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Analysis and management of outbursts: with particular reference to the Bulli coal seam

Christopher Royce Harvey

University of Wollongong

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ANALYSIS AND MANAGEMENT OF OUTBURSTSS

with particular reference to the Bulli coal seam
ANALYSIS AND MANAGEMENT OF OUTBURSTS
with particular reference to the Bulli coal seam

A thesis submitted in fulfilment of the requirements for the award of a
degree of

Doctor of Philosophy

from

THE UNIVERSITY OF WOLLONGONG

by

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Bachelor of Engineering (Mining); Sydney
Master of Management; Wollongong
Master of Environmental Studies; New South Wales

MINING ENGINEERING DIVISION
FACULTY OF ENGINEERING

2001
DECLARATION

This is to certify that the work as presented in this thesis was carried out by the author in the Mining Engineering Division of the Faculty of Engineering, within The University of Wollongong, and has not been submitted to any other university or institute for a degree.

C R HARVEY
ACKNOWLEDGEMENTS

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The author gratefully acknowledges the support and assistance of the following people and organizations:

The late Dr Ripu Lama whose knowledge and understanding are sorely missed. Also for his initial work (with the author) in establishing gas drainage at West Cliff Colliery.

Mr Bruce McKensey who as the New South Wales Chief Inspector of Coal Mines initiated the idea of this study with the author's involvement on the Steering Committee for the Management of Outbursts in the Bulli Seam.

The Organising Committee for the 1995 International Symposium-cum-Workshop on Management and Control of High Gas Emissions and Outbursts in Underground Coal Mines, (of which the author is secretary) which has continued to organise regular half day outburst seminars for the local industry.

The New South Wales Department of Mineral Resources, for providing access to various reports regarding outbursts and their management and support for the opportunity to present a paper on "Outbursts in the Bulli Coal Seam" at the International Symposium on Rock Bursts and Sudden Outbursts; at St. Petersburg 1994, and a study tour involving mining operations in Poland, Czech Republic and Bulgaria.

Finally the author wishes to thank his family for their forbearance and extended support over the years of study.
ABSTRACT

The Bulli Coal Seam, located in the Illawarra Coalfield of New South Wales, Australia has a long and varied history of sudden outbursts. From available information this problem has resulted in twelve (12) fatalities over the last one hundred and five (105) years, with over four hundred (400) separate outburst incidents being identified. These incidents vary in severity and intensity from the discharge of 1 to 2 tonnes of coal, with a slight increase in gas emission, to the discharge of 200 to 400 tonnes of coal some 6,000 m³ of gas being liberated and large items of mining equipment being pushed 1 to 2 metres down the roadway.

Knowledge and experience gained in studying overseas experiences in the management of outbursts is of great benefit. When incorporated with the research and understanding developed in local conditions there is the potential to enhance mine safety and allow valuable coal resources to be mined. The analysis of mining techniques along with the review of specialised methods to predict and prevent outbursts are of major importance, with the ultimate barrier being to protect mine workers if and when an outburst type incident does occur.

The primary aim underlying this thesis is to outline the various issues that relate to understanding the causal mechanisms that contribute to outbursts, how they impact upon mining operations in the Bulli coal seam and ultimately to identify strategies, procedures and processes to manage the outburst risk.

The methodology adopted was to identify the factors that contribute to outbursts throughout the world but more specifically focus upon the Bulli coal seam, especially in respect of current techniques used to manage the outburst risk and ensure safe working conditions for mine workers.
To achieve these aims the following strategy was utilised:

- Identify the characteristics that define and or determine an outburst
- Review the nature and occurrence of outburst incidents throughout the world
- Review in detail the factors associated with Bulli seam outbursts focusing on:
  - Bulli seam geology
  - Outburst characteristics
  - Review of fatal outburst incidents for Bulli seam mines
- Consider mechanisms to predict, prevent and provide protection from outbursts
- Detailed review of current outburst management strategies
- Undertake case studies of outburst management plans for three indicative mines

For modern day mining operations excessive risk associated with outbursts, is considered as unacceptable. The challenge therefore is to fully understand the outburst phenomena, the various techniques and technologies which can be utilised to predict, prevent and control outbursts and develop robust management systems which guarantee the safety of mine workers. Anything less is considered unacceptable.

This thesis is mainly concerned with the development, application and specific implementation of outburst management plans for mines operating in the Bulli coal seam. The outcome of this approach to the management of outbursts, has dramatically reduced the number of outbursts incidents for Bulli Seam mines and thereby enhanced mine safety.
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CHAPTER ONE

THE NATURE OF OUTBURSTS
CHAPTER 1

THE NATURE OF OUTBURSTS

1.1 INTRODUCTION
The Bulli Coal Seam as a primary source of coking coal is a major economic resource for New South Wales. Geological conditions associated with this seam have required the development of specialised mining techniques and the adaptation of mining equipment, for coalmines to remain competitive. For many years outbursts have been regarded as a mining phenomenon "one of the many quirks of nature which make underground coal mining inherently dangerous". Today this type of approach is unacceptable.

1.2 OUTBURST CHARACTERISTICS
In general terms, it is universally recognized that an outburst is the sudden release of a large quantity of gas in conjunction with the ejection of coal and associated rock, into the working face or mine workings. The violent and unexpected nature of these events enhance the risk and danger to mine workers. It is also recognized that numerous factors can contribute to the specific nature or characteristics associated with outbursts in a particular coalfield with the three primary factors being:

- Intense stress within the coal seam
- High gas content and high gas desorbability
- Low coal strength

This represents the current state of understanding and is generally accepted as "fact" by experts or researchers who have investigated instantaneous outbursts of coal and gas, around the world. However, this has not always been the case as numerous observations of outburst phenomenon have brought about this understanding, supported by the development of various concepts to explain these characteristics.
Chapter 1  THE NATURE OF OUTBURSTS

Over the years there has been vigorous debate as to which component could be regarded as the primary trigger for an outburst, is it gas or rock pressure? With each outburst, theories and concepts have been refined, postulated or discarded and each new finding gives a different understanding as to what characterizes an outburst. In reviewing the concepts which have been proposed and developed, it is important to remember the level of scientific understanding and related factors which impacted upon mining, the techniques and technologies used to mine the coal and other related facets, which put the work of the researchers in context.

1.3  EARLY THOUGHTS ON THE NATURE OF OUTBURSTS

It is reasonable to assume that the earliest experiences of gas and coal outbursts were exceedingly frightening and were attributed to the vagaries and peculiarities of coal mining. Coal mining, particularly mining at greater depths, where both in situ gas content and ground pressures (stress regimes inherent in the strata) combine and tend to create a natural or inherent risk to coal mine workers. After all, coal mining has historically been recognized as a very dangerous and hazardous activity with outbursts, explosions, roof falls, noxious gas, water inundation etc, all being recognized as standard or mandatory risks.

The identification of the specific set of circumstances attributed to “outbursts” is believed to have followed from the observations of Taylor (1852-53). This study identified three types of gas emissions, the first form of gas emission being characterised as the free gas, which is emitted from the coal to atmosphere and is in equilibrium with the atmosphere. The second form of gas emission was identified as being associated with highly compressible gas being present within the coal at high pressure. A particular characteristic of this gas emission is its slow release through the natural structure and pathways within the coal, creating the cracking, dislodgement and “bursting” of small pieces of coal as the gas is emitted.
The third form of gas emission was identified as a variation of the second form and was associated with variations in the coal structure, which have disturbed or stopped the flow of the higher compressible gas. It was identified that the presence of faults and basalt intrusions caused the gas or the migration of gas through the coal seam to become irregular or non-uniform, resulting in "gas pockets" in certain areas.

Taylor postulated that the mining of these areas would subsequently result in sudden emissions of gas and its sudden dispersion into the mine workings. Hence an early and accurate definition of outbursts was developed, which identified the role of geological structures, folds and dykes, changes in structure of the coal and the existence of high gas pressure.

With the mining of coal at greater depths and the growing incidence of rock bursts, a number of theories were developed primarily relating to tectonic factors and stress induced within the coal seam and adjacent rock strata. Caulfield (1931) based upon his experiences with mining in the Crows Nest coalfield was of the opinion that the primary cause of outbursts and rock bursts are stress related. The debate as to whether gas or rock stress acts as the initiating factor in outbursts was vigorously contested by a number of authors.

Pechuk (1933) identified outbursts as being the resultant liberation of potential energy accumulated in rock during the process of tectonic movement. Gas that is liberated during the crushing of the coal was considered secondary. Similarly, Wilson (1931) associated outbursts with tectonic movement, which caused the coal to be crushed forming clusters. The accumulated tectonic stress then caused the pulverised coal to burst out.

In contrast Bykov (1936) assigned the dominating role to gas being present under pressure thereby filling the various pores and cracks, which had been created by the tectonic stresses and mining. This identified the active and
passive role of the surrounding rock, realising that in the case of small outbursts the surrounding rock has a passive role. For outbursts of greater magnitude the active role of the surrounding rock increases with increased tectonic stress. This is exemplified by the sudden failure of the coal mass with the creation of a new stress regime, which favours the ejection of coal and gas into the mine opening. The debate or argument as to whether outbursts are a geo-dynamic (related to tectonic stress) or a gas-dynamic (related to in situ gas pressures) phenomenon is still current and debated vigorously, particularly amongst researchers from Eastern Europe.

1.4 MORE RECENT CONCEPTS ON OUTBURSTS

The interaction of seam gas, that is gas content (m$^3$/tonne) and gas pressure, in combination with tectonic characteristics (seam structures, dykes, faults etc) has been identified as determining the outburst potential. Nekrasovski (1951) identified possibly for the first time that outbursts are not the result of a single factor but rather a multiplicity of factors acting together. It was identified that gravity has a role to play particularly for steeply dipping seams where the potential for outbursts to be initiated in roadways driven to the rise, is greater than for roadways driven to the dip.

Characteristics relating to seam gas were raised by Ettinger (1952) when it was identified that coal seams liable to outbursts tended to belong to the same class or stage of metamorphism (i.e. have undergone the same degree of coalification) and may possess the same capacity to sorb gas as coal seams not liable to outburst. However, the major difference was their rate of desorption. Coal liable to outburst was characterised as having a much faster rate of gas desorption. Numerous methods to assess desorption rates and the determination of a “sorption/desorption indices” subsequently followed, in an endeavour to predict outbursts and this has proven to be a recognised indicator worldwide.
Hargraves (1958) through his study of outbursts in Australia, predominantly at the Metropolitan Colliery in the Illawarra Coalfield, identified a multiplicity of factors, which render a coal seam outburst prone. A differentiation was made between outbursts and rock bursts, in terms of their location and the desire to separate outbursts from "bumps" (rock bursts) and gas blowers (where the gas is rapidly desorbed from the coal seam without any violence).

Hargraves (1993) further refined his assessment of the major factors that contribute to outbursts as:

1. A coal under high stress due to depth of working and/or high lateral stress environment.
2. A coal of middle bituminous to anthracitic rank giving a higher sorptive capacity and lower permeability.
3. A seam gas in considerable quantity (sorbed gas) particularly if rich in CO₂.
4. A geologically disturbed coal or coal in a geologically disturbed environment as follows:
   a) By faulting, macerating and/or weakening the coal mass or;
   b) By intrusion, up ranking and weakening the coal mass.
5. High surface relief creating a concentration of stress locally within the virgin seam.
6. Mining with a geometry in the working seam that creates high stress abutments (and steep gas pressure gradients) in virgin coal, very close to the advancing face.
7. Prior working of adjacent seams with pillars being left having the effect of creating high local stress concentrations (usually vertical stress) in the virgin seam. A converse of this occurs where prior total extraction in adjacent seams has relieved stress and reduced gas pressure (and gassiness) of the working seam. Then the outburst proneness of the working seam may be reduced to a benign condition.
8. High rates of advance of faces into virgin coal creating high gas pressure gradients around advancing places and rapid stress adjustment.

The concept that mining induced stress creating an abutment zone, in advance of a face, which subsequently increases in situ gas pressure, by reducing coal permeability, has been proposed. This was believed to be the case for a number mines operating at greater depth and high gas content within the Bulli seam, with high development rates and an increased incidences of outbursts. To some extent this was supported by Gritskov et al (1995) in that it was claimed that the process of coal and gas outbursts begins with the formation of gas filled fractures in the seam, parallel to the face and is caused by rock pressure. Together with the fractures, there is a surface on which gas pressure is acting and it serves as a barrier (slice) between the fracture and the workings. If the barrier does not bear the gas pressure and breaks, crushed coal is thrown out into the workings. Then the next barrier collapses, i.e. an avalanche of coal takes place. It stops at the expense of coal filling the workings or the outburst cavity. It was further identified that under high rates of drivage and high gas content at the seam edge, this process will go on within the seam but with a greater intensity.

By investigating outbursts in the Bulli Coal Seam and developing techniques to promote safe mining practices for mines within the Illawarra coalfields, Lama (1991) identified that the most important factors that influence the occurrence of outbursts are:

1) Gassiness of the coal
2) Tectonics
3) Properties of the coal and rock and;
4) Vertical and lateral stresses occurring in the seam and/or rock as part of the coal seam
It was further identified that the role of each factor may vary from coalfield to coalfield hence the emphasis that needs to be placed in any investigation will vary. In a virgin area it is not easy to define the role of these factors. The interpretation and the relative role of these factors will become clear at a latter stage when preliminary excavations are driven (e.g., shafts, cross-cuts or roadways) in the coal. It is almost impossible to predict whether an outburst will always occur and if so what size? However, it is possible to predict the probability of occurrences with some degree of confidence if sufficient data have been collected.

### 1.5 CURRENT OUTBURST CONCEPTS

While it may be of academic interest to identify whether an outburst is initiated by gas or tectonic stress, or a combination of both, it does not progress the effective management or control of this phenomenon. The mechanisms causing an instantaneous coal and gas outburst are not easily observed. However, there is now a shared opinion amongst most researchers that the outburst process can be divided into four stages:

1) **Initial stage** – (stressing or releasing stage). Within the coal mass new coal surfaces are created due to the coal fissuring under high stress regimes, which exceed the strength of the coal. These high stresses may be due to strata loading (vertical and/or horizontal), blasting or coal working by different cutting or drilling machines.

2) **Free Gas Stage** – The opened fissures are initially gas free and this gives rise to the great concentration gradients of free and sorbed gas in the vicinity of the new coal surfaces. The rapid gas emission from coal gives rise to the cracking of the coal and thereby enhances the liberation of free gas. The increasing gas pressure within the coal fissures causes the displacement of fissured coal solids towards the working face. This is the beginning of a coal and gas outburst.
3) Sorbed Gas Stage – The rate of gas desorption increases as the coal is crushed and displaced. During this stage coal is crushed into fine grains mainly due to high gas concentrations in association with tensile stress. These stresses are generated by high gas concentration gradients in advance of mine workings, occurring in the coal close to the newly formed surfaces, being due to a shrinkage effect within the de-gassed coal. These gas concentration stresses are similar in nature to stresses, which cause the cracking and fissuring of clay layers upon drying, or to the thermal stresses, which develop in solid bodies, subjected to rapid cooling.

4) Final Stage – The force generated in the coal by the free gas pressure will have to surpass a limiting value, if the outburst process is to continue. This value is reached only when the rate of coal crushing is higher than the rate of gas emission. Under reverse conditions where the gas pressure drops faster than the rate at which the coal grains are losing their bonds with the coal mass, the liberating gas is not able to produce a coal outburst.

The outburst process (ejection process) terminates when accumulated crushed coal (being in a loose state) has been entirely removed from the created outburst cavity by the expanding gas. This thereby identifies the interaction of gas content, gas pressure, tectonic stresses, mining induced stresses and other coal seam specific features which all characterise the outburst phenomenon.

1.6 THE NEED FOR FURTHER RESEARCH
There is more than sufficient evidence to show that outbursts are a worldwide problem. However there is little evidence to show that outbursts and the risks associated with outbursts have been effectively managed especially within the modern day mining environment. There is reasonable understanding of the various aspects, which contrive to cause an outburst but the detailed
inter-relationship of these causal components is not fully known on a scientific level. For example it is known that in situ stress, coal strength, gas content, gas composition, gas pressure and the presence of geological structures all contribute to the outbursting of coal. However it is not known how, with a specific gas content and gas composition, changes in the coal strength can induce outbursts and to what degree these changes might endanger mineworkers. This is the case for all the components that contribute to an assessment of outburst potential. In most instances the outburst potential is not realised until an outburst incident actually occurs.

It follows that to effectively manage the outburst risk a multi-disciplined approach must be taken, to ensure that a number of safety barriers are in place to protect mineworkers, as there is no single answer to the prediction and prevention of outbursts. There is therefore, a need to research the various mechanisms, processes and procedures, which can be used to manage outbursts and ensure mineworker safety. This must be done in consideration of modern mining operations and the need for fast development rates and high longwall production.

1.7 RESEARCH APPROACH

In order to better understand how outbursts could be effectively and efficiently managed the approach to researching this matter has required the ongoing involvement of the author in various working groups, steering committees, task groups and a committee formed to convene a symposium cum workshop on the "Management and Control of High Gas Emissions and Outbursts in Underground Coal Mines" (as held in March 1995 at Wollongong). The work of this committee has been ongoing and regular half-day seminars (every six months) have been held to continue to promote awareness of outbursts and an understanding of how these phenomena can best be managed. The interchange of ideas and concepts that this type of forum engenders is seen as essential.
ANALYSIS AND MANAGEMENT OF OUTBURSTS

with particular reference to the Bulli coal seam

Figure 1.1 RESEARCH PLAN
A review of the majority of the outburst incidents, which have occurred in the Illawarra Coalfield (especially the fatal outburst incidents), in combination with reviewing the various outbursts management plans has been fundamental to research undertaken on the problem. The particular nature of outburst problems for the Bulli seam has been the focus for this research as well as the effective management and control of outbursts, an aspect considered by some industry or mining people to have already been achieved. However, too often history has proven that complacency in respect of outbursts leads to fatalities and the mining industry is then forced to repeat its mistakes. Research in this area of outburst management should at least reduce the number of mistakes and at best save lives. The attached Research Plan (Figure 1.1) outlines the approach taken to achieve these goals.

1.8 SUMMARY

Sudden instantaneous outbursts of gas and coal have been a problem throughout the world causing loss of life and mines to close due to their inability to effectively understand and manage the outburst risk. The challenge to modern day mine management is to recognise the outburst problem, research and understand it, then develop mining and management systems so that as much coal as possible can be mined as safely as possible. This chapter has endeavoured to explain how the level of knowledge and understanding of outbursts in general has changed over the years.

There is a need for further research to better understand in a scientific manner, the way in which the particular components of outbursts inter-react and the understanding of each specific component can assist in the management of the overall outburst risk. Ensuring the safety of mine workers is the ideal outcome for the effective management of the outburst risk.
CHAPTER TWO

WORLD WIDE EXPERIENCE OF OUTBURSTS
CHAPTER 2

WORLD WIDE EXPERIENCE OF OUTBURSTS

2.1 INTRODUCTION
This chapter presents a summary of outburst characteristics and incidents compiled from various reports, reviews, papers and presentations obtained over the last six years. The 1995 International Symposium cum Workshop involved a number of eminent people who have researched outburst related phenomena worldwide (edited by Lama, 1995). The late Dr Ripu Lama along with the author was closely involved in the organization of this Symposium and the collection of information to give a worldwide perspective on outbursts.

Special files and records held by the New South Wales Department of Mineral Resources proved to provide a wealth of information on New South Wales outbursts along with the proceedings of various seminars and Symposiums. Recent half-day seminars convened by the Southern Coalfields Outburst Committee (the author is an active member of this committee and undertakes the duties of secretary) have also assisted in the dissemination of information. The understanding as to the nature and characteristics of outbursts throughout the world, along with the mechanisms used to control or manage outbursts, gives a valuable insight into the outburst phenomenon and how the mining of coal can be undertaken safely.

2.2 REVIEW OF INTERNATIONAL EXPERIENCE OF OUTBURSTS

2.2.1 Belgium
The coalfields of Belgium belong to the Carboniferous period of the Palaeozoic era and can be divided into two basins to the North and South separated by the central Brabant anticline. The northern basin extends some 60 km, covering an area of 600 km². The Southern basin is about 100 km long with a width of 5 - 15 km covering an area of 1,500 km².
Outbursts have been identified as occurring in the Southern part of Belgium, the Liege, Charleroi and Centre, Borinage coalfields, with the first outburst being recorded in 1847. Most outbursts have occurred at a depth greater than 250 m and are described by Stassart and Lemaire (1910), primarily for the period 1892 to 1908 as well as describing outbursts from 1847 to 1891.

It is of interest to note that a very high percentage of outbursts were initiated on extraction (longwall) faces compared to development roadways. During the period 1957-63, 119 outbursts have been recorded by Vandeloise (1964) as occurring in the Belgium coalfields with 39 of these being induced outbursts. Large outbursts associated with the ejection of 1,440 tonnes occurred in 1959 and 1,200 tonnes in 1962. Both these outbursts occurred while intersecting the coal seams, with the most violent incident occurring whilst driving a heading to the rise in the Epuisoire coal seam, on 17 April 1979 when 420 tonnes of coal was ejected and about 100,000 m$^3$ of gas was liberated. This outburst caused a massive explosion and resulted in 121 fatalities.

In the mid fifties considerable research was directed into the areas of outburst prediction and control with a “V” index being devised to identify areas with low or high outburst risk. A number of methods to promote control of outbursts were identified as:

- De-stressing of coal seams
- Inducer shot-firing
- Complete extraction without leaving pillars
- De-stressing during development by advance cutting in rock
- Development of roadways along the dip
- Limiting number of workmen at the face

Inducer shot-firing was utilised as the primary outburst control method for Belgium coal mines in 1920. Medium diameter (115 mm) borehole drilling techniques were also used to limit outbursts in support of inducer shot-firing in 1950.
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2.2.2 Bulgaria

The Balkan Basin with coal seams of thickness varying from 0.1 - 0.6 m to 20 -30 m dipping at 65-90° is the primary outburst location in Bulgaria. The coal from these seams is from the Mesozoic era, with rank varying from gassy semi-coking to coking coal, with methane being the main gas. The geology of the coalfield is considered to be highly complex, with normal and reverse faulting causing major and sudden changes in the dip and strike of the coal seam along with changes in seam thickness.

High percentages of Clarain with clay banding have been noted as a characteristic of outburst prone coal, with a high density of micro cracking with crack length of 7.5 - 10.2 mm/mm² and spacing of 0.03 - 0.1 mm, along with gas pressure varying from 0.5 MPa to 2.3 MPa for seams with a high outburst risk. Seams not liable to outburst have a higher percentage of Durain, with pyrite and quartz bands and are associated with micro cracking with the length of cracks 3.0 - 5.0 mm/mm² and spacing of 0.1 - 0.2 mm, along with gas pressures of 0.1 - 0.3 MPa (Lama and Bodziony 1996).

The mining method most commonly utilised is longwall advancing using drilling and blasting techniques, with geological disturbances severely limiting the use of mine mechanisation. Over 250 outbursts have been recorded in Bulgarian coal mines as indicated below:

- 50 % Outbursts of gas and coal
- 30 - 35 % Displacement of coal with increased gas emission
- 15 - 20 % Displacement of coal without increased gas emission

The major method utilised to control outbursts is de-stressing with camouflet blasting. De-stressing the coal seam is only possible in 10 to 30 % of the mining areas due to the extreme variability of mining conditions. High pressure water infusion, advanced drainage and hydraulic washing have occasionally been used, with inducer shot-firing being rarely adopted as a method to control outbursts.
2.2.3 Canada

Four distinct coal mining districts have been associated with outbursts of gas and coal and gas and rock: namely:

- Nanaimo district, Vancouver Island, British Columbia
- Crows Nest district of South Eastern British Columbia
- Canmore district, near Banff, Alberta
- Sydney coalfield, Cape Breton Island, Nova Scotia (Aston and Cain, 1985)

Of the above regions, the first three are located in the mountainous Western Canada area, where the coal is highly disturbed by tectonic movement. Bord and pillar mining is the dominant mining method for seams with a thickness of 2.5 to 3.5 metres, with virtually all outbursts occurring during the drivage of headings and were associated with methane gas.

_Nanaimo District:_ The coal seams in this district are highly disturbed due to tectonic activity. Outbursts are more prevalent where the Douglas coal seam has been mined at depths ranging from 67 to 200 metres, with a seam thickness varying from 0.3 to 8.0 metres, with a mean of 2.7 metres at a general dip of 18°.

The Douglas coal seam is highly disturbed by tectonic movements, hence bord and pillar mining is the only viable method. Although the roof of the seam appears fairly regular, horizontal movement has caused slickensided structures within the seam and the floor has undergone high deformation. Prior to 1921 no records of outbursts were kept however during 1921 - 1927 some 268 incidents occurred in the Cassidy Colliery, with the largest outburst occurring on 5 August 1922, when 1,200 tonnes were ejected along with a very large emission of gas.

_Crows Nest District:_ The first outburst in this district occurred in 1903 when 130 tonnes of coal was ejected. The largest outburst occurred in 1904 with
the ejection of 3,500 tonnes of coal and an estimated gas emission of 160,000 - 140,000 m³. For the period 1903 - 1928, over 200 outbursts were recorded in the Crows Nest area.

**Canmore District:** The # 4 coal seam and the Upper Marsh coal seams have been associated with outbursts in the Canmore District. The first outburst occurred in the # 4 seam in 1944 at a depth of 200 metres during shaft sinking operations. The Upper Marsh seam recorded its first outburst in 1950, as the seam was being exposed. Mining in the Canmore district was terminated by 1970.

**Sydney Coalfield:** This coalfield is located in North-Eastern Canada where roof outbursts occurred in the sandstone strata immediately above the Harbour coal seam. The #26 Colliery and the Phallen Colliery have both recorded significant outburst incidents at depths greater than 700 m. A total of 37 outbursts were recorded at the #26 Colliery between 1977 and 1984, with the largest outburst creating a 316m³ cavern. The mine was later closed and flooded as a result of a fire (Cain, 1995).

The first gas and sandstone outburst occurred in the Phallen Colliery in 1994, at a depth of 697 m associated with the development of main headings. It was estimated that 1,350 m³ of gas was emitted; several mine arches were destroyed and a Voest Alpine AM75 road-header, weighing 75 tonnes was displaced 2 metres by the outburst.

