



EXTRACT OF CONSULTANTS' REPORT

Double fatality at Austar Coal Mine on 15 April 2014

Mine Safety Investigation Unit



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BACKGROUND

Austar Coal Mine is a longwall mine near Cessnock in the NSW Hunter Valley and at the time of the incident was the only underground mine extracting the Greta Seam. Typically, seam thickness ranges from 4 to 6 metres and depth of mining from 480 to 560 metres, making it one of the deepest operating coal mines in Australia. The mine was previously known as Southlands Colliery and, prior to that, Ellalong Colliery.

On 15 April 2014, a pressure burst occurred in the left hand rib at the active mining face of B Heading, 2 to 3 cut-through, Maingate A9 panel, during development of the gateroad for the ninth longwall top coal caving panel. Strata in the general vicinity was affected by disturbed geology and geological structure.

At the time of the incident, the face was being advanced by a crew of seven mine workers. Jamie Mitchell and Phillip Grant were on a working platform on the left hand side of a continuous miner, immediately adjacent to a ribline that was supported with bolts and mesh. They were engulfed by material ejected from the ribline during the pressure burst and died at the scene.

Following the incident, Emeritus Professor Jim Galvin, and Professor Bruce Hebblewhite (the authors) were engaged by the Mine Safety Investigation Unit, of the then NSW Department of Trade and Investment to assist with the investigation into the incident. Specifically, the authors were instructed to review all available information pertaining to the incident, with a view to assisting the Investigation Unit in the determination of the cause(s) of the incident.

Following the initial period of inspection, information gathering and preliminary evaluation, the authors were requested to prepare an independent report, the scope of which was agreed to include inter-alia the following:

- a factual summary of the incident
- an outline of accepted international terminology regarding pressure bursts and related events
- an historical assessment of relevant mining experience at Austar Coal Mine
- a summary of international experience of coal mine pressure bumps and bursts – with particular reference to US experience
- a discussion of the geotechnical factors and the mechanics of coal pressure bursts, based on the current state of knowledge within the discipline on this topic, and with reference to the geological and geotechnical conditions prevailing at the event location at Austar
- on the basis of the above, to identify the primary causal factors that may have led to the event occurring.

TERMINOLOGY

There are a number of terms used across the international underground mining industry (including both hard and soft rock mining) that are of relevance to any discussion of dynamic ground failure events in underground mines, including the type of event that occurred at Austar Coal Mine on 15 April 2014.

In any situation, four conditions have to be satisfied simultaneously in order for a dynamic (violent) rock failure to occur. The first is self-evident and implicit in the other three conditions reported by Salamon & Wagner (1979). These four conditions are:

1. The stress environment must be sufficiently high to result in rock failure.
2. A situation must exist which can result in a state of unstable equilibrium. This could be a low friction bedding plane, for example, where the potential exists for the coefficient of friction to drop rapidly from its static to dynamic value once movement is initiated along this plane.
3. A change in the loading system. Potential triggers include, for example, a reduction in system strength due to a local change in rock mass material or structural properties, an increase in system stress associated with a local geological structure, or a decrease in confinement due to the formation of one or more excavations.
4. A large amount of energy has to be stored in the system. This energy can be generated, for example, by depth of mining, bridging strata or geological structures.

While these conditions were applied by Salamon and Wagner to rock burst behaviour, they are potentially applicable to all the types of events listed below, other than outbursts. (These factors are discussed further in relation to the Austar Coal Mine later in this report.)

There is no universally accepted and unique set of definitions for all of these terms, as is reported below, however the following descriptions are widely regarded as appropriate – at least within the Australian mining context.

The terms to be discussed are as follows:

- rock burst
- strain burst
- pressure bump
- pressure burst
- outburst
- coal bump
- coal burst
- pillar bump
- pillar burst

All of the above describe events associated with some form of dynamic energy release, usually associated with intact rock failure. This release of energy can vary greatly in magnitude and may or may not generate a measurable seismic signal.

Rock bursts and strain bursts are terms used to describe such dynamic energy releases and rock failure associated with hard rock mining. The source of the energy is directly related to stress levels within the rock, albeit that the manifestation of the stresses, and the triggers for the release of the energy can be quite complex, involving many factors. The difference between a rock burst and a strain burst is simply one of consequence scale due to different energy magnitudes – with strain bursts being of much lower energy magnitude, such that the

resulting rock damage is far less than for a typical rock burst. These terms are not generally used in underground coal mining, although the geotechnical mechanisms involved may be very similar to the coal mining equivalent events summarised below.

The next two terms are those most commonly used to describe dynamic energy releases in underground coal mining – pressure bumps and pressure bursts. Both terms refer again to dynamic energy events associated with stress levels in the rock mass, which includes coal seams. However, the commonly accepted difference between a pressure bump and a pressure burst relates to the magnitude and hence consequence. A pressure bump is a dynamic release of energy within the rock mass in a coal mine, often due to intact rock failure or failure/displacement along a geological structure, that generates - an audible signal; ground vibration and potential for displacement of existing loose or fractured material into mine openings (A pressure bump is also sometimes referred to as a bounce).

On the other hand, a pressure burst is a pressure bump that actually causes consequent dynamic rock/coal failure in the vicinity of a mine opening, resulting in high velocity expulsion of this broken/failed material into the mine opening. The energy levels, and hence velocities involved here can cause significant damage to, or destruction of conventional installed ground support elements such as bolts and mesh.

An outburst in Australian mining terminology, is also a dynamic energy release leading to some form of rock failure, however the source of energy is primarily associated with in situ gas pressure, sometimes also accompanied by stress-related energy. Outbursts are therefore normally only associated with coal mining (where there is more prevalence of in situ gas), and usually only occur within the coal seam. However there are exceptions to this, such as gas pressure in shale and other strata units containing gas in proximity to the mining horizon and also in non-coal mines where gas can be present, such as evaporites, including salt and potash mines.

Caution is emphasised with the use of the term outburst, when reviewing international literature. While most European deep coal mining industries adopt the terminology as described above, the US coal industry uses the term outburst to describe dynamic events that are purely stress driven as the energy source – events that in Australia would be referred to as a pressure burst or a coal burst. An example of this was the August 2007 Crandall Canyon multiple fatality event (Gates et al., 2008) where large sections of panel pillars failed dynamically, trapping and killing the pillar extraction mining crew, and subsequently some of the rescue team. While the title of the MSHA Report of Investigation makes reference to the two “Coal Burst Accidents” that occurred, within the body of the report, these events are also described as outbursts, although there is no evidence of any gas being involved in the event as an energy source.

The terms coal bump and coal burst, together with pillar bump and pillar burst are generally synonymous with pressure bump and pressure burst - and are all terms used to describe such dynamic events in underground coal mining. These terms are in some ways an alternative name for a sub-set of the more general events covered by pressure bump and pressure burst. Coal bumps and bursts are specific to events emanating from within the coal seam (as opposed to roof or floor origin), while pillar bumps and bursts relate to events within pillars as opposed to either in solid development drivage or on a longwall face, for example.

On the basis of the terminology descriptions above, the Crandall Canyon event could be referred to as either a pressure burst, or a coal or pillar burst (but not an outburst – in terms of

accepted Australian terminology). It is also worth noting, that a number of burst events in the US coal industry are also referred to as bumps.

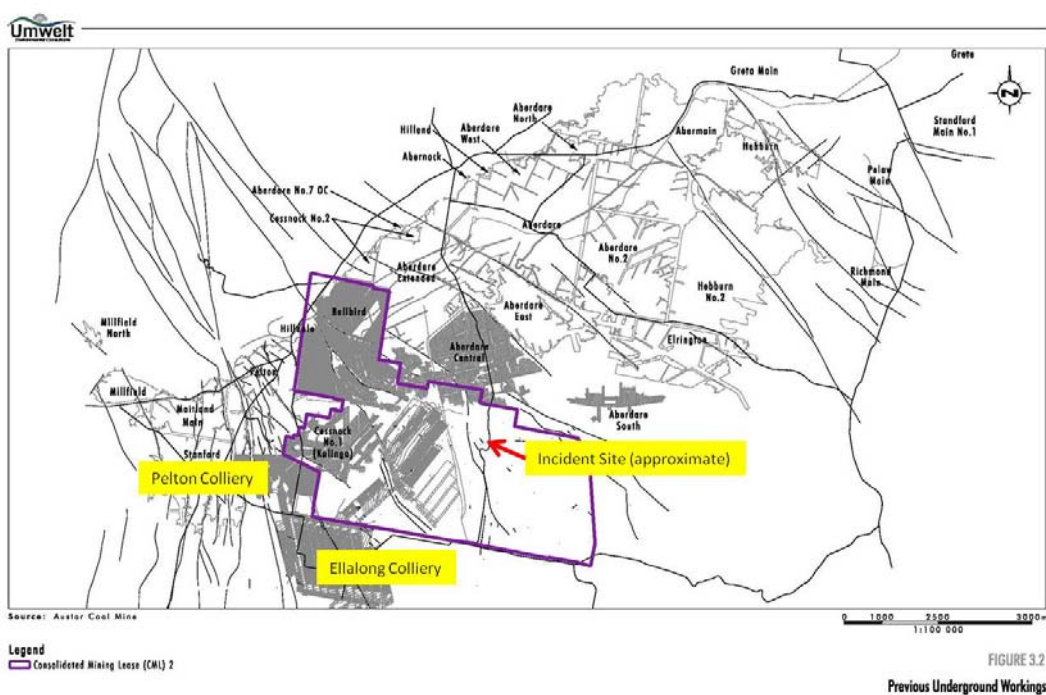
In all subsequent discussion in this report, the event that occurred at Austar on 15 April 2014 is described as a pressure burst. The report also describes other events at Austar Coal Mine, which included pressure bumps.

HISTORY OF MINE DEVELOPMENT

Austar Coal Mine Pty Ltd (Austar) operates the Austar Coal Mine, which was formerly known as Southland Colliery and, prior to that, Ellalong Colliery. It is the last underground mine extracting the Greta Seam and abuts the mine workings of a number of defunct mines, with its mining lease incorporating portions of a number of these mines.

The earliest mine workings in Austar Coal Mine date back to those of Pelton Colliery, which commenced production in 1916 (Umwelt, 2008). In the late 1960s, Cessnock No. 1 Colliery (also known as Kalingo Colliery) was amalgamated into Pelton Colliery. Pelton Colliery developed into Ellalong Colliery, Figure 1, which was opened officially in July 1979. The first longwall went into production in 1983. In 1994, these operations were impacted by high gas levels in the southern part of the mine, limiting further development of Ellalong Colliery.

Figure 1: Location of Austar Coal Mine relative to other collieries that have mined the Greta Seam (extracted from Umwelt, 2008).



