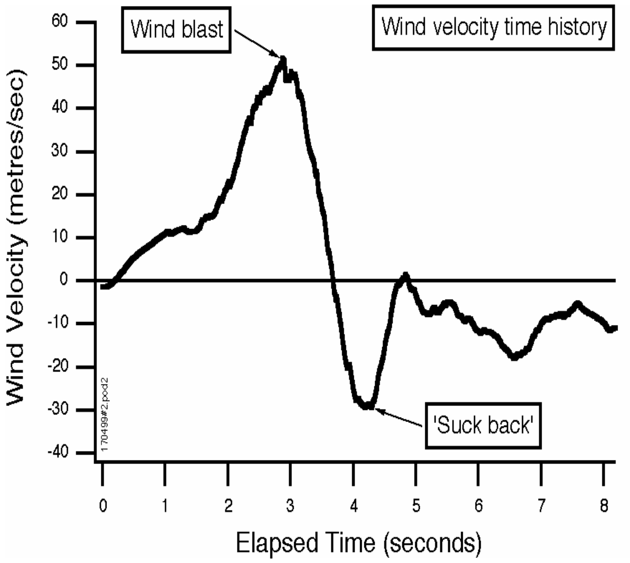


**Fig 4: Windblast velocity from Goaf Fall #1, Longwall 3, Moonee Colliery.**

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[1] This is coal industry Research and Development programme funded by a $0.05 per tonne levy on all coal produced in Australia.

Following the windblast incident in January 1998 described in the introduction to this paper, a risk assessment team was set up to develop a more extensive windblast management plan.  This risk assessment team included mine management, strata control experts, shift coordinators, crew leaders and mining technicians with windblast experience.  At the same time and as part of the windblast management system a microseismic management system was also developed.  The total system provides the information detail and arrangements by which Moonee Colliery manages and controls the risk of windblast during longwall operations.  It provides the systems, standards and procedures in addition to processing the data and communications relevant to the control of risk from windblast.

The windblast management system includes a range of measures designed to minimise the risk of injury during a windblast.  These include extensive personal protective equipment ie. full face helmets, leather jackets, knee guards and elbow guards.  All personnel are attached to a rock climbing lifeline which is located on the face and in the maingate conveyor road.  These protective measures are taken at any time where more than 20 metres of goaf is standing.  Refuge areas are provided for on every second longwall support and at several places at the maingate area.  Any procedure that needs to be carried out in a ‘red zone’ (where more than 20 metres or 2000m$^3$ of goaf is standing) is covered by a detailed risk assessment and written procedures for the tasks involved.  The face must be stopped before any individual is permitted to travel from the face down the maingate roadway.  This plan is under continuous review by the Windblast Management Committee and is subject to a formal auditing process at least once per year.  The plan also formalises all duties of personnel in relation to windblast management.

The microseismic monitoring system consists of an array of geophones installed in the maingate and tailgate roadways near the face.  Each geophone transmits an analogue signal backed to a multi-seismic unit and this data is then converted into a serial signal by an ethernet server and fibreoptic link.  This signal  is then transmitted from the underground seismic station to the surface monitoring computers.  This system as installed at Moonee Colliery aims to employ the build up of microseismic activity as an indicator of the onset of large scale failure which ultimately results in caving and possibly windblasts. It consists of a highly sophisticated combination of geophones, seismic processes, data links and computers that enable a surface operator to record and interpret microseismic activity and issue warnings as required.  A schematic diagram is shown in figure 5.