**2.2.4 China**

China has the distinction of having the largest number of recorded outburst events, with outbursts occurring in a number of large coal mines in most of the Chinese coalfields. These coalfields are located within the provinces of Shanxi (Yangquan); Liaoning (Beipiao); Henan (Jiaozuo); Sichuan (Nantang and Chonquing) and Hebei (Kailuan).
Coal and gas outbursts in China are differentiated into four categories:

1. Coal bursts with no gas
2. Gas bursts
3. Coal and gas outbursts
4. Rock and gas outbursts

This classification of outbursts is based upon the following observations:

- Existence of a cavity, its specific shape and the effect of gravity if any
- Particle size distribution of the outburst coal
- Distance to which the coal has been ejected from the cavity
- Tonnage of material ejected
- Volume of gas liberated and direction of flow (in line or against the ventilation current)
- Violence of outburst
- Symptoms preceding the outburst
- Location of the outburst
- Type of work in operation when outburst occurred

Mining conditions vary widely along with mining methods, although the most common method is longwall extraction. Outbursts are most common on structures such as sheared coal, faults, dykes, splitting of coal seams, changes in the rank of the coal due to contact with volcanics and sudden changes in the thickness of the coal seams.

During the period 1950 to 1981 some 9,485 outbursts were recorded in China with methane being the predominant gas and only a small number being associated with carbon dioxide. In general the risk of an outburst increases with an increase in the thickness of the soft coal within the coal seam, with both bituminous and anthracite coals being associated with outbursts.
The largest outburst ejected 12,780 tonnes of coal and liberated 140,000 m³ of gas. Up until 1981 there had been 69 outbursts in China, which had ejected more than 1,000 tonnes of coal each with the smallest outburst being less than one tonne. Generally there is little correlation between the gas content of the coal seam and the size of the outburst event or the gas emitted. The size of an outburst would appear to be related to the size of the excavation, with outbursts on longwall faces being significantly larger and a higher amount of gas being emitted, than for normal roadway development.

Gas drainage is utilised as the primary control method with 26% of the mines operating a gas drainage facility. Other methods, such as hydraulic fracturing, water infusion and the mining of protective seams are also used. Predictive techniques include seismic surveys, monitoring of emission values and the use of complex indices involving several factors to determine the risk of an outburst.

*Liaoning and Henan Provinces:* The Beipiao coalfield is located in the Liaoning province with six mines operating in this coalfield experiencing outbursts. From 1951 to 1986, 1,688 outbursts were recorded (Wang 1988) with the depth of some operations approaching 800 metres. Outbursts have also occurred in the Jiaozuo mining area located within the Henan province. The seams belonging to the Shanxi group contain the only minable seams and these are liable to outburst. With 13 mines operating in this area at depths of 300 to 450 metres, 11 of them are liable to outburst with the largest outburst ejecting 1,500 tonne of material. Statistical analysis of 166 outbursts shows a minimum safe gas pressure level of 0.61 MPa.

*Shanxi Province:* The Yangquan coalfield within the Shanxi province belongs to the middle Carboniferous to early Permian period and has experienced 466 outbursts during the period 1982 to 1986, all within the #3 seam. This seam varies in thickness from 1.4 m to 2.2 m and is a stable, strong anthracite coal with a strong roof prone to sudden failure. Eighty
percent of these outbursts have occurred on the longwall face, the largest outburst involving the ejection of 525 tonnes of coal and 18,750 m$^3$ of methane (Qi and Zhang, 1989).

**Sichuan and Hebei Provinces:** The coal in the Nantang coalfield (Sichuan province) is from the Mesozoic era and is highly disturbed, with a high stress regime, magmatic intrusions, folding and faulting. As of 1983, 731 outbursts had been recorded predominantly occurring in semi anthracitic coals and characterised by an increase in rank ($R^0_{\text{max}}=1.5\%$) with high emissions of gas, (90 m$^3$/tonne). Hence rank has been utilised as a predictive tool or mechanism to assess the potential for outbursts.

In the Kaiping coalfield (Hebei province) gas and coal outbursts have occurred at a number of mines predominantly related to the mining of bituminous coal. In the Zhaogezhuang mine the first recorded outburst was in 1955 at a depth of 600 metres. The largest outburst occurred in 1973 with the release of 3,000 m$^3$ of gas and the ejection of 100 tonnes of coal. In the Majcagou Colliery, the first outburst occurred in 1976 during the development of the #6 seam, at a depth of 500 metres, emitting 18,387 m$^3$ of gas and 255 tonnes of coal. Some of the identifiable characteristics of outburst in this region are as follows:

- Outbursts occur in the form of "bursts", "press outs", "flow outs" and "gush outs" from drill holes.
- These are frequently accompanied by a loud noise causing the roof and sides to fall.
- The outbursts have a close relationship with the geological structures and are concentrated near faults, folds and, changes in the dip of the seam. Stress as a consequence of these geological structures tends to intensify the outbursts.
- Outbursts occur in soft coal in the lower section of the seam identified as the tectonoclastic zone (Lama and Bodziony, 1996).
Preventive measures include:

- Gas drainage to reduce gas pressures below 0.6 MPa.
- Resin injection into cross cut boreholes when intersecting very soft coal in the seam; the holes are closely spaced with an effective radius of 1.5 m.
- Drilling of "relieving" holes of 100 mm diameter in advance of the face.

**Heilongjian Province:** The Nan Shan coalmine, in the Heilongjian Province had its first outburst in 1983, when 627 tonnes of coal and 11,830 m³ of methane were ejected. The general gas content of the coal is 16.3 m³/tonne at a gas pressure of 27 MPa. Outbursts have occurred on development roadways within the seam and as a preventative measure the crosscuts are developed to a minimum distance of 10 metres where, through the use of advanced drilling, the gas pressure is lowered to 1.0 MPa. Full face blasting is used with milli-second delays with a maximum delay of 30 seconds (Xiao and Xu 1995). The Diado Colliery (Jixi City) has experienced 713 outbursts during the period 1950 to 1992, for 11 out of 17 of the coal seams being mined. The coal seams are from the Jurassic period and are intersected by 46 faults with throws greater than 30 metres along with numerous igneous intrusions (Cai and Luan 1995).

The Largest outburst to occur in the area resulted in 800 tonnes of material being ejected. Outbursts have occurred during extraction, opening out of the seams, in rock cross measure drifts and during the drilling of advanced gas drainage boreholes. Of the 713 outbursts, 413 occurred during inseam drivage (at an average size of 28 tonne/outburst) and 300 outbursts occurred during coal extraction (at an average size of 15.3 tonne/outburst). The primary predictive methods are desorption tests and flow measurements in boreholes and gas pressure tests from boreholes, in advance of the face. In development headings gas pressures in the 6 m advance holes is 0.4 MPa with a gas content of 16.9 m³/tonne. Outbursts tend to occur when the emission rate in these boreholes exceeds 7 l/m and control methods involve long-hole drilling in conjunction with gas drainage (Cai and Luan, 1995).
2.2.5 Czech Republic

Outbursts of gas and coal and, outbursts of gas and rock have occurred in the following coalfields of the Czech Republic:

- Ostrava - Karvina coal field of Upper Silesian basin
- Slany coal field of Kladno - Rakovnik basin
- Rosice - Oslavany coal field
- Zacler - Slatonovice coal field of Lower Silesian basin

Most of the outbursts have occurred in the Ostrava - Karvina coalfield that has an extensive history of some 469 outbursts up to 1988 with majority being associated with the development of roadways in coal. The Slany coalfield is relatively under developed with six outbursts being recorded as of 1988 at depths ranging from 814 m to 908 m and mostly associated with shaft sinking (Lama and Bodziony, 1996). The Rosice - Oslavany coalfield also has limited development with a total of five outbursts being recorded as of 1987, with four of these occurring in development headings in coal. Only three outbursts have occurred up until 1988 in the Zacler - Slatonovice coalfield.

**Ostrava - Karvina Coal Field of the Upper Silesian Basin:** The Ostrava - Karvina coal field is an integral part of the Upper Silesian basin that extends into the Czech and Polish Republics with the Czech part covering an area of 1,600 km². The coal bearing strata is from the Palaeozoic period in the Carboniferous Era, identified as the Ostrava - Karvina formation. The thickness of the coal measures varies between 600 - 3,000 metres with a high degree of tectonic disturbance, the coal sequence being completely over turned in some instances.

The first outburst in this coalfield occurred in 1884 at Ignat Colliery (now J. Sverna Colliery) in the Anna coal seam at a depth of 226 metres and displaced 580 tonnes of coal with gas mixture of both CO₂ and CH₄. During the period 1894 to 1988, 469 outbursts had been recorded with most of these
outbursts occurring in development drivage where blasting is the common method of mining. Blasting was also used as an outburst control method. Research indicated that outbursts occurred only in coal seams with a volatile matter in the range of 14 - 32%, in seams of low strength, with high sorptive capacity and increased fracturing. In the majority of cases outbursts tended to occur in mines west of the major fault (Michalovicki) that splits the coalfield in two being more pronounced in locations of tectonic disturbance or deformation of the coal seam, particularly in close proximity to such disturbances (Cwik and Swidzinski 1980).

**Slany Coal Field of Kladno - Rakovnik Coal Basin:** The Slany coalfield covers the northern part of the Kladno - Rakovnik coal basin. The seams are quiet flat (approx 5° dip) and are of the middle Carboniferous period. There are two major systems of faults, which intersect the coalfields; the older faults tend ENE - WSW with the younger faults tending NNW - SSE. A recent mine development, the Slany Mine experienced six outbursts during shaft sinking operations. The outbursts occurred at depths of 814 - 909 metres in medium to coarse-grained sandstone and fine-grained conglomerate. These rocks tended to exhibit a low uniaxial compressive strength of 14 - 21 MPa and a tensile strength of 1.3 - 2.3 MPa. The horizontal stress component within the strata has been assessed as four times the vertical stress (Klepis and Minol, 1988).

**Rosice - Oslavany Coal Field:** The coal within this coal field is from the Permian to Carboniferous era, with mining being undertaken at depths of 1,400 metres in the # 1 seam. The seam varies in thickness from 1.5 to 14 m at a varying dip of 28° - 40° and this tends to cause difficulty in defining the outburst potential (known as the outburst probability index). Up to 1987, 5 outbursts of coal and gas had been recorded in this seam with 4 of the outbursts occurring in development headings in coal and one in rock (Rocek et al, 1988).
2.2.6 France

There have been recorded outbursts of gas (both Carbon dioxide and Methane) and coal in the following coalfields of France:

- Nord - Pas - de Calais (methane)
- Lorraine (methane)
- Loire (methane)
- Dauphine (carbon dioxide)
- Centre (carbon dioxide) Gard (des Cevennes) (methane and carbon dioxide)

The first carbon dioxide outburst in the world was recorded at the Centre coalfield of France in 1856 (Lama and Bodziony, 1996), with the first recorded outburst of methane in France occurring in 1843 in Issac Colliery in the Loire coalfield. There has been a wide range of outburst events particularly in the Gard coalfield and this led to the formation of a “Committee for Research in Outbursts” in 1913, which was the first attempt to integrate research and control of outbursts. Even with extensive research, the various problems and issues in the controlling and managing outbursts ultimately led to the discontinuance of mining in all French coal seams liable to outburst, in the 1980's.

**Nord - Pas - de Calais Coal Field:** This coalfield is an extension of the Southern coalfield of Belgium with the coal being from the Permian period of the Palaeozoic era. The coalfield covers an area of 1,000 km² with the predominant gas being methane. The seams vary in thickness up to 2 metres, with a total of fifty seams at depths up to 1,200 metres, comprising of coals varying from bituminous to anthracite. Some 344 methane outbursts have been recorded for the period 1912 to 1959, with the largest occurring at Ricard Colliery, in 1938, at a depth of 240 metres, when 1,270 tonnes of coal and an estimated 140,000 m³ of gas was liberated (Belin et al, 1969).
**Lorraine Coal Field:** This coalfield is an extension of the Saar coalfields of Germany with the coal belonging to the Carboniferous period of the Palaeozoic era. Seventy seams have been identified as containing minable reserves with the prominent gas being methane. Forty outburst incidents have been recorded during the period 1919 - 1964 for the Lorraine coalfield (Lama, 1991).

**Loire Coal Field:** The Loire coalfield has an elongated shape (in a NE - SW direction) and is located in the eastern part of the French massive with the prominent gas being methane. The first outburst occurred in the Issac Colliery in 1843 and 26 outburst incidents have been recorded for this coalfield in the period to 1980 (Lama, 1991).

**Dauphine Coal Field:** The prominent seam in this coalfield is a single anthracite coal seam of varying thickness, ranging from zero up to forty metres, (averaging 15 m to 20 m). The seam is steeply dipping, from $60^\circ$ - $70^\circ$ with the dominant gas being methane. Up until 1985, 275 outbursts have been recorded in this coalfield with the first outburst occurring in 1940. The largest outburst incident occurred in 1983 when 3,300 tonnes of coal were ejected along with 130,000 m$^3$ of carbon dioxide, averaging 40 m$^3$ of CO$_2$ per tonne of coal ejected. Most of these 275 outbursts were induced by shot firing with the development of main roadways, driven to the rise. This coal seam has also experienced a number of "push outs" of coal (20 - 70 tonnes) associated with the collapse of coal roof and sides. Whilst the release of carbon dioxide has also accompanied these events, the lower dynamics and gas pressures mean that these events were not classified as outbursts. Mining within this coalfield was discontinued in 1985 (Josien and Luneau, 1989).

**Centre Coal Field:** 172 outbursts have been recorded for this coalfield as of 1986 with the first outburst occurring in 1856, associated with the liberation of carbon dioxide (Lama and Bodziony, 1996).
Gard Coal Field: The coal from the Gard coalfield is from the Carboniferous period of the Palaeozoic era and is located on the South Eastern part of the French Massive. There is a major magmatic mass, which divides the coalfield in two. The first outburst occurred in Fontanes Colliery, on 1 April 1879, during shaft sinking operations at a depth of 323 metres and ejected 4,000 tonnes of coal, associated with carbon dioxide gas. The largest outburst occurred at the same mine in 1921 and was responsible for the ejection of 5,200 tonnes of coal along with 100,000 m³ of carbon dioxide.

Over the period from April 1878 to August 1968, some 6,318 outbursts were recorded in the Gard coalfield (Belin et al, 1969). A total of 350 of these outbursts occurred during normal mining operations and were responsible for 171 fatalities. The amount of material ejected varied from 20 - 5,500 tonnes with carbon dioxide being the most common gas.

2.2.7 Germany

The Aachen and Ruhr coalfields have both experienced outbursts. Although it forms part of the Ruhr coalfield the Ibbenburen coalfield is regarded as a separate coalfield due to different geo-technical conditions and the greater potential for outbursts. The Aachen coalfield has a very limited and sporadic history of outbursts.

Ruhr Coal Field: There are up to 300 separate coal seams in the Ruhr coalfield of varying thickness from 0.2 cm to more than 5 m and variable dip, from virtually flat to 45°. Gas and coal outbursts commenced in 1903 and have been recorded at the Hugu, Nordstern and Haard Collieries. During the period 1956 to 1970, 21 outbursts occurred within the Ruhr and Aachen coalfields with the largest being on 26 July 1958, at the Maria Hauptschacht Colliery, where 220 tonnes of coal and 66,000 m³ of gas were liberated. Most outbursts in the Ruhr coalfield have occurred in development roadways and as of 1995 none of the nine mines operating in the coalfield had experienced outbursts (the outburst prone mines had ceased operation).
Research undertaken more recently (Noack et al, 1995) has characterised the outbursts for the Ruhr and Aachen coalfields into four distinct and different categories (up to 1993):

1. Outbursts of gas and coal; 26 events
2. Outbursts of gas and rock; 0 events
3. Heavy floor gas emissions; 15 events and;
4. Other sudden liberations of major amounts of gas; 57 events

The prominent current problem within the Ruhr coalfield is the sudden liberation of large amounts of gas from major floor breaks or rock bursts in the floor strata (Hinderfeld et al, 1991). These floor bursts have been known to emit as much as 100,000 m$^3$ of gas over a 72-hour period causing major disruption to mining operations.

**Ibbenburen Coal Field:** The Ibbenburen coal measures are an elevated carbon horst, located approximately 90 km to the north of the Ruhr Valley covering an area of 60 km$^2$. The block has been divided by several transverse faults into sub-blocks with some of the upper seams outcropping to the surface (Paul, 1974). The coal was subjected to secondary coalification during the Upper Cretaceous period, which resulted in an increase in rank from bituminous to anthracite along with elevated levels of methane. The surrounding rock strata, particularly the porous sandstones underwent changes, which included methane enrichment and, at subsequent stages the porosity of these sandstones decreased due to a closing of the pores. Hence outbursts in this coalfield occur not only in the coal seams but in the rocks adjacent to the seams as well (Kowing, 1977, 1981).

During the period from 1970 to 1993, 240 outbursts were recorded in the Ibbenburen coalfield, which included 55 outbursts of gas and rock. The coal has a comparatively high strength of 15 MPa and increased depth of cover along with high gas content, is believed to be the major cause of outbursts. There have been no outbursts of gas and rock since 1983 and no floor outbursts (Lama and Bodziony, 1996).
2.2.8 Hungary

The Mecsek coal basin has been associated with outbursts of coal and gas. There are a large number of coal seams, which belong to the Jurassic period of the Mesozoic era however, only 19 to 26 of the 175 identified seams are considered economically recoverable. The seams are highly deformed tectonically, of variable thickness and subject to sudden changes in geological conditions. The entire basin has a high thermal gradient; at 550 metres depth, the rock temperature is 42°C and increases to 51°C at 750 metres. The first outburst recorded in the Mecsek coal field occurred in 1894 with a secondary outburst occurring at the same place the following day, resulting in two fatalities. Since then 600 outbursts have occurred in this coalfield up til 1989. On 4 November 1957, an outburst ejecting 1,400 tonnes of coal and 273,000 m³ of methane occurred at a depth of 480 metres but after a delay of 36 hours. The largest outburst occurred at Zobak Colliery in 1981 and ejected 1,800 tonnes of coal. The large number of delayed outbursts in this coalfield has necessitated the use of inducer shot firing as the primary method of outburst control. The hydraulic washing of coal in advance of the face is the most common method utilised to induce outbursts when developing headings or when cross cuts are to intersect the coal seams (Szirtes, 1964 and Janositz et al, 1989).

2.2.9 Japan

The Hokkaido and Kyushu coalfields (the North and South islands of Japan respectively) have both experienced outbursts. The coal measures within these coalfields belong to the Eocene and middle Oligocene age, tend to have a high vitrinite level, are highly disturbed, faulted, folded and intruded with volcanics. The presence of slickensides and structures with a low inherent strength are associated with outbursts.

Hokkaido and Kyushu Coal Fields: The first outbursts occurred at Suyama Colliery at a depth of 573 metres. During the period 1926 to 1968, 920 outburst incidents were recorded with 525 occurring in Hokkaido and 395
in Kyushu. The Hokkaido coalfields have had the largest outbursts of size < 1,000 tonne. The largest outburst occurred at a depth of 1,138 m in Yubari New Colliery, at 12:41 pm on 16 October 1981. It ejected 4,000 m³ of coal and 600,000 m³ of gas (predominantly methane). As a direct consequence of the outburst 83 miners were killed by suffocation (including 15 people who were trapped inbye of the coal ejected by the outburst). A further 10 people were killed in a secondary gas explosion caused when a static charge (from a sheet of plastic used by the rescue party) ignited the methane liberated by the initial outburst. The closure of a number of mines along with the successful use of gas drainage has brought about a major reduction in the number of outburst events.

The geological conditions, which characterise outbursts in Japan, have been described as follows:

- Regions with tectonic disturbances
- Regions disturbed by volcanics
- Changes in seam thickness
- Changes in direction of strike and configuration of surrounding rocks
- High gas content and brittle coal with low strength. (Sugawarra et al, 1995)

2.2.10 Kazakhstan

The Karaganda coalfield lies to the North of Tashkent and is the only coal field in Kazakhstan to experience outbursts. The coal belongs to the Carboniferous period and covers an area of 3,000 km². The coal field has 80 coal seams with a total combined thickness of 110 m however, only 30 of these seams (varying in thickness, from 0.6 m to 8 m) are considered minable with a rank varying from bituminous to anthracite. Most of the mines operate at depths greater then 600m with methane being the dominant gas. Due to increasing depth of cover, the number of coal seams deemed liable to outburst has also increased, with the minimum depth for outbursts being 400 metres.
A total of 45 outbursts have been recorded for the period 1956 to 1988 (Smorchkov et al, 1989) within the Karaganda coalfield, with all outbursts occurring in development workings. Inducer shot firing, gas drainage and hydraulic perforation have been used as control methods for outbursts.

2.2.11 New Zealand

There are limited coal resources and minimal coal production within New Zealand, especially in comparison to Australia and the Unites States of America. New Zealand's coal measures are considered to be upper Cretaceous to mid Tertiary in age and the majority of the coal resources (assessed to the level of indicated resource information) are lignite and located in the South East corner of the South Island. Some sub-bituminous and bituminous coals located on the West Coast of the South Island have been identified through recent exploration.

The coal resources of New Zealand were not considered to be outburst prone until 1997, when the Mount Davy mine recorded New Zealand's first outburst incident. The Mount Davy mine is located within the Greymouth Coalfield, on the Western side of the South Island. The target coal seams for the Mount Davy Colliery are at a depth of cover of between 600 to 700 metres and were accessed by two drifts. The first recorded outburst occurred not long after Drift 1 had accessed the coal seam and resulted in 250 tonnes of coal being ejected along with an estimated 5,000 m³ of methane. Following this incident, outburst management systems similar to those developed for the Bulli seam mines were implemented, focusing upon an Authority to Mine regime. This approach required the documentation of details on the drivage dimensions, gas content, mining method and ventilation requirements, all to be signed off by the responsible mining official.

This approach was based upon and reflected the assumption that the primary risk of outbursts were related to the mining of the coal seams, which later proved to be a false and fatal assumption. At about 4.03pm on 4th June 1998
an outburst occurred ejecting approximately 15 tonnes of coal and mudstone, along with 1,080 m$^3$ of methane, from the face into Drift 2, at the Mount Davy mine. Two men who had been operating a road-header at the face of the drift 9,687 metres from the portal at a vertical depth of 470 metres were asphyxiated as a consequence of the outburst.

As described by Hughes (2000), the outburst incidents and the inability to mine the coal safely, lead to the ultimate closure of the Mount Davy coal mine. In summary the mine closed after developing two 1,100 metre drifts, mining 12,000 tonnes of coal, experiencing 13 outbursts, 2 rock bursts, 4 petroleum ignitions and 1 explosion, all at a cost $52 (million) and 3 lives lost. A summary of the outburst incidents for Mount Davy is given in Table 2.1

<table>
<thead>
<tr>
<th>Outburst Incident</th>
<th>Date</th>
<th>Material Ejected (tonnes)</th>
<th>Gas Liberated (cubic metres)</th>
<th>Geology / Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3/11/97</td>
<td>~250 t stone &amp; coal</td>
<td>~5,000 m$^3$ CH$_4$</td>
<td>Small fault</td>
</tr>
<tr>
<td>2</td>
<td>27/5/98</td>
<td>100 kg coal</td>
<td>unknown</td>
<td>Intense shearing</td>
</tr>
<tr>
<td>3</td>
<td>4/6/98</td>
<td>~15 t stone &amp; coal</td>
<td>~1,080 m$^3$ CH$_4$</td>
<td>2 killed</td>
</tr>
<tr>
<td>4</td>
<td>8/1/99</td>
<td>51 t coal</td>
<td>~1,080 m$^3$ CH$_4$</td>
<td>Induced by shot-firing</td>
</tr>
<tr>
<td>5</td>
<td>20/1/99</td>
<td>41 t coal</td>
<td>~1,148 m$^3$ CH$_4$</td>
<td>Induced by shot-firing</td>
</tr>
<tr>
<td>6</td>
<td>22/1/99</td>
<td>100 t coal</td>
<td>15,094 m$^3$ CH$_4$</td>
<td>Induced by shot-firing</td>
</tr>
<tr>
<td>7</td>
<td>15/2/99</td>
<td>78 t coal</td>
<td>1,165 m$^3$ CH$_4$</td>
<td>Induced by shot-firing</td>
</tr>
<tr>
<td>8</td>
<td>21/2/99</td>
<td>92 t coal</td>
<td>1,788 m$^3$ CH$_4$</td>
<td>Faulting stone &amp; coal</td>
</tr>
<tr>
<td>9</td>
<td>19/3/99</td>
<td>240 t coal</td>
<td>6,287 m$^3$ CH$_4$</td>
<td>Faulting stone &amp; coal</td>
</tr>
<tr>
<td>10</td>
<td>12/4/99</td>
<td>170 t coal</td>
<td>11,829 m$^3$ CH$_4$</td>
<td>Induced by shot-firing</td>
</tr>
<tr>
<td>11</td>
<td>21/4/99</td>
<td>147 t coal</td>
<td>14,607 m$^3$ CH$_4$</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>22/4/99</td>
<td>&gt;&gt; 422 t coal</td>
<td>18,488 m$^3$ CH$_4$</td>
<td>Steep dipping seam 35°</td>
</tr>
<tr>
<td>13</td>
<td>1/7/99</td>
<td>&gt;&gt; 2,000 t coal</td>
<td>&gt;&gt;13,250 m$^3$ CH$_4$</td>
<td>Induced by shot-firing 26m cavity</td>
</tr>
</tbody>
</table>
2.2.12 Poland

The Lower Silesian coal basin and the Upper Silesian coal basin have both recorded outburst incidents. A brief description is presented below

**Lower Silesian Coal Basin:** Most of the outbursts incidents in Poland have occurred in this coalfield, which is located in the South West of Poland and covers an area of 600 km². The coal seams being from the Carboniferous period are mostly high grade coking, semi anthracite and anthracite coals. The coalfield has been affected by volcanics, which penetrated the coal seams as sills and dykes. The high level of tectonic activity has created a large number of folds and faults, which have greatly deformed the coalfield creating a complex structure with methane and carbon dioxide being the prominent gases.

Outbursts of coal and gas are not specifically associated with any stratigraphic level but are closely associated with the tectonics, in particular the major faults and boundaries of the coal basin. The horizontal thrust movements within the coalfield have played a dominant role causing the coal to undergo shearing and pulverisation. In particular the coal seam 410/412 can be regarded as a typical example in that the structure of the coal has been destroyed (Suchodolski, 1977).

Outbursts have been considered to be such an important mining related problem that the "Commission on Safety against Outbursts of Gas and Coal" was established and the various characteristics associated with outbursts have been published in detail. The first outburst associated with carbon dioxide occurred at Zofia Colliery at a depth of only 80 m and this is believed to be the shallowest outburst ever recorded in Poland.
The catastrophic nature of outbursts in Poland is exemplified in the following outburst incidents:

1. A delayed outburst occurred at Waclaw Colliery (now closed) on 9 July 1930 and resulted in 151 fatalities;
2. On 10 May 1941 an outburst occurred at Nowa Ruda Colliery, resulting in the death of 187 miners.
3. The largest outburst occurred at the Nowa Ruda Colliery on 22 October 1958, ejecting 5,000 tonnes of coal and an estimated 750,000 m\(^3\) of Gas (Kruk et al 1963)

Methods such as the use of de-stressing seams and inducer shot firing are utilised to control outbursts. Since 1990 most mines operating in outburst prone conditions have closed.