In the meantime, a coal resource had been proven in the Greta Seam in an adjacent area referred to as Bellbird South, Figures 1 and 2. Development consent was granted to extend Ellalong Colliery into the Bellbird South area in 1996. Southland Coal Pty Limited acquired Ellalong and Pelton Collieries in 1998 and amalgamated them with Bellbird South and Cessnock No. 1 (Kalingo) leases to form Southland Colliery. This mine was operated until 2003 when it had to be sealed due to an outbreak of fire in an operating longwall panel. At

that point in time, 13 so-called Ellalong longwall panels and 4 so-called Southland longwall panels had been extracted (including that in which the fire developed). Subsequently, the mine was placed into receivership and operations were put on care and maintenance (Umwelt, 2008).

Figure 2: Location of Austar Coal Mine and its planned future workings relative to towns and mines in the region - note that the mine plan is not identical but very similar to that at the time of the incident (extracted from Umwelt, 2008).

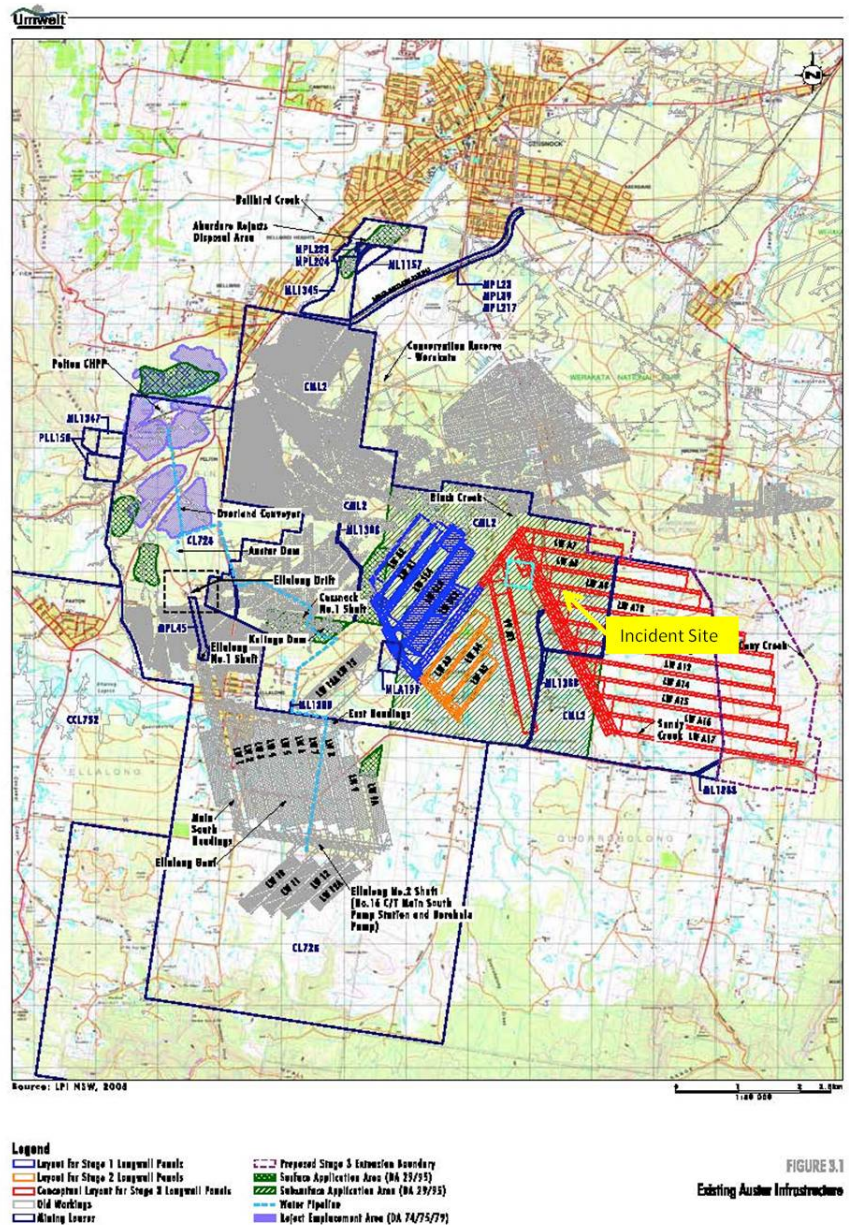


FIGURE 3.1
 Existing Austar Infrastructure

In December 2004, Yancoal Australia purchased the Southland Coal assets and changed the name of the mine to Austar Coal Mine. Mining recommenced using the LTCC method for the first time in Australia. As at 15 April 2014, the extraction of the seventh LTCC panel was almost complete. In the meantime, a new ventilation shaft was sunk, enabling most of the Ellalong Colliery workings to be sealed, Figure 2.

SUMMARY HISTORY OF BUMPS

GRETA SEAM

There is a long history of pressure bumps associated with mining in the Greta Seam. Much of this is anecdotal, particularly within mine management circles. Inquiries were made of some retired mine managers. By way of example, one former manager recalls attempting to drive underground roadways to connect Aberdare East Mine with Aberdare South Mine. These mines are to the north and north-east of the incident site, as shown in Figure 1. Large and frequent bumps were experienced in first workings at a depth of around 300 m, especially when mining through geological structures. A manager reported that the bumps were most severe in the up-dip corner of roadways when mining on a cross-grade and could be quite frightening to the uninitiated.

An ex-mine manager of Ellalong Colliery reported that bumping was so frequent during pillar extraction at a depth of only 100 to 130 m at Pelton Colliery, that up to three shuttle cars of coal could be loaded without needing to start the cutter heads of the continuous miner. Bumps were also known to result in the bending of 300 x 200 mm RSJs used as roadway cross-support in poor ground conditions at that mine. Floor heave was also reported to be associated with a number of bump events. Bumping was so prevalent during extraction of Longwall 1 at Ellalong Colliery that the shearer basically acted only as a coal loader, with the panel being extracted without consuming one full box of cutter picks. Later during the extraction of Longwall 4, a bump occurred that was so severe that it dislodged the shearer off its tracks.

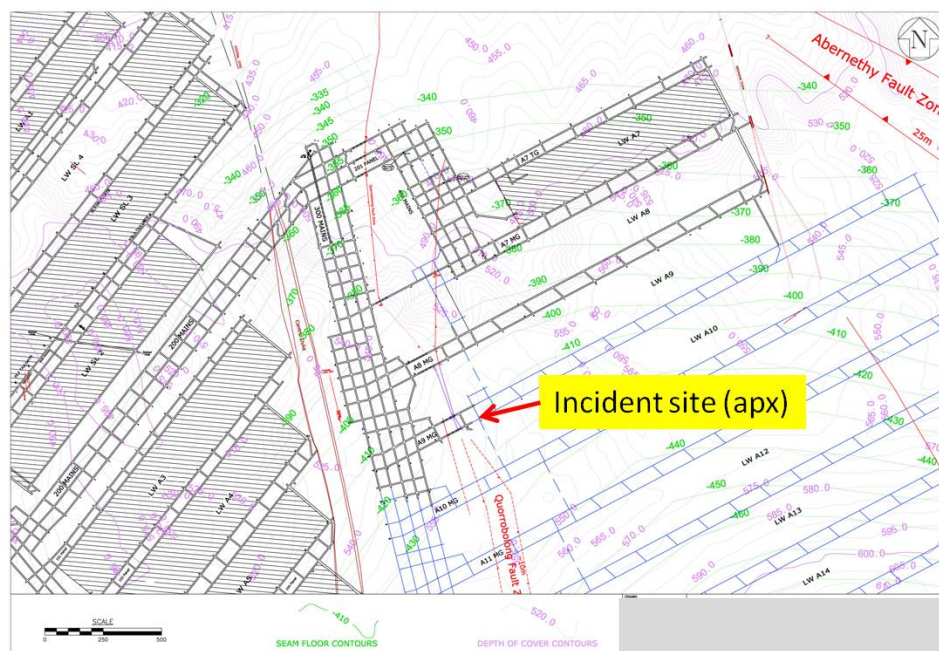
All ex-mine managers of whom inquiries were made, consistently reported that rib spall was associated with bumps. There was some uncertainty as to whether some bumps may have constituted coal bursts. They all expressed an unsolicited view that bumping was 'normal' in the Greta Seam and could be quite severe.

PELTON - ELLALONG COLLIERY

A mine worker also reported that bumps were common at Ellalong Colliery. However they considered that the magnitude and size of the bumps were not as severe as the bumps experienced at Austar.

200 MAINS DEVELOPMENT

Figure 3 shows the incident site relative to the 200 Mains Development, the 300 Mains Development, and Longwall A7; depth contours throughout this region; and geological structures.



Geotechnical reports commissioned by the mine make reference to bumps in the 200 Mains Development.

300 MAINS DEVELOPMENT – OUTBYE

A conference paper entitled *Geotechnical Considerations for Longwall Top Coal Caving at Austar Coal Mine*, reported in February 2011 that:

The operation experiences significant pressure bumps on development typically in association with the stiffer rock units located above and below the seam.

A report by Austar Coal Mine in 2012 records that:

On the 2nd of July 2011 during night shift there was an unusually loud pressure bump in the 300 Mains immediate to 5ct D heading. The continuous miner was working in C heading and had advanced about 15m down C heading inbye of 5ct. The bump displaced water off the floor immediate to the continuous miner, potentially moved mesh on a pod in the first cut through outbye and displaced an area of unconfined rib in D heading.

Typically the strata at Austar experiences bumps during development but the close proximity to the excavation made the apparent magnitude of this event raise concern as to the mechanism that had caused the event.

Previously the operation has experienced bumping of increased magnitude between 4 and 8ct in the 200 Mains. The increased bump magnitude in the 200 Mains between

4ct and 8ct was found to be in association to stiff floor unit (strong sandstone/conglomerate) and stiff roof strata (sandstone channel). Stiff strata units allow for the horizontal stress to move close to the excavation at which point when the strata units relieve due to mining induced stress the apparent magnitude of the bumping event into the excavation is amplified due to the close proximity.

As part of the investigation into the incident of 15 April 2014, the Investigation Unit made inquiries of a range of Austar Coal Mine employees in relation to this 2011 incident. They also visited the site, along with the authors of this report. These inquiries did not produce consistent and reliable information, primarily due to the passage of time and the different levels of exposure to the incident of the persons interviewed. Hence, this report has had regard only to reports prepared around the time of the incident.

Austar commissioned two geotechnical reports in relation to the 2011 300 Mains incident. The first report noted:

An underground seismic event occurred in 300 Mains and caused mobilisation of the lower section of the rib coal under the rib mesh. It also caused additional floor heave in the area. There was no reported change in roof deformation.

Seismic events are well known at Austar, and are typically related to fracture of the strata in the roof and floor. During longwall retreat seismic events occur due to fracture on (sic) the strata about the face and in particular within the Branxton Formation.

Seismic activity is also common about development roadways during driveage in zones impacted by elevated horizontal stress. The seismic activity is consistent with fracture of strata units within the roof and floor section. This type of activity was common in the 300 Mains headings.

The seismic event associated with the rib mobilisation and floor heave was a larger event than was previously experienced in the 300 Mains, and occurred outbye of the working face.