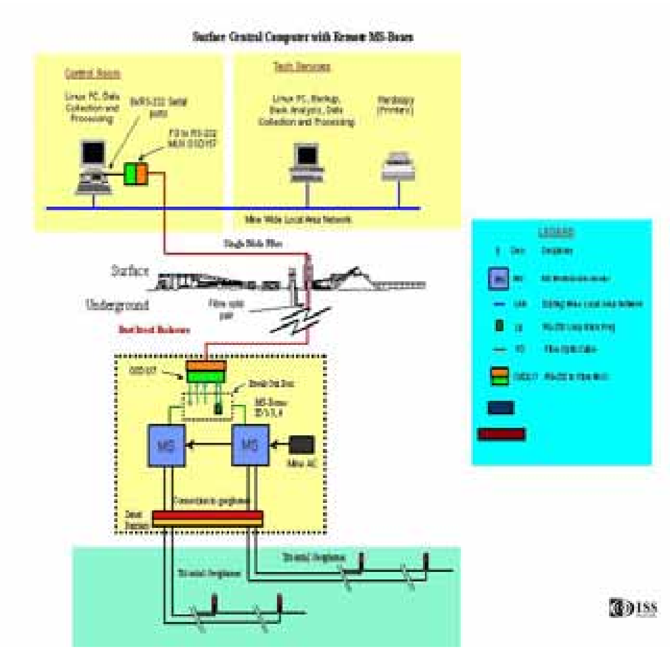

Fig.5: Microseismic Schematic

The system runs on a Linux based graphics work station and the software used for the system has been developed by the South African company ISS and was originally developed for rockburst monitoring. The system is manned on the surface full time whenever the longwall has any crew members present. The microseismic personnel (who are all trained geologists) are trained to recognise three types of alarms – *trend, magnitude and frequency alarms.* A trend alarm occurs when the apparent volume (a measure of the volume of rock mass affected by microseismic activity) rises rapidly, a magnitude alarm occurs when two or more seismic events occur in 2 minutes with a richter magnitude larger than –1.0. A frequency alarm occurs when five multiple geophone events occur within 60 seconds or there are continuous multigeophone events. Typical geophone location is shown in figure 6.

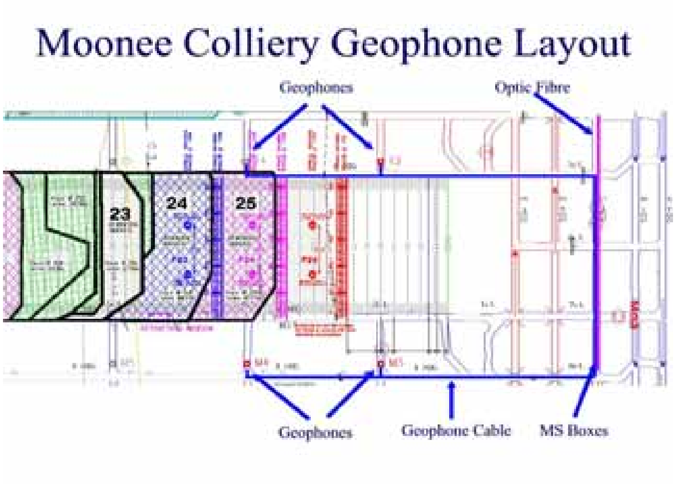

Fig.6 Typical Geophone Layout

The system can also be set to auto and in this mode an alarm is triggered when 6 microseismic events occur within a period of 10 seconds. The auto mode is not very discriminatory and tends to cause a lot of false alarms so therefore the operators rarely use this function. Activation of the alarm can be done from the surface by the microseismic operator or it can be done from the longwall face by any personnel on the face or in the maingate. Activation of the alarm immediately shuts down the power to the longwall face and activates strobe lights on the face so that all personnel are aware that a strata alarm has been activated and they are to proceed to the nearest safe haven. In addition to the microseismic type of alarms there is also a leg support system pressure alarm which activates with 3 or more adjacent supports see a rapid rise in pressure. In addition a windflap shutdown system is installed in the maingate and this cuts off power immediately to the longwall if a windblast event occurs.

With the implementation of the extensive windblast management plan including the microseismic prediction system the remainder of longwall 1 and all of longwall 2 remained injury free from windblast. The microseismic system was able to give sufficient warning of impending roof falls that could cause windblast in approximately 90% of cases.

## SOME IDEAS CONSIDERED

Many other ideas for the minimisation of the effects of windblast or the elimination of windblast entirely were considered, including the widening or narrowing of the longwall face. Geotechnical modeling of wider or narrower faces concluded that neither option could guarantee that windblast would be eliminated. The concept of weakening the rib pillars was also examined but rejected on the grounds of safety and impracticality. Concepts such as supporting the middle of the face behind the supports were considered and evaluated as both impractical and unlikely to impact on the magnitude of the windblast event. Blasting from the surface was in fact trialled on Longwall 1 where access was available and this failed to initiate any falls of ground. Surface access for blasting purposes is very limited due to governmental access limitations.[2]

## WINDBLAST ON APRIL 30 1999

The windblast that occurred on April 30 1999 was a major turning point in the history of Moonee Colliery. The time was 8.57am and the longwall face was stopped due to a minor electrical problem. The crew leader, who was very experienced in windblast conditions, was speaking on the telephone at No. 4 Support and 2 other technicians were located in the maingate. Unusually, there was no audible warning of impending roof fall and no microseismic warning of the event. The crew leader was blown approximately 3 metres bodily against the No. 2 Support and suffered multiple compound fractures of the left arm. The photo below shows his transport by rescue helicopter.