**Upper Silesian Coal Basin:** The Rybnik coalfield of the Upper Silesian Basin has experienced fewer outbursts than the Lower Silesian Basin coalfields. The Rybnik coalfield covers an area of 1,300 km\(^2\) and is located in the Southern part of Poland near the Czech Republic Boarder. It was predicted that based upon the dynamics of gas emissions whilst mining the coal, outbursts were likely within the Rybnik coalfield. This was supported by the common occurrence of outbursts within the Ostrava - Karvina coalfield across the boarder in the Czech Republic (Borowski, 1971). Consequently gas drainage has been extensively utilised to reduce the danger of outbursts, hence the outbursts, which have occurred have been sporadic and dispersed (Lama and Bodziony, 1996).

**2.2.13 Republic of South Africa**

Outbursts in South Africa have occurred in the Secunda coalfield (within the Karoo coal basin) at the Twistdraai Colliery. Four seams occur at this colliery however the #4 seam is the only seam mined. Methane is the predominant gas type along with the regular occurrence of dolerite sills. Bord and pillar mining is the mining method utilised to extract the coal in a seam of thickness
varying from 2.8 to 3.1 metres with a near horizontal dip. The first outburst occurred on 18 February 1993 when a diesel driven LHD was loading coal. Three subsequent outburst incidents, along with the first outburst occurred when a roadway intersected a dyke from the rise side. A fifth outburst occurred when the same dyke was intersected from the dip side. Drilling in advance is used to locate possible intersections with dykes and blasting is then undertaken as a control mechanism for unexpected outburst incidents.

2.2.14 Russia

There are five distinct coal basins within Russia, which have the most significant history of outburst incidents, these being:

- Kuznetsk coal basin
- Pechora coal basin
- Yegorshinsko - kamenski coalfield and Far East coal basin
- Donest coal basin (including the Rostov coal field)

**Kuznetsk Coal Basin:** This coal basin covers an area of 23,000 km² and contains coal measures belonging to the Carboniferous, Permian, Triassic and Jurassic periods. Mining is performed in 14 regions (coal-fields) in seams of varying thickness from 0.7 m to more then 20 m. The dip of these seams also varies from horizontal to vertical with methane being the dominant gas. Most of the seams have a complex geological structure as the seams within the coalfields are folded and in turn flanked by large folds and secondary folding. The majority of outbursts and rock bursts have occurred in the Kemerovo and Prokopensko - kiselevski coalfields where inclined and steeply inclined seams are extracted (Vylegzhanin et al, 1990). The first outburst occurred in 1943 in the #9 Colliery during development work. The minimum depth for an outburst is 150 metres with most of the incidents occurring in development headings and only 4% occurring on longwalls (Vylegzhanin et al, 1995). Gas drainage and the use of de-stressing seams are the two mechanisms used to control outbursts in this coal basin.
Pechora Coal Basin: The Pechora coal basin is located to the North of Russia and covers an area of 90,000 km$^2$. Coal measures within the basin are from the Permian period of the Palaeozoic era and contain 28 to 42 identified seams of thickness varying from 3 to 22 metres. The rank of the coal varies from brown coal to coking coal with mining operations working at depths of 1,020 metres having methane as the dominant seam gas. Six mines have experienced outburst conditions, with the first outburst being recorded in 1950 at Kapitalnaya Colliery in the Vorkuta coalfield at a depth of 340 metres. This outburst ejected 80 tonnes of coal and 7,000 m$^3$ of methane. As recorded a total of 251 outbursts had occurred by 1990 with 204 (84%) being associated with the formation of development headings (Vylegzhanin et al, 1990).

Yegorshinsk - kamenski Coal Field: Located in the Eastern part of the Yekaterinburg district, this coalfield belongs to the Carboniferous period. The coal basin has a complex synclinal structure with the dominant gas being methane. Mining conditions are difficult due to high gas content within the coal and tectonic disturbances. There are 4 to 15 seams of varying thickness with a mean of 1 m up to 5 m within the coalfield. The first outburst of methane and coal occurred in the Bursunka Colliery in 1944 at a depth of 200 metres and ejected 80 tonnes of coal and 7,000 m$^3$ of gas. By 1963, 190 outbursts had occurred mainly at depths exceeding 250 m (Lama and Bodziony, 1996).

Far-East Coal Basin: There are four basins within the far Eastern part of Russia, these being:

- Partizanski coal basin
- Tavrychanski coal field
- Suchanski coal basin and;
- Sakhalin Island coal basin.

The Partizanski coal basin is considered to be the most important as it covers a total area of 4,500 km$^2$ and is comprised of 20 coal seams with a total thickness of 30 metres. The predominant coal type is thermal or fuel coal.
with a complex geological structure and high gas content. As mining is undertaken at depths greater than 500 metres sporadic outbursts have occurred and six seams have been identified as outburst prone.

The Suchanski coal basin has coal measures belonging to the Jurassic period and has large anticlinal structures where the steeply angled seams attain dips of 55°. The first outburst occurred in the Verkhnyi Kedrovyi seam at #2-5 Colliery in 1927, ejecting 70 tonnes of coal. Subsequently a total of 70 outburst incidents were recorded for the period 1927 to 1974, and these occurred at depths greater than 160 metres.

The Sakhalim Island coal basin is an extension of the Hokkaido basin of Japan. These coal measures form an elongated synclinal structure trending north - South. Only one seam is regarded as outburst prone and minor sporadic outbursts have been recorded for the period 1973 to 1977 (Lama and Bodziony, 1996).

2.2.15 Taiwan

The coalfields of Taiwan are located in the Northern part of the island and cover an area of 2,400 km², with the coal belonging to the Tertiary - Miocene period. More then 300 mines have been in operation on the island however, many have closed leaving less than 80 in production by 1988. The deepest mines are working at a maximum depth of 1,000 metres, with the average depth of cover being 500 m. Over the period from 1972 to 1986, 61 outbursts were documented with most of these (52.4%) occurring during coal cutting on longwalls and in advance of headings. The majority of the outbursts were regarded as small with only 7 of the 61 outbursts exceeding 100 tonnes and approximately 49% of the outbursts occurred without warning. Table 2.2 relates the outbursts to geological conditions.

Mechanisms to control outbursts include the drilling of 90 - 120 mm diameter holes, 20 to 80 m in length, drilled parallel to the longwall face at 3 to 5 m intervals. Short holes (up to 10 m in length) are drilled as de-stressing holes
in advance of the faces. Inducer and de-stressing shot-firing is also used to a limited extent due to the difficulty of undertaking these procedures in the highly disturbed seam environment. Consistent and regular monitoring of gas flows from bore holes drilled in advance of the face are used as the primary prediction tool with the “safe” gas flow range being set at 8 to 30 L/min but this varies from mine to mine (Tseng et al, 1988).

Table 2.2. Geological conditions associated with outbursts in Taiwan (Tseng et al, 1988)

<table>
<thead>
<tr>
<th>Geological Conditions</th>
<th>Outbursts</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitching seam</td>
<td>4</td>
<td>6.6</td>
</tr>
<tr>
<td>Thinning of seam</td>
<td>5</td>
<td>8.2</td>
</tr>
<tr>
<td>Thickening of seam</td>
<td>24</td>
<td>39.3</td>
</tr>
<tr>
<td>No change</td>
<td>12</td>
<td>19.7</td>
</tr>
<tr>
<td>Changing coal quality</td>
<td>11</td>
<td>18.0</td>
</tr>
<tr>
<td>Pinch-off</td>
<td>2</td>
<td>3.3</td>
</tr>
<tr>
<td>Not available or recorded</td>
<td>3</td>
<td>4.9</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>61</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

2.2.16 Turkey

Outbursts in Turkey have occurred in the Zonguldak coalfield which boarders the Black Sea. The coal measures are from the Carboniferous period and have been extensively disturbed by tectonic activity. A total of 57 seams have been identified of which 38 are regarded as workable, with a seam thickness varying from 0.7 to 30 metres at a dip of 0 to 90°. Outbursts have occurred at a depth as low as 110 metres with the largest outburst ejecting 700 tonnes of coal and 11,000 m³ of methane. The first outburst occurred at Kozlu Colliery in 1962, at a depth of 300 metres beneath the sea, when a cross cut was being driven to intersect the seam. It ejected 250 tonnes of coal and filled a length of roadway for a distance of up to 40 metres (Okten et al, 1995).
Outbursts were not officially recorded and documented until 1969 and Table 2.3 provided some details on outburst incidents at Kozlu and Karadon collieries, which are the two mines reporting the greatest frequency of outburst incidents. Kozlu Colliery, whilst experiencing a similar number of outburst incidents as Karadon Colliery, has had many more fatalities from outbursts.

### Table 2.3 Spontaneous gas and coal outbursts in Turkey

(Okten et al, 1995)

<table>
<thead>
<tr>
<th>Years</th>
<th>Kozlu Colliery</th>
<th>Karadon Colliery</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Incidents</td>
<td>Deaths</td>
<td>Injuries</td>
</tr>
<tr>
<td>1969</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1970</td>
<td>4</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>1971</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1972</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1973</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1974</td>
<td>5</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>1975</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1976</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>1977</td>
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<td>-</td>
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<td>1978</td>
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<td>2</td>
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</tr>
<tr>
<td>1979</td>
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<td>1</td>
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<tr>
<td>1980</td>
<td>1</td>
<td>-</td>
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<td>1982</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1983</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>1984</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1985</td>
<td>-</td>
<td>-</td>
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<td>1986</td>
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<td>-</td>
<td>-</td>
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<td>1988</td>
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<td>1989</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>1990</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1991</td>
<td>3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1992</td>
<td>2</td>
<td>263</td>
<td>77</td>
</tr>
<tr>
<td>1993</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>30</td>
<td>283</td>
<td>92</td>
</tr>
</tbody>
</table>
Preventative measures used in these mines include:

- Drilling of three pilot holes of 65 mm diameter at the face 30 m ahead with a 5 m overlap
- Forcing system of face ventilation
- In longwall operations, gate roadways are driven no further then 2 m ahead of the face for ventilation roadways and 10 m ahead for main-gate roadways
- Geological disturbances are mapped in detail
- Blasting is practised as a means of mining through geological disturbances, up to 200 m before encountering the structure.
- Methane gas make (as a percentage) is monitored as a warning against outbursts
- Personnel receive training in the recognition of outburst warning signs.

2.2.17 Ukraine

The Donetsk coal basin is the main coal producing area of the Ukraine with some of the deepest mines in the world. The basin covers an area of 60,000 km\(^2\) and extends into Russia where it is referred to as the Rostov coalfield. The coal measures belong to the Carboniferous period of the Palaeozoic era and have formed into a major synclinal structure with a large number of faults in the South Western portion of the basin and a highly disturbed tectonic area to the North. The first recorded outburst occurred at the Novaya Smolanka Colliery (subsequently renamed the #1 Shernik Colliery) in 1906. This was associated with the initial development of the Smolanovski coal seam at a depth of 728 m. During the period from 1906 through to 1943, 1,364 outbursts were recorded at mines in the Donetsk coal basin, with a further 1,985 outbursts occurring in the period 1946 to 1988. The largest outburst occurred at Gagarin Colliery in 1969 with the initial mining of the Mazurka coal seam. This seam has an average thickness of 1 m, a dip of 68° at a depth of 710 m. The outburst ejected 14,500 tonnes of coal and liberated 600,000 m\(^3\) of gas (Stepanovich et al, 1976).
Mining operations within the Donetsk coal basin have used a number of mechanisms for the control of outbursts, particularly:

- Use of Protection seams
- Methane drainage
- Water infusion
- Hydraulic fracturing
- Inducer shot firing
- Advance drilling
- De-stressing slits (due to difficulty in cutting these slits this method is less commonly utilised)
- Seismic techniques including signal analysis
- Electro-magnetic impulse method.

These control methods have enabled the mining of deeper outburst prone seams in conjunction with an improved safety environment.

2.2.18 United Kingdom

Outbursts of coal and gas have occurred at different times in a number of coalfields throughout the United Kingdom however the West Wales coalfields have recorded the greatest number of outburst incidents.

West Wales Coalfields: Outbursts of coal and gas have been predominantly associated with the Western part of this coalfield, particularly within that area known as the Gwendraeth Valley as part of the North Western anthracite field. As this coal field is on the North Western limb of the main South Wales Syncline, the entire field is highly dislocated with normal faulting due to north south trending faults associated with displacements varying up to 330 m and folding and or thrust faulting has occurred along a general east west axis. The changes in structure accompanied with rapid variations in seam thickness have been allied with plate movement but more importantly these have been documented as having a close association with outbursts. The size of the structure and the seam
displacement is often not revealed until after the outburst incident with the
clean up of the discharged material (Williams and Morris, 1972).

There are nine seams mined in this area with thicknesses varying from 0.6 to
3 m, of anthracitic coal and methane being the prominent gas associated with
all outburst incidents. In an endeavour to combat the problems associated
with outbursts the mining methods have varied since 1901 when the first
incident occurred. For thin coal seams a stepped longwall with a non-regular
face was utilised and in thick seams, a pillar and stall mining method with
irregular or incomplete pillar extraction was used. Work undertaken by Price
(1959) identified that those seams, which are liable to outbursts have a
strong, thick sandstone or siltstone roof as opposed to seams with a shale
roof having no recorded outburst incidents. This has been utilised as a
positive indicator for outburst potential.

The largest outburst occurred at the Cynheidre/Pentremawr Colliery on 6
April 1971, which resulted in 67 people being injured of whom 6 sustained
fatal injuries. A roadway was being driven between two headings in the Big
Seam at a depth of 620 metres, with an estimated 400 tonnes of coal and
57,000 m³ of methane being ejected. This was associated with a twenty two
hour delay after inducer shot firing had been used as a mechanism of
initiating the outburst. This "control method" was introduced in 1926, however
further studies undertaken by Pescod (1947 - 48) identified that outbursts still
occurred, as the inducer shot system required the exact and correct siting of
the shot for maximum effect.

As a consequence other methods were utilised in an attempt to control
outbursts, which were primarily associated with the stress component of
outbursts:

- Advancing longwalls with gate roadways in line with the face
- Avoiding the additive stress effect of excavations within the seam or
  neighbouring seams
• Maintenance of a straight line face
• Avoiding sharp angles in excavation formations
• Decreasing convergence of roof and floor

A number of tests and coefficients were proposed by the National Coal Board such as outburst ratio and coal friability, which were mainly related to the characteristics of the coal such as its strength etc. However, these were not effective in controlling outbursts. Micro-seismic monitoring was also trialled in the mid eighties as an outburst prediction method. These however, were not effective as all the outburst prone mines in the West Wales Coalfield were closed as was the Cynheidre/Pentremawr Colliery in the mid eighties.

2.3 AUSTRALIAN EXPERIENCE
Outbursts have occurred in the Sydney Basin (Illawarra Coalfield) and the Bowen Basin (Northern and Central Queensland). These two Basins are linked geologically and cover an area of 220,000 km², but have been defined separately upon regional and or local characteristics. In all over 700 outbursts have been recorded within Australia over 106 years.

The Bulli Coal Seam (located within the Illawarra Coalfield to the south of Sydney) has the dubious privilege of having the first recorded outburst in Australia at Metropolitan Colliery, 10 September 1895. The various characteristics and peculiarities of Bulli seam outbursts are discussed in more detail in Chapter 3.

With regard to the Bowen Basin in Queensland, three collieries have experienced outburst incidents, these being mines in the Collinsville area along with Leichhardt and Moura Collieries. Both methane and carbon dioxide outbursts have been recorded with the primary characteristics being the presence of geological structures and a higher level of in situ seam gas.
This in combination with in situ stresses, along with mining induced stress especially as identified at Leichhardt Colliery, are believed to be the main contributing features of outbursts in Australia. It should be noted that in recent times a number of coal mining operations in both New South Wales and Queensland whilst not recording any outburst incidents, are considered to be potentially outburst prone and gas drainage associated with outburst management plans have been developed as a precautionary matter.

A more detailed review of the Queensland outbursts follows:

2.3.1 Collinsville Area

Instantaneous outbursts in the Collinsville area were referenced by Hargraves, (1958) and most recently by Lama and Bodziony, (1996). In general terms the Bowen coal seam which was mined at the Collinsville State mine was a medium hard, high rank, bituminous coking coal with 17.9% volatiles, 1.0% moisture and on average 16.5% ash content. The seam outcrops on the northern rim of the Bowen Basin and has been subjected to various levels of deformation as identified in the nature and frequency of faulting, the rank of the coal and the wide spread occurrence of igneous intrusions. Low reverse angle thrust faults, in conjunction with bedding plane and slip strike faults were common. The Western extent of mining within the No.2 State Mine was limited or controlled by the Three Mile Creek Fault, which is a thrust fault with 400 metres of throw.

The first outburst incident for the Collinsville area occurred at the State Mine in 1954 at a depth of 250 metres. It resulted in the death of seven men and three horses, with carbon dioxide being the prominent gas. A royal Commission was held in 1956 following these fatalities. Since 1954 there have been nineteen outburst incidents recorded for the Collinsville area as indicated in Table 2.4 (Williams and Rogis, 1980).
Table 2.4  Outburst details for the Collinsville Coalfield  (Williams and Rogis, 1980)

<table>
<thead>
<tr>
<th>Locality</th>
<th>No.</th>
<th>Date</th>
<th>Size of outbursts (t)</th>
<th>Faulting</th>
<th>Other Structures</th>
<th>Seam thickness (m)</th>
<th>*Rank of coal (%)</th>
<th>Emission Value cc/g</th>
<th>Gas Composition %</th>
<th>Depth of Cover (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>State Mine</td>
<td>1</td>
<td>13/10/54</td>
<td>500 500</td>
<td>Thrust, Normal</td>
<td>5 dyke</td>
<td>3 m</td>
<td>4.6</td>
<td></td>
<td>98</td>
<td>185</td>
</tr>
<tr>
<td>State Mine</td>
<td>2</td>
<td>4/3/60</td>
<td>360 450</td>
<td>Thrust, Normal</td>
<td>10.5 0.6</td>
<td>3 m</td>
<td>4.6</td>
<td></td>
<td>92</td>
<td>94</td>
</tr>
<tr>
<td>State Mine</td>
<td>3</td>
<td>19/4/60</td>
<td>90 400</td>
<td>Strike-slip</td>
<td>0.4</td>
<td></td>
<td>4.6</td>
<td></td>
<td>51</td>
<td>61</td>
</tr>
<tr>
<td>State Mine</td>
<td>4</td>
<td>13/5/60</td>
<td>100 280</td>
<td>Strike-slip</td>
<td>0.7</td>
<td></td>
<td>4.6</td>
<td></td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>State Mine</td>
<td>5</td>
<td>27/5/60</td>
<td>60 450</td>
<td>Strike-slip</td>
<td>0.7</td>
<td></td>
<td>4.6</td>
<td></td>
<td>51</td>
<td>61</td>
</tr>
<tr>
<td>State Mine</td>
<td>6</td>
<td>7/6/60</td>
<td>0.5 450</td>
<td>Strike-slip</td>
<td>0.3</td>
<td></td>
<td>4.6</td>
<td></td>
<td>51</td>
<td>61</td>
</tr>
<tr>
<td>State Mine</td>
<td>7</td>
<td>21/6/60</td>
<td>15 450</td>
<td>Strike-slip</td>
<td>0.1</td>
<td></td>
<td>4.6</td>
<td></td>
<td>51</td>
<td>61</td>
</tr>
<tr>
<td>State Mine</td>
<td>8</td>
<td>5/8/60</td>
<td>70 450</td>
<td>Thrust</td>
<td>3.2</td>
<td></td>
<td>4.6</td>
<td></td>
<td>51</td>
<td>61</td>
</tr>
<tr>
<td>State Mine</td>
<td>9</td>
<td>9/11/60</td>
<td>60 450</td>
<td>Strike-slip</td>
<td>0.5</td>
<td></td>
<td>4.6</td>
<td></td>
<td>51</td>
<td>61</td>
</tr>
<tr>
<td>State Mine</td>
<td>10</td>
<td>17/11/60</td>
<td>100 280</td>
<td>Strike-slip</td>
<td>0.3</td>
<td></td>
<td>4.6</td>
<td></td>
<td>51</td>
<td>61</td>
</tr>
<tr>
<td>State Mine</td>
<td>11</td>
<td>7/2/61</td>
<td>60 280</td>
<td>Strike-slip</td>
<td>0.1</td>
<td></td>
<td>4.4</td>
<td></td>
<td>51</td>
<td>61</td>
</tr>
<tr>
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<td>12</td>
<td>6/3/61</td>
<td>1 280</td>
<td>Strike-slip, 0.2</td>
<td></td>
<td>0.3 m sill</td>
<td>4.4</td>
<td></td>
<td>51</td>
<td>61</td>
</tr>
<tr>
<td>State Mine</td>
<td>13</td>
<td>21/3/61</td>
<td>5 280</td>
<td></td>
<td></td>
<td>0.3 m sill</td>
<td>4.4</td>
<td></td>
<td>51</td>
<td>61</td>
</tr>
<tr>
<td>No. 3 Mine</td>
<td>14</td>
<td>30/3/72</td>
<td>1 280</td>
<td>Strike-slip 0.1</td>
<td></td>
<td></td>
<td>4.3</td>
<td>1.29 1.23</td>
<td>92.1 6.5 1.2</td>
<td>230</td>
</tr>
<tr>
<td>No. 3 Mine</td>
<td>15</td>
<td>14/4/72</td>
<td>1 280</td>
<td>Strike-slip 0.1</td>
<td></td>
<td></td>
<td>4.3</td>
<td>1.29 1.10</td>
<td>92.1 6.5 1.2</td>
<td>230</td>
</tr>
<tr>
<td>No. 2 Mine</td>
<td>16</td>
<td>8/9/79</td>
<td>25 280</td>
<td>Thrust 6.0</td>
<td></td>
<td></td>
<td>5.8</td>
<td>1.26 1.28</td>
<td>6.5 1.2</td>
<td>260</td>
</tr>
<tr>
<td>No. 2 Mine</td>
<td>17</td>
<td>27/10/78</td>
<td>1 280</td>
<td>Thrust 6.0</td>
<td></td>
<td></td>
<td>5.8</td>
<td>1.26 1.28</td>
<td>6.5 1.2</td>
<td>260</td>
</tr>
<tr>
<td>No. 2 Mine</td>
<td>18</td>
<td>22/11/78</td>
<td>0.14 280</td>
<td>Thrust 6.0</td>
<td></td>
<td></td>
<td>5.8</td>
<td>1.26 1.28</td>
<td>6.5 1.2</td>
<td>265</td>
</tr>
<tr>
<td>No. 2 Mine</td>
<td>19</td>
<td>23/11/78</td>
<td>19.2 280</td>
<td>Thrust, strike-slip 6.0 0.5</td>
<td></td>
<td></td>
<td>6.8</td>
<td>1.26 1.28</td>
<td>6.5 1.2</td>
<td>265</td>
</tr>
</tbody>
</table>
It would appear that as mining operations developed within the Collinsville area and it became more difficult to manage or control the outbursts, the mines were closed and re-started at shallower depths, near the outcrop. Consequently four separate mining operations have been undertaken in the Bowen coal seam, over a 50 year period, with operations being closed or restarting at shallower cover as the depth of workings approached the critical depth, ranging from 250 metres to 280 metres.

2.3.2 Leichhardt Colliery

Leichhardt Colliery is located within the Bowen Basin, to the South of the central Queensland town of Blackwater. As described by Hanes (1994) and Lama and Bodziony (1996), the colliery reported its first outburst incident in 1974 while mining the Gemini coal seam at an overall seam thickness of 6 metres (with an average working or extraction thickness of 2.5 to 2.8 metres) and depth of cover ranging from 350 metres to 410 metres. The local geology at the mine was regarded as structurally complex due to a number of faults of less than 10 metres throw, striking to the North West. The colliery workings were intersected by three prominent faults, two being steeply dipping normal faults of throw greater than 10 metres and the third being a shallow dipping reverse fault of 3.5 metres throw. Gas content of the Gemini coal seam was measured at 16 m$^3$/tonne, being predominantly CH$_4$.

The first recorded outburst occurred in 1974 when mine workings had only developed 175 metres from the seam inset of the No. 2 shaft. In all, more then 200 outburst incidents were recorded at Leichhardt Colliery with three dislodging 300 tonnes or more of material. The largest outburst occurred on the shallow dipping reverse fault with minor displacement (~200 mm). The outburst was associated with sheared and brecciated coal in the vicinity of the fault, ejecting 500 tonnes of coal and approximately the same amount of rock. This outburst is believed to have been instrumental in the decision to close the mine.
Coal mining operations were undertaken using either a Joy 10CM or a Voest Alpine road header (used to cut a profiled roadway) until 1978 when following a major outburst, shot-firing was used. It was believed that outbursts at Leichhardt Colliery were stress controlled and gas induced. This was further complicated by mining induced cleavage and stress within the coal, which when combined with a directional permeability tended to create a higher than normal gas pressure gradient, based primarily upon the direction and orientation of the mine workings. The interplay between horizontal stress (identified as being the maximum principal stress) vertical stress and mining induced stress was best described by Hanes (1995) and is shown diagrammatically in Figure 2.1. The nature of mining conditions, gas content and ultimately the inability to successfully manage or control outbursts, all contributed to the mine being closed in 1982.

2.3.3 Moura Colliery

Moura No. 4 mine was an underground mine developed off the high wall of an open cut. The seam being mined had a total height of 5.2 m with the lower 2.5 metres being mined and a shale/sooty coal band (reported to be mylotinised coal) in the roof. Gas content for the seam was measured at between 8 – 9 m³/tonne with a maximum seam gas pressure of 1.03 MPa (gauge) for a vertical depth of 135 metres (Troung et al, 1983).