Seismic events or bumps associated with increased roadway deformation have been experienced in other parts of the mine complex. Such events were noted in 200 Mains and in SL2 gateroads within defined zones. These zones were inferred to be associated with elevated horizontal stress or zones where sandstone channels existed close to the seam.

Seismic events or bumps are also known to occur in the USA as a result of sudden failure of coal within pillars. This can occur during longwall retreat or development mining. The mechanism for the bump in these cases is failure of the coal within the pillar due to a sudden loss of confinement.....

Roof and floor deformation may occur during such events, however, the primary mechanism is failure and violent expulsion of coal due to the energy release in the ribside.

The inferred mechanism of loss of confinement and failure is a sudden stick-slip along the undulating coal contact surfaces.

The seismic event at Austar is considered to be most likely associated with failure of a unit within the floor due to elevated horizontal stress. The energy associated with such events

can propagate as a wave and displace the strata in the form of a "pressure pulse". The effect of this can be to dislodge loose material about the roadway.

It is possible that undulating contacts with the seam may increase the potential for stick slip failures of the coal ribside, however, if this mechanism were the primary cause, then many more failures would be anticipated during longwall retreat (as noted in the USA). This does not occur (irrespective of the geological zone) and as such the rib bump mechanism is not likely to be a primary cause of the seismic events.

It is very difficult to predict the likelihood of the larger seismic events, other than they appear to be related to high horizontal stress and potentially exacerbated by geological changes which may cause local variation in the stress field, strata units and the nature of the contact surfaces of the coal seam. Previous experience has been that they occur in narrow zones.

Approaches to minimise such impacts

- i. Improve the rib reinforcement system to maintain the coal rib during seismic events.*

A key improvement is to anchor the mesh to the base of the seam. The bolts at the top of the seam appear to be well placed, and the centre and lower bolts are the ones which may need review.

This may require specific bolting between shifts to ensure that the mesh is secured with a long bolt capable of anchoring into competent coal and being well grouted. Such bolting should be as close to the face as practicable.

- ii. Awareness of high stress zones and potential geological changes which may increase the potential for sudden events.*

- iii. Ensure that the roof reinforcement system is well placed and appropriate to the stress conditions and TARPS. The aim of this is to maintain the roof integrity such that it can withstand such seismic events without being dislodged.*

The report noted that bumps occur in coal pillars in the USA and associated the mechanism with the sudden loss of confinement. This is consistent with a range of research findings including those of Holland (1958), Babcock & Bickel (1984) and Iannacchione (1990). It also noted that this loss of confinement results in failure that was a sudden stick-slip movement along the undulating coal contact surfaces.

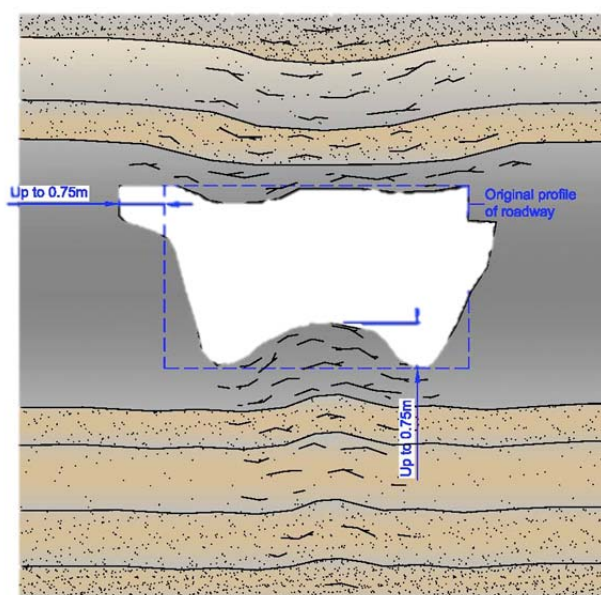
The report discounts this mechanism as a primary source of the seismic events at Austar Coal Mine as at 2011. This is apparently on the basis that many more coal bursts would be anticipated during longwall retreat (as experienced in the USA) if it were a primary rib bump mechanism at Austar Coal Mine. The report considered that the incident of 2 July 2011 was most likely associated with the failure of a unit in the floor. Notwithstanding this, it did not state that a coal burst could not occur at Austar Coal Mine.

The second geotechnical report in relation to the 300 Mains incident stated:

- 1. Several weeks after the roadway was developed and while the miner was in C Hdg (i) a large audible bump was reported inbye of 5 C/T in D Hdg and (ii) on*

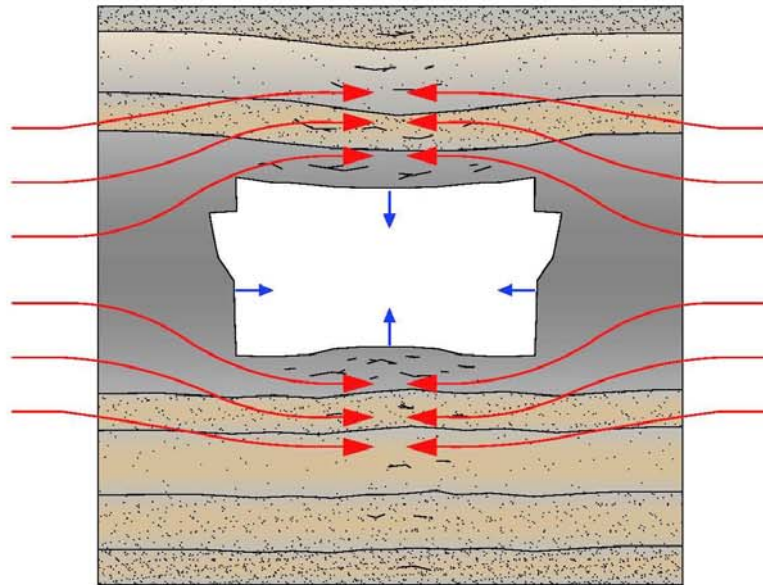
subsequent inspection, 70 to 80m of the left hand rib was found to have spalled for a distance of 1 to 2m into the roadway (see Figures ... and 2) - note: a) although it is not certain when it occurred, up to 0.75m of floor heave was noted in D Hdg and b) some degree of rib spall and floor heave was also noted in 5 C/T.

Figure 2 of the report is produced below.

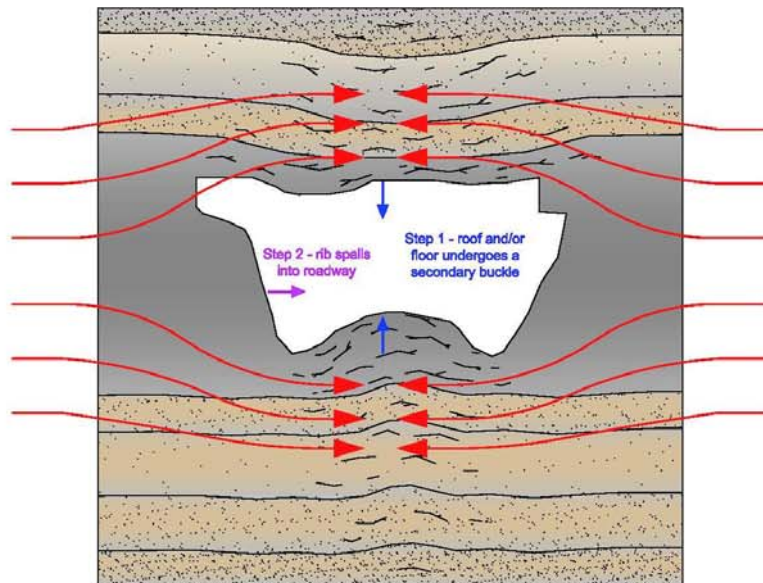


2. *Considering both the rate and the magnitude of the failure, this event has since been termed a bump - note: a) in the US, the term "coal bump" refers to a violent and uncontrolled failure of rib, roof and/or floor and b) generally in the US, coal bumps are associated with high vertical stress.*
3. *Critical to this assessment is the fact that at the time of the bump, a pillar had not been formed between C and D Hdgs...*
4. *On the basis of the above, it is assessed that the bump and the associated failure of the rib was (i) related to a sudden and large-scale secondary buckling event in the roof and/or floor strata and that (ii) this failure was driven by high horizontal stress...*
5. *Figure 11 of the report is produced below:*

Stage 1 - Roof, Floor and Ribs Buckle During Roadway Development



Stage 2 - Roof and/or Floor Store Horizontal Stress and Undergo a Secondary More Violent Buckle Sometime After Roadway Development



6. *At this stage, although it is not clear as to what has caused the horizontal stress to increase and/or the strata to react in such a violent manner, possible contributing factors include (i) the 545m depth of cover¹, (ii) the panel's location between two zones of structural disturbance², (iii) the roadway's angle of intersection with the major horizontal stress, (iv) the sedimentary dyke recorded on the inbye side of D5 intersection³ and the associated increased proximity of more competent strata in the immediate roof and (v) stress notching around the Area 2 longwall goafs.*
7. *Standard roadways mined to a coal roof*
 - a. *Rib support -3 x 1.5m long mechanically anchored rib bolts every 1m off the miner and 1 x 4m long megabolt every 1 m outbye of the miner - note: a) the megabolts should be grouted no more than 50m outbye of the face and/or after no more than 72 hours and where applicable, before the intersection is formed and b) so as to maximise aerial coverage, these cables should be installed in a "w" pattern approximately 1.5 and 2.5m above the floor.*
8. *In order to optimise the support design, future consideration should be given to.....*
 - (vi) *3m long cables in the ribs - note: assuming 1.5 to 2m of rib failed during the bump, it is assumed that no more than 1 m of anchorage will be required into presumably, more solid coal.*

The second report attributed the incident to the *sudden and large-scale secondary buckling event in the roof and/or floor strata*. This is not inconsistent with the first report's conclusion that *the seismic event at Austar is considered to be most likely associated with failure of a unit within the floor due to elevated horizontal stress*. This type of mechanism cannot account for the incident of 15 April 2014 since the pressure burst was in the side of a roadway and, therefore, in an area relieved of horizontal stress. This raises the question of whether the incidents of 2 July 2011 and 15 April 2014 are associated with different mechanisms or whether the incident of 2 July 2011 was, in fact, a coal pressure burst, either in its own right or as a result of being triggered by a bump in the immediate roof or floor strata.

The second report notes that *in the US, coal bumps are associated with high vertical stress*. The first report associated bumps in a coal seam with *a sudden loss of confinement*. As already noted, there is a range of literature that attributes coal seam bumps to a loss of confinement. The concepts presented in both reports are not inconsistent. It is not the absolute magnitude of stress that is the determining factor but rather the ratio between the driving stress and the (lateral) confining stress. The preceding figure (being Figure 11 of the second report) provides a good basis for visualising how removal of confinement can result in rock failure without any further increase in driving force. The figure is based on the removal of vertical stress, such that horizontal stress then overcomes the strength of the rock mass.