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[2] The mine surface area is largely within the bounds of a designated New South Wales State Recreation Area, is subject to Native Title claim and contains some allegedly threatened species of vegetation, making access for industrial purposes difficult to secure.

The helmet he was wearing and the phone piece he was holding were blown more than 40 metres through the adjacent cut-through. This was the first major injury suffered from windblast in the whole time Moonee had been operating the longwall. The Mines Department Inspector issued a stop work notice and refused to allow the mine to restart. The mine was at a major crisis point and faced initially shut down and then possible closure.

Most of the operators at the mine were sent on leave while the company considered what possible options it had that could enable the safe restart of the longwall face. Improvements were made to the sensitivity of the microseismic system, the level of protective clothing being used was improved, all tasks and procedures were again reviewed and the support pressure monitoring was further refined. In addition the concept of fracturing the rock with high pressure water injection, although considered a low probability of success, was attempted as a trial initially from the surface into an old goaf area.

## TOWARDS 'DIAL-A-FALL'

Hydraulic fracturing is a well proven petroleum industry technology that is widely used to stimulate oil and gas flows. Water is typically injected into a short section of borehole at sufficient pressure to overcome the stresses in the rock and the tensile strength of the rock. Once the fluid pressure rises high enough to overcome the forces holding the rock around the borehole together a fracture is initiated and this fracture spreads laterally away from the hole and aligns itself in a direction perpendicular to the lowest stress acting in the ground. In the case of Moonee Colliery, this means that the fracture grows in the horizontal plane (Jeffrey & Mills, 1999).

Some success using hydraulic fracturing techniques was occurring at a block caving operation in the Northparkes mine in central NSW (pers.corr. Rob Jeffrey of CSIRO[3]). Strata Control Technology (SCT) and the CSIRO Petroleum division were commissioned to coordinate a trial of hydraulic fracturing as a tool to produce controlled caving events. In June 1999 a surface trial was conducted to determine

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[3] Commonwealth Scientific and Industrial Research Organisation

the parameters of the hydraulic pressure required and rock characteristics such as permeability, porosity and other factors including rate of fracture growth.

The surface holes were drilled into a previously shallow caved goaf of Longwall 2 and this failed to cause any apparent further underground caving of the goaf. In spite of this it was decided that an undergound trial would be conducted and this was done from a shallow trajectory long hole predrilled from the Maingate to terminate at a position 10m above the base of the conglomerate and approximately in the middle of what would be 55m of standing goaf. The hole was installed with 25mm steel pipe fully grouted in place to within 2m of the end of the hole. On June 30 1999, this hole was injected with 41,000 litres of high pressure water for a period of approximately 2 hours and resulted in the caving of approximately 70,000 tonnes of rock. The concept of drilling inclined shallow projectory holes from the maingate was not economic as these holes were costing more than A$100,000 per hole to drill due to the fully cored nature of the holes[4]. Consequently the next hole that was drilled was an uphole from the middle of the longwall face. The fracture was initiated in this hole and after 51 minutes of treatment resulted in a fall of approximately 100,000 tonnes. The number of holes per fracture was refined to 2 holes, 1 at approximately 1/3 of the distance along the face and 1 at 2/3 along the face with approximately 47 metres of goaf standing when the fracture was initiated. This was the system that was used for the remainder of longwall 3.

The first trials of hydraulic fracturing targeted a point approximately 12 metres above the roof in the centre of the longwall panel. An idealized diagram of this is shown in fig.7.

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[4] . The shallow trajectory through the immediate mudstone roof and the accuracy required for the positioning of the end of the hole necessitated full coring at approximately 75mm diameter.