In all three (3) outbursts have been recorded for Moura No. 4 Colliery with two of the three incidents being related to a major joint zone. The third outburst was believed to be associated with a zone of weak coal, uncharacteristic of normal condition in the mine. Generally outbursts were not considered to be a significant mining related problem due to the high strength of the coal, the low seam gas content and the slow desorption rate. In 1995 the mine was closed following a methane gas explosion, which resulted in 9 fatalities.
Figure 2.1 Directional control for mining strain patterns at Leichhardt Colliery
(Hanes, 1995)
2.4 SUMMARY

It is evident that outbursts are a mining problem throughout the world. The nature and magnitude of the risk varies from country to country and from coalfield to coalfield, however, the fundamental factors as outlined in Chapter 1 appear to be consistent. In some circumstances outbursts are a geo-dynamic phenomenon (i.e. they are primarily related to very high in situ stress). In other circumstances outbursts are considered a gas-dynamic phenomenon (i.e. they are related to accumulations of free, desorbable gas). Ultimately the end result being injury and or death is the same. This supports the overall correlation between outbursts and depth of cover. The deeper the mining operation, the higher the gas and the greater the stress hence, the potential to experience outbursts.

It would appear that the most effective means of overcoming outbursts for many mining operations has been to simply close, cease mining. In this light the success experienced with Bulli seam mines is of international significance. The focus on managing the outburst risk with the need to maintain high production levels and economic viability has been realised. This will be discussed in greater detail within this thesis.
CHAPTER THREE

BULLI SEAM OUTBURSTS
CHAPTER 3

BULLI SEAM OUTBURSTS

3.1 INTRODUCTION
The Bulli Coal Seam as a primary source of coking coal is a major economic resource for New South Wales and Australia. Geological conditions associated with this seam have required the development of specialised mining techniques and the adaptation of mining equipment, for coal mines to remain competitive. This includes the development of specialised mining systems and techniques to manage outbursts. This chapter details geological and mining characteristics as well as the history of outbursts within the Bulli seam.

3.2 THE BULLI COAL SEAM

3.2.1 Background
The Bulli coal seam is the uppermost seam in the Illawarra coal measures. It lies to the South and Southwest of the Sydney region with Wollongong being the mining and industrial centre (Figure 3.1, shows the boundary of the Illawarra Coalfield and its location within Australia).

Mining operations for the Illawarra Coalfield first commenced in 1847 at the Mt Keira Colliery, near Wollongong, located some 75 km South of Sydney. The Bulli Seam has been mined at various locations along the Illawarra Escarpment with mine workings gradually progressing to the west, as the "easier" or more accessible coal was worked out. Saleable coal production from the Illawarra coalfield for the fiscal year 1999-2000 was 10.52 million tonnes with 79% (8.3 million tonnes) coming from seven mines operating in the Bulli seam. Longwall retreat mining is now the predominant mining method used in these seven Bulli Seam mines. Approximately fifty four percent (5.75 million tonnes) of the 10.52 million tonnes of saleable coal is used for domestic purposes, mainly steel making. The remaining 4.77 million tonnes is sold on the export market as a coking coal with Japan and Korea being the two major markets. It follows that coal production from the Illawarra Coalfield is of
regional and national importance. Hence mining problems such as sudden outbursts, which have the potential to endanger mine workers and restrict coal production, are of major concern to the Industry and the Government.

3.2.2 Geology of the Bulli Coal Seam
The Illawarra Coalfield covers an area of approximately 8,600 square kilometres and as shown in Figure 3.1, lies immediately to the south of Sydney. It forms the southern extent of the Sydney Basin, a sedimentary basin comprised of terrestrial and paralic sediments lain down in a shallow marine to fluvic-deltaic environment during the Permian and Triassic Age. As shown in Table 3.1, the Illawarra Coal Measures make up the primary economic coal seams, which overlie a series of sandstone and siltstone formations. The Narrabeen and Hawkesbury sandstones overlie the coal measures, with their high strength characteristics providing a number of mining related problems.

The Bulli seam being the uppermost seam of the Illawarra Coal Measures sub-crops along the coastal Illawarra Escarpment. This was the site of early mining due to the ease of access to the various coal measures. From the coastal escarpment the coal measures have a regional dip of 2° to the Northwest with some localised variations of 5° or more. Hence the depth of cover increases to the north and the west due to the regional dip and a series of east south easterly trending folds and faults. Currently mining operations are proceeding at depths ranging from 300 to 550 metres.

3.2.3 Structure of the Bulli Coal Seam
In terms of structure, the northerly plunging Camden Syncline is the most dominant feature of the Illawarra Coalfield (see Figure 3.2). This structure represents the axis of the Sydney Basin, and was active during sedimentation. A series of folds with east south easterly trending axes have developed on the eastern limb of this syncline plunging towards the northwest. On the western limb of the Camden Syncline the predominant structures are a series of north-south trending monoclines and faults.
Figure 3.1 Boundary of the Illawarra Coalfield
Two of these features, which have displacements of up to 100 metres, are the Lapstone Monocline/Nepean Fault and the Oakdale Monocline. These features are sub-parallel to the structure contours on the top of the Illawarra Coal Measures and the direction of down warping is towards the basin centre. The majority of faults in the Illawarra Coalfields are normal faults, although strike slip and high angle reverse faults are known to exist as well. Displacement on these faults ranges from zero up to 100 metres and may vary from a single fracture to zones more than 100 metres wide. The displacement is also known to vary both along strike and with depth.

**Table 3.1 Stratigraphy of the Illawarra Coalfield**

<table>
<thead>
<tr>
<th>AGE</th>
<th>GROUP</th>
<th>SUB-GROUP</th>
<th>FORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Triassic</strong></td>
<td>WIANAMATTA</td>
<td></td>
<td>BRINGELLY SHALE</td>
</tr>
<tr>
<td></td>
<td>GROUP</td>
<td></td>
<td>MINCHINBURY SANDSTONE</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>ASHFIELD SHALE</td>
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<td></td>
<td>MITTAGONG FORMATION</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>HAWKESBURY</td>
<td></td>
<td>NEWPORT FORMATION</td>
</tr>
<tr>
<td></td>
<td>SANDSTONE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NARRABEEN</td>
<td>CLIFTON SUBGROU</td>
<td>GARIE FORMATION</td>
</tr>
<tr>
<td></td>
<td>GROUP</td>
<td>P</td>
<td>BALD HILL CLAYSTONE</td>
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<td></td>
<td>BULGO SANDSTONE</td>
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<td></td>
<td>STANWELL PARK CLAYSTONE</td>
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<td>SCARBOROUGH SANDSTONE</td>
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<td></td>
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<td>WOMBARRA CLAYSTONE</td>
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<td>COALCLIFF SANDSTONE</td>
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<td></td>
<td>ILLAWARRA</td>
<td>SYDNEY SUBGROU</td>
<td>BULLI COAL</td>
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<td>COAL MEASURES</td>
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<td>ECKERSLEY FORMATION</td>
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<td>WONGAWILLI COAL</td>
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<td></td>
<td>TONGARRA COAL</td>
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<td>WILTON FORMATION</td>
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<td>CUMBERLAND SUB</td>
<td>ERINS VALE FORMATION</td>
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<td>GROU</td>
<td>PHEASANTS NEST FORMATION</td>
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<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Figure 3.2 Structural Features of the Illawarra Coalfield
Interpretation of the tectonic history suggests that the Illawarra Coalfield has been subject to an east-west compressive stress probably related to a subduction process to the east of the Australian continent. The Camden Syncline is the principal feature associated with this stress field. Various folds and faults on the eastern limb of the Camden Syncline indicate that an additional northeast-southwest compression stress field has affected the region.

3.2.4 Coal Quality
The Illawarra Coal Measures contain up to eleven named seams of which two, the Bulli and Wongawilli are currently mined. The Balgownie and Tongarra seams were also mined, however, they displayed large variability in properties and their economic development is limited in geographic extent.

The Bulli Seam is by far the most important seam in the region, providing the highest quality coking coal available in New South Wales. Although traditionally a source of low and medium volatile coking coals for domestic and export markets, the Bulli and Wongawilli seams also provide substantial tonnages of fuel coal either in the raw state or as a middlings product.

In the current mining areas the Bulli seam yields a medium volatile, high rank coking coal (see Table 3.2). Volatile matter ranges from 18 to 23 percent (air dried). The ash level may be relatively high in the raw coal, but can usually be beneficiated to around 8 to 10 percent (air dried) but the sulphur content, like that of most Australian coals is very low (0.3 percent). The crucible swelling number is usually 5 to 7. Although the vitrinite content is only moderate (45%) and the inertinite content rather high (50%), the Bulli Seam is an excellent medium volatile component of coking blends.
### Table 3.2 Indicative Coal Analyses for the Illawarra Coal Measures

<table>
<thead>
<tr>
<th></th>
<th>Bulli</th>
<th>Balgownie</th>
<th>Wongawilli</th>
<th>Tongarra</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximate Analysis</strong> (% ad)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Inherent Moisture</td>
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<td>1.1-1.4</td>
<td>1.1-2.0</td>
<td>1.4</td>
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<tr>
<td>Ash</td>
<td>8.2-12.9</td>
<td>10.9-11.1</td>
<td>10.5-17.9</td>
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<td>Volatile Matter</td>
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<td>24.2-30.8</td>
<td>23.6</td>
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<td>Fixed Carbon</td>
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<td>52.3-63.2</td>
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<td>6½-7</td>
<td>5½-8½</td>
<td>5½</td>
</tr>
<tr>
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<td>G3-G4</td>
<td>G4-G9</td>
<td>G1</td>
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<tr>
<td>Hardgrove Grind Index</td>
<td>70</td>
<td>-</td>
<td>70</td>
<td>65</td>
</tr>
<tr>
<td><strong>Ash Fusion Properties</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Flow temperature (°C)</td>
<td>+1600</td>
<td>1300</td>
<td>1550</td>
<td>1450</td>
</tr>
<tr>
<td>- Roga Index</td>
<td>29-69</td>
<td>80</td>
<td>65-85</td>
<td>59</td>
</tr>
<tr>
<td>- R’o Max</td>
<td>0.91-1.31</td>
<td>1.32</td>
<td>1.36-1.43</td>
<td>1.42</td>
</tr>
<tr>
<td><strong>Ultimate Analysis (%)</strong></td>
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<td></td>
</tr>
<tr>
<td>Carbon (daf)</td>
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<td>87.5-89.0</td>
<td>86.5-87.3</td>
<td>87.1</td>
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<tr>
<td>Hydrogen (daf)</td>
<td>4.6-5.2</td>
<td>4.8-5.0</td>
<td>5.2-5.4</td>
<td>5.1</td>
</tr>
<tr>
<td>Nitrogen (daf)</td>
<td>1.4-1.9</td>
<td>1.6-1.7</td>
<td>1.7-1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Oxygen (daf)</td>
<td>4.2-8.1</td>
<td>3.9-5.2</td>
<td>4.6-9.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Carbonates (daf)</td>
<td>0.1-0.7</td>
<td>0.3-0.5</td>
<td>0.1-0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Phosphorous (db)</td>
<td>0.01-0.09</td>
<td>0.01</td>
<td>0.01</td>
<td>0.10</td>
</tr>
<tr>
<td>Chlorine (db)</td>
<td>0.01-0.03</td>
<td>-</td>
<td>0.01-0.02</td>
<td>-</td>
</tr>
<tr>
<td>Total Sulphur (db)</td>
<td>0.3-0.5</td>
<td>0.4</td>
<td>0.5-0.7</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Maceral Analysis (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitrinite</td>
<td>30-59</td>
<td>61</td>
<td>66-79</td>
<td>51</td>
</tr>
<tr>
<td>Exinite</td>
<td>tr.-4</td>
<td>tr.</td>
<td>tr.-7</td>
<td>tr.</td>
</tr>
<tr>
<td>Micrinite</td>
<td>8-22</td>
<td>5</td>
<td>2-8</td>
<td>11</td>
</tr>
<tr>
<td>Semi Fusinite</td>
<td>21-43</td>
<td>27</td>
<td>9-23</td>
<td>27</td>
</tr>
<tr>
<td>Fusinite</td>
<td>1-3</td>
<td>3</td>
<td>1-4</td>
<td>2</td>
</tr>
<tr>
<td>Mineral Matter</td>
<td>4-6</td>
<td>4</td>
<td>4-13</td>
<td>9</td>
</tr>
</tbody>
</table>

### 3.2.5 Seam Gas

Seam gas content and composition varies significantly throughout the Illawarra Coalfields, with the depth of cover and proximity to geological structures (faults and dykes) being the two primary determinants. Because the Bulli coal seam is the most extensively mined and the only Illawarra seam accredited with outbursts, it has been the subject of most of the outburst related research.

In the coastal areas adjacent to the Bulli seam sub-crop, gas contents are low, in the order of 1-3 m³/tonne. Hence in early mining operations localised variations in gas composition whilst being recognised did not cause major
concern to mine operators. With increasing depth and the development of workings some considerable distance from the seam sub-crop, gas content in the order of 13 to 16 m³/tonne, for a depth of 550 m, located some 25 km from the coastal sub-crop, have been encountered with 20 m³/tonne of CO₂ being reputed to be the highest gas content so far (Piper, 1998).

The change in seam gas composition from predominantly CH₄ to predominantly CO₂ has been noted on a regional basis. Generally CO₂ increases to the north, and to the west. Whether this is a true regional trend or the effects of localised igneous activity and major fault zones has yet to be determined. For each colliery the potential for seam gas composition to vary considerably is well recognised. The occurrence of "Illawarra Bottom Gas", a combination of CH₄ and CO₂, which has been known to accumulate on the floor in low places and give a "gas gap" on an oil flame safety lamp, has been well documented.

The apparent correlation between seam gas content and geological structures (faults and dykes), was discussed by Hargraves (1963) where the tendency to higher percentages of CH₄ along faults was noted but thought to be circumstantial support for CO₂ in the seam being due to igneous activity. Whether this is the case or the seam gas variations in the Bulli seam are due to migration along faults from lower seams has not been proven. However, the general correlation between igneous activity and increased CO₂ content has been noted in a number of collieries in the coalfield.

3.3 BULLI SEAM OUTBURSTS

The first reported outburst incident in the Illawarra Coalfield occurred on 30 September 1895, according to Hargraves (1965). Details as to the size and intensity of this and other early incidents are very sketchy, however it would appear that all the early incidents (1895 to 1911) were associated with faults, dykes or zones of fractured coal, the discharge of CO₂ and occurred at Metropolitan Colliery.
Since 1895 there have been over 150 outburst incidents at Metropolitan Colliery and this mine developed a reputation for being outburst prone, particularly during the period 1961 to 1968, when shot firing was used to induce and or control outbursts. Generally the high incidents of faults, dykes, sills, cindered and disturbed coal at Metropolitan Colliery was believed to be the primary cause for the high number of outburst incidents.

Table 3.3 gives an indication as to the number of outburst type incidents attributed to each mine working the Bulli Coal Seam and Section 3.4 provides some insight into the specific details of those outburst incidents, which proved to be fatal. The outburst phenomenon was not treated with the same degree of importance as that exhibited in some coalfields throughout Europe and elsewhere in the world, due primarily to the comparative low fatality rate. The major coal mining problems to influence mining operations in the Bulli seam were most obviously the control and management of methane (190 fatalities from two incidents) and the problems associated with roof control under total extraction.

To date, other coal seams within the Illawarra Coalfield have not exhibited the tendency to outburst and while a number of theories relating to different seam characteristics could be used to explain this, the limited extent of mine workings in these other seams (particularly for depths of cover greater than 350 metres) would appear to be the main factor. Whilst outbursts have been a phenomenon associated with mining the Bulli Coal Seam for the last one hundred years the mechanism behind outbursts was not fully understood and hence the various outburst parameters were not defined. This lack of background information was due mainly to each mine being fully responsible for its own operations; an overall inability to admit that outbursts were a problem for all Bulli seam mines and a lack of technology and information transfer between mines.
### Table 3.3 Bulli Seam Outbursts

<table>
<thead>
<tr>
<th>Colliery</th>
<th>No. of Outbursts</th>
<th>Size in tonnes</th>
<th>Gas</th>
<th>Geological Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appin</td>
<td>26</td>
<td>2 - 88</td>
<td>mainly CH4 &amp; CO2 on dykes.</td>
<td>Predominantly strike slip faults; mylonite zones.</td>
</tr>
<tr>
<td>Brimstone</td>
<td>2</td>
<td>30</td>
<td>CO2</td>
<td>Mainly dyke related structures with strike slip movement.</td>
</tr>
<tr>
<td>(closed)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrimal</td>
<td>4</td>
<td>12</td>
<td>CH4 &amp; CO2</td>
<td>Shear zone associated with minor faulting &amp; dykes.</td>
</tr>
<tr>
<td>(closed)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kemira</td>
<td>2</td>
<td>60 - 100</td>
<td>CO2</td>
<td>normal fault with mylonite.</td>
</tr>
<tr>
<td>(closed)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metropolitan</td>
<td>154</td>
<td>250</td>
<td>mainly CO2 with minor amounts of CH4</td>
<td>Predominantly with dykes &amp; faults that exhibit slicken sides &amp; mylonite.</td>
</tr>
<tr>
<td>Bellambi West</td>
<td>13</td>
<td>1 - 300</td>
<td>mainly CO2</td>
<td>Strike slip faults with mylonite; dyke zones &amp; thrust faults.</td>
</tr>
<tr>
<td>(South Bulli)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tahmoor</td>
<td>90</td>
<td>5 - 400</td>
<td>mainly CO2</td>
<td>Mainly strike slip faults; with dykes (110° - 135°) &amp; thrust faults: mylonite usually present.</td>
</tr>
<tr>
<td>Tower</td>
<td>19</td>
<td>1 - 80</td>
<td>mainly CH4</td>
<td>Mainly strike slip faults with dykes.</td>
</tr>
<tr>
<td>West Cliff</td>
<td>254</td>
<td>4 - 320</td>
<td>mainly CH4 with CO2 to the NE development</td>
<td>Predominantly strike slip faults (100° - 110°) with slicken sides &amp; mylonite; dykes and thrust faults have been associated with outbursts.</td>
</tr>
</tbody>
</table>

This situation changed drastically after the South Bulli Outburst, 25 July 1991 where three miners were killed. Various working groups and task groups were established to identify the mechanisms causing outbursts. This included recommendations on the most suitable means of managing the outburst risk, the need for a standardised data collection and information interchange within the local coal mining industry and ongoing review of outburst prediction techniques and recommendations for future research.

It followed that a mine by mine review gave the best means of assessing the characteristics of outbursts. Following from this review and subsequent analysis by the expert steering committee, a greater understanding and awareness of the characteristics for Bulli Seam outburst was developed.
3.3.1 Characteristics of Bulli Seam Outbursts

The current information on outbursts in the Bulli seam tends to involve the following factors.

- Geological structures have a major link with the incidence of outbursts particularly strike slip faults.
- Compression type structures, such as reverse or thrust faults and strike slip faults have a greater potential to create mylonite, sheared and crushed coal than tensional structures such as normal faults.
- Mylonite and crushed coal has the potential to desorb very rapidly and when combined with localised stress conditions, which greatly reduce permeability, there is the potential for pockets of pressurised gas to be associated with structures.

This tends to reflect the general belief and assumption, based upon previous outburst incidents, that Bulli seam outbursts are largely considered to be a gas-dynamic phenomenon, rather than geo-dynamic. The necessary high strata stress component is related to geological anomalies rather than being a normal in situ seam condition induced by depth of burial, high lateral stress and mining induced stress.

Following a number of reviews of Bulli seam outburst incidents undertaken by the specialised "Steering Committee for the Management of Outbursts in the Bulli Seam" as convened by the then Chief Inspector of Coal Mines for New South Wales, the following management or outburst control mechanisms were identified:

- Gas drainage or any systematic approach to either reduce gas content or gas pressure is viewed as the most positive means of preventing or minimising outbursts.
- In seam drilling, in advance of mine development roadways is an acceptable means of detecting outburst prone areas. The various mechanisms whereby structures can be detected, such as bogging of
the drill bit is partially dependent upon equipment selection and operator expertise.

- Regular gas sampling to determine gas content and composition is required as a means of determining outburst potential.

3.3.2 Mine by Mine Experiences

The primary requirements for an outburst in the Bulli coal seam, as identified by Ryncarz (1992), are believed to be:

a) Intense stresses in the coal seam
b) High gas content and high gas desorbability
c) Low coal strength

The tectonic component identified by Lama (1991) is generally believed not to be present for Bulli seam mines. Hence as these characteristics and circumstances occur in differing degrees for each mine, a mine by mine assessment of outburst history and outburst characteristics is given below.

(I) Appin Colliery

Appin Colliery has recorded 26 outbursts varying in size from less than 2 tonnes through to a reported 88 tonnes (see Figure 3.3). The first outburst occurred in May 1966. It ejected 50 tonnes of coal along with an unknown but significant amount of CH₄ and was related to a zone of joints that were evident in the immediate roof. Five small outbursts mainly less than 8 tonne but one up to 20 tonne have occurred with no prominent geological structure. Strike slip faults tend to account for the majority of the outbursts along with one occurring adjacent to a dyke and associated with cindered coal. The largest recorded outburst occurred in July 1969, ejecting 88 tonnes of coal and a large amount of CH₄ (4% CH₄ was measured in the general body of air some 2 hours after the event). This outburst was associated with a strike slip fault and a readily identifiable mylonite zone 0.05 metres wide.
Gas content at Appin is in the order of 13 m$^3$/tonne and an extensive gas drainage system is used to prevent or minimise the risk of outbursts and manage gas liberated during mining. Composition of the gas is predominantly CH$_4$, however high CO$_2$ has been recorded adjacent to faults and dykes.

(II) **Corrimal Colliery**

Corrimal Colliery (now part of Cordeaux colliery) recorded four outbursts associated with a north easterly trending shear zone, minor faulting and dykes (see Figure 3.4). The first outburst occurred in October 1967, ejecting 5 tonnes of coal and an unknown amount of gas. It was associated with a shear zone exhibiting strike slip faulting, crushed coal and mylonite as well as two thin dykes, less than 1m in thickness. The largest outburst occurred in November 1967 discharging up to 12 tonne of coal with both methane and carbon dioxide in unknown quantities being given off. All the Corrimal outbursts were associated with a shear zone that bisected the colliery with outbursts being reported in the central and southern extent of the zone. The outburst prone areas were related to intense jointing and mylonite being present in lateral bands and within the cleat near the roof. This shear zone is a prominent geological structure and is recognisable on aerial photographs.

(III) **Kemira Colliery**

Kemira Colliery (now closed) recorded two outbursts (May 1980 and May 1981) on a single normal fault of 0.4 to 0.7 metres vertical displacement (see Figure 3.4). Also mylonite was identified in bands and within the cleats near the roof at the outburst sites. Carbon dioxide was the predominant gas with 60 and 100 tonnes of coal being discharged.
Figure 3.3 Recorded Outbursts in Appin, Tower and West Cliff Collieries
(Harvey, 1994)
Figure 3.4 Recorded Outbursts in Bellambi West, Cordeaux and Kemira Collieries
(Harvey, 1994)
Bellambi West Colliery (formerly known as South Bulli Colliery) had its first outburst on a 110° "shear zone", located in the northern part of the mine (see Figure 3.4). A small hole or cone near the roof was associated with the outburst. Further small outbursts have occurred along the same shear zone with 5-30 cm of mylonite being identified. Also in the northern part of the mine the dip of the seam changes from 1° to 10° with accompanying bedding plane shears in a claystone band located 10-15 cm from the roof. This acts as a preferred shear band and as many of the outbursts occurred at this level the sheared claystone area was regarded as having outburst potential. In the southern part of the mine an outburst occurred associated with a dyke zone. This had a breccia pipe inside the dyke zone, cindered coal and liberated significant quantities of carbon dioxide.

The fatal outburst at South Bulli Colliery (25 July 1991) was also the largest recorded for the colliery and related to a low angle thrust fault with a 35 cm band of powdered coal. Approximately 2 metres of the face collapsed with the outburst and a cavity was formed in the right hand side of the face resulting in 300 tonne of coal being discharged. The gas liberated was predominantly CO₂ with high gas pressures being noted from drill holes used to prove the fault after the outburst incident.

Metropolitan Colliery
This mine has the longest history of outbursts in the Bulli Seam, going back to 1895, has recorded a total of 154 outburst incidents and has been associated with the greatest number of outburst related fatalities, (7 lives lost). A review of relevant reports and information indicates that majority of the outbursts occurred on structures (see Figure 3.5), especially a zone known at the mine as the "soft outburst zone". Gas composition and gas content varies greatly throughout the mine, with the presence of faults and dykes being considered the primary cause.
Work undertaken by Hargraves (1965) showed a correlation between mining method, advance rate and outbursts. Inducer shot firing was used at Metropolitan Colliery as a means of initiating outbursts. The largest recorded outburst ejected 250 tonnes of coal and was induced by shot firing. Between 1961 and 1968 some 100 outburst incidents were believed to be related to inducer shot firing.

Zones of outburst potential can be plotted on the colliery plan based upon previous experience. With the last fatal outburst at Metropolitan being in 1954 it could be argued that management of the outburst risk was satisfactory. However, the most recent outburst (September 1992) had the potential to endanger mineworkers especially as the various warning signs while being clearly evident were not recognised.

(VI)  

Tahmoor Colliery

Tahmoor Colliery has had 90 outbursts since 1981 with the majority of them being associated with east south easterly structures, mainly dykes and strike-slip faults, with an orientation of 110° to 135° (see Figure 3.6). It is believed that the dykes have been reworked with strike slip fault movement. A series of north easterly reverse faults have been associated with four outburst incidents and these structures have been difficult to drill by conventional rotary methods. The following is a summary of outbursts at Tahmoor:

<table>
<thead>
<tr>
<th>Structure</th>
<th>N° of Outbursts</th>
<th>Violent</th>
<th>Size (tonne discharged)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Across Dyke</td>
<td>3</td>
<td>3</td>
<td>5-400</td>
</tr>
<tr>
<td>Strike slip/dyke</td>
<td>28</td>
<td>17</td>
<td>5-120</td>
</tr>
<tr>
<td>Strike slip fault</td>
<td>55</td>
<td>18</td>
<td>5-100</td>
</tr>
<tr>
<td>Reverse fault</td>
<td>4</td>
<td>1</td>
<td>5-40</td>
</tr>
</tbody>
</table>
The largest outburst incident at Tahmoor colliery occurred in June 1985, ejecting 400 tonnes of coal and an estimated 4,500 m$^3$ of CO$_2$ into the development heading, burying both the continuous mining machine and the shuttle car. The miner driver was asphyxiated (see section 3.4). In recent times gas drainage has been used and where gas content cannot be reduced low enough shot firing is the preferred approach.

(VII) **Tower Colliery**

Tower Colliery has recorded 19 outbursts, with the first incident occurring in July 1981 and so far this has also been the largest outburst. The size of outbursts has varied from less than 1 tonne to 80 tonne with unknown amounts of CH$_4$ being liberated. These have predominantly occurred in the south western part of the mine, against a dyke with associated strike slip faulting (see Figure 3.3). Low intensity bumping and slumping has been experienced with outburst type conditions where seam gas content of 10-12 m$^3$/tonne was recorded with gas composition being predominantly methane. A gas drainage system is currently utilised to reduce the in seam gas content and control gas during mining operations.