However, the same situation is associated with removal of lateral stress when a roadway is formed, thus allowing vertical stress to overcome the strength of the rock mass.

¹ The depth of cover at the site of the 15 April 2014 incident was ~555 m.

² The incident site of 15 April 2014 was between two geological structures.

³ A sedimentary dyke was present on the outbye side of the incident site of 15 April 2014.

As highlighted by the footnotes to the preceding point 6, a number of possible contributing factors identified in relation to the 2011 incident are also common to the 15 April 2014 incident. Both reports also identified a change in rib support design as a control measure.

In February 2012, Austar Coal Mine issued a report relating to the bump of July 2011 in the 300 Mains (Austar Coal Mine, 2012). Among other things, this report advised that:

1. *The area in 300 Mains was inspected on the 4th of July by Austar technical staff and it was suspected that the event was typical of what had occurred outbye between 4ct and 8ct 200 Mains. However due to the lack of geological information about the surrounding strata it was decided that a more extensive investigation be undertaken to remove concerns raised by external consultants about the mechanisms and potentials of these events occurring again.*
2. *Since the event, the area has been inspected and mapped by a number of internal and external professionals. The 300 Mains has undergone an extensive amount of roof/floor coring, bore scoping with numerous meetings and risk assessments conducted in order to maintain a high level of confidence for the safety of all personnel entering the underground.*
3. *Since the most significant pressure bump in July 2011, several additional bumps have been experienced all in association with the location of the channel system in the immediate roof of the 300 Mains. Also since the occurrence of the initial bump it has been ruled out that the occurrence of the bump is in relation to small pillar (sic) or as a direct result of vertical stress. It is evident that the bumps in the 300 Mains are in association with a sandstone channel located immediate to the top of the seam and high magnitude relieving horizontal stress.*
4. *There are no concerns for the safety of the operators within the workings. The pressure bumps are uncomfortable due to the sudden unexpected noise, however there has never been any coal or strata forced out under pressure as a result of a bump. Only loose unconfined coal has ever moved as a result of the bumps. The Greta seam coal is not capable of retaining stress due to the highly structured nature of the coal, so is not capable of causing any form of rock bursting.*
5. *Mining in the area is safe. The events, "pressure bumps" will continue as part of the normal operations at Austar. The apparent magnitude of the pressure bumps will vary dependent upon the proximity of the stiffer units in relation to the excavation.*
6. *Mining in the area is safe.*
7. *The coal contains too many discontinuities (cleat) to transfer any stress so is unable to rock burst.*
8. *These bumps will always be present at Austar due to the nature of the geology, they will continue to shock anyone in close proximity when these bumps occur, there is no single method of defining when these pressure bumps will occur but they will typically be associated with stiffer and strong rock units.*

9. *Further work will be conducted reviewing the effects of the horizontal stress in the immediate roof, this program will include the use of extensometers and shears strips to determine the magnitude and the association of the increased horizontal stress in relation the various geological sequences. This will allow for the forecast of the areas most susceptible to the pressure bumps.*

LONGWALL A7

Interviews established that pressure bumps occurred on the longwall A7 face. An undermanager reported that pressure bumps occurred on the longwall face, with '*all of the big ones*' on the longwall face and on development occurring during cutting. A technical services staff member at the time of the incident, confirmed that bumps occurred on the longwall face and that '*typically you'll get most of the bumps when you're actually cutting*'.

In February 2013, Shen et al (2013) presented a conference paper titled *Monitoring Longwall Weighting at Austar Mine Using Microseismic Systems and Stressmeters*. The monitoring system was designed specifically to detect stress changes and microseismic activity associated with cyclic (periodic) weighting during the extraction of longwall A5. Only strong events were analysed and located. The majority of these events were located within the longwall panel being mined and concentrated towards the tailgate side.

MAINGATE A8

Interviews established that pressure bumps occurred during drivage of Maingate A8 development. A mechanical technician reported that the main area where bumps occurred in Maingate A8 was in the 2 to 3 cut-through area, inbye of the fault. This is in a similar relative position to the incident of 15 April 2014 in Maingate A9. A deputy reported that bumps had occurred in Maingate A8, both during and outside of production periods. He described their scale as *small to moderate*.

300 MAINS – FACE AREA

The heading direction of the 300 Mains was approximately 160°, compared to that of approximately 60° for the headings of Maingate A9. At the time of the incident, the working faces in the 300 Mains were within about 400 m of those in Maingate A9. An undermanager reported that the support rules for both the roof and the ribs in 300 Panel were always on code orange.⁴ This constituted the highest level of support requirement while permitting production to continue. The next most extreme level (red) required the deputy (employee supervisor) to *ensure production is stopped and the face is secured*. As a point of reference, at the incident site, the roof conditions were code orange but the rib conditions were at the next less extreme level, being code yellow. An undermanager noted that the gate roads were in better condition than the workings in 300 Panel.

A deputy described how there were ribs in 300 Panel that looked a lot worse than that at the incident site. He described how:

⁴ The hierarchy from good to poor being Green, Yellow, Orange, Red.

...when we started having problems with pressure bumps and a few rib issues that they had going down 300 and they decided that, always with 300 just put code orange in, all the time, because of those issues that they had with the ribs...

Another deputy in 300 Panel, advised investigators that conditions in Maingate A9 seemed better than in 300 Panel. When asked if he recalled if there had been a slow progressive deterioration in conditions in 300 Panel or had it been much the same the whole time, the deputy thought the latter. When asked about the intensity of the pressure bumps and had there been any time when they had become more intense, the deputy advised that:

We have had some larger ones and it was... the explanation I understood was if you get more, if you have continual pressure bumps all the time, it's not too bad. Like that's a good thing. If we haven't had pressure bumps for a while that could be, like things were building up and maybe you'll get a bigger bump...

The deputy went on to state that he did not think pressure bumps were related to a position in the panel. They could occur in any heading or cut-through. An undermanager told investigators that he had concerns about pressure bumps. The undermanager did not know whether issues raised with his superior were taken to the technical services meetings, and he received no feedback from those meetings. However, he could recall having a conversation with the technical services department and being assured that the pressure bumps were not a source of concern. In raising his concerns, he used the term *outburst*, not *pressure burst*. He advised that at the time, he was not aware of the phenomenon of pressure burst or rock burst. He only became aware of it after the incident. He stated that he was told by technical services that *the pressure bumps were related to a massive sandstone wash above 300 panel*.

MAINGATE A9

The deputies' statutory reports obtained by the Investigation Unit make references to the occurrence of pressure bumps and ribs blowing out in Maingate A9 and 300 Mains Panel for the period 21 March 2014 to 14 April 2014.

The interviews by the Investigation Unit have produced detailed and consistent information concerning bump activity in Maingate A9 Panel in the four shifts immediately preceding the incident. Information regarding earlier bump activity is not comprehensive. There was variation between supervisors in the reporting of bumps and the manner in which these reports were made. Some incidents were recorded in writing only in deputies' statutory reports, some only in deputies' production reports and some in both. There is also a range of evidence that some were only reported verbally.

THE INCIDENT

During the preceding shifts, some bump activity had occurred, including a large bump during afternoon shift of the previous day (14 April). Mining conditions in B Heading at the time included some spall of the right hand rib, below the Dosco Band (see Figure 6, for an image of the Dosco Band parting within the coal seam). However the left hand rib was standing straight. Roof conditions had deteriorated, and so some supplementary forward, low-angled spiling with cable bolts had been installed in the centre of the roadway.

At the time the burst took place on 15 April, the miner had been cutting the face and had just loaded a shuttle car. A decision had been made in the previous shifts not to proceed with simultaneous cutting and bolting. So at this time the face area (roof and ribs) had been

previously bolted, prior to the miner recommencing cutting, but no drilling or bolting was occurring. However, although they were not carrying out simultaneous bolting while cutting, some members of the crew were standing on board the bolting platform of the miner while cutting was taking place. This included Messrs Mitchell and Grant – who were on the left hand side of the machine.

In regard to the prevailing geological conditions, A Heading, inbye of 2 cut-through (on the left of the panel facing inbye) had previously struck a fault with a resulting roof fall. A “dog-leg” angled stub heading had been driven to the right of the panel off an extension of 2 cut-through, in an effort to locate the possible faulting ahead of the panel. The dog-leg drivage again resulted in a roof fall at the face, although it is difficult to ascertain whether the projected fault expected in the vicinity was actually exposed in the face, or whether the poor conditions that led to the fall were associated with poor ground leading up to the fault.

Based on projections of the faulting and geological structure already encountered (structure referring to any form of geological discontinuity in the coal seam such as faults, dykes etc), B Heading was approaching and expecting to intersect the same faulted, structured ground that had been encountered in A Heading, and possibly in the dog-leg stub.

B Heading was being driven at the time of the accident, with a number of bumps experienced in the shifts leading up to the pressure burst from the left hand rib. The heading had advanced approximately 25 m past 2 cut-through. The mine layout is shown in Figure 4.

Figure 5 shows a plan sketch of the continuous miner position when the burst occurred from the left hand rib beside the miner, striking and engulfing the two men who had been standing on the platform on board the miner.

Figure 4: Maingate A9 development status at time of accident on 15 April 2014.



Figure 5: Plan view showing continuous miner position relative to face and burst location.