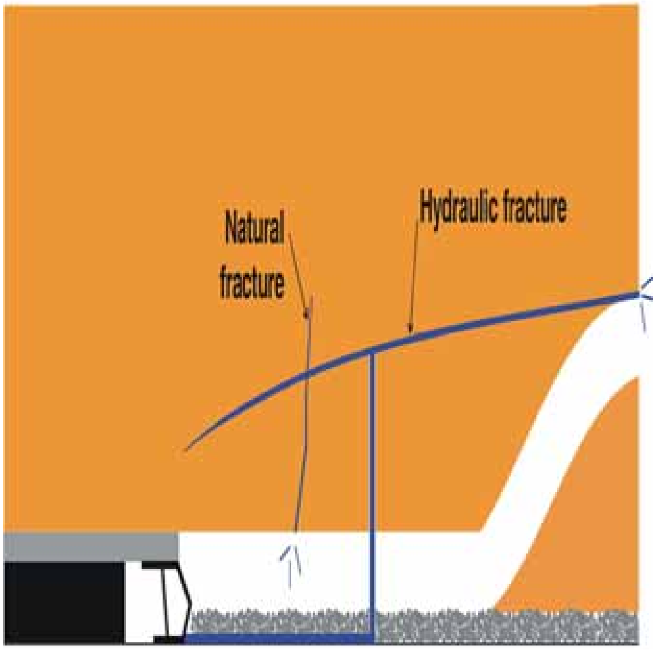


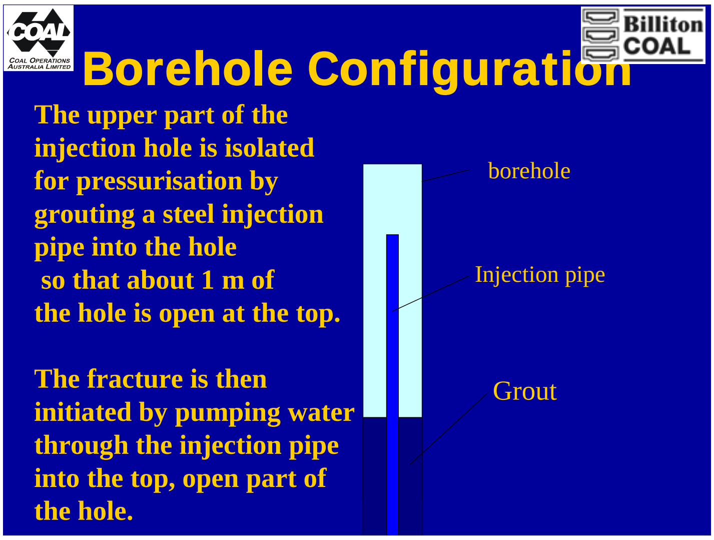
**Fig 7: Idealised Hydrofracturing at Moonee**

## “FRAC” PROCESS ON LONGWALL 3

The generalized hydraulic fracturing process used at Moonee Colliery for most of Longwall 3 consisted of the following procedure:

1. Retreat the face 20m from the last goaf fall
2. Drill vertical “frac” holes at 17 & 35 supports to a depth to ensure a minimum of 7m of conglomerate
3. Grout “frac” pipes into place with hydraulic hoses attached
4. Retreat the longwall face a further 27m
5. Attach hoses to the appropriate pumping system (either mine water or support pressure)
6. Commence pumping from the remotely located pump station.

The photo below shows the drilling of a hydrofrac hole on the longwall face.



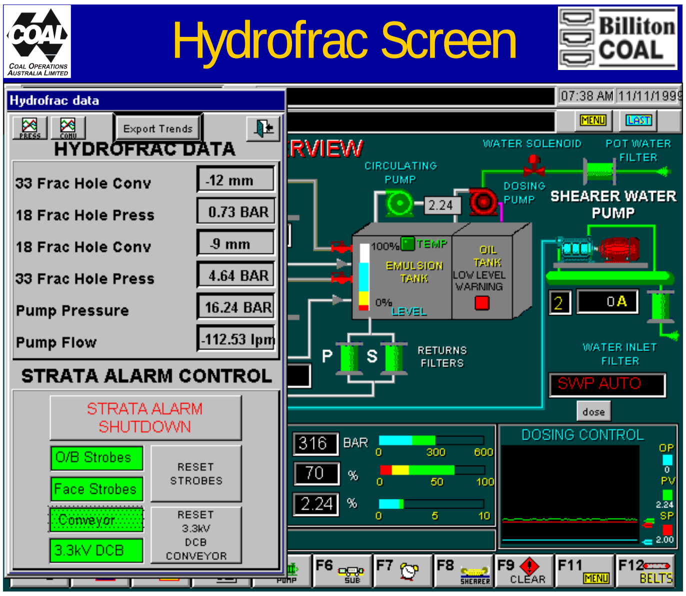
### Borehole Configuration

The upper part of the injection hole is isolated for pressurisation by grouting a steel injection pipe into the hole
so that about 1 m of the hole is open at the top.