(VIII) **West Cliff Colliery**

West Cliff Colliery had its first outburst in December 1976 and since that time 252 outburst incidents have been recorded. This first incident ejected 120 tonnes of coal and was related to a shear zone, with strike slip faulting and mylonite and this zone proved to be the site and focus for a number of subsequent outbursts. The size of the outbursts has varied from 4 tonnes to over 320 tonnes with the majority being related to zones of strike slip faulting having a strike approximately 100°-110° (see Figure 3.3).
Figure 3.6  Recorded Outbursts in Tahmoor Colliery  
(Harvey, 1994)
The largest outburst, some 320 tonne of coal occurred at the northwest end of a normal fault where the gas drainage holes had not penetrated. There was a major joint zone 3-4 m wide in the roof associated with this outburst site and a mylonite band some 30 mm thick.

The gas composition has been predominantly methane but several outburst events in the north eastern part of the mine have involved very high levels of gas (>16 m³/tonne) and >95% CO₂. Mining operations at this colliery have only been possible through the use of gas drainage and specified outburst mining procedures and a purpose built continuous mining machine to afford protection to the miner driver. This has minimised the risk of injury to the mineworkers and permitted mine development through many outburst zones.

West Cliff Colliery has the dubious distinction of recording the only outburst so far to have occurred on a retreating longwall face within the Illawarra coalfield. On 3rd of April 1998 two outburst incidents of low intensity occurred on the longwall face 23. The area where this occurred had not been adequately covered by gas drainage as the take off point for the face had been relocated to give an additional 45 metres of longwall coal. The outbursts were identified by 2 cavities or cones in the face at the roof extending about 1 metre into the coal. Gas samples taken after the incident but in close proximity recorded 98% CO₂ at a seam gas content of up to 21 m³/tonne.

There was no apparent structure at the face and it was believed that the outburst occurred due to the high gas content, the localised stress conditions (including mining induced stress) and the extremely low permeability of the coal (Piper, 1998 and Walsh, 1999). The West Cliff Outburst Management Plan has since been amended to ensure that all longwall panels are effectively pre-drained.
3.4 Review of Fatal Bulli Seam Outbursts

Up to July 2001 there have been twelve fatalities attributed to outbursts in the Bulli seam. These are summarised in Table 3.5 and discussed in considerably more detail below. The reports and documentation on the earlier incidents are sketchy and limited to the reports prepared and available at the time. Records from the Department of Mineral Resources have proven to be the most informative.

Table 3.5 Fatal Bulli Seam Outbursts

<table>
<thead>
<tr>
<th>COLLIERY</th>
<th>DATE</th>
<th>No. KILLED</th>
<th>SIZE (tonnes)</th>
<th>GAS</th>
<th>STRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metropolitan</td>
<td>10 June 1896</td>
<td>3</td>
<td>Unknown</td>
<td>CH₄ (firedamp)</td>
<td>Dyke and soft fault zone</td>
</tr>
<tr>
<td>Metropolitan</td>
<td>27 July 1926</td>
<td>2</td>
<td>140</td>
<td>CO₂</td>
<td>Fault with 5m throw</td>
</tr>
<tr>
<td>Metropolitan</td>
<td>2 December 1954</td>
<td>2</td>
<td>90</td>
<td>CO₂</td>
<td>Normal fault with 0.3m throw</td>
</tr>
<tr>
<td>Tahmoor</td>
<td>24 June 1985</td>
<td>1</td>
<td>400</td>
<td>CO₂</td>
<td>Behind a dyke associated with strike slip movement</td>
</tr>
<tr>
<td>South Bulli</td>
<td>25 July 1991</td>
<td>3</td>
<td>266</td>
<td>CO₂ &amp; CH₄</td>
<td>Thrust fault with 35 cm of mylonitic coal; very high gas pressure.</td>
</tr>
<tr>
<td>West Cliff</td>
<td>25 January 1994</td>
<td>1</td>
<td>350</td>
<td>CO₂</td>
<td>Intersection of 2 strike slip structures; 30 cm of mylonitic coal.</td>
</tr>
</tbody>
</table>

10 June 1896

On 10 June 1896, three men were killed by an outburst of coal and gas at Metropolitan Colliery (Enoch Pugh; James Borton and H. Shipton). The men were suffocated by the gas (claimed to be fire damp) from the outburst in the No. 7 West Heading. An inquest was held on 11th June 1896 at the Metropolitan Colliery Office by the District Coroner, C.C. Russell, Esq. and the jury returned a verdict of accidental death.
27 July 1925

On 27th July 1925, two men were killed by an outburst of natural gas and coal at the Metropolitan Colliery (George West and Fredrick Green). The men were suffocated by the gas emitted (identified in 2 samples as being between 50% and 62% CO\textsubscript{2}) from the outburst site and was associated with an upthrow fault immediately adjacent to a dyke in the 70 yard heading of the Western area section of the mine (see Figures 3.7 and 3.8). Approximately 220 tones of coal were ejected with the gas concentration being sufficient to kill a horse approximately 103.5 metres away from the outburst site.

Miners working the area had commented that the coal immediately prior to the outburst was harder than usual. It had been identified in previous outburst incidents that these events were related to geological structures, particularly dykes where the characteristics of the coal had been significantly altered, and fortunately these incidents had not been fatal. The concept of one district or part of the mine having outburst prone zones was recognised.

Hence the comments of the Inspector reporting on the fatality and the mechanisms used to alleviate outburst problems are quite telling: - "Since the outburst, boreholes have been kept ahead in all places in the near vicinity of the fault and these have given off a little gas which has proved to be practically pure carbon dioxide". Similarly the mechanism underlying the principles behind outbursts in the Bulli Seam were alluded to when the same inspector commented. "The last four feet or so of coal worked by the miners in this place was harder than usual, and no gas had been given off..." "This hard section of coal may have acted as a dam and retarded the escape of the gas which is given off freely from the coal faces in this section."
Outburst of Gas—Metropolitan Colliery.

Figure 3.7  Plan of Fatal Outburst; 27 July 1925, Metropolitan Colliery  
(Harvey and Singh, 1998)
2 December 1954

On 2 December 1954, two men were killed by an outburst at the Metropolitan Colliery (Names not given in Dept. Annual report). The men were asphyxiated by the gas, deduced to be CO₂ and a boring machine operator rendered unconscious.

The outburst was in an area of known faulting with the site being associated with two small down throw faults with several defined vertical joint planes in the shale roof and a well defined "slicken sides" in the seam, coal in the fault area was soft; and being worked under fully mechanised mining methods. The use of boreholes to identify outburst structures was raised in the Chief Inspector of Coal Mines' report, stating:

"In my opinion, the recent happenings clearly indicate the necessity for maintaining the boreholes well in advance of all solid places and, in addition to the centre hole, flank holes are being bored in each rib and the holes are being maintained at least twenty five feet in advance of the faces".

24 June 1985

On 24 June 1985, one man was killed (Michael Joseph Penny) whilst operating a continuous mining machine in an outburst prone area (C heading of 204 panel) of Tahmoor Colliery. The outburst resulted in approximately 400 tonnes of coal and roof shale material and an estimated 4,500 cubic metres of gas, comprised predominantly of carbon dioxide. Figure 3.9 shows the outburst site with the continuous miner being buried.

The outburst was associated with a known dyke structure, which had been intersected, in three previous panels with increasing thickness from 20 cm to 1m. The thickness of the outburst site could not be determined due to roof falls. In 204 panel, about four metres before the dyke an off shoot of an igneous intrusion (about 30m thick) was identified along with a shear zone and severe jointing being evident in the roof.
Due to previous outburst events and the proximity of the dyke the area to be mined was considered to be outburst prone. Hence outburst precautions were to be taken. The continuous miner was set up to cut out the right hand side of the heading with the head of the machine being sumped in at the roof.

At the time of the incident the shuttle car was behind the continuous miner and the driver sustained superficial facial injuries from small particles of coal and other material ejected by the outburst. Material ejected in the outburst covered the continuous miner and the shuttle car, with the only access to the operator's cabin of the continuous miner being via the rear of the canopy. The autopsy report indicated that the operator of the continuous mining machine died from asphyxiation. The other four men (including the shuttle car driver) recovered after making their way to fresh air.

An inquest into the event was held on 4 November 1985 before Coroner Donna Maria Delaney in the Campbelltown Coroner's Court. The finding was "died of asphyxiation due to the inhalation of coal gas from an outburst".

As a consequence of this incident the following recommendations were given to enhance safety whilst mining in outburst prone areas of Tahmoor mine.

1) Upgrade the miner driver's cockpit to give the driver better protection as well as having an independent air supply.
2) Gas drainage is to be carried out to the satisfaction of the District Inspector of Coal Mines.
3) It is intended to require the manager to use pulsed infusion shot firing similar to a recent practice of Metropolitan Colliery, if the gas drainage results do not prove satisfactory.
4) Modified precautionary measures will be put into practice whilst mining through outburst prone areas.
24 July 1991

On 24 July 1991, three men were killed (Craig John Broughton, Robert Kelvin Coltman and Leigh Ronald Pearce) by an outburst of coal and gas at the South Bulli Colliery. The outburst in “B” heading of W12 Panel ejected an estimated 300 tonnes of coal and 6,000 m³ of gas (predominantly CO₂) into the working area.

This occurred with sufficient force to dislodge the ventilation ducting, losing the auxiliary fan ventilation, slew the shuttle car sideways and had sufficient force to blow open the outbye ventilation doors causing a short circuit in the ventilation. The continuous miner driver was buried to his neck with outburst material and it is believed he died instantaneously from the effects of carbon dioxide. The shuttle car was being driven away from the continuous miner at the time of the outburst and from the injuries sustained by the car driver it would appear he was thrown out of the driver’s compartment by the force of the outburst. It would appear that the third miner killed, died attempting to assist the car driver and, was overcome by the gas.

Although the outburst had not been predicted, the investigation revealed that there were significant changes in face conditions with such factors as ingress of water, changes in stress direction, roof jointing, roof guttering, poor mining conditions, fluctuations in gas concentrations and gas composition. The presence of greasy backs, slicken sides, white clayey material in the roof and softening of the coal were also observed. The inability to recognise and understand the significance of these changes ultimately led to the death of these men.

25 January 1994

On 25 January 1994, one man was killed (Malcolm Leslie Butt) by an outburst of coal and carbon dioxide gas at West Cliff Colliery. The outburst occurred in “B” heading of 486 Panel and ejected 266 tonnes of coal, with a large but unquantifiable amount of carbon dioxide from the right hand rib side.
On the previous shift, mining activity in the panel was operating under "normal" mining procedures (not outburst mining procedures). A number of changes in mining conditions were noted, particularly the hardness of the coal at the face, deterioration in roof conditions, the presence of a "greasy back" otherwise known as slicken sides in the roof trending longitudinally down the heading and, an increase in carbon dioxide being emitted during mining operations.

These changes in mining conditions were deemed to be of significance, causing mining to continue only under outburst mining procedures. It is believed that this decision prevented other people from being killed, injured or affected, as outburst mining procedures limited the number of people working in the vicinity of the face.

The continuous mining machine in use was equipped with a purpose designed and built outburst protection canopy, including a supply of filtered air for breathing, via a half facemask. However, even with this protection, the miner driver was killed in the outburst. A post mortem revealed that the miner driver had died of anoxia and had sustained a small linear fracture to the rear of the skull, believed to have been caused by direct impact with the filtered air supply regulator gauge, at the time of the outburst.

The coal (approximately 266 tonnes) ejected from the outburst entirely covered the continuous mining machine and back to a distance of thirty metres from the face. The carbon dioxide gas given off with the outburst was of sufficient quantity to entirely fill the face area, displace all oxygen and proceed to migrate back down the panel, filling number seven cut through and affecting the adjacent heading.
As shown in Figures 3.10, 3.11 and 3.12, the outburst was associated with a combination of two strike slip fault zones (one trending 350°, the other 280° magnetic). The intersection of these two fault structures created a zone of intense shearing/jointing resulting in lower coal permeability and increased stress in the coal and associated roof strata. This in combination with the presence of Mylonite and gouge material was believed to account for the volume of gas released.

The dominant 350° fault zone appeared to have a similar alignment with strike slip fault structures identified in previous mining, associated with development headings for panels 484 and 485. Drilling immediately in advance of mining, in “B” heading of 486 panel did not accurately identify the location of this structure.

Gas drainage holes drilled from 485 panel failed to reach across the longwall block and effectively drain the development heading of 486 panel. Also whilst holes had been drilled in advance of mining in 486 panel, they had not penetrated the structure. These holes had deviated to the left (south) and were identified in the left hand rib and face.

3.4.1 ASSESSMENT OF FATAL OUTBURSTS
The level of knowledge and understanding in managing the risk of outbursts for Bulli seam mines has definitely improved. One hundred and six years ago outbursts were regarded as an inevitable risk of mining and to some extent were treated as an “act of god”. Currently gas drainage is utilised as the primary mechanism for taking the energy out of an outburst structure and thereby making it safe to mine.
Figure 3.10 Plan of Fatal Outburst; 25 January 1994, West Cliff Colliery
(Harvey and Singh, 1998)
Figure 3.11 Side Elevation of Fatal Outburst; 25 January 1994, West Cliff
(Harvey and Singh, 1998)
Figure 3.12 Detailed Geology of Fatal Outburst, 25 January 1994;

486 Panel West Cliff Colliery;

(Harvey and Singh, 1998)
The success in managing the outburst risk has the potential to generate complacency and for this reason attention must be directed to improved and more consistent management of the outburst risk and more effective gas drainage techniques. It is possible that guidance for the future may come from past observations particularly the comments of the Inspector reporting on the 1925 fatality; "Since the outburst, boreholes have been kept ahead in all places in the near vicinity of the fault, and these have given off a little gas which has proven on analysis to be practically pure carbon dioxide."

Also the comments from the Chief Inspector of Coal Mines reporting on the 1954 fatality; "In my opinion, the recent happenings clearly indicate the necessity for maintaining the boreholes well in advance of all solid places and, in addition to the centre hole, flank holes are being bored in each rib and the holes are being maintained at least twenty five feet in advance of the faces". Gas drainage would appear to be part of the answer but what are the limitations of this technology?

3.5 Summary

Outbursts in the Bulli Coal Seam have been the subject of various conferences, numerous papers and several committees and working groups. All the study and research has been directed towards analysing the various factors associated with outbursts so that a better understanding will give safer mining operations.

In 1895 when the first outburst in the Bulli Seam occurred at Metropolitan Colliery, it was looked upon as being just one of those phenomena associated with underground coal mining. With each outburst incident the level of understanding improved, particularly when lives were lost. The unexpected nature of outbursts and the apparent infrequency of incidents for each mine conspired to limit the understanding and commitment to dealing with the problem.
The triple fatality at South Bulli Colliery (now known as Bellambi West) on 25 July 1991, initiated a great deal of research and analysis into outbursts and a number of key factors emerged (DMR, 1992):

1. Outbursts in the Bulli Seam are predominantly associated with geological structures.
2. Compression type geological structures such as thrust faults, strike slip faults and shear zones associated with dykes appear to have the greatest outburst potential.
3. Initial studies indicate that for some mines in the Illawarra Coalfield appropriate gas thresholds for structure free coal are 10 m$^3$/tonne of CH$_4$ and 7 m$^3$/tonne of CO$_2$; for sheared coal this is reduced to 8 m$^3$/tonne of CH$_4$ and 4 m$^3$/tonne of CO$_2$. A version of these gas content thresholds has been adopted as an initial benchmark pending ongoing review and assessment.
4. Gas Drainage is the most appropriate mechanism to prevent or minimise outbursts.
5. Structure drilling and the assessment of gas content/composition in advance of mine development are the two most effective means of predicting outbursts.
6. Training in the identification of outburst warning signs and the use of special purpose built equipment with appropriate procedures would appear to be the most positive means of protecting workers from outbursts.

This being largely based upon the outburst history of the Bulli seam, which tends to consider outbursts as being gas-dynamic in nature, with variations or occurrences of higher seam stress conditions being created by geological structures.

Unlike earlier studies and research these working groups were able to concentrate on the management of the outburst risk, rather then the phenomenon itself. It follows that understanding all the factors mentioned
above will not lead to safe mining practice unless an appropriate system or plan is developed to manage the outburst risk. As no one technology or mining technique will eliminate the outburst risk, a management plan will provide multiple barriers or levels of protection.

Adequate standards similar to the ISO 9000 Series for the development of Quality Management Systems (as discussed in more detail in Chapter 7) have been encouraged for all Bulli Seam mines. The purpose behind such management plans is to establish a control document, which specifies practices, resources, activities and responsibilities so that all procedures designed to manage the outburst risk are in place, to guarantee the safety of mine workers.
CHAPTER FOUR

PREDICTION OF OUTBURSTS
CHAPTER 4

PREDICTION OF OUTBURSTS

4.1 INTRODUCTION
Universally, wherever outbursts have occurred there have been various attempts to analyse the main causal components and subsequently predict the presence of possible outburst structures and general outburst characteristics. This approach is based upon giving mineworkers a warning that outburst type conditions are possible and preventative or protection procedures should be instigated. Hence an understanding of the key factors that comprise outbursts for each particular region or location is fundamental to the prediction of outbursts.

In this regard the three most critical factors, which are universally acknowledged and have been associated with outbursts in the Bulli Seam, are geological structures, excessive gas content within the coal and high tectonic stresses. It is generally regarded that geological disturbances play a role in fixing the location of an outbursts, that gas content determines the energy stored in an outburst, which subsequently determines the consequence (how much gas and coal is ejected). The stress in conjunction with the strength of the coal or rock strata will reflect the ease with which an outburst can be initiated. Outburst prediction techniques focus on the identification of one or more of these factors in advance of mining operation. A review of the various mechanisms used to identify these factors follows.

4.2 GEOLOGICAL STRUCTURES
From various reviews of outburst incidents recorded in the Bulli Coal Seam, there is a direct and consistent link between outbursts and geological structures. This correlation has also been noted throughout the world, in that geological structures are viewed as providing higher localized tectonic stress and a mechanism for the storage of large quantities of gas.
In some respect this is also associated with weak coal or strata (especially within a structure zone) and more impermeable coal, which restricts gas migration (especially either side of the structure zone). This association is common for geological structures which are compressive in nature (such as thrust faults) and is described schematically in Figure 4.1

Consequently the detection of geological structures has primarily focused upon the identification of seam abnormalities either actively by drilling, passively by electromagnetic/radio wave propagation or a combination of both.

4.2.1 In-seam Drilling

This is the most widely used mechanism for determining and plotting potential outburst zones in advance of the mine face. The logging of the various drilling parameters (such as thrusts, rotational speed, penetration rate, drilling/flushing fluid pressure etc) can give an effective indication of geological structures. In particular the drilling of small diameter holes (up to 75mm in diameter) can detect outburst prone structures by the drill string “bogging” or sticking in the hole.

This is especially true when accompanied by the ejection of gas “splits” (the rhythmic ejection of coal, gas and drilling water), the production of finer cuttings (particularly Mylonite) and on some occasions the expulsion of larger coal fragments. Physical limitations with the design and operational capabilities of smaller less powerful drill rigs have been regarded as a possible aid or assistance in the detection of outburst prone structures for with such a drill rig this “bogging” characteristic is more likely to be noticed. However these smaller drilling rigs do limit the length of inseam drill holes (in the order of 100m to 250m), with reduced ability to stay in the coal seam and maintain the desired direction/orientation.
Figure 4.1 Schematic of an outburst structure
The most vital component with the successful utilization of in-seam drilling to locate outburst prone structures is the effective surveying of all drill holes. The need for efficient surveying techniques became all too apparent after the fatal outburst at West Cliff Colliery in 1994. Unforeseen deviations in drill holes used to locate outbursts structures and de-gas the coal left a potential outburst zone un-drained and undetected. The commonly held belief that holes deviated with the direction of rotation and uniformly dropped were incorrect.

Traditional surveying techniques such as the Eastman Whip stock Survey tool were found to be slow and prone to error (each survey stopped the drilling process and only provided one off point indications of direction and inclination). These limitations have led to the universal adoption of down the hole motor (DHM) drilling techniques, where a direct read-out from a survey tool located immediately behind the drilling head permits suitable adjustment to be made during drilling to control and steer the drilling head (see Figure 4.2).

Conventional rotary drilling, especially using the Pro-Ram drill rig as developed by BHP (Hanes 2001) has proven to be effective in detecting geological structures, but more importantly the taking of core samples in advance of a development face, to determine seam gas content. However industry requirements have largely supported the use of DHM drilling techniques.

A major benefit of DHM drilling techniques is the potential to drill longer holes (longer than 1000m), the full length of a proposed longwall panel and future gate road developments. Such holes are usually kept on line for gas drainage purposes for a longer period to achieve appropriate seam gas content levels and gas threshold values. The disadvantage of this approach is that the longer holes, when used for gas drainage purposes require longer lead times in comparison to the shorter holes drill across a longwall panel.
Figure 4.2  Down the hole motor drilling assembly
This does represent a potential problem when mining operations intersect these long holes and/or they become blocked causing a potential outburst situation in their own right. Hence specific management plans are required to effectively manage the risk of intersecting such holes and accommodating the gas that would then be liberated into the mine workings.

Ultimately whether long DHM drilling or shorter rotary drilling is used, the skill and training of the drilling crews is of utmost importance. This is especially true when the identification of geological structures and particularly outburst prone structures, is considered to be the prime requirement behind the drilling. However as is the case in most instances, the drilling program at a mine (especially for Bulli seam operations) is primarily directed towards gas drainage, rather than the detection of structures. In this case structure identifications and drilling is directed more at outburst prevention rather then outburst prediction.

### 4.2.2 Real Time Mud Logging

This process or technology has been developed to continually monitor specific aspects of borehole drilling associated with both gas drainage and general in seam exploratory drilling (Lunarzewski, 1998). Drilling parameters such as thrust, rotation, drilling or penetration rate, flushing fluid pressure etc are all monitored via a computer as the drilling is performed (in real time). This information when combined with real time logging of gas flow, gas pressure and gas composition has the potential to identify variations within the coal seam that can locate geological structures and potential outburst zones.

The system and layout as shown in Figure 4.3 was developed as a research project through the Australian Coal Association Research Program (ACARP). To date limited trials have proven the potential for this technology to work
within the operating mine environment however, this has not as yet been fully proved.

Gas flow monitoring as shown in Figure 4.4 can predict and locate outburst zones and structures. Recent modifications make the system more compatible with down the hole drilling and surveying technologies, as described by Verhoef (2001).

In effect this technology or process provides a mechanism where drilling parameters, gas flows and changes in drill cuttings, as recorded subjectively by the driller are documented in a consistent and pre-determined manner. This can take subjective interpretation and assessment out of the drilling process and provide a consistent and reliable means of detecting outbursts

4.2.3 Geo-physical Logging

This technology was initially researched in the early to mid 1990’s at Bulli seam and Queensland collieries. The basic approach with this technique as indicated by Hatherly et al (1995), is the use of a calliper type tool or a sonic probe inserted into a strategically placed drill hole to give a graphic output or "log" which is subsequently interpreted by a specialist. As such it utilizes the different sonic/seismic properties of different rocks recognizing variations in the seismic wave velocity to indicate a change in rock type, rock strength and through significant reductions in the wave velocity, shear zones and faults. Obvious indications of structures are then correlated to known mapping results, thereby predicting possible outburst prone structures.

This is a technique initially used for surface boreholes and adapted for in-seam operations. A major problem is the physical handling of the equipment within a working seam and maintaining adequate contact between the sides of the hole and the probe. In addition the need to rely upon expert interpretation introduces delay and added complexity further limiting the use of this technology as part of a normal mining cycle.
Figure 4.3 **Underground Drilling Fluid Logging System**  
(Lunarzewski, 1998)
Figure 4.4 *Gas Flow Signatures as used to detect Seam Variations*  
(Verhoef, 2001)
4.2.4 Structural Mapping

The mapping of geological structures known on both a regional and localized (for a particular mine) scale is used to project potential outburst structures in advance of mine development. On the localised or mine scale the projection of structures mapped from one set of longwall gate roads to the next set of gate roads can provide warning of possible structures ahead of the advancing face and serve as a target for in-seam drilling. However small structures can disappear or new structures start within short distances (i.e. within 50m to 200m) between two sets of gate roads for a longwall panel.

While mapping is an essential requisite for the full interpretation and understanding of geological structures and the interpretation of in-seam drilling, it is largely reactive (as opposed to predictive) identifying structures after mining has occurred. The interdependence upon information from neighbouring mines further emphasises that structural mapping is not considered as reliable enough to be a predictive tool in its own right, it must be supported by one or more other predictive techniques.

4.2.5 In-seam Seismic

In basic terms this technique is largely the adaptation of surface based seismic and geophysical methods for underground and in-seam conditions. The transmission and reflection of ground vibration (selected frequency sonic waves) horizontally through a prospective longwall panel is used to identify seam variations. At certain mines particularly where shale roof conditions prevail, in-seam seismic has been shown to be a reliable and predictive tool for the detection of structures with half seam thickness displacement, up to 250m ahead of existing mine workings as identified in the Report by the Steering Committee for the Management of Outbursts in the Bulli Seam (DMR, 1992) (the author was secretary of this committee). It is however less reliable for the detection of small structures, under sandstone roof conditions and with varying orientation (i.e. greater than 0° to 45°) to the roadways being advanced.
4.2.6 Radio Imaging Method (RIM)

This prediction method relies upon the identification of geological structures via the use of radio imaging. In essence it involves the projection of radio waves through the solid coal, thereby providing an image (tomograph) of the seam in advance of mining. The technique relies on the natural properties of coal, in particular the level of electrical conductivity associated with a target coal seam and or rock stratum. In areas of homogeneous coal the radio waves are attenuated at a predictable and repeatable rate. This in turn allows variations in the seam (either faults, dykes or other geological structures) to be shown as a variation in the attenuation and the overall conductivity of the seam.

As identified by the Steering Committee for the Management of Outbursts in the Bulli Seam (DMR, 1992) and from trials undertaken in the Illawarra coalfield it has been shown that RIM has the potential to delineate a geological structure, which has a displacement as small as 50mm. This can be achieved by imaging between two development roadways (across a longwall block) or between an in-seam borehole and a roadway. This does incur a number of logistical problems such as drilling a hole long enough in advance of mining, accurately surveying the hole and man handling the equipment. There is the potential to use RIM between two boreholes (up to 200m long) flanking proposed development roadways to improve the confidence of structure prediction.