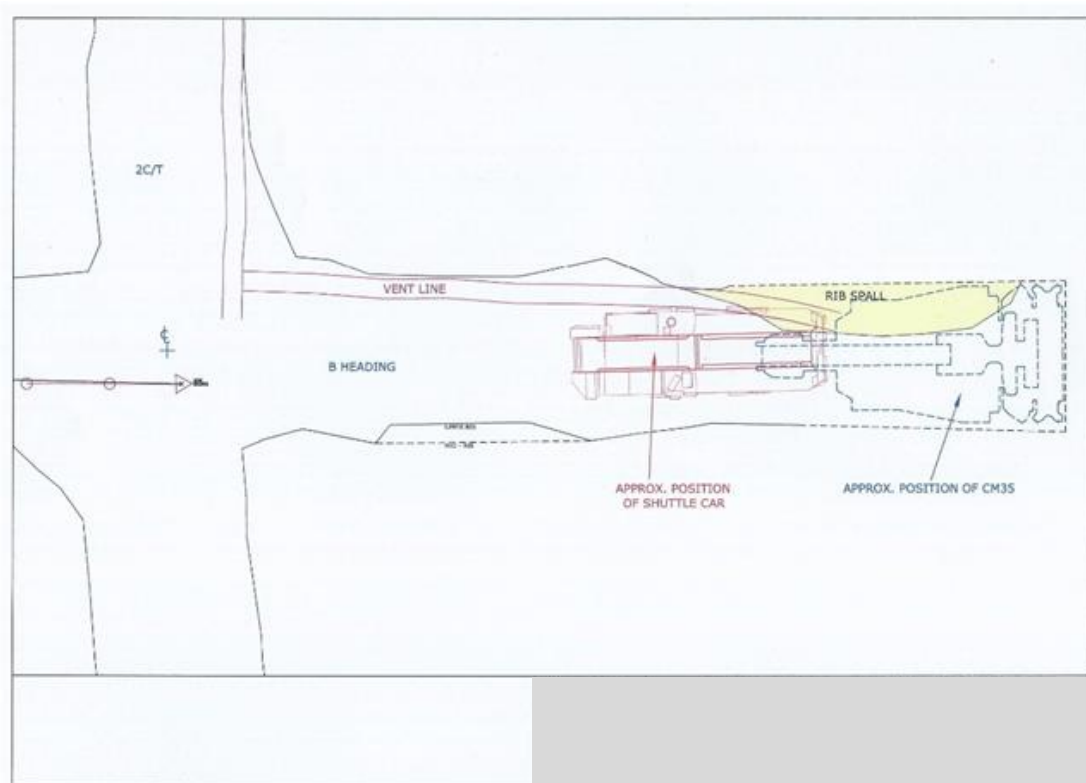
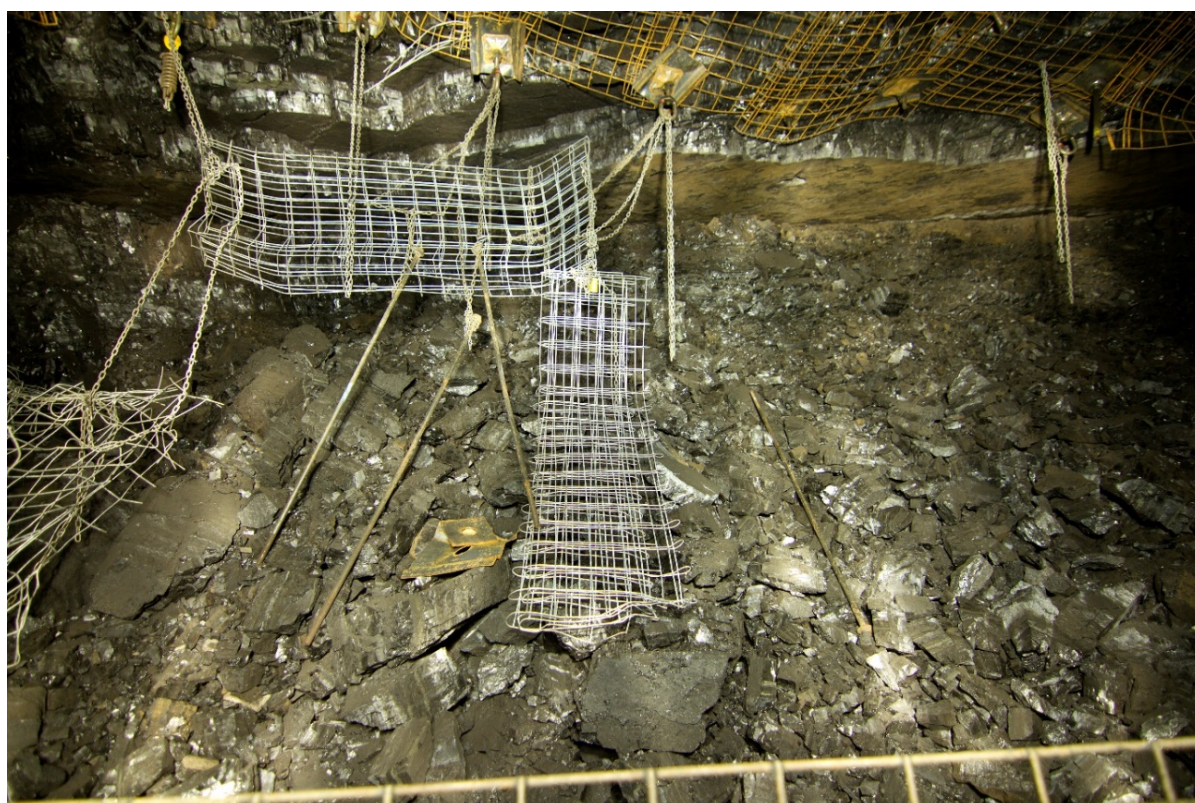


Figure 6 shows the central portion of the burst cavity, taken from where the continuous miner had been located. The actual burst location extended several metres either side of this location. Clearly evident in this photograph is the marker band in the seam known as the Dosco Band. This appears to have formed an upper-bound to the burst cavity, and has acted as a shear plane below which the coal has moved out horizontally during the dynamic failure process. The bedding plane surface of the Dosco Band also clearly exhibits evidence of shearing, and the distinctive reddish brown colouring, which has been reported from other burst locations around the world, associated with the fine dust caused by high stress pulverising/shearing of the coal particles. The extent of the burst cavity into the rib has not been accurately established, but it clearly extended beyond the depth of the previously installed rib support.

Figure 6: Looking into the burst cavity from the position of the continuous miner.



Subsequent investigations have found no evidence of any significant levels of gas involved in this accident, ruling out a gas driven component to the failure, so it cannot be classed as a gas outburst.

Figure 7 is a view looking into B Heading while the continuous miner and shuttle car were still in place at the face. This shows the pressure burst cavity beside the left hand side of the miner. It also shows the deterioration in the roof conditions at the location, prior to the event. Cable bolts had been installed over the miner location in a supplementary spiling support pattern to add stability to the roof, prior to the event occurring. Reasonably good rib conditions are evident on the left hand side, outbye the burst location, in contrast to more damaged ribs on the right hand side. Figure 8 is a close-up photograph of the burst cavity beside the miner, clearly showing the distinctive smooth shear plane of the Dosco Band that formed the upper bound of the burst cavity.

Figure 7: Burst location on the left side of shuttle car parked at the back of the continuous miner, looking inbye in B Heading.



Figure 8: Close-up of burst coal pile adjacent to the continuous miner.



PRESSURE BURST MECHANICS

FUNDAMENTAL PRINCIPLES

The four principles that have to be satisfied simultaneously in order to generate a dynamic rock failure in an underground mine are repeated here to provide context for discussing the mechanics of pressure bursts. These principles are:

1. The stress environment must be sufficiently high to result in rock failure.
2. A situation must exist which can result in a state of unstable equilibrium. This could be a low friction bedding plane, for example, where the potential exists for the coefficient of friction to drop rapidly from its static to dynamic value once movement is initiated along this plane.
3. A change in the loading system. Potential triggers include, for example, a reduction in system strength due to a local change in rock mass material or structural properties, an increase in system stress associated with a local geological structure, or a decrease in confinement due to the formation of one or more excavations.
4. A large amount of energy has to be stored in the system. This energy can be generated, for example, by depth of mining, bridging strata or geological structures.

Any form of pressure burst is a complex phenomenon, usually involving multiple factors. It is not always possible to unravel the different or dominant causal factors that may lead to a burst. However, using these four conditions, it is possible to gain an insight into how such events might occur. It may also be possible to use these fundamental principles to develop potential prediction and control strategies.

Firstly, the level of stress in the rock mass, which includes coal seams, must be high in order to cause either rock or coal failure. A coal burst may represent a secondary or primary dynamic failure. Failure of rock in either the near-roof or floor can lead to a sudden release of stored energy, which is then transmitted to the coal seam with subsequent secondary coal failure. The high stresses may be either vertical or horizontal, however the stress levels leading to a direct or primary dynamic event are almost certainly going to be due to vertical stress. This can be as a result of depth, plus any mining-induced stresses (either regionally or locally) superimposed on the coal. Mining at depths of 500 m and greater, as was occurring at Austar, would satisfy this high stress condition – quite apart from any consideration of additional mining-induced vertical stresses, or other stress concentrations or rotations caused by geological structure.

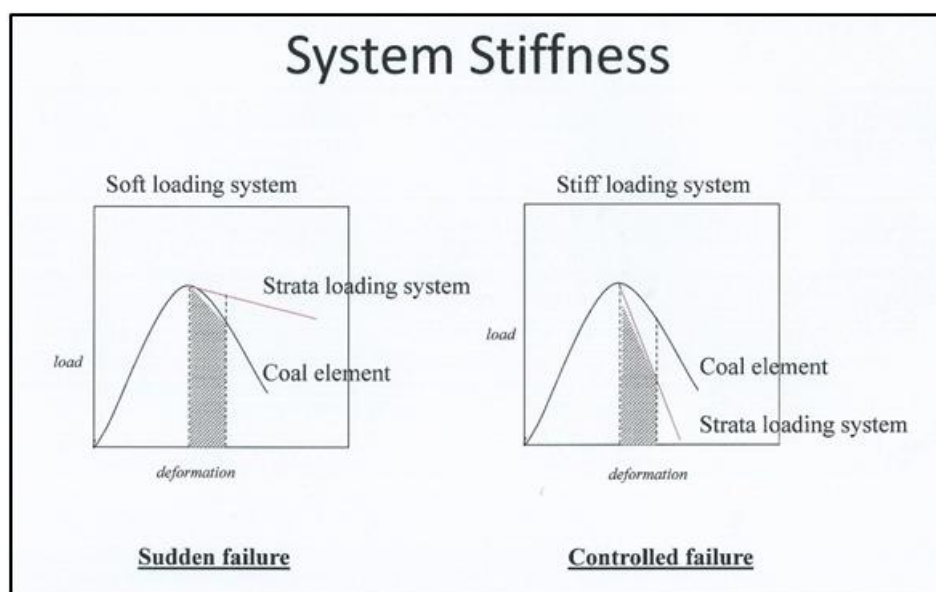
Secondly, there needs to be some form of trigger within the rock fabric to lead to an unstable equilibrium situation – as suggested above, this could be a low friction bedding or shear plane where shear failure can occur under a dynamic reduction of friction on the failure surface, resulting in rapid displacement of material adjacent to such a surface. The bedding plane represented by the Dosco Band clearly acted as a dynamic slip plane and limiting boundary for the coal displaced by the Austar Coal Mine burst (as is evident in Figures 6 and 8). There may also have been low friction planes that were mobilised within the coal seam or the surrounding strata, associated with the complex array of faults and shear zones in the area.

Thirdly, the change in the loading system is needed to create the energy release trigger. Prior to the event, the stresses in the ground are in a state of equilibrium. There must be some form of load change, or rock property change under a steady state loading regime, to initiate the dynamic failure event. In a rock burst situation in hard rock mining, this is very often created by an adjacent blasting activity which puts sufficient additional energy into the rock to cause failure. In other hard rock or coal situations, the change to the system can be changes to rock strength as a result of simple lithological variation (e.g. massive thick overburden units thinning out, or being intersected by major geological structure, leading to failure of a previously stiff and strong overburden roof beam); or sheared or highly structured coal or rock in the vicinity of major geological structure; or simple loss of confining pressure due to the presence of approaching/adjacent mining. Confining stress within intact rock results in a significant increase in rock strength, relative to the unconfined, or uniaxial strength. As mining approaches, the horizontal confinement provided by the intact coal is progressively removed and so the rock mass close to the roadway or mining excavation changes from a state of triaxial compression with high strength, to a state approaching much lower uniaxial strength. This can be sufficient to cause a highly stressed section of rock or coal to fail, potentially in a dynamic and violent manner.