The fracture is then initiated by pumping water through the injection pipe into the top, open part of the hole.

**Fig.8 : Borehole Configuration**

The microseismic monitoring of the frac process is carried out simultaneously with the injection system. An example of the hydrofrac process screen display on longwall 3 is shown in **figure 9** .



### Hydrofrac Screen

Hydrofrac data

HYDROFRAC DATA

| | |
|---|---|
| 33 Frac Hole Conv | -12 mm |
| 18 Frac Hole Press | 0.73 BAR |
| 18 Frac Hole Conv | -9 mm |
| 33 Frac Hole Press | 4.64 BAR |
| Pump Pressure | 16.24 BAR |
| Pump Flow | -112.53 lpm |

STRATA ALARM CONTROL

07:38 AM 11/11/1999

316 BAR
70 %
2.24 %

**Fig.9: Hydraulic fracturing screen**

The current configuration being used on Longwall 4 is one where the pipework has been replaced by hydraulic hose to the butt end of the hole. An example of the progress of a successful hydrofrac is shown in figure 10 below. The y-axis is the pressure in bars and the x-axis is time. The top trace shows the pressure in one hole and the bottom shows the pressure in the other hole whilst pumping water into the holes. The sudden drop-off at the end of the lines is when the fall occurred. Time from initial pump start to time of fall was 30 minutes.

**Fig 10: Hydrofrac with 2 holes Longwall 3**

## RESULTS SO FAR

26 hydraulic fracturing operations were carried out on Longwall 3 and of these 18 resulted in nearly immediate falls after injection of less than 150 minutes. Of the remaining 8 hydraulic fractures, 7 falls occurred before the face had retreated another 10 metres and in all instances microseismic warning of these falls occurred. The average pressure required to initiate the hydraulic fracture was approximately 8 Mpa. The consistency and greater predictability of this operation compared to previous natural falls is illustrated by figure 11 which is a plan of the falls across an area of longwall 1,2 and 3. In the same area where 300m of goaf stood before a natural fall on longwall 2, hydrofracturing enabled falls which averaged less than 50m long.

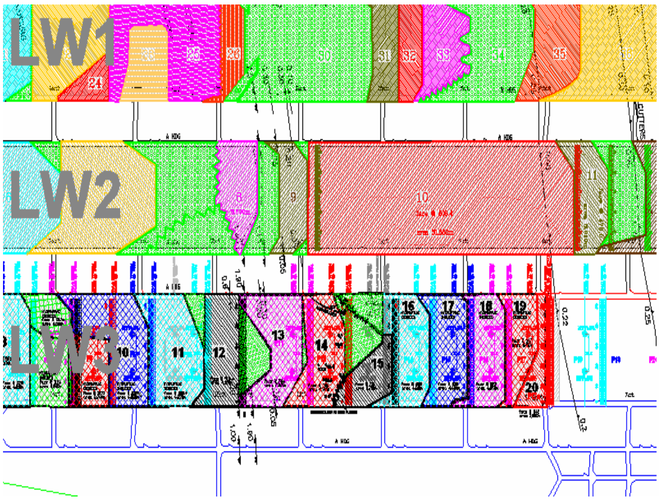


**Fig.11 Comparison of Fall Length**

In a measure designed to reduce the time lost during the hydrofrac hole drilling process, the design of the hydrofrac process for Longwall 4 was changed. This involved the fracturing of a single hole some 10m inbye of the last fall. In addition, the volume at the end of the hole left open to pressurize was reduced from about 1m to a few cm. Unfortunately the results on Longwall 4 have not been as satisfactory as on Longwall 3- the falls have been shallower and less consistent. A new method is now being trialled which reintroduces a larger void area in the hole to be pressurized. Fine tuning of the process continues. Production at the mine has returned almost to the levels previously achieved before hydraulic fracturing was introduced.