The end result of a RIM survey is a tomographic image of the seam and as Thomson et al, (1995) identified it is important to position the transmitter and the receiver in a sub parallel arrangement to achieve optimum results. The accurate surveying of the boreholes and/or the drivage used in the process has proven to be fundamental in the interpretation of the tomographic image and locating potential outburst structures.
The potential effectiveness of RIM has been demonstrated by Thomson (1995), through actual filed results for mines in the Illawarra Coalfield. This has shown that RIM, in addition to identifying geological structures, has the potential to identify outburst prone structures and assess the effectiveness of gas drainage. The radio signal propagated through the coal seam is initially affected by changes in the seam density. It has been further shown that variations in moisture within the seam are also identified and due to the correlation between high moisture and high gas content, "pockets" of gas can be detected. The large number of outburst incidents, which have recorded or identified moisture further reinforces the benefits of this technology. Figures 4.5 and 4.6 show tomographic images taken for Bulli seam operations and their potential application in predicting outburst structures. The ability for RIM to identify potential outburst structures is clearly indicated in the comparison of these two tomographs showing a block of coal with no structures or outburst potential and an area, which has outburst potential.

RIM when used in conjunction with in-seam drilling and gas content sampling definitively has great potential as an effective outburst prediction tool. However the real challenge is to take the technology from trial status to full time operational status, integrated with the mining cycle.

4.2.7 Surface Seismic

High resolution, surface seismic and some associated variations (such as 3D walkabout) have been used as "common place" geological tools within the Illawarra Coalfields, based upon the findings of the Report by the Steering Committee for the Management of Outbursts in the Bulli Seam, (DMR, 1992).
Figure 4.5 RIM tomograph free of structures and low outburst risk

Compliments of METS Pty Ltd & Oakdale Colliery
Figure 4.6  RIM tomograph with structure and high outburst risk
(Compliments of METS Pty Ltd & Oakdale Colliery)
The trend over the last twenty years towards bigger longwall panels and the corresponding need for advanced geological information has been the primary motivation behind the use and development of this technology. Current limitations mean that geological structures with no more than full seam displacement (3m to 5m) can be detected, but smaller structures are not shown. However, in identifying the larger structures, surface seismic can be used to identify potential outburst prone "off shoots" which may exist with the larger structures. When combined with full and complete understanding of the prevailing regional structural geology, surface seismic can assist outburst prediction via the identification of target areas where more selective techniques and additional drilling can be directed.

4.2.8 Radar

Ground probing radar has been used in a number of civil engineering practices relating to the detection of buried pipelines, cables, tunnels etc. It follows that this technology could be used to identify variations in a coal seam, especially outburst prone structures. The technique involves transmitting a packet of electromagnetic energy that is reflected when it hits an interface (object) of different dielectric properties. A receiver then picks up the reflected wave. The magnitude of the reflected wave varies with the difference in the dielectric properties of the two layers (matrix vs. object); the higher the dielectric constant, the higher the amount of energy reflected.

Research work in this technique and the particular use of radar, to detect in-seam structures has been undertaken by CSIRO, Division of Applied Physics in Australia. Papers by Hatherly et al (1995) and Murray (1995) identified the potential for radar used in either boreholes or mounted on a continuous miner. Trials have confirmed the potential of the technology (with limitations on its range). However, the equipment is not as yet sufficiently reliable and robust for use in underground coal mining operations.
4.3 SEAM GAS CONTENT
This is regarded as the second major component for an outburst, and, for
outbursts in the Bulli Seam, gas is considered to be the "energy" component.
That is to say, if sufficient gas is contained within the coal at a suitably high
pressure, the coal will burst when the pressure of free gas exceeds the
tensile strength of the coal. It would therefore require a higher gas pressure
to produce an outburst from cleat-free normal coal than from highly fractured,
sheared coal or Mylonite. As the parameters, which control and influence
gas content and the associated outburst potential can vary from seam to
seam and within particular localities in the same seam, each mine should
determine the pressure and related gas content necessary for an outburst to
occur. This should be based upon site-specific geological and geophysical
conditions.

Research work undertaken by Lama (1995c), tends to indicate for some
mines that desorbable gas contents (measured at least 5 m from the face)
less than 10 m$^3$/tonne of CH$_4$ and 7 m$^3$/tonne of CO$_2$, for structure free coal
and 8 m$^3$/tonne of CH$_4$ and 4 m$^3$/tonne of CO$_2$, for sheared coal would be
insufficient to initiate and/or induce a violent outburst. These are largely
empirical threshold levels, which have to be supported by further
measurement and research for each mine. More specifically the role played
by "threshold values" is considered within Chapter 6 as an outburst
prevention technique, due largely to its intrinsic association with gas drainage
techniques.

The prediction of outburst prone areas is therefore related to the amount of
gas present in the coal and the existence of structures. Techniques for
assessing gas parameters as a predictive tool are discussed.
4.3.1 Gas Pressure Testing

With the use of a suitable "packer" in a drill hole (1 m from the end of the hole) it is possible to monitor the pressure rise curve to equilibrium. Thereby gas pressure levels in advance of mining can be used to determine outbursting potential (Lama, 1980). There are a number of operational problems, primarily related to obtaining an effective seal by the "packer" and structural integrity of the coal in the borehole, which will influence the reliability of using gas pressure as an effective prediction tool.

The identification and subsequent measurement of gas pressure has been regarded as a possible indicator of outburst potential. It obviously follows that the greater the in situ gas pressure, the greater the outburst potential. This approach was to some extent researched by Cui (1990) in endeavouring to correlate gas pressure with coal strength. However, this relied largely upon laboratory type testing with little direction as to how both in situ gas pressure and coal strength could be measured within the normal mining process.

There is no universal limit or indicator that identifies a particular gas pressure as being outburst prone. It is generally accepted that any gas pressure, which is higher, than the in situ hydro static pressure should be treated with caution. Lama and Bodziony, (1996) show a range of gas pressures and their relationship to hydrostatic pressure, including a number of Bulli seam mines (see Table 4.1). However gas pressure threshold values have not been developed for the Bulli seam as yet. The lack of this information (i.e. the setting of specific threshold values for gas pressure), in combination with the difficulty in measuring in situ gas pressure in advance of the face, tends to make gas pressure less suitable as an effective prediction measure for outbursts, especially in modern mining operations, with high development rates.
### Table 4.1 Gas Pressure data in some Australian Mines

(Lama and Bodziony, 1996)

<table>
<thead>
<tr>
<th>Collery</th>
<th>Dominant Gas</th>
<th>Depth (m)</th>
<th>Gas pressure (MPa)</th>
<th>Ratio (gas pressure/ Hydrostatic head)</th>
<th>Remarks on gas pressure measurement</th>
<th>Permeability ($\times 10^{-8}$ m/s)</th>
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#### 4.3.2 Direct Measurement of Gas Content

Australian Standard AS 3080 specifies the test procedure for determining the gas desorbed from a core sample. In general terms it involves the taking of a core sample of coal via a drill hole and enclosing the sample or part thereof, as soon as possible in a "bomb" and measuring the gas released with respect to time.

The gas released is measured via a water displacement method (Q2) until no further gas is given off. The rate at which the gas is initially released is logged and used to determine the gas lost during the taking of the sample (Q1), (assuming the square root law applies). The core sample is then crushed in a sealed bomb and the gas given off via this crushing is measured and deemed to be the residual or inherent gas (Q3). Therefore total gas content for the sample is expressed as: $Q = Q1 + Q2 + Q3$. 

...
Chapter 4 PREDICTION OF OUTBURSTS

This procedure is time consuming and is to some degree dependent upon particle size and volume of the coal sample. Williams et al (1992) identified the possibility of speeding up this process through the reduction of particle size via grinding the whole sample. While this can hasten the process it may result in a higher volume of gas being given off than would otherwise occur for the standard procedure without crushing.

4.3.3 Indirect Measurement of Gas Content

This involves a process or procedure whereby gas content is inferred from the measurement of pressure or gas volume desorbed over a short time period. It is dependent upon the development of sorption isotherm curves for each mine with laboratory-based correction. This tends to be costly and can be time consuming with limitations on the accuracy of the results. Furthermore the variability of a sample taken in close proximity to the face, in conjunction with position in the seam and resultant anisotropic permeability effects, can reduce the applicability of these methods for outburst prediction. Similarly, through work by Lama and Bartosiewicz (1982), localised variations in the density of the seam gas, which may occur from changes in gas composition, can lead to significant errors in calculating the gas content.

4.3.4 Gas Content from Drill Cuttings

As a direct consequence of possible delays in obtaining in situ gas content information and the potential impacts this might have upon coal operations and production, a mechanism to assess the seam gas content from drill cuttings has been proposed. Work by Lunarzewski and Merrick, (1995) and Lama (1995c) relates to the potential use of the Polish desorbometer to quickly determine gas content. This involves the use of drill cuttings being placed in a sealed chamber (4 grams of coal between -1mm and +0.5mm) and a manometer attached and to the coal chamber measuring the gas, which is given off.
While this small and robust instrument as developed by the Barbara Experimental Mine, Mikolow, Poland, has been used for the prediction of gas and coal outbursts in many European mining operations, the level of accuracy obtained for Bulli seam mines was considered less than desirable to support its overall use. The need to have a dry coal sample and undertake the test within 90 seconds of drilling correspondingly imposes limits on drilling and the location of the sample as well as introducing added variability.

4.3.5 Gas Composition

The selection of suitable gas content threshold values is dependent upon gas composition. Hence reported gas content should be correlated with the gas composition of the coal in situ. Changes in gas composition with time should be reflected in any desorption testing along with the overall gas composition for the total gas desorbed. Lama (1995a) identified the manner in which gas pressure, based upon field observations, changed with variations of seam gas composition (see Figure 4.5).

In this regard it would appear, that CO₂ is considered to be more outburst prone and, in accordance with Harvey and Singh (1995), CO₂ has the potential to exist as a semi critical liquid due to hydrostatic and localised seam conditions, thereby supporting the overall concept that CO₂ is more outburst prone.

However, while this is seen as an important consideration in terms of predicting outbursts, it is uncertain whether this merely reflects the downstream or end results and consequences of a CO₂ vs. CH₄ outburst upon the mine and mine workers.

4.4 STRESS REGIME

The development of stress either within the coal seam being mined and or the roof and floor strata has long been recognised as a factor, which contributes to outbursts.
Figure 4.7 Sorption isotherms for CH₄ and CO₂ for samples of Bulli coal (Lama, 1995a)
This is the case whether the stresses exist naturally by virtue of the geology (depth of cover, tectonic activity, faulting or folding etc) or are induced by the action of mining, where rapid rates of mining advance have been shown to create major stress concentrations in the immediate roof and ribs resulting in minor “rock bursts”. In this regard stress plays its primary role in initiating outbursts and as such is more important in the deeper mining operations. Also the role of stress and its ultimate consequence must be considered in relation to rock and or coal strength.

Outburst prediction techniques, which rely upon the measurement and identification of regions and or pockets of high or concentrated stress whilst being feasible, are usually identified as geophysical methods but are not widely utilised within the industry in general and the Bulli seam in particular. The techniques, which have shown the greatest potential, are discussed.

### 4.4.1 Seismo-Acoustic Method

The use of this particular method for identifying variations within the stress regime in advance of the mining operations relies upon the identification of natural impulses generated within the seam as a result of fracture propagation due to stress changes within the coal. The propagation of these fractures and any associated desorption of gas, creates acoustic impulses, which can be detected (provided the correct frequency range is utilised).

Based upon work undertaken at Cynheidre Colliery (Wales UK) Styles (1995) has identified the correlation or interconnection between outburst events and recorded changes in seismo-acoustic activity. It was found that by monitoring micro-seismic activity, an outburst type event was typified as a coalescence of many acoustic emissions or micro-seismic events. Based upon this work Styles (1995) believed that it was the structural weakness within the coal that controls the location of the outburst and that the process behind an outburst was initiated several days before the final catastrophic incident. In addition it has been shown that gas-driven outbursts generate their own particular impulses with a specific frequency.
In the case of Cynheidre Colliery with CH₄ outbursts these impulses occur before the outburst events, have a duration of 600 milliseconds and are symmetrically headed with a principal frequency of 32 Hz. For Tahmoor Colliery (Hatherly et al. 1995) similar impulses were identified with a frequency of 12 Hz. These events are believed to be related to the instantaneous desorption of gas from the coal in dilatant micro-fractures. While various trials have been initiated in the belief that identification of changes in seismo-acoustic activity could give sufficient warning of an outburst event to permit the withdrawal of men, the method has not been successfully adopted or incorporated within the mining cycle.

4.4.2 Seismic Signal Analysis

This method is based upon the direct monitoring of seismic activity as mining is undertaken. The number of seismic impulses and their energy increases as the stress changes (it is also possible for the reverse to occur) just prior to an outburst. By placing a number of seismometers or by using a 3-D seismometer, the site where most of the energy is being released can be identified.

Seismic monitoring of rock bursts was first undertaken in the mining industry some forty years ago (Antsyferov 1966), however its adaptation for outburst monitoring and prediction has only been considered recently. In Donetsk (Kolesov et al. 1995) a correlation between outburst prone events and frequency variations has been developed. Just prior to an outburst, the low frequency amplitude gradually increases and the high frequency amplitude decreases. This change can be used for outburst hazard prediction in that the ratio of high frequency amplitude AB (>600 Hz) and the low frequency amplitude AH (<240 Hz) is used as a criterion such that the ratio

$$K = \frac{AB}{AH} > 3$$

describes potential outburst conditions. A system utilising this has been established where the results of drilling or cutting machine vibrations within the coal seam are used for analysis. The data is transferred to the surface
and with continual monitoring sufficient warning can be provided to underground operators.

A range of problems largely related to the selection of the most appropriate frequency range and the placement and or location of the seismometers/accelerometers severely limits the use of passive seismic techniques within the Bulli seam. This is over and above the logistical problems, associated with establishing and utilising the equipment within the context of the mining operations.

4.4.3 Electromagnetic Impulse Analysis
Electromagnetic impulse analysis is based upon observations that rock strata while being stressed and cracks propagate, packets of electromagnetic energy (EME) are emitted and as such can be used to measure the state of stress within the rock. A number of studies, largely based within the USSR (Lama 1996), show a relationship between the stages of rock failure and the changes in electrical impulse being emitted.

4.5 SUMMARY
The various methods for determining the presence of outburst prone structures and measuring the gas content of coal have been discussed above. In the interests of practical application, time and cost, mines have concentrated upon the use of geological mapping to extrapolate the potential for known outburst prone structures to effect future mine drivages and, in-seam drilling in advance of roadway development, being undertaken in conjunction with measuring seam gas content. The potential for an outburst is then determined by the existence of geological structures, measured seam gas content and gas composition, as determined against gas content threshold values. The accuracy of these threshold values and their importance are discussed in Chapter 5.
CHAPTER FIVE

PREVENTION OF OUTBURSTS
CHAPTER 5

PREVENTION OF OUTBURSTS

5.1 INTRODUCTION
The prevention of outbursts primarily involves removing the energy either gas or tectonic, from the working seam immediately in advance of the working face. Gas drainage is considered as the primary mechanism of relieving the outburst energy due to seam gas pressure. Tectonic forces or in situ rock stress are either related to geological factors (particularly depth of cover, local stress characteristics, effects of folding, faults, joints and dykes) and mining-related or mining-induced stresses. In order to mitigate the damage of outbursts inducer shot firing has been used to achieve some de-stressing of the seam and the immediate working face area.

The various characteristics of outburst prevention and the techniques and technology used are discussed in greater detail, sighting the particular characteristics and factors utilised by the mining industry as they relate to operations in the Bulli seam within the Illawarra Coalfield.

5.2 OUTBURST PREVENTION
Mechanisms and/or techniques, which can be claimed as "preventing" outbursts, have, as a common goal, the removal of the "energy" or initiating force identified as being intrinsic in an outburst event. The removal of the energy associated with outburst-prone zones, seams or strata then allows mining to progress under normal conditions thereby ensuring the safety and well-being of the mine workers. As discussed previously, the energy inherent in an outburst can stem from either the gas or tectonic stresses within the coal seam or a combination of both. The removal of this energy then minimises the outburst risk, hence the various techniques used to achieve this goal are discussed.
5.3 SEAM DE-STRESSING

Two of the key elements associated with outbursts as identified earlier are gas and tectonic stress. Just as gas drainage involves the prevention of outbursts by removing the gas, seam de-stressing relates to relieving stresses in the seam and/or associated rock strata to prevent outbursts. Currently, there are four different mechanisms used to de-stress a seam for the prevention of outbursts, these being stress relief drilling, stress relief mining, inducer shot firing and water infusion. These forms of seam de-stressing are considered in detail. It should be noted that this type of approach to outburst prevention is predominantly utilised in Europe, e.g., Poland, Russia, Germany and France.

5.3.1 Stress Relief Drilling

The drilling of boreholes immediately in advance of the mining face has been used to provide stress relief. Invariably this involves holes of about 100 to 200mm in diameter, drilled in a pattern as shown in Figure 5.1 as referenced by Smid et al, (1985). Invariably these holes are relatively short (i.e. no more than 20m) and the number of holes required depends upon certain factors such as the degree of danger defined by whether the critical values are less than critical (identified as $D_1$), critical (identified as $D_2$) or when 70% of the indices are above critical (identified as $D_3$) and all specified, based upon Polish experience by Smid et al, (1989) in Table 5.1.

Drilling in advance of the face has been trialed in the Bulli seam with minimal success, as reported by Hargraves et al (1964) and Hargraves (1995). In these circumstances, boreholes of 150mm in diameter were drilled up to 18m in length with little change in stress and gas content. The generally high extractive rates associated with mining operations in the Bulli seam were sighted as both a cause for inducing higher stress and gas pressure gradient and a limitation on the success of stress-relief drilling.
Table 5.1  No. of De-stressing Holes used by Czech Collieries
(Smid et al, 1989)

<table>
<thead>
<tr>
<th>Factor</th>
<th>No. of holes at an angle to the axis</th>
<th>No. of holes parallel to the axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seam thickness</td>
<td>&lt; 1.4 m</td>
</tr>
<tr>
<td>D₁</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>D₂</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>D₃</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

5.3.2 Stress Relief Mining

The successful use of this technique relates to locations where multiple seams are mined and are closely spaced. In addition, for this to be a success in the prevention of outbursts, one of the seams is deemed not outburst prone (or at least less liable to outburst than the other seams). The seam deemed not outburst prone is mined first providing some regional de-stressing of the neighbouring coal seams, as well as gas drainage. This type of mining is usually planned in a sequential manner, first the de-stressing seam followed by the de-stressed seam.

This principal has been successfully used in Poland (Tarnowski, 1974) USSR (Airuni, 1981) as well as Germany, Bulgaria and China. The factors, which determine the success of this technique, are:

- Distance between the two seams
- Thickness of the de-stressing seam
- Respective location of the faces in the two seams
- Mechanical properties of the rock separating the two seams
- The method of mining, caving or packing
- Whether the de-stressing seam is above or below the de-stressed seam
- Dip of the seam and associated strata
Figure 5.1 Distribution of De-stressing Boreholes Forming an Outburst Protection Zone (Smid et al, 1985)
In addition, wherever possible, the de-stressing seam should utilise a mining method, which does not involve the leaving of coal pillars. These remanent coal pillars can in effect induce higher stress levels in the underlying seam, thereby increasing the outburst risk. This type of approach has not been trialed in the Bulli coal seam.

5.3.3 Inducer Shot Firing

This is considered to be the oldest and most widely used method to control outbursts and was initially developed in France for use in the Gord coalfield. As initially outlined in the publication “On Methods of Outburst Elimination” by Lange (1892) the method depends upon firing an amount of explosive in the coalface to provide stress relief and induce an outburst.

A major concern with this technique as used throughout Europe and as was used at the Metropolitan Colliery (Hargraves et al, 1964) is the apparent increase in the number of outbursts experienced at a particular mine over and above what was previously or usually the case. More specifically in the early 1960s, inducer shot firing was viewed as the most appropriate means of mining in outburst-prone areas, especially where CO₂ was involved. This was also the case for the N° 1 State Mine in Collinsville, Queensland where, according to Hardie and Hargraves (1960) “the only widely adopted and generally applicable safety measure against instantaneous outburst is the practice of inducer shot firing”. Consequently, special regulations relating to the use of inducer shot firing were developed for both New South Wales and Queensland.

There is debate amongst various researchers as to whether this is an outburst prevention technique or whether inducer shot firing actually provokes an outburst. This relates to two fundamental questions:

a) The position in the heading, where the face preparation will induce an outburst and where it is essential
b) The depth of the blast (pull) that when blasted, will initiate an outburst.

This can lead to undesirable effects in that either there is no induced outburst or the outburst is delayed; the latter creating a potentially greater danger via the delay. To overcome this problem, mechanisms to accurately determine the depth of pull were promulgated by Khodot (1961) and subsequently by Suchodolski et al (1976) who developed “double-pull” inducer shot firing.

In respect of inducer shot firing being used as a mechanism to control outbursts in the Bulli seam, the work of Hargraves et al (1964) provides the following observations that “at no time did the outburst products build up to jeopardise safety at 90 metres on the intake side of the place fired. Any gas accumulation was not instantaneous but rather slow, rising in level from the floor, giving warning to the approaching shot firer by its warmth, smell and its extinguishing effect on his safety lamp”. The preventive nature of inducer shot firing was also identified by Moore and Hanes (1980) in considering its use at the Leichhardt Colliery in Queensland.

However the greatest benefit of inducer shot firing has got to be the potential to de-stress the seam and remove the workmen from the location or point of danger. The greatest limiting component for Bulli seam mines is the slow development rate.

5.3.4 Water Infusion

This is a mechanism, which has been utilised in Bulgaria, China, France and Russia. It involves in general terms, the pumping or injection of water into the coal seam to induce or open up fractures in the coal. The increased moisture content of the coal restricts rapid desorption and forces the methane gas out from the coal. In this regard it is a form of de-stressing leading to induced gas flows similar to hydro-fracing, as used in surface wells.
Trials by Gil and Swidzinski (1988) have shown that this technique can work under low permeability conditions with pumping pressures of up to 15 MPa and slow pumping rates over a period of 20 to 25 days, using hole spacings of 2m. Major limitations with this technique are the distinct lack of success with carbon dioxide, given its high solubility with water and for the potential to induce outburst conditions associated with a phase change of the gas (Harvey & Singh 1995). Also, the time constraints (i.e. 20 to 25 day pumping rate) limit the rate of development and production from the working face.

5.4 GAS THRESHOLD VALUES

The direct link between coal and seam gas and outbursts has been indicated numerous times. In many instances it is the toxic or asphyxiating effects of the seam gas (especially carbon dioxide), which has led to many of the fatal outburst incidents. This is especially true for the Bulli coal seam and Harvey and Singh (1995) clearly identified the high probability that due to gas and tectonic pressures, carbon dioxide could exist in a critical liquid state, thereby explaining the added violence of carbon dioxide outbursts (discussed previously in section 4.3.5).

Lama (1980) developed a predictive table for outbursts, based upon the comparison of certain parameters relating to various coal seams both in Australia and overseas, (see Table 5.2).

Similar predictive methods have been developed overseas on both a regional and a site-specific basis. Commonly accepted predictive methods were identified by Lama (1991).

i. Measurement of gas quantity liberated from cuttings collected during drilling ahead of the working face (used in China, Germany, Poland and Russia)

ii. Rate of flow of gas released from boreholes per unit of length of hole (Czech Republic, Poland and Russia)
iii. Temperature change (-ve) in boreholes (Poland and Russia)

iv. Measurement of over-pressure for CH₄ (0.8 atm) and CO₂ (0.3 atm) (used in Poland)

v. Desorption intensity (120mm H₂O) or 1.44 m³/g, depending upon equipment used (Poland and France).

vi. Gas content varies (between 8 – 16 m³/tonne) depending upon local conditions (used in China, Poland and Russia).

Table 5.2 Criteria for Prediction of Outburst Conditions in Mines (Lama, 1980)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniaxial compressive strength</td>
<td>&lt; 1.2</td>
</tr>
<tr>
<td>Vertical stress ratio</td>
<td></td>
</tr>
<tr>
<td>Fracture surface energy of coal, ergs/cm²</td>
<td>&lt; 1.5 x 10⁵</td>
</tr>
<tr>
<td>Apparent porosity</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>True porosity</td>
<td></td>
</tr>
<tr>
<td>Mean pore radius</td>
<td>&lt; 0.005</td>
</tr>
<tr>
<td>Gas content, m³/tonne</td>
<td></td>
</tr>
<tr>
<td>Rate of change of gas desorption rate (for CH₄)</td>
<td>&gt; 0.75</td>
</tr>
<tr>
<td>Gas pressure / equivalent hydraulic depth</td>
<td>&gt; 0.6</td>
</tr>
<tr>
<td>Presence of geological anomalies</td>
<td>Shear zones, reverse faults and zones of compression favour outbursts</td>
</tr>
</tbody>
</table>

The use of these predictive methods and the subsequent extrapolation into outburst prevention relates to the following factors:

(a) Tensile strength of coal
(b) Gas emission rate
(c) Gas pressure gradient
(d) Moisture level
(e) Depth or stress levels

The inter-relationship of these factors was suggested by Tarnowskio (1990) from the function:

Outburst Coefficient = Depth X Threshold value

4000 X uniaxial compressive strength
Based upon this, Lama (1995a) proposed general threshold values (based on desorbable gas content and coal strength) for different countries as shown in Table 5.3. This identified that for an outburst to occur in the Bulli seam without the presence of a structure, the gas content value will have to be at least 13 m³/tonne of desorbable gas or 15.5 m³/tonne of total gas.

In addition it was recognised that mining operations within the Bulli seam predominantly experience outbursts associated with geological structures, where the primary driving force behind the outburst is gas. The higher production rates associated with Bulli seam operations (giving rise to higher rate of advance than normally experienced overseas) tend to create higher gas gradients which in turn mean that the critical values of gas content are lower than those accepted in other countries.

These higher production rates require a more rapid assessment of gas content. This has resulted in changes to the method of estimation of gas content whereby the core sample is crushed and total gas content values are measured (as opposed to desorbable gas values).