In the case of the Austar Coal Mine incident of 15 April 2014, there were high strength, massive strata units (layers of competent rock) present – both in the immediate roof and in the floor. Whether variation in thickness and or strength of these units occurred in the vicinity of Maingate A9, which could have led to a sudden failure, is unknown, but is a potential factor. There is no doubt that there was an extensive array of regional and localised geological features in the vicinity of the accident site that would represent a likely contributor to the trigger event for a pressure burst – either by creating a stress change, or by causing significant degradation in rock/coal mass strength due to structure (cleats, joints, shear zones, etc). Finally, there will always be a reduction in confinement when a mining excavation advances into an area of solid rock or coal.

Fourthly, for a large burst event to occur (as was the case at Austar Coal Mine), the rock mass involved must be capable of storing sufficient energy in the first place. Particularly weak and soft coals or rocks are far less likely to be able to store sufficient energy to enable a major event to occur. Energy storage is related to both strength and stiffness (related to elastic modulus of the material involved). In other words, the rock must be strong enough to be able to absorb or carry high levels of stress, without significant deformation occurring (i.e. stiff). This can lead to the rock material storing a large amount of stress-driven potential energy stored in the competent rock mass. Not only must the rock be able to store large amounts of energy, but it must also release that energy in a dynamic (and potentially violent) rather than controlled manner, for a burst event to occur. This then leads to the understanding of the total loading system in the rock mass. Figure 9 illustrates this concept with respect to an element of coal being loaded between surrounding strata.

Figure 9: Concept of soft and stiff loading systems.



This figure shows a load-deformation curve for the coal material, as well as a loading curve for the surrounding system (e.g. overburden or floor rock units). The area under a load-deformation curve, for a given increment of deformation, represents a measure of energy involved. Firstly, the coal must be strong enough to store sufficient energy, but if and when it fails, the coal must be stiffer than the surrounding rock mass such that the coal unloading curve can store more energy than the amount of energy being imparted by the strata loading system. In this figure, the area under the unloading curve of the coal, for a given increment of deformation, must be greater than the area under the loading system curve (see right hand controlled failure situation, compared to the left hand sudden failure where the strata is imparting more energy than can be absorbed by the coal).

Interpreting this behaviour model – especially in relation to potential direct coal burst failures under vertical loading – it could, and historically was once interpreted that only some coals with high strength and brittle (steep) unloading characteristics were capable of coal or pressure bursts, at least of great magnitude. In isolation from other factors, this conclusion may have been correct. However, in the real world, all the other previously noted factors above need to be considered together, and when this is done (representing the real world, and the world of Austar Maingate A9) such a conclusion is not valid. Even the role of loss of confinement in a three dimensional stress environment, may lead to a violent failure of a block of coal that has been stressed well above its uniaxial strength. Simple unloading curves or post-failure curves such as illustrated in Figure 9, do not take account of triaxial conditions adequately, and certainly do not introduce the larger scale geological factors that may also be involved.

INTERNATIONAL EXPERIENCE

Bräuner (1994) provides a comprehensive discussion of international experience with regard to dynamic burst events in coal mining. He discusses the extensive European experience in countries such as Germany and Poland where a number of empirical prediction techniques for bump/burst-proneness have been developed over decades of deep mining experience. These include the use of regular trial drill holes to measure the quantity of cuttings produced – as a

measure of locations of high stress and/or lower coal strength (relative to stress). Such techniques are valuable where there is a sizable database that has been correlated against bump or burst occurrence. However, in isolation, such techniques have limited value and caution in reliance on them alone must be adopted.

European experience for prevention of bursts also included the use of large diameter boreholes drilled parallel with developing rib lines, within the region of high stress abutments (say within 2m – 5m of the rib line). The purpose of such holes was to provide an opportunity for controlled stress relief or localised failure of the coal into the boreholes so that the coal was allowed to yield “within” the rib and the rib line was protected from the hazard of a high stress-driven burst event. European mines have claimed considerable success with this method over the years it was practised. It is similar to the concept of controlled shotfiring at or ahead of the face in both hard rock mining, and in some coal mining applications – to soften and stress relieve the ground ahead of the advancing mining face. Shotfiring has also been widely used in Europe for control of gas outburst-prone coal conditions. Recent discussions with Iannacchione (2014) also referred to US trials by US Steel of large diameter (23 inch) auger boreholes for stress relief in burst-prone coal. This form of prevention or control strategy warrants further investigation for the future, when mining under identified high bump/burst-prone conditions.

One caution with interpretation or direct adoption of European experience, quite apart from any differences in geology, is that the type of mining is generally different to modern retreat longwall mining as practised in either Australia or the US. Many of the European practices were developed in multi-seam advancing longwall conditions where the stress regime around the mining excavations can be quite different, and where rates of mining were far lower than would be typically experienced in retreat mining – either on development or at the longwall face. Rates of mining can have a major impact on the ability of the rock or coal to deform and relax/yield under a high stress situation, with low mining rates tending to be more “forgiving”.

The previous section of this report discussed fundamental rock mechanics theories concerning stiff and soft loading systems and their impact on different coal types – especially with regard to post-failure behaviour. In spite of the different geotechnical properties of coal material, especially the strength, modulus and post-failure stiffness or brittleness, which can affect the amount of energy that can be absorbed in a soft loading environment, overseas pressure burst events and field and laboratory research that predate the incident suggest, as noted earlier, that:

- variations in the physical and mechanical properties of coal are not necessarily key factors in determining propensity to bursting (Bräuner, 1994, Iannacchione & Zelanko, 1995);
- many, if not most, bituminous coals have a potential to burst (Babcock & Bickel, 1984, Iannacchione & Zelanko, 1995, Iannacchione, 2014, Mark, 2014a); and
- bursts can occur in soft coals in a strong roof and floor environment (Peng, 2008)

It should be noted that different authors in the USA coal mining literature use the terms ‘bump’ and ‘burst’ almost interchangeably, without making the distinction of dynamic

expulsion of previously intact coal or rock in a burst – as has been defined earlier in this report. Therefore the reader must analyse each event described as a bump, to understand if it might be better defined as a burst.

Iannacchione & Zelanko (1995) published a historical review of US bumps⁵ in 1995 in the Proceedings of a US Bureau of Mines series of seminars titled '*Mechanics and Mitigation of Violent Failure in Coal and Hard-Rock Mines*'. This review analysed records of 172 coal bump incidents that had been reported and analysed by USBM researchers. Within this 172 case database, 21 bumps were recorded in development mining locations. Many of the bumps in the database were associated with extraction practices – either on or around longwall faces, or pillar extraction panels. One of the major conclusions of this review was that high stress was a universal factor – arising from significant depth, and also from mining induced effects of multi-seam mining, mining in or near highly stressed barrier pillars, or in proximity to goaf areas. However, Iannacchione & Zelanko, also noted that virtually all bump events occurred in coal seams where there was a proximity to strong, thick rock strata in either the overburden or floor. Iannacchione (2014) reconfirmed that this characteristic of bump-prone locations continues to prevail in 2014 (together with high stress, and quite often, regions of structurally disturbed geology). He also commented that changes in roof or floor lithology, such as rolls and thinning or lensing of thick stiff strata units was a critical factor to consider.

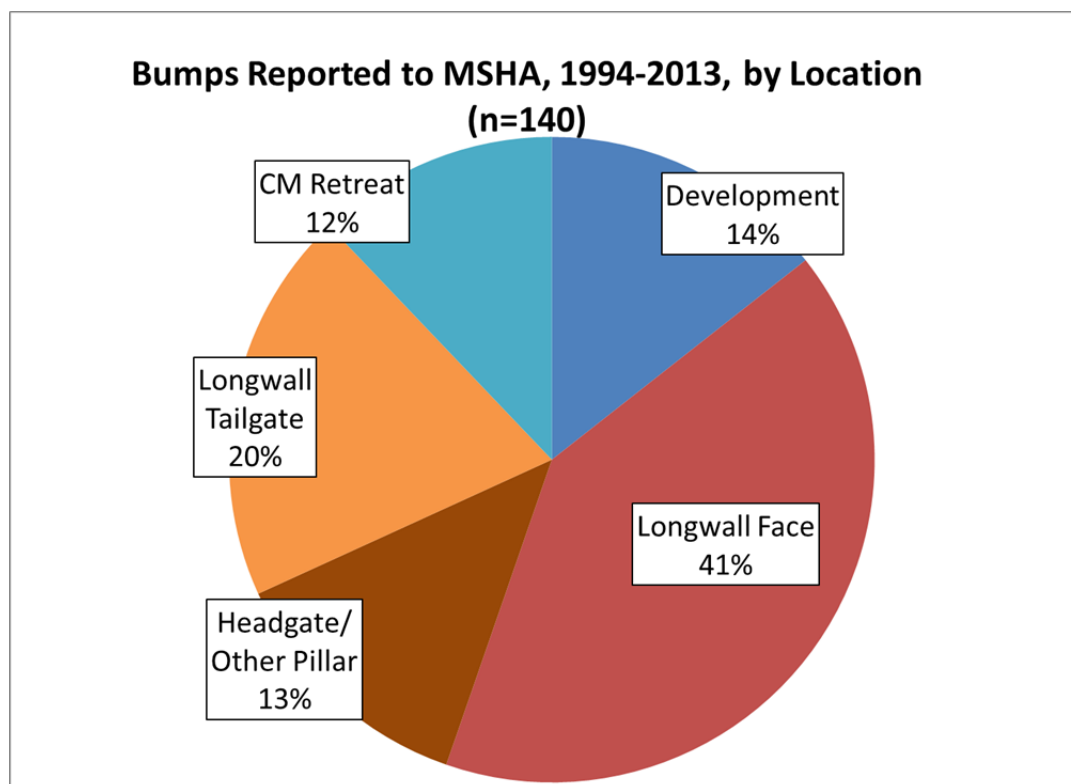
Newman (2002) describes a series of bumps⁶ that occurred in a bord and pillar development panel at a mine in Kentucky. The mine was a multi-seam mine with massive sandstone units (ranging from 10 m up to 35 m thick) in proximity to the coal seams. Bumps occurred in two different development panels as they crossed beneath barrier pillars in the older upper seam workings. This again confirms the role of mining-induced stress levels as a factor. In the first panel bump there was no pre-cursor activity or evidence, prior to the major bump which damaged several pillars. As a result, mining ceased and the panel was sealed. However, in the second, adjacent panel, from two days prior to the event, there were signs of numerous small bumps occurring and “cutter roof” (closely spaced shearing or failure of the roof strata) developing back from the advancing face. After the event, which again damaged multiple pillars and equipment, there was evidence in some locations of reddish brown coal, claimed to be indicative of highly stressed coal.

Mark (2014b) provided an update of the 1995 US coal burst database review, in his keynote paper delivered to the AusRock 2014 Conference in Sydney in November, 2014. He analysed a further 140 burst events in US coal mines between 1994 and 2013. Figure 10 is a summary of the locations of these events relative to the mining operation.