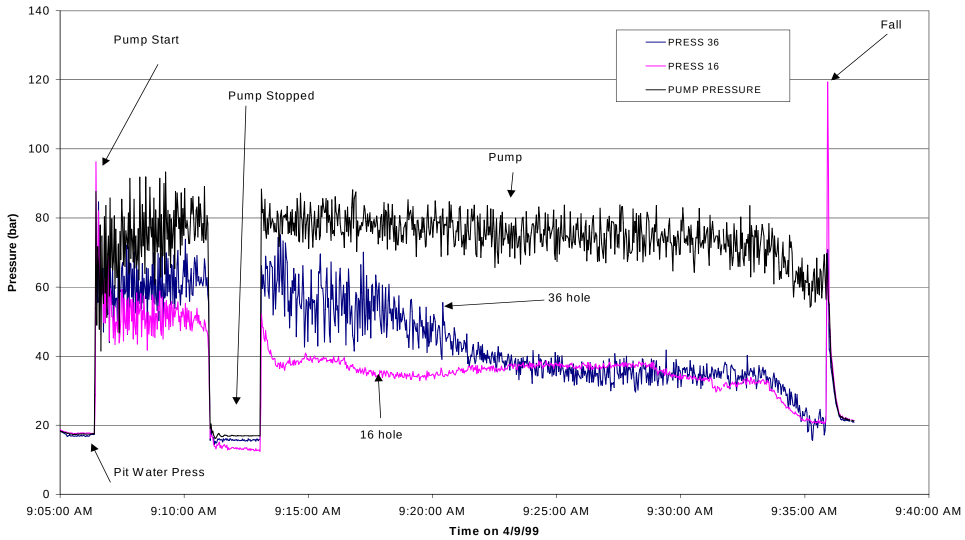
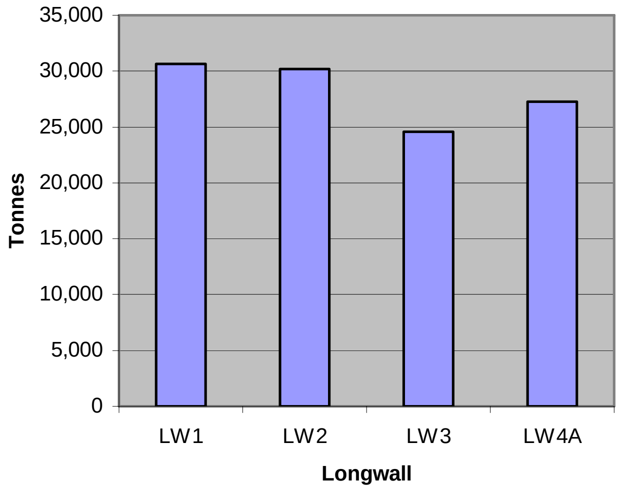


**FIG 12 Moonee Colliery**
**Average Weekly Longwall Production**



## CONCLUSIONS

The introduction of hydraulic fracturing accompanied by real-time microseismic monitoring as part of the production process at Moonee Colliery has enabled the mine to regain the level of productivity required to remain financially viable. These processes together have significantly reduced the risk of injury from windblast. Without this process it is unlikely the mine would have survived. The press clipping from the Newcastle Herald sums up the situation well.

Sport

Newcastle Herald 4/9/99.
P.24
fax to AJH f: windblast

# Mine jobs, lives saved

## New underground technology a 'lifeline' for Moonee Colliery workers

By SALLY CROXTON

THE future of Catherine Hill Bay's Moonee Colliery and hundreds of jobs have been secured by new technology which allows the mine roof to be brought down 'on demand'.

The underground colliery was closed temporarily earlier this year by Department of Mineral Resources inspectors after a wind blast seriously injured Belmont miner Steven Chandler on April 30.

It was the second wind blast at the mine in 15 months, with 19 miners injured in January last year.

'The new technology is an absolute lifeline for us,' Moonee Colliery mine manager Ross Campbell said yesterday.

'The seriousness of the safety issues at Moonee threatened the survival of the entire operation, which may well have resulted in the loss of hundreds of jobs and two million tonnes of premium export coal.'

He said that generally when the longwall miner moved forward the roof fell in behind it.

'But because it's conglomerate (rock) the roofs are so strong, up to 300 metres will stay up and when that falls in it blows us inside out,' he said.

'We couldn't continue the way we were with the uncertainty of the roof coming in.'

But he said the new process added time to mining and he was hopeful it would be refined to get back to full production by next month.

Dr Ken Mills of Wollongong's Strata Control Technology was aware of CSIRO Petroleum's success in using hydraulic fracturing to induce caving at a metal mine in NSW. He suggested to Moonee that the strata conditions there were likely to be suitable to use the same technology to induce caving 'on demand'.

The technology used at Moonee Colliery is expected to have widespread applications in making Australian coalmines safer and also has major export potential.

Salinity

## ACKNOWLEDGEMENTS

The author thanks the people at Moonee Colliery for their dedication in the development and ongoing refinement of the best-practice windblast management processes in daily use at the mine.

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