### Table 5.3 Proposed Gas Threshold Values (Lama, 1995a)

<table>
<thead>
<tr>
<th>Country</th>
<th>Type of coal</th>
<th>Range of uniaxial compressive strength MPa</th>
<th>Depth of occurrence, m</th>
<th>Threshold values THV CcAg (desorbable)</th>
<th>Minimum OB Coeff.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CO₂</td>
<td>CH₄</td>
</tr>
<tr>
<td>Australia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td>Coking</td>
<td>4 – 30</td>
<td>350 – 550</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>No structure</td>
<td>Coking</td>
<td></td>
<td>350 – 550</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Poland</td>
<td>Coking</td>
<td>2 – 4</td>
<td>400 – 600</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>(i)</td>
<td>Coking</td>
<td>10 – 20</td>
<td>400 – 700</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>(ii)</td>
<td>Coking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td>Anthracite</td>
<td>2 – 7</td>
<td>600 – 1,300</td>
<td>10 – 12</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>Coking</td>
<td>6 – 10</td>
<td>800 – 1,300</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Bulgaria</td>
<td>Coking</td>
<td>1.2 – 7</td>
<td>250</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>Coking &amp; Anthracite</td>
<td>1 – 1.1</td>
<td>&gt; 10,000</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
The concept of developing and utilising critical gas threshold values is based upon the following considerations:

(I) Instantaneous outbursts are high gas and high stress phenomena

(II) Adequate reduction of one of these contributory factors means that an outburst will not occur

(III) Gas is the easier of the two factors to reduce and to measure, thereby verifying the reduction

(IV) Local de-gassing will in addition achieve localised de-stressing as high gas and high stress are regarded as co-dependent in respect of outbursts.

Hence, the outburst risk is reduced to a level low enough to permit normal mining when the total gas content of the coal seam is reduced below the threshold value thereby preventing outburst incidents.

5.4.1 Statutory Standards

In 1994, following a fatality at West Cliff Colliery relating to an outburst incident, a notice under section 61 of the Coal Mines Regulation Act, 1982 was issued to all mines operating in the Bulli coal seam. In effect, this notice enforced gas threshold values on these mines to the extent that normal mining was only permitted where the total gas content of the coal proposed to be mined was less than 9 m³/tonne of CH₄ or 6 m³/tonne of CO₂ (see Figure 5.2). This notice is still in force for all Bulli seam mines and is seen, in combination with outburst management plans, to be the primary reason for the marked reduction in outbursts.
Seam Gas Threshold Values

Remote Mining Operations

Normal Mining Conditions

Figure 5.2 Seam gas threshold value as imposed by Coal Mines Inspectors

5.5 GAS DRAINAGE
On a worldwide scale, gas drainage is the most consistently used and can be the most effective technique to prevent outbursts. In addition, the benefits associated with controlling the overall mine environment and ensuring safe working conditions make gas drainage an essential and integral component of modern underground coal mining operations. The need to comply with certain statutory or legislative requirements further supports the benefits of gas drainage.

5.5.1 Gas in Coal
As coal originates from plant or vegetation material, which is the result of decomposition, millions of years of burial and high pressure, it logically follows that any gases resulting from the degradation of this vegetation should be trapped along with the coal. The gases most commonly associated with coal are methane (CH₄) and carbon dioxide (CO₂). They tend to vary in
concentration and quantity with the type of coal, depth of cover, distance from 
an exposed face, permeability of the coal and its associated strata and any 
structural features (faults, joints and cleat) which have the potential to provide 
pathways for the gases to escape. These gases are occluded in the coal 
itself or other associated strata such as the seam roof and floor.

Gases, and in particular methane, occur with all coal deposits. The other 
factors mentioned will determine the amount of gas trapped within the coal or 
associated strata. Over time the gas will tend to migrate through the coal 
measures and the strata associated with the coal. Whilst not being directly 
and or initially responsible for the formation of the gas, these adjacent strata 
can still be capable of storing the gas, depending upon their porosity and 
permeability. The permeability is very important, as it will determine the rate 
and extent of gas migration. For a seam of coal or associated measures to 
store gas accumulated over many years, an impermeable barrier is necessary 
to entrap the gas. Similarly, highly permeable strata will allow the gas to 
escape.

The relative density of the gases tends to influence the direction of gas 
migration. For example methane being light will tend to rise to a top or higher 
impermeable barrier, while carbon dioxide (being heavy) will tend to fall to the 
bottom of the seam or coal measures. For this reason, depending upon the 
permeability of the various coal seams and the intermediate strata in a 
sequence of seams, or coal measures, it could be expected that the top 
seams will have higher concentration of methane and the lower seams a 
higher concentration of carbon dioxide. This will only occur in permeable 
seams and strata. In addition, structures within the seam such as faults, 
joints and dykes whilst acting as a conduit to facilitate gas migration within a 
seam, can also act as a barrier due to small, localised variations in 
permeability.
Of the coalfields in NSW, gas is associated mainly with the Illawarra Coal Measures where its occurrence is of major importance. The Illawarra Coal measures form the southern extremity of the Sydney Basin. In this region the measures are comprised of seven coal seams with a depth of cover (burial) for the top seam varying from 30 to over 600 metres, the seams occurring or pinching out at various locations throughout the region. Generally, gas content of all coal seams in the Illawarra region increases with depth of cover and distance from the coast. Hence, as mining operations progress to the west, they encounter greater amounts of gas in all seams. Currently the main seam being extracted is the top seam, the Bulli Seam. This general relationship, between depth of cover, gas content and outburst potential has been experienced throughout the world.

5.5.2 Review of International Gas Drainage Experience

Gas drainage as a technology is relatively new to Australian coal mining operations and is principally used in the Illawarra coalfields. The techniques have been developed from overseas experience and practices; hence an understanding of practices elsewhere in the world is desirable.

(a) Great Britain

It is common practice in some operating coal mines in Britain to use gas drainage as a means of controlling the amount of gas emitted into the mine's ventilation system. Also it has been shown that the gas after capture by the gas drainage system can be of economic value and used either to supplement supplies of natural gas, via the main distribution pipelines or used in gas turbines for the generation of electrical power for the mine and the national grid system.

Due to the nature of the coal seams, associated strata and the gas formed within the coal, many of the horizons above a coal seam in Britain have what is termed a "top gas horizon", which is above the top seam in the sequence and/or the seam being extracted. That is to say that the gas has migrated
through the various strata to a top impermeable barrier. As the coal is mined and the roof caves, the gas is then able to mix with the mine’s ventilation system.

Hence, the main type of gas drainage used involves the drilling of holes up into the roof, immediately above the area that has been mined (most commonly by the longwall advancing techniques). The gas which collects at this top horizon is then drained via an underground pipeline network, which is in turn connected to vacuum exhauster fans and or pumps. Generally this type of “Post Drainage” (i.e. after mining) is more common in Britain than “Pre Drainage” (i.e. before mining) and as such is not directly related to outburst prevention.

(b) USA
Due to the very high permeability of some of the American coal seams, in particular the Pittsburgh seam, a large amount of time, money and effort has been used to develop a number of methods of gas drainage with particular emphasis on pre drainage. The high permeability means that large amounts of gas can be drained from a large area of coal using a limited number of drainage holes. This can be done in conjunction with mining or as a separate operation well in advance of and prior to mining.

This approach to methane extraction well in advance of mining, utilises the sinking of a shaft to seam level followed by the drilling of long boreholes from an in seam “gallery”. These holes are over 1,000 metres in length, approximately 100 mm in diameter and remain entirely within the seam. Each hole may have a number of branches to de-gas a greater area. The gas is tapped off via these holes and the flow pressures are usually high enough to preclude the use of exhauster pumps.

A variation to this method involves the use of water and sand, being pumped into the holes under pressure, to fracture the coal. The sand is used to
maintain the fracture spacing after the water is drained out. This drastically increases the permeability of the coal with an associated increase in flows. Outbursts have not and are not considered as a regular mining problem in the USA, especially given the permeability of the coal seams.

(c) Japan

The nature of the coal seams in Japan, tend to prevent the use of any methods of large-scale pre drainage, similar to that used in America. The Japanese coal seams are deep, heavily jointed, faulted and steeply dipping. For these reasons long horizontal drilling is not considered viable.

A pre drainage method has been used extensively in Japan and has been termed the "pin-cushion" method. This involves drilling a large number of small diameter holes (about 50mm to 75mm diameter) to a maximum length of 200 metres, radiating from existing mine development headings as they are being formed. This gives adequate coverage of the immediate mining areas although the life of each individual hole is limited to approximately 9 months. In addition it affords the dual safeguard of draining the gas and preventing outbursts, which have been known to occur in some of the deeper Japanese mines.

(d) The Australian Situation

Due to the relationship between gas content, depth of cover and distance from an exposed face, gas occurs predominantly in the western portion of the Illawarra coalfields, i.e. in the Appin, Campbelltown, Tahmoor areas. The low permeability of the coal in this region tends to limit the use of the American system as the influence of a hole drilled into the seam has been estimated to be only in the order of 10 to 30 metres, compared to 100 to 200 metres for the Pittsburgh seam.

At present virtually all Bulli seam mines utilise some form of gas drainage to manage gas make within the underground working environment and to
effectively manage outbursts. The two mines with the longest history of utilising gas drainage techniques are West Cliff and Appin Collieries and both utilise the gas to generate electrical power.

5.5.3 Current Gas Drainage Techniques
The various techniques used to extract the gas from coal seams and mine workings can best be classified into two general categories: — Pre-drainage (before mining or coal extraction) and post-drainage (after mining or coal extraction). It is then possible to further subdivide each of these categories in terms of the location of the drilling equipment; either surface (above the coal seam) or in-seam (within the underground workings). The ultimate choice as to which technique is utilised will depend upon specific geological conditions, on a mine by mine basis. The inherent costs associated with the drilling of drainage holes and the subsequent recovery, extraction and utilisation of the gas, all impact upon the economics of gas drainage. However a majority of the Bulli seam mines have to use gas drainage to meet regulatory and statutory conditions.

In respect of preventing outbursts, pre-drainage is utilised, either by in-seam drilling in advance of the working face and/or surface drilling before mining is proposed.

5.5.4 Pre-drainage using In-seam Drilling
This is the most widely utilised means of preventing outbursts and involves the drilling of holes in advance of the working face, to permit the gas flow out of the coal either by its natural gas pressure or with the aid of vacuum pumps. Typical drilling patterns are shown in Figure 5.3 and these reflect the specific conditions for the target seams where factors such as in situ total gas content, seam permeability, gas composition, principle stress direction, direction of cleat and lead time until mining, all influence the final drilling pattern for the pre-drainage of retreating longwall panels.
Gas Drainage Holes:
Drilled across a longwall panel, in advance of gate road development.
This approach when combined with indicative "Gas Drainage Lead Time Curves" (see Figure 5.4) developed for that particular seam at that particular mine, can lead to an effective reduction in total gas content. Drilling patterns as shown can also pre-drain the coal in advance of the next set of gate-roads, used to form the longwall panel. A borehole pattern as shown in Figure 5.5 is used to both sample gas in advance of the developing coal face and extract any residual gas ahead and adjacent to the proposed roadway.

In-seam drilling techniques in conjunction with borehole surveying (to accurately locate samples and assess the effectiveness of the pre-drainage) have been developed (this is covered in section 4.2.1). The use of down the hole motor, drilling techniques has permitted the drilling of very long holes (i.e., 500 to 1500 metres) for both geological interpretation (identification of seam structures, dykes, faults etc) and the pre-drainage of seam gas.

To aid the extraction of the gas and its removal from the working coal seam, an elaborate network of pipes is established and invariably connected to an extraction plant. Large vacuum pumps located on the surface are connected to the underground gas extraction range, either by a large diameter borehole (in the order of 500mm) or a large diameter pipe suspended in a shaft or drift, used to access the coal seam. This type of system then facilitates the utilisation of the gas, especially methane for power generation.

5.5.5 Pre-drainage from the surface
The drilling of vertical boreholes from the surface, targeting underground coal seams, has been used as a pre-drainage, de-gassing mechanism extensively in the USA. In particular, Jim Walters Resources Inc has used this process for mines in the Black Warrior Coal Basin of North Alabama, as described by Dunn (1995). This type of approach draws heavily on oil drilling and oil well completion technologies where the extraction of water from the wells using surface based pumps is necessary to allow the gas to flow.
Gas Drainage Lead Time Curves.
(the drainage time to reduce seam gas content to a specified level)

Figure 5.4 **Indicative gas drainage lead time curves**
(Harvey, 1994)
(a) Inset

Drainage Line

Drainage holes

(b)

Boring station

Gate road in coalbed

Methane drainage hole

Plan view

Figure 5.5 Drilling for gas sampling & drainage in advance of development headings
Hydraulic fracture stimulation (commonly known as hydro-fracing) is extensively used to enhance gas flows from vertical wells. This technique consists of creating a vertical hydraulic fracture, starting from a vertical borehole and extending into the coal seam over long distances (in the order of 300 and 500 metres on either side). Water under pressure (14 KPa) is used to initiate and propagate the fracture and fine-grained sand is then used to keep the fracture open. A number of seams within the one coal basin can be targeted and de-gassed utilising this technology.

The spacing of wells (or boreholes) is largely dependent upon coal permeability and the lead-time before the coal will be mined. In the case of the Black Warrior Basin and other areas in the USA, coal permeability is quite high, thereby enhancing the overall effectiveness of this technique.

A further modification to this technique as reported by Nguyen et al, (1995), involves the use of horizontal drilling technology from vertical/surface boreholes. This can utilise either down the hole motor technology and/or deviated drilling, as shown diagrammatically in Figure 5.6. This approach drastically increases the area of influence and the scope of pre-drainage in advance of mining.

While this surface-based vertical well technology has been used most successfully in the USA, the potential benefits in de-gassing coal seams in advance of underground coal mining are obvious. The removal of the gas improves the overall mining environment and can be used to significantly limit the risk of outbursts. In respect of the Bulli coal seam, the success of this technology will be proven if and when coal within the Camden area (at depths greater than 600m) is mined. Currently, a petroleum-based company, Sydney Gas Pty Ltd, is using vertical holes with hydro-fracing techniques to recover pipeline quality methane from the coal seams.
Figure 5.6  Deviated drilling using DHM from the surface
(Nguyen et al, 1995)
5.5.6 Post-drainage using In-seam Drilling

This type of approach and associated technology is primarily focused on controlling and managing gas, which has the potential to migrate into the mine workings, thereby endangering life. In this circumstance, holes are drilled into the floor and/or roof of the coal seam being worked and in advance of the longwall coal being extracted (they are sometimes referred to as cross-measure holes). These holes are usually inactive or dormant prior to longwall extraction and only start to liberate significant gas flows as the floor and/or roof fractures with the extraction of the coal. This fracturing tends to have a similar effect to that associated with the hydro-fracing of a surface well. The drilling pattern must target the main gas horizons or seams either above or below the seam being mined. A layout as shown in Figure 5.7 is a typical example of post-drainage floor holes used in Bulli Seam mines.

Figure 5.7 Post-Drainage or Cross Measure Drilling Pattern
It must be noted that the fracturing of the roof or floor will jeopardise the integrity of any borehole and, as such, the drilling site must be afforded protection (usually by an adjoining coal pillar) so that the flow can be measured and the boreholes can be connected to the main gas range. Furthermore, the effective entrapment and removal of water (especially for floor holes) must be given effective consideration. As the gas flow from the post-drainage floor holes generally liberates large quantities of water (which is blown out of the hole by the gas), this can only be captured in the main gas pipe range and released via purpose built water traps or water separation mechanisms.

5.5.7 Post-drainage from the Surface

This technique of gas drainage has primarily been used to entrap and prevent the release of gas accumulated in or associated with gas-bearing strata, which overlie the coal seam being actively mined. It has been used with limited success for certain mining operations in the Bulli Seam where geological conditions support the formation of a gas horizon above the seam.

In particular, the Bulgo Sandstones (located above the Bulli Coal Seam) do contain significant quantities of gas, which can be drawn down into the mine via the numerous roof fractures caused by the collapse of the roof, after longwall extraction. Gas associated with these sandstone strata differs from the underlying coal seam gas in that it contains small amounts of ethane ($C_2H_6$) and other higher-order hydrocarbons, not usually found in the seam gas.

These surface-based boreholes are usually 150 mm in diameter and are fully cased down to the top of the Bulgo sandstones to prevent the contamination of overlying aquifers in the Hawkesbury sandstones by water/gas released from these holes. As is the case with surface-based pre-drainage holes, water is released along with the gas and is subsequently separated on the surface.
5.6 SUMMARY

A number of mines in the Illawarra Coalfield operate a systematic gas drainage system, which is believed to prevent and/or significantly minimise the outburst potential. Holes are drilled across the longwall block (see Figure 5.3) and then subjected to a negative pressure, with the use of vacuum pumps to improve the safety of the mining operation. By lowering gas content the potential for outbursts is reduced, the drainage holes assist in locating outburst prone structures, along with reducing gas make in return and intake roadways thereby reducing the amount of gas liberated when longwall mining actually occurs.

By regularly monitoring gas content, gas flows and gas composition, indicative "Gas Drainage Lead Time Curves" can be developed (see Figure 5.4). These curves provide a guide as to how long gas drainage should be applied to a particular part of the mine to reach specific values and thereby mine safely. These curves are dependent upon the drainage hole spacing. It is not essential to have elaborate pipeline networks and expensive extraction pumps as holes drilled into the coal in advance of mining will give off gas, be it more slowly.

The speed with which mine gate road panels in the Bulli Seam are advanced (40-50 m/day) and constraints on drilling equipment make it difficult to drill drainage holes any longer than 250 m and stay in the coal seam. This, in conjunction with the low permeability of the Bulli Seam means that the "pin cushion" approach has been the most successful and proven to effectively prevent outbursts. Bores developed from the surface are ineffective for pre-drainage due to the depth of cover, low seam permeability and in situ stress conditions. The high development rates in the Bulli seam and logistical problems associated with other outburst prevention mechanisms mean that gas drainage will remain the primary prevention technique.
CHAPTER SIX

PROTECTION FROM OUTBURSTS
CHAPTER 6

PROTECTION FROM OUTBURSTS

6.1 INTRODUCTION

To some extent the protection of mine workers from the effects or consequences of an outburst incident could be viewed as the last resort or ultimate barrier. The use of outburst "warning signs" and specialized mining machinery indicates that the mechanisms or techniques used to predict and prevent outbursts have to some extent failed. It acknowledges that an outburst is likely to occur and that in order to mitigate the consequences the protection must be given to the mineworkers.

The need to have established procedures and practices, which when combined with purpose-designed mining equipment will prevent mine workers from being injured by outbursts identifies that, while it may not be possible to predict or prevent an actual outburst event, sufficient warning may still be given to utilize these procedures and practices. The remote control of mining machinery is included in this category as the mining equipment must be specially adapted and supported by procedures and practices to ensure no mineworker is endangered.

In studying many outbursts particularly those associated with fatalities, Harvey and Singh (1998) found that two important issues emerged.

a) "Warning signs" were evident as mining approached an outburst prone structure.

b) If specific equipment designed to afford physical protection and supply fresh air was in use, then in most cases lives would not have been lost.
Hence the role of protection either through training or specialized mining equipment is considered in greater detail.

### 6.2 WARNING SIGNS

It has been identified through the direct association between geological structures and outbursts, the recognition of changes to the coal seam and the related geology can and does give warning of the potential dangers, which may lie ahead. These changes are sometimes marked and obvious or subtle and only apparent to the trained eye. Too often the latter is the case resulting in fatal consequences and in hind-sight all the specific markings or indicators were present.

Where mineworkers have been suitably trained in the recognition of outburst warning signs, there is opportunity to take precautionary action so that lives are not endangered. Various specialised working groups (in which the author was involved) were established after the South Bulli fatality (25 July 1991) and a list of warning signs which can be used to identify potential outbursts (DMR, 1992) were developed, these being:

1. Stretch marks on the roof.
2. Joints - increase in joint frequency, change of joint direction or orientation.
3. Slicken sides or greasy surfaces on joint planes.
4. Calcite banding - especially in mid seam or base of the seam.
5. Coal changing colour - particularly a reddish brown tinge.
6. Mylonite (bands of crushed coal) is common in the roof but unusual in mid seam.
7. Fluctuation in gas make.
8. Softening of coal.
9. "Gas blowers".
10. Dyke stringers in the face.
While the signs listed can occur in non-outburst situations the benefits in having mineworkers trained in recognising these signs are self-evident. This is ultimately the last protection barrier and is treated as such in many of the outburst management plans. As mentioned by Harvey and Singh (1998) following a detailed review of all fatal outbursts in the Bulli seam, warning signs as mentioned above were present in all the fatal incidents and if the mine workers were able to recognize these signs lives could have been saved.

The overall benefit of "outburst awareness training" has been exemplified by the importance shown by the New South Wales Coal Mining Inspectorate, in that Inspectors of coal mines (supported by other technically competent, trained people) have undertaken a series of audits of outburst management plans for all mines operating in the Bulli seam. This audit focused upon the training aspects of the outburst management plans in the realization that the recognition of warning signs is a fundamental protection barrier, and is common in all outburst management plans.

6.3 OUTBURST MINING PROCEDURES

With the advent of outburst incidents at the West Cliff Colliery in 1975, a specialized mine development system and procedure was established. The concept underlying this procedure was designed to permit mine development through potential outburst zones and minimize the dangers to mine workers. The crew, which undertook this role, became known as the "Bomb Squad". It was manned solely by volunteers who utilized rigorous operating procedures. Up until 1994 when West Cliff Colliery recorded its first outburst related fatality, this system proved to be highly effective, as over 240 outburst events had been recorded with no serious injury.

The general requirement for specialized outburst mining procedures has been identified as a key element in most outburst management plans developed for the Bulli seam operations. These procedures differ from mine
to mine to reflect the particular mining and geological conditions and largely relate to continuous miner and shuttle car operations in roadway development.

There are however certain similarities as described below:

- A "fresh air base" is established no closer than the last completed cut through outbye of the face and special rescue equipment and self-contained breathing apparatus (such as Fenzy oxygen escape units and Saba rescue units) are stored at this location.
- Only the continuous miner driver is to be at the face while coal-cutting operations are under way.
- No person to work or travel on the return side of the continuous mining machine whilst operating under outburst procedures.
- A minimum wait time (usually 5 minutes) is enforced after coal-cutting operations have been completed, before any person is permitted to travel inbye of the fresh air base to the face area.
- Appropriate self-contained escape devices (Fenzy units) to be carried by all persons in the panel.
- Mine workers who are involved in securing the roof after coal cutting and waiting time, are to be equipped with a continuous filtered air supply.
- No person is to enter the panel and travel to the face without the direct consent of the panel Deputy.
- All mineworkers that form the mining crew must have current training in the use of emergency breathing apparatus, outburst mining procedures and outburst warning signs.

Adherence to these procedures is ultimately the primary protection to the mineworkers against serious injury. While mine development under these conditions is slow (due largely to the waiting times), it has been successfully used to mine through recognized outburst structures.
6.4 PURPOSE BUILT EQUIPMENT

The use of specifically designed and purpose built equipment supports the procedures associated with outburst mining. The use of this equipment in conjunction with formal procedures has been utilised as a means of mining through outburst prone areas and not endangering mineworkers. The major focus is to provide protection to the continuous miner driver or machine operator with particular focus upon the driver’s compartment being designed to withstand the force of an outburst and prevent inundation by coal and stone. More specifically the key requirements are:

- Ensure the physical protection against the inundation of coal and stone ejected as a consequence of an outburst.
- Ensure a constant supply of breathable air
- Provide both secondary and tertiary air supply, should the primary air supply be cut off as a result of the outburst. It should be activated automatically and expel the air within the driver’s cabin within five seconds.
- Maintain a positive air pressure within the driver’s cabin in the event of a major gas outburst preventing the ingress of gases.
- Enable the mining operation to be conducted entirely by the miner driver through the use of controls to operate the flights of the conveyor in the shuttle car.
- Provide effective radio voice communications between the miner driver, panel deputy and other crewmembers at all times.

The continuous mining machines used in support of outburst mining have been equipped with purpose built driver’s cabins with specific features including rear entry, laminated glass, radio communications and a streamlined structure designed to deflect ejected material. The machine also has additional lighting for better visibility and truly one-man operations. The layout of the cabin is shown in Figure 6.1 and Figure 6.2. The design of the cabin has evolved over twenty years through direct discussion and input from outburst mining crews, mine management and machinery manufacturers.
Figure 6.2  Driver's Cabin of Continuous Miner
(showing emergency air supply)
6.5 REMOTE CONTROL MINING

The withdrawal of mine workers from the face area has been identified as the ultimate protection strategy (Harvey 1994). This is the case for a number of mining related issues such as ground/roof control, ventilation, dust and outbursts. Remote control mining equipment has been developed for road headers, continuous mining machines, longwall mining equipment (both coal cutting and roof support) and mobile roof supports as used in pillar extraction operations. In all these instances radio control units have been adapted for use in the underground coal-mining environment (mainly intrinsically safe) and designed to permit the machine operator to be located in a remote and safe position.

6.5.1 Longwall Equipment

The incidence of outbursts occurring on a longwall face is considered extremely low (Bruggemann 1999) both from international and Australian experience. The only Australian incident was reported at West Cliff Colliery in 1998 (Walsh 1999) and occurred on a longwall retreating face. In this particular incident remote control operations provided suitable protection to all workmen at the face.

Radio control units in conjunction with electronic sequencing controls for longwall chocks allow the face machinery to be operated from the main gate end of the wall. While this was initially instigated for reasons relating to dust and ventilation, it also provided outbursts protection. Recently remote controls for longwall shearsers have utilized pre-programmed computer controls to maintain a specific cutting horizon. In addition sensors to indicate the proximity of both roof and floor strata have been used (based upon the specific conductive and or ultrasonic properties of roof or floor versus coal) in conjunction with the activation of chock movements as the trailing drum passes each support.
The use of this technology has the potential to provide the following advantages:

- Permits better and more consistent horizon control
- Provides a uniform roof and graded floor
- Eliminates the exposure of workmen to various face hazards

In respect of outbursts the last factor (removal of men from danger) is by far the most advantageous.

6.5.2 Roadway Development

The use of outburst mining procedures and purpose built continuous mining machinery (as outlined in 6.2 and 6.3) has enabled certain mines to develop roadways through geological structures, which were identified on both a regional and local scale, as being outburst prone. However certain shortcomings are apparent with this particular approach, such as:

- Securing the roof via the use of hand held bolting equipment and after coal-cutting operations have been completed, has the potential to endanger workmen.
- Outbursts mining procedures restrict the development rates to about 2 metres per shift, which in turn impacts upon the development rates for future longwalls and the overall operational viability of the mine.

As identified by Wynne and Case (1995) full remote mining operations were researched and undertaken at Tahmoor Colliery. The Voest Alpine ABM20 was chosen as the preferred mining machine because the roof bolting rigs as fitted to the machine took most of the hard work out of the bolting and roof support operations and removed the two operators form the face area. Also the ABM20 was equipped with a sophisticated radio control mechanism, which gives feedback via a LCD display at the radio control unit. In addition as the ABM20 is a full face or full width-mining machine there is no need to relocate the machine from one side of the roadway to the other. The success and suitability was enhanced through the use of video cameras, which permitted the machine operator to be located in the fresh air base some
considerable distance from the face. In the Tahmoor case, the ABM20 was used to mine through a known fault and an outburst, which ejected about 80 tonnes of coal was encountered.