⁵ Referred to as *bumps* by Iannacchione and Zelanko.

⁶ Referred to as *bumps* by Newman.

Figure 10. US burst locations reported over period 1994-2013 (after Mark, 2014b).



Notably, only 14% of the reported bursts occurred during development, with 41% occurring on the longwall face. This should not be seen as a reason for complacency regarding the risk of bursts on development in longwall mines. Rather, it is a warning that in areas where bumps or bursts can occur, the longwall face is potentially an even greater risk than development.

Four of the 140 events in the new database resulted in a total of five fatalities, two on longwalls, and three during two pillar recovery events. It is reported by Mark (2014b) that the Crandall Canyon mine disaster which claimed six lives was not included in the database. Mark states “*That event was unique and can be best describe as a catastrophic, mine-wide, pillar system failure*”. Nevertheless, it should be regarded as a pillar burst under the terminology adopted in this report, and was clearly a result of high stresses associated with overloaded pillars during pillar extraction.

In regard to prevention, Mark makes the following pertinent statements:

“Managing the risk of coal bursts begins with an evaluation of the factors that increase the likelihood of bursts. These include the depth of cover, the presence of past mining above or below, the roof and floor geology, and the presence of faults and other geologic factors. A past history of bursts is one of the most powerful indicators of burst risk during any type of mining. Major bursts have often been preceded by smaller ones. Often these “precursors” have occurred at the same stage in the mining process as the subsequent large event (for example, in the same location on the longwall face). Also, once a mine has experienced bursts, later situations with similar geology and mining methods should also be considered high risk.”

Once zones at elevated risk of bursts are identified, the next step is to determine appropriate control techniques to employ within each one. According to risk management principles, the most effective way to reduce a risk is to eliminate it entirely (Iannacchione et al., 2008). In the context of burst control, this would be achieved by not mining at all in the areas of greatest risk.

Where the risk is not great enough to indicate complete avoidance, mining may be limited to development only. For example, in a mountainous area, the main entries might be developed beneath the ridgeline where the cover is deepest.

Pillar design is the primary engineering control for minimizing the risks of pillar failure and coal bursts during retreat mining under deep cover. In longwall mines, inter-panel barriers have successfully reduced the burst risk under the deepest cover. Operational techniques used by longwall mines to reduce the burst risk include reducing the depth of the web, reducing the speed of the shearer, uni-directional cutting, and/or avoiding double cuts at the gate ends.

Administrative controls can be used to limit the exposure of miners to the areas of highest burst risk (Varley and Whyatt, 2008). They can include:

- *Allowing only the minimum number of persons required to extract the coal into the areas where coal is being mined.*
- *Positioning remote-control equipment operators as far from the active mining as practical (depending on radio signal range and visibility constraints)."*

As stated above by Mark, the used of fully remote control equipment is an obvious objective going forward, in relation to mining in burst-prone conditions.

Since much of the US burst experience has been associated with pillar failures, and failures adjacent to longwall faces in gate end areas, one of the major control strategies in the US has been the use of appropriate pillar designs to manage the stress levels present. For a number of decades now, US mines in deep (500 m+) conditions have adopted a variety of yield pillar configurations to prevent high stresses adjacent to critical longwall face ends, or in main gate roadways. Different combinations of two, three and four heading gateroad developments are practised. In the western areas, two heading developments are used with a single yielding pillar between them (as narrow as 10 m). In other areas with three or four gate roads, combinations of yield-stable, or yield-stable-yield are used with the wider stable pillar carrying the regional load while the yield pillar is located adjacent to the location to be protected, and creates a stress relief region after yielding has occurred (although the actual yielding of the pillar can be quite a dynamic and sometimes violent event when it does take place). NSA Engineering (2000) prepared a report for UNSW on yield pillar systems in the US coal industry. This report, subsequently released as a component of the Australian Coal Association Research Program (ACARP) project C9018, provides a comprehensive summary of different forms of yield pillar practices in the US coal industry and related geotechnical considerations.

SITE GEOLOGICAL CONDITIONS

Figure 11 is a stratigraphic section through a series of boreholes in the vicinity of Maingate A9. This shows the presence of a number of stiff sandstone units above the coal seam, with some lensing. These are moderately thick sandstones within the first 20m of roof, overlain by the massive Branxton Sandstone formation, located about 20-25 m above the Greta Seam in the vicinity. Unfortunately these boreholes do not penetrate more than 10 m into the floor. However other data from the region (such as reported as near-seam stratigraphy in the Longwall A7 Geological Hazard Plan), together with geological data from nearby boreholes does indicate the presence of both conglomerate and sandstone massive strata units below the Greta Seam in this region of mining, in close proximity to the seam floor.

Figure 11. Stratigraphic section of overburden geology close to Maingate A9.

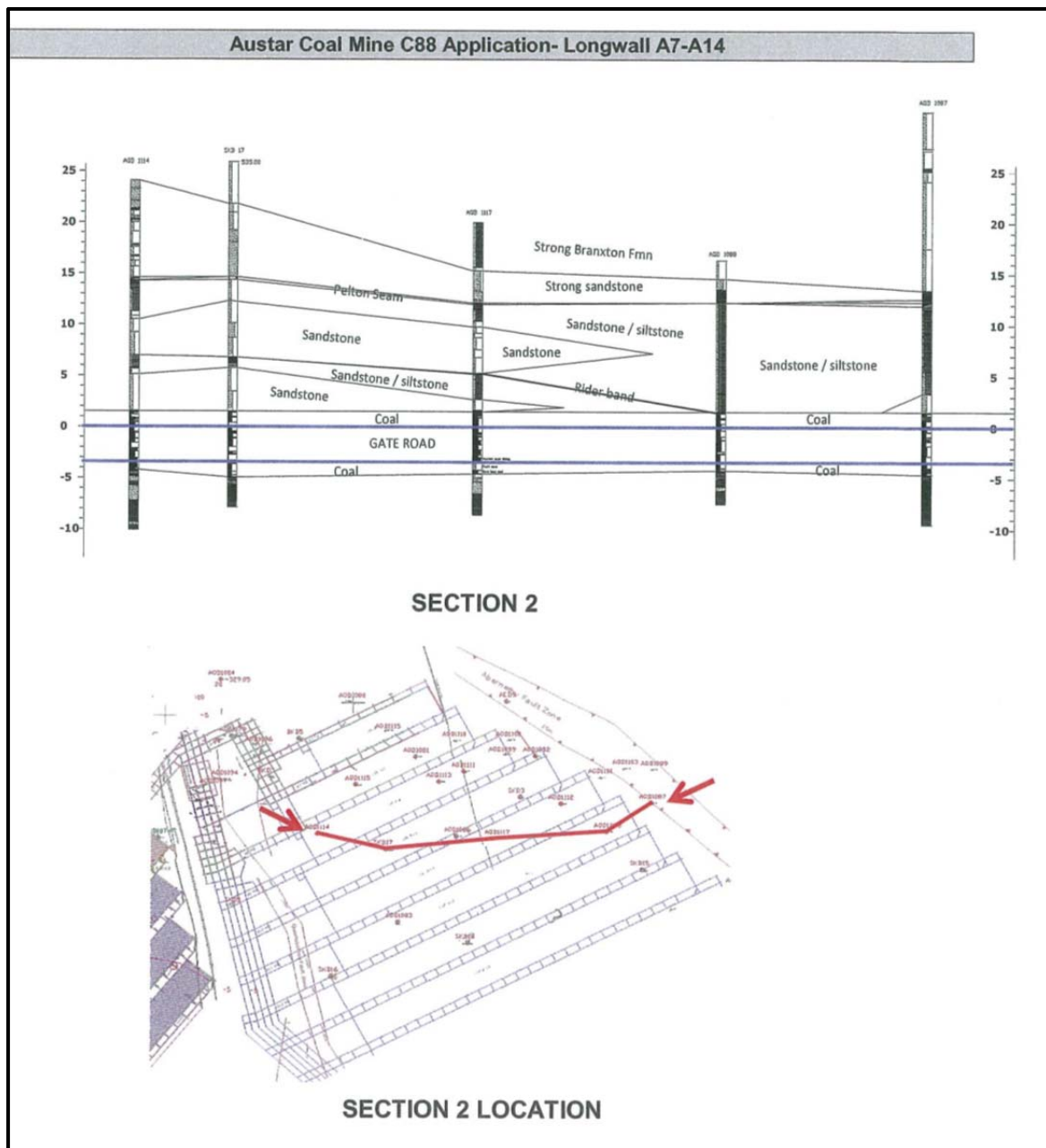


Figure 12 shows the presence of known and projected geological structure in the region of longwall panels A7 to A9, and in the area of the 300 Mains development panel. Regionally, the area is affected by the corridor of the Quorrobolong fault zone running sub-parallel and adjacent to 300 Mains. Adjacent to this zone (and essentially a part of it) are the group of faults that were encountered within the first three pillar lengths of Maingate A9. The combination of these major regional structures, together with the clustering of localised faults, have had an impact on the integrity of the rock and coal properties in the area, as well as almost certainly impacting on stress magnitudes and directions (vertically and horizontally).

Figure 12. Structural geology features in the vicinity of Maingate A9

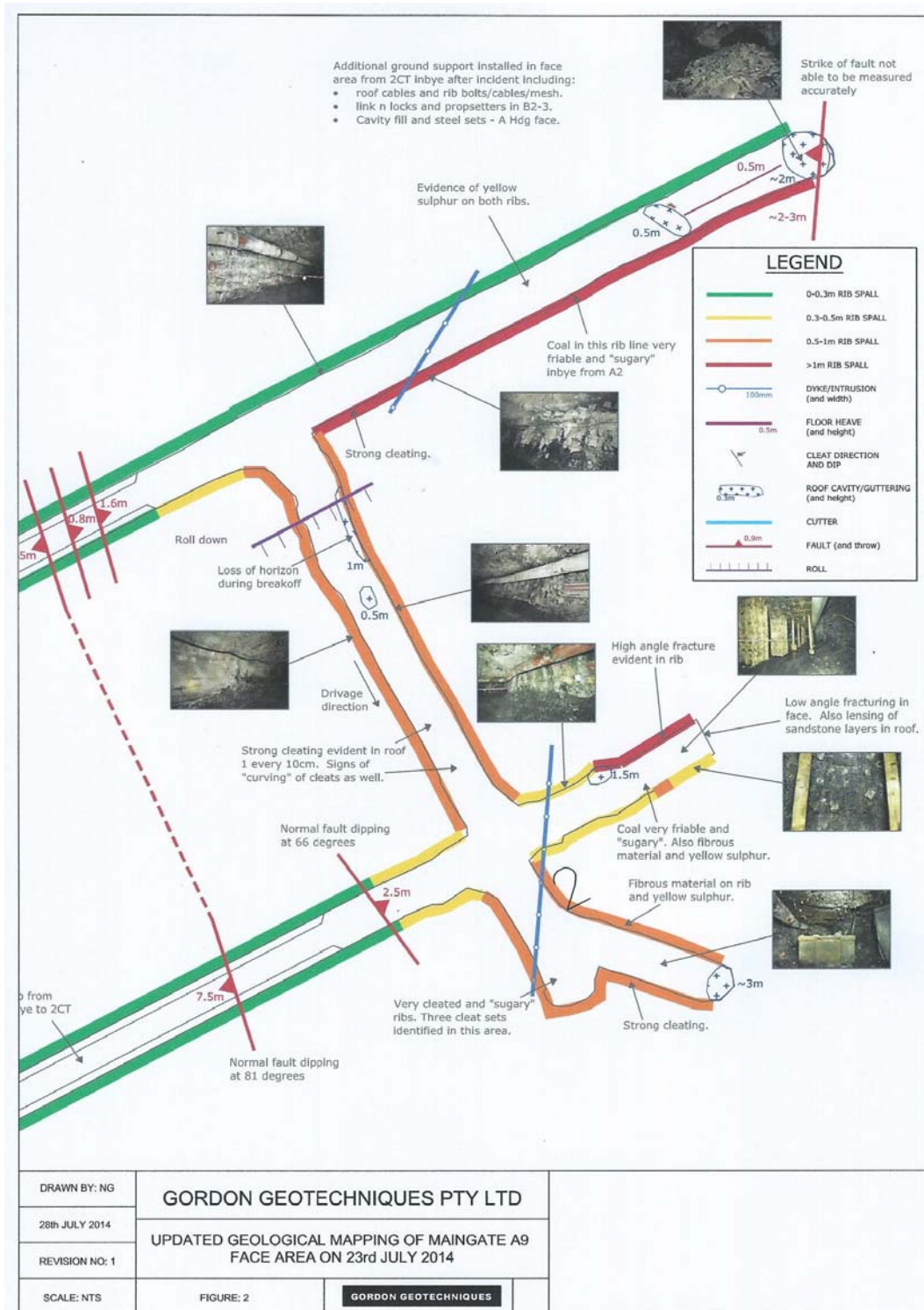


Directional longhole drilling was undertaken from the 300 Mains in advance of Maingate A9 development, to establish the presence and nature of some of these projected geological features, as well as to inform on coal seam continuity and gradients ahead of Maingate A9 development. Figure 13 shows the pattern of holes that were drilled in the vicinity. While these holes clearly penetrated the cluster of faults that crossed Maingate A9 between 1 and 2 cut-through, they appeared to have all stopped short of the structures that were encountered beyond 2 cut-through in A Heading, and that were projected to lie just beyond the face of B Heading and the dog-leg heading at the time of the incident.

It may be noteworthy that Figure 13 records *bogging* conditions at the end of the two longest boreholes.

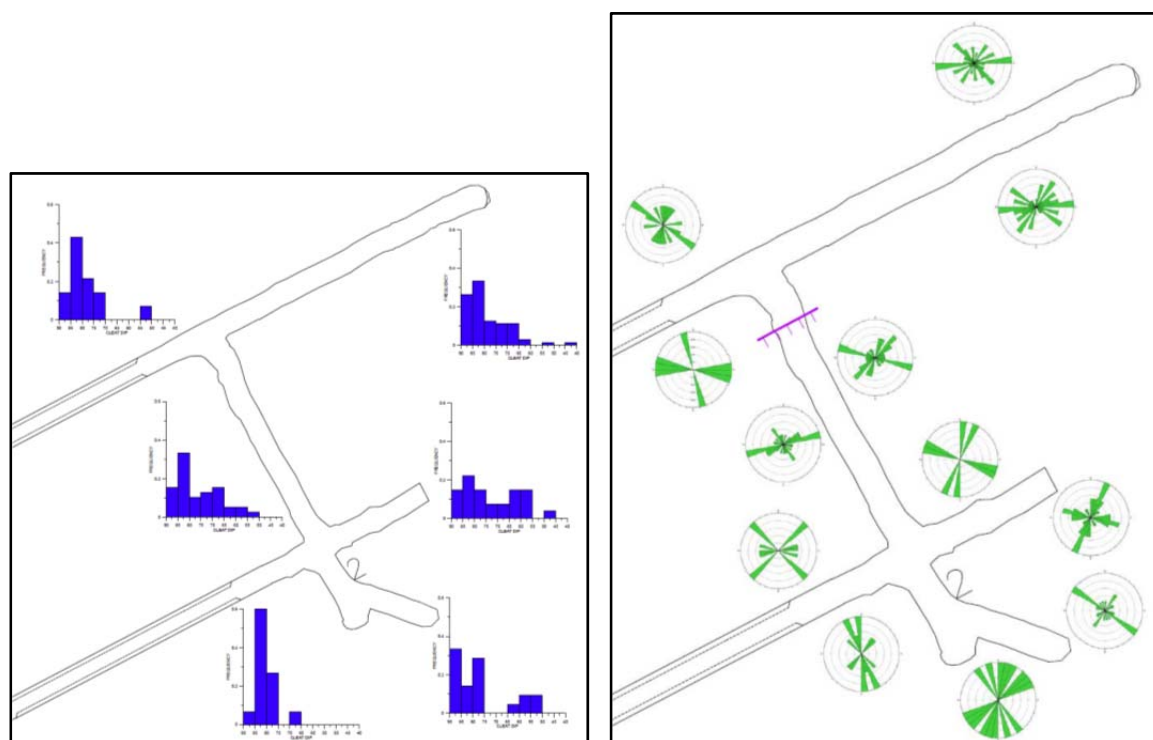
There is no doubt that in areas of structural disturbance such as this, where there is history of pressure bump and possibly burst conditions, forward knowledge of the structural geology

Figure 14. Rib condition and cleat mapping in Maingate A9.



Once again, any ability to detect such regions of geological disturbance on a more localised scale could assist in identifying areas that may be potentially more prone to bumps and bursts in the future.

Figure 15. Summary of cleat dip and direction in Maingate A9.



(a) Summary of cleat dip

(b) Summary of cleat strike

RIB BEHAVIOUR

Deputies' statutory reports made reference to large pressure bumps under the headings of state of 'roof and sides' and 'any other source of danger, location and nature'. In some cases, these entries were repeated in their production reports. An entry on a deputy's statutory report of a nature of 'large pressure bumps' would usually be taken as a notification of a condition of danger, especially if it appeared under the heading of 'any other source of danger'. However, based on the interviews undertaken by the Investigation Unit, the situation appears to have been different at Austar Coal Mine around the time of the 15 April 2014 incident.

Hence, it appears that the deputies' statutory reports of frequent pressure bumps and/or large pressure bumps were not viewed by management as the deputies reporting a risk associated with a potential or actual unsafe situation but, rather, as the reporting of a positive development. That is, something positive had happened to prevent a build-up of pressure that might lead to an even larger bump. Therefore, these reported occurrences were not normally raised as a concern with higher management and technical support staff.

It is apparent from the interviews conducted by the Investigation Unit that the undermanagers regularly brought reports of bumping to the attention of crews at their start-of-shift addresses.

It emerges from the interviews that a standard response to large and/or frequent bumps in a panel at Austar Coal Mine was for the deputy of the panel to instruct the crew to revert to non-simultaneous cutting and bolting. That is, the face would be advanced by cutting and then cutting would cease while the area was supported. This is a standard action in rock burst and gas outburst situations, in order to remove persons from the hazardous area for the duration of the time that it is most likely to fail dynamically.

Prior to the incident of 15 April 2014, the panel deputy had implemented non-simultaneous cutting and bolting in light of the large bump and frequent bumping that his crew had experienced in the same area on the previous day. Messrs Mitchell and Grant were on the working platform on the left hand side of the bolter miner at the time of the pressure burst.

This situation came about because the motive for not simultaneously cutting and bolting at Austar Coal Mine was to be able to support the ribs before they deteriorated extensively. Interviews with deputies established that it was employed regularly in bump prone conditions because of the adverse impact of bumps on unsupported ribs.

PRESSURE BURST - CAUSAL FACTORS

There is no doubt that the mechanics of what causes a pressure burst, and what are the contributing factors, is extremely complex. There remains a considerable amount of research effort to be applied in the future to this complex and dynamic rock failure behaviour – in all its different manifestations. However there is extensive international experience already available. International experience with bumps and bursts suggests that most such events are the result of multiple different mechanisms and factors coming together.

It is not possible on the evidence available to categorically state the cause(s) of the pressure burst on 15 April 2014, nor to state the factors and their contributory roles, with a high degree of certainty or quantification. However, what is clear is that the following factors played a role in this incident:

- High stress, associated with the depth of mining, and possibly supplemented by some additional stress concentrations resulting from any or all of
 - regional faulting zones immediately adjacent to the event location;
 - lensing and variations in stiff overburden sandstone units (and possibly also floor units).
- The presence of quite intense regional geological structure in the area, combined with severely distorted and complex local geology, including an unusual and highly variable cleat regime.
- The presence of massive sandstone units within the immediate 20 m+ of overburden roof, and an unknown possibility of massive units also in the floor.
- A very dominant, smooth horizontal shear plane represented by the Dosco Band, providing a dynamic shear failure surface below which the crushed and sheared coal could move.
- The effect of development mining providing a trigger either to destabilising the rock material above the burst zone in proximity to the fault surfaces ahead of mining, and/or providing a loss of confinement to the highly stressed coal in the rib that was undoubtedly subject to high levels of vertical stress.

CONCLUSIONS

The event that occurred on 15 April 2014 at Austar Coal Mine, leading to the death of Messrs Mitchell and Grant, was clearly a pressure burst, within the accepted terminology.

It is not possible to provide a definitive cause for the Austar Coal Mine pressure burst. However there is no doubt that contributing factors included:

- a. high levels of pre-mining vertical stress due to the depth of mining (+500 m).
- b. potential additional stress contributions (in both magnitude and direction) due to the presence of disturbed structural geology in the region, and variable thickness massive sandstone units in the near roof overburden. Floor geology could also have been a factor, with evidence of massive sandstone and conglomerate units present in the floor, in close proximity to the Greta Seam in this region of the mine.
- c. presence of a large scale zone of regional structural faulting represented by the Quorrobolong Fault Zone, together with off shoot faulting in the vicinity of Maingate A9.
- d. presence of an intense and highly disturbed localised structural geology domain inbye of 2 cut-through, Maingate A9, as evidenced by a highly variable cleat pattern.
- e. the smooth and dominant shear surface presented by the Dosco Band within the Greta Seam, which appears to have acted as a dynamic shear failure plane, once some form of triggered loading (or unloading) event occurred.
- f. reduction in confinement of the highly vertically stressed coal in the ribs due to the development mining process, within the above complex geological environment.

It is not possible to determine whether the initial release of energy was confined to a simple failure of the highly loaded coal resulting in a direct or primary coal burst energy release; or whether the coal failure was a secondary consequence to some initial rock failure and energy release in the surrounding rock mass. Either scenario remains a possibility, based on the evidence available.