6.5.3 Case Studies of Remote Control Mining

Further work and research was undertaken via an Australian Coal Association Research Program (ACARP) project (Wynne and Case 1995) to refine the remote control potential of the ABM20. A separately ventilated control room was developed along with enhanced video cameras. The system as developed at Tahmoor utilized the control room as the fresh air base as shown in Figure 6.3, which due to the separate ventilation system with continuous fresh air allowed the use of non-flame proof and non-intrinsically safe equipment. The two video cameras gave views of the cutting head of the ABM20 and the coal transfer into the shuttle car. The raising and lowering of the miner's canopy, operation of the shuttle car flight conveyor and the cutting operation were all performed via a radio transmitter and associated layout as shown in Figure 6.4.

Operational problems relating to the cabling and the distinct lack of flexibility the cabling imposed were subsequently addressed. As shown in Figure 6.5, a modified system using the separately ventilated control room, micro-wave video transmission and a power line carrier for monitoring and control purposes, was trialed and this represented a more adaptable system.

(i) Tahmoor Colliery experience

Tahmoor colliery developed the remote control mining process to allow development through area of “tight coal”. This was characterized by homogeneously strong and hard coal, which was extremely difficult to drain (even with hole spacings as close as two metres) and consequently gas threshold values could not be achieved to permit normal mining. The remote control mining process while achieving its initial aims did prove to be expensive, complex to install and operate, giving a very slow advance rate.
Figure 6.3  Separately Ventilated Purged Control Room (Wynne and Case 1995)
Figure 6.4 Initial Panel Layout for Remote Mining (Wynne and Case, 1995)
**Figure 6.5 Proposed Panel Layout for Remote Control Mining** (Wynne and Case, 1995)
As outlined by Wynne (2000) the preferred option became the use of shot firing by grunching (shot firing off the solid face) through these zones where gas could not be drained to below the threshold levels. This was regarded as remote mining in that no person was at the face when the shot was fired and coal was being extracted. This did prove to be more effective with 200 metres of roadway being driven in 1999 and a further 120 metres in 2000. While development was slow (2.4 metres every shift), it was consistent, easy to change from normal mining to grunching and back again and there were no adverse impacts upon roof and sides.

(ii) **Tower Colliery experience**

Tower Colliery has experienced similar "tight coal" conditions to those encountered at Tahmoor Colliery, initially in panel MG18. As described by Eason (2000) the management of Tower Colliery instigated a remote control mining process and procedure similar to that used at Tahmoor Colliery to develop roadways through this zone of tight coal which was associated with a known structure and gas contents of 12 to 14 m³/tonne. A Voest Alpine ABM20 with appropriate remote control equipment was provided with video cameras to permit the machine to be operated from a safe working station, located 300 metres from the face. All operating data was relayed to the surface control room and real time gas monitoring was provided on the return side of the face and at the cutting head of the ABM20. Development rates through the tight coal zones averaged 4 metres per shift, with a maximum rate of 6 metres per shift. The remote control process and procedures were used to develop 240 metres of roadway within 8 weeks.

On 9th December 2000, while using remote control mining techniques, an outburst occurred in panel MG19 at Tower Colliery. The outburst incident as described by Benson (2001) was associated with a thrust fault inbye of a dyke, with seam gas content in the order of 13 m³/tonne. In keeping with the remote control mining procedure no person was in the vicinity of the face or
inbye of the fresh air base at the time of the outburst and no workmen were endangered. The control base was located 275 metres outbye of the outburst site and the procedure developed by the colliery for the use of remote control mining was strictly followed. The outburst was identified after the power to the mining machine had automatically cut off for the second time, due to high gas. Upon inspection, the panel deputy observed a cavity in the right hand side, on the corner of the face and the rib. Subsequent review of the real time gas monitors identified a peak gas level of 1.28% CH$_4$ at the face and 1.2% CH$_4$ on the immediate return side of the face. The value of the process and procedures for remote mining as developed at Tower Colliery was fully proven by this incident and the fact that at no stage were any mineworkers endangered.

6.6 Summary
The various research and development projects undertaken within the Illawarra Coalfield, especially for Bulli seam operations, have led to the development of special purpose built mining equipment. This equipment has been primarily designed to provide a safe working environment for the machine operator either by a specially designed and ventilated driver's cabin or through the use of remote control technology which allows the machine operator to be located some considerable distance from the face (in the order of 300 metres) so that in the event of an outburst, people are not in the immediate vicinity of the face.

Equipment and purpose built fittings, while being important are considered only part of the total picture, for the provision of a safe working environment. The development and strict implementation of well thought out work practices and operational procedures not only control the manner in which the mining equipment is used, but response and action of workmen at all stages of the mining operation (limiting people at the face and on the return side of the mining machine, specifying emergency and rescue equipment).
The realisation by the work force that these processes and procedures are in place to ensure their safety is ultimately reinforced when mining is successfully undertaken through outburst prone conditions, similar to those experienced at Tahmoor and Tower Collieries. The Tahmoor Colliery and Tower Colliery experience demonstrates that outburst mining procedures and mining equipment must be developed and designed for each mine. What has proven to be successful for one mine will not necessarily work at another mine.

Ultimately, as indicated by Harvey and Singh (1998) all fatal outburst incidents in the Bulli seam exhibited what have been termed as warning signs. The appropriate training of mine workers in outburst awareness, focusing on the various outburst warning signs as they relate to a particular mine, is a vital and integral component in any outburst management plan. To some degree the use of purpose built equipment, outburst mining procedures and reliance upon outburst warning signs is a safety net which recognises that all other mechanisms to manage and or control the outburst risk, have for one reason or another not proven to be successful. Outburst mining and especially the timely recognition of outburst warning signs is the final safety barrier.
CHAPTER SEVEN

OUTBURST MANAGEMENT
CHAPTER 7

OUTBURST MANAGEMENT

7.1 INTRODUCTION
Outburst management differs from outburst prevention in that outburst management relates to managing the outburst risk and as such will utilize outburst prediction and prevention techniques with the ultimate “fall back” being the protection of mine workers, from the consequence of outburst incidents. It follows that the primary focus of outburst management is to reduce, to an acceptable level the risk of mine workers being injured and/or killed by coal and gas outbursts. As such, it has a human focus rather than technological and would therefore involve procedures and processes all aimed at and achieving the management aim.

The various components, which are, deemed to be necessary within an effective outburst management plan, as related to Bulli Seam operations are discussed in greater detail.

7.2 MANAGEMENT OF THE OUTBURST RISK
As identified previously, outburst management relates to managing the risks associated with outbursts, utilizing outburst prediction, outburst prevention and techniques to protect people against outbursts, via a management system, which has a human focus for the implementation of technologies and processes as shown diagrammatically in Figure 7.1. This concept was first brought to the notice of mines operating in the Bulli coal seam after the triple fatality at South Bulli coal mine in July 1991. It involved the concept that the management of risk associated with outbursts requires the establishment and maintenance of specific “barriers” (as identified in an Energy/Barrier Chart), which prevents the “energy” from being released into the mine environment by an outburst, and endangering mine workers (Joy 1991).
Figure 7.1 Diagrammatic representation of outburst management
In more general terms, it was identified that there was no one specific technology or mining technique, which could be used to guarantee safety in outburst prone mines. Moreover, the effective management of outbursts to ensure safe working conditions, involved a number of techniques and technologies ("barriers"), which when put together in a particular format (management system) could effectively manage the outburst risk (e.g., measurement of seam gas content and composition, identification of geological structures, use of gas drainage techniques, identifying in situ and mining-induced stress regimes etc).

From this understanding the concepts of outburst management plans were developed with the primary goal of guaranteeing safety within the mine. The various background concepts of management systems and more specifically, quality management concepts were fundamental to the development of outburst management plans.

7.3 MANAGEMENT SYSTEMS

The most important aspect of a management system is that it represents a holistic approach to risk management, which includes as a fundamental component human/technology interactions, as its main focus (Figure 7.2, Reczek, 1995). Any such system takes into account the basic unreliable nature of human beings, including "people" within the system and provides for their failings via redundancies. Hence, people are not endangered by human failings and/or inherent weaknesses in specific technologies. Phrases such as "fail safe" and "making the right decisions for the right reasons" flow from a management system approach.

In this regard, a management system becomes an independent self-regulating entity where all necessary and appropriate tools are utilized to build, operate and maintain the various elements within the system. Thus a major component of a safety management system as identified by Reczek
(1995) and exemplified in Figure 7.1 and Figure 7.2 is the interaction between "hazard identification", "risk assessment" and the key role of "audit/review". In this instance, risk assessment evaluates the adequacy of controls or barriers by which hazards may be constrained or eliminated. The audit/review process ensures that the management system is properly implemented and regularly updated as technologies and techniques change.

It follows that in this regard a management system identifies how the various controls and barriers can be maintained in proper order, after they have been defined, implemented and have become operational.

**Figure 7.2 Flow Chart of a Safety Management System**

(Reczek 1995)

![Flow Chart of a Safety Management System](image)

7.3.1 Quality Management

Quality management systems have been defined by the various standards organizations, Australian Standards (AS 3900) and International Standards
Organization (ISO 9000). The publications associated with these standards clearly outline and document the scope of any management plan or system; definitions associated with the management system; the various process elements which make up the system; verification that each component of the management system has been undertaken as required; that all documents that form the management system are maintained and that a system of audit and review is instigated to ensure the management system is implemented as intended.

With a quality management system there is a higher level of certainty that the end result or objective, which is fundamental to that particular management system, is achieved. At all stages within the system there is documentary and traceable evidence that specific actions have been undertaken, processes implemented and desirable results achieved. Equally important, a quality management system ensures that if for one reason or another a single component or element of the system is not in place or is defective, the management system will identify the defect without jeopardising or compromising the final product and the aim or objective of the management system.

The use of quality management systems was seen by the New South Wales Coal Mining Inspectorate in general, and the Chief Inspector of Coal Mines, Mr Bruce McKensey in particular, as an effective tool to manage the various aspects of coal mine safety. The focus being the concept that in today’s coal mining industry no death is acceptable nor inevitable and that employers (mine management) have a clear duty to provide safe systems of work as part of ensuring the health, safety and welfare of all employees (McKensey 1995). In this regard a workplace fatality is seen as the result of the absence or failure of any predetermined safe system of work. Hence, a well documented management system is seen as the only realistic means of achieving a zero fatality goal.
7.4 OUTBURST MANAGEMENT PLANS

The various characteristics, which lead to identifying the outburst potential, and subsequently to the outburst risk, have clearly been shown as site specific. Geological conditions and the mining methods utilised at any one particular mine site will necessitate the development of a specialised outburst management plan for that mine. This will not only reflect the techniques and technologies used at that mine to manage the outburst risk, but must reflect the "culture" at that mine, the way work is performed and the way mine management relates and interacts with the workforce. In this regard the human and organisational aspects of the plan can be considered as equal in importance to the technologies utilised, as the acceptance of an outburst management plan and its implementation is just as important as any other aspect of outburst prevention.

While it is of primary importance that any outburst management plan is developed for each specific site with due regard for geological and mining conditions, for the plan to be considered as acceptable it must have a number of key elements. These elements are considered in greater detail below and are based on the Guidance documentation as provided by the Department of Mineral Resources, Coal Mining Inspectorate, MDG 1004 (DMR, 1995). The manner in which the key components of an Outburst Management Plan fit within a Safety Management System is shown in Figure 7.3.

7.4.1 General Requirements

To define the scope of an outburst management plan the following general requirements are seen as essential:

(a) **Clearly Defined Objective**

An outburst management plan must have a clearly defined objective, which relates to preventing injury to the mine works. This must involve an assessment of the outburst risk at that particular mine site, along with a full
understanding of the specific elements which generate the outburst risk (e.g., high seam gas content, variation is seam gas composition, presence of geological structures, dykes, faults, high tectonic stress conditions either associated with the seam geology or related to particular mining techniques or methods). The various factors, which make up the outburst risk, can then be included within the plan's objective, thereby identifying what will be managed to achieve the goal of safe mining.

(b) Documented Processes

The outburst management plan must be fully documented to ensure that the various processes, techniques, technologies and standards to be used at that mine for the management of the outburst risk are in fact used in the correct sequence, in accordance with the plan. By documenting these processes and procedures the plan can be properly communicated to all employees at the mine and it is not subject to vagaries of understanding and/or interpretation. Copies of the plan are thereby readily available to all workers.

(c) Policy Statement

A clearly defined and understood policy statement signed by the most senior mining official must be included within any outburst management plan. This policy statement should contain an expression of the broad objectives of the plan and the corporation's or organization's commitment to the attainment of these objectives. Having the statement signed by the most senior mining official is seen as a top level commitment to the supply of all essential resources (equipment, people and financial) necessary for the implementation of the outburst management plan, leading to the effective management of the outburst risk. Top management is thereby accountable.

7.4.2 Mandatory Elements

The following elements are seen as essential components for an effective outburst management plan:
Figure 7.3 Outburst Management Plans as a Safety Management System
(a) **Organization**

The responsibilities and authorities of all people who have a role to play within the outburst management plan must be clearly identified and defined. This will include all people who manage activities; people who perform work; people who make strategic decisions and, people who initiate or participate in the processes designed to change the outburst management plan. This organisational structure will reflect the organization within the mine and devices such as organization charts, job or position descriptions or statements of duties, are often used and directed to explain the responsibilities and accountabilities of people, as they relate to the outburst management plan in particular.

(b) **Review**

Timely and effective review of the content and operation of the outburst management plan must be undertaken. The purpose behind this review is ongoing assessment of the plan's continued suitability and effectiveness for managing the outburst related risks at a particular mine. A key component of any review of the outburst management plan is a review protocol, which contains the following:

- Review must re-assess the overall outburst risk being addressed within the outburst management plan
- The protocol defines who initiates and who is to participate in reviews
- All aspects of the outburst management plan including general elements, required processes and technical standards must be included in the review
- The review protocol must define review triggers (i.e., conditions which cause a review to be undertaken). Such triggers must be either time or event based with a minimum requirement to conduct a review at least annually
• An event based trigger must include the initiation of a review on any significant change in mining systems or conditions and may include such factors as change of equipment, change of management, change of geological conditions, unexpected or abnormal outbursts

• In the event that a review indicates the outburst management plan no longer effectively manages the outburst risk at the mine, management must implement corrective action to amend the plan to make it suitable and effective for this purpose.

(c) Audit

Effective and timely audits are a valuable means whereby management of a mine can gain assurance that the requirements of the outburst management plan are being adhered to in practice. The outburst management plan must be implemented and adhered to for it to be effective and a number of the key components of any audit process include:

• A schedule of both internal and external audits must be prepared and adhered to so that over a specified period all aspects of the outburst management plan are audited

• Audits must be designed to effectively determine compliance with and adequacy of the outburst management plan

• All audits both internal and external must be carried out by people who are independent of any identified responsibility for the aspect of the outburst management plan, which is the subject of the audit. A statutory authority may impose an external audit regime either separate from or as part of the mine’s external audit schedule

• The people conducting the audit must be suitably trained

• A record of all internal and external audits must be maintained at the mine
• Where a non-conformity to the plan is identified by an audit, it must be fully investigated and corrective action taken and duly recorded.

(d) Information Control
Up to date information must be communicated to those people who need such information for the effective operation and implementation of the outburst management plan. There must also be objective evidence that this information was supplied to the people who required it and in a timely manner. Current issues of information must be made available at all locations where operations dependent on the information are undertaken. Out of date or superseded information must be removed.

(e) Goods/Services Acquisition Control
The mine must implement, in conjunction with the outburst management plan, a mechanism that ensures the appropriate equipment and services are provided in support of the plan. In this regard equipment acquisition must be reviewed with the aim of ensuring that such equipment is compatible with the outburst management plan and meets any relevant statutory requirement. Similarly, the providers of services (external contractors) must be assessed with the aim of ensuring that the service is of an appropriate standard and is consistent with the aims of the plan, eg, drilling, geophysical, geological and core testing services.

(f) Permit to Mine
This could be regarded as the main central component of any outburst management plan where the three elements of prediction, protection and prevention come together and it is deemed safe to mine. In this regard mining shall only proceed where:

• Evaluation of all information as required by the outburst management plan has been completed
- A documentary form of authorisation to verify the evaluation is issued
- The type of mining system and the area or location in which it is to be used is stated
- Authorisation documentation is signed off by the mine Manager or person as specified in the outburst management plan
- Only those personnel with adequate competency are to be allowed to comprise or be involved with outburst mining crews, drilling crews or act as contractors performing work which is under the control of the outburst management plan

(g) *Plan Monitoring*
All people involved in the operation of the outburst management plan have a role in monitoring the performance of the plan particularly with respect to it being followed at all times and the various physical and other circumstances being adequately covered by the plan. This leads to a suitable level of flexibility whereby the plan is under continual review, adjustment and modification. As such all people must be empowered to make recommendations, improvements as well as reporting instances where the plan is not followed or conditions have changed, so that the plan may not adequately cover specific circumstances.

(h) *Corrective Action*
An effective outburst management plan in being adequate, suitable, flexible and under continual review must have a mechanism, which ensures that non-conformities and/or irregularities associated with the plan are investigated and corrective action is both developed and implemented. Any proposals to amend or correct apparent inadequacies must be investigated in a predetermined manner, which ensures the plan is not weakened and people’s lives are not endangered. Review or benchmarking by an expert committee could be incorporated as part of the corrective action mechanism.
(i) **Training**

The mining operation, as part of the outburst management plan, must ensure that a training plan is developed and implemented. Any person who has a role in respect of the outburst management plan must have sufficient training to safely and effectively undertake their duties. In this regard, the training of all development crews in the recognition of "outburst warning signs" is considered imperative. Such training must also be repeated at regular intervals.

7.4.3 **Process Requirements**

Mining operations experiencing outburst-prone conditions must have specific processes and operational procedures in place as part of an outburst management plan. Appropriate controls must be established for these processes and must include documented instructions defining the manner in which processes must proceed; the use of specific equipment; compliance with relevant standards; assessment criteria to judge the success of processes and approval of processes by responsible mine officials prior to initial implementation or variation of the processes.

Key processes associated with an outburst management plan must address outburst prediction, change detection, evaluation and decision making, outburst prevention and protection of mine workers. These are discussed in greater detail below:

(a) **Outburst Prediction**

A mine must have processes for the timely collection of appropriate information related to outburst risk to reliably predict the likelihood and severity of outbursts. These outburst prediction processes must address the following:

- Determining the total seam gas content and composition of the coal to be mined
• Evaluation of the outburst related history for both the mine and any adjacent or prior mining operations

• Evaluating and recording the geological and geo-technical environment for the mine with regard to structures, gas content and composition

• Evaluation of all available external information

(b) **Change Detection**

Processes focused upon the detection of changes within the mine's operating environment, which may indicate an increased risk of outbursts must be established. Where significant change is detected mining must stop, a review undertaken and a new permit to mine re-issued. To ensure the effectiveness of this change detection process, all workers must have appropriate training in the identification of outburst warning signs that represent a substantial change to mining conditions.

(c) **Evaluation and Decision Making**

Processes must be in place for the timely evaluation of information gathered from all sources and for decisions to be made based on that information regarding the operation of the outburst management plan. In particular, documented evaluation and decision making processes must address:

• Structure location;

• Gas environment;

• Delineation of outburst-prone areas;

• Mining process to be undertaken — outburst, normal or remote mining;

• The need for and adequacy of gas drainage; and

• Response to detected change which may indicate outburst proneness
The documentation of evaluation and decision making processes is essential, along with identifying who must be involved and who has authority for the decisions.

(d) **Outburst Prevention**

The mine must have in place processes to prevent the occurrence of outbursts. In the majority of instances this will involve a comprehensive gas drainage system designed to reduce the total gas content of the coal to be mined to a predetermined level. Alternatively, stress relief mechanisms may be utilised along with alternate mining processes such as shot firing, for the purpose of alleviating the likelihood and severity of outbursts.

(e) **Protection of Mine Workers**

As an ultimate “fall back” position in the event that outburst prediction and prevention techniques do not adequately address the outburst risk, outburst mining processes must be developed. The primary intent of these processes is to ensure that mining in outburst-prone areas will be undertaken with the maximum practicable protection for personnel at all times. This will address:

- Procedures for coal cutting
- Face area strata support activities
- Shuttle car deployment and coal handling
- Personnel deployment during (and for a defined period after) coal cutting
- Control of access to return airways
- Control of all other operations which may be taking place in the Panel (for example drilling operations) and
- Control of entry by persons to the Panel
These processes may encompass procedures associated with the use of remote control mining equipment and must address processes relating to escape/first response rescue in the event of an outburst.

(f) **Technical Standards**

Specific technical standards used in the support of any outburst management plan can be either external (applicable to all mines) or internal (intended to suit local conditions). The external standard AS 3980 covers the means, by which seam gas content and composition shall be determined. Similarly the New South Wales Chief Inspector of Coal Mines has set the standard in respect of seam gas thresholds for the Bulli seam (see section 5.4).

Each mine must establish its own particular standards in respect of drilling (equipment, drilling patterns, borehole spacing, borehole survey, drilling log sheets etc) and gas drainage (hole integrity, gas capture, flow monitoring, seam gas pressure monitoring etc), outburst mining, escape/first response rescue and training. The implementation and maintenance of these standards must be covered as part of any audit and review process for the overall outburst management plan.

### 7.5 EFFECTIVENESS OF OUTBURST MANAGEMENT

The Outburst Mining Guideline MDG 1004 as developed by the Coal Mining Inspectorate within the New South Wales Department of Mineral Resources is regarded as the most comprehensive document defining and outlining an outburst management plan within Australia. This was developed primarily for mines operating in the Bulli coal seam and the success of this approach and the implementation of a systems management approach (i.e., the use of outburst management plans), has led to a significant reduction in the number of outburst incidents recorded for the mines operating in the Bulli seam.
The success of the Management Plan approach in combination with gas threshold values for Bulli seam operations is clearly exemplified in Figure 7.4, which show the major reduction in outburst incidents for the Bulli seam since the management mechanism was established for outbursts.

**Recent History of Outburst Occurrences**

![Graph showing recent history of outburst occurrences]

**Notes**
- *Inspectorate intervention May 1994*
- *Recordable Outburst 92/93 only*
- *Only 7 minor Outbursts since 1994*

**Figure 7.4 Recorded Outburst Incidents Since 1990**
(Harvey, 2001)

Showing the success of outburst management plans and Gas threshold values for Bulli seam operations

### 7.6 SUMMARY

There is no doubt that outbursts can be prevented, either by gas drainage or de-stressing of the coal seam. The outburst management plan however represents the means by which outburst prediction, worker protection and outburst prevention are combined in a systematic manner to ensure safe mining. No one answer to outbursts exits. The management plan when combined with gas threshold values allows the various techniques, technologies and standards to be combined.
The permit to mine approach is seen as being a major component to guaranteeing safety and effective management of the outburst risk. The mine manager has to verify that it is safe to mine. This is then documented and could be reproduced in a court of law, should an accident or fatality occur. In this instance the manager and any mine official could be held personally culpable for any death.
CHAPTER EIGHT

CASE STUDIES OF OUTBURST MANAGEMENT
CHAPTER 8

CASE STUDIES OF OUTBURST MANAGEMENT

8.1 INTRODUCTION

In order to better understand how the outburst management plans work and how all the various component within the plans inter-react a review of three outburst management plans was undertaken. The three collieries (Appin, Dartbrook and Tahmoor) were chosen to identify and demonstrate the manner in which each outburst management plan must be purposefully designed to deal with the specific issues and outburst risk as it relates to that mine. Each colliery has developed a different approach, which reflects the particular nature of the outburst problem and the associated risks. The only common components are that at all times the mining operations endeavour to be competitive (as a coal producer) and maintain a safe working environment for all mine workers. Hence, outburst management must be considered as one component within a larger more complicated management system and process.

8.2 APPIN COLLIERY

Appin Colliery, which mines the Bulli Seam in the vicinity of the Appin Township, is regarded as one of the deepest underground mining operations in the state. With a depth of working of 550 metres, an average seam gas content of between 12 - 15 m$^3$/tonne (predominantly CH$_4$) and a history of 26 outburst incidents the mine is considered outburst prone.

It logically follows that the primary focus for the outburst management plan is to minimise and prevent outbursts via the use of gas drainage in advance of all development roadways. The use of outburst mining procedures, purpose built equipment and or remote control mining equipment is not considered as an option within the Appin outburst management plan. Commitment to these
principles is fundamental to the overall plan and is endorsed by the Mines General Manager.

Following on from this approach, the objective for the outburst management plan clearly identifies the dependence upon exploratory in-seam drilling and gas drainage, with the overall aim of reducing the seam gas content, in advance of development roadways to a level that permits normal mining, as determined by the gas threshold values. The gas level threshold values are defined within the plan (Figure 8.1) and focus on carbon dioxide content with the alternate seam gas being predominantly methane. It should be noted that these threshold values are slightly different from the values as initially imposed by the Mines Inspectorate in 1994 (Figure 5.2). The Chief Inspector of Coal Mines changed these after due representation and consideration.

The Outburst Risk Review Team undertakes an assessment of the overall effectiveness of the in-seam gas drainage along with an assessment of the outburst potential, with the result being the formulation of an Authority to Mine. The membership of the Outburst Risk Review Team is stipulated within the outburst management plan, with the key personnel being the Mine Manager (or Under-manager in Charge), Gas Drainage Engineer, Mine Surveyor, Mine Geologist, a Work-force representative and any other personnel as required by the team, to provide specialist information to ensure safe mining operations.

The Appin Outburst Management Plan does include operational provisions, which focus on outburst prediction (primarily using data from in-seam drilling, geological mapping and projection of known structures), outburst prevention (using gas drainage as the primary mechanism) and finally normal mining operations (when gas content has been reduced to a level less than the threshold values). Consequently the only determinant for safe mining is that the seam gas content is less than the threshold value.
Appin Colliery
Outburst Thresholds

Figure 8.1 Gas Threshold Values for Appin Colliery
(Appin Colliery Outburst Management Plan)
This is supported or achieved by gas drainage in advance of mining and seam gas analysis (for composition and content) from coal samples taken in advance of mining. The location and extent of sampling is determined by the proximity to and potential for outburst prone structures. Figure 8.2 defines the location and number of samples required as a condition of the outburst management plan and relates to the potential or risk of an outburst occurring.

The plan and the Authority to mine requires that mining shall not proceed unless a coal sample and subsequent gas analysis (for both composition and content) has been taken with the sample point being is at least five metres in advance of mining. Indirectly this requires all sample or core holes to be fully surveyed. The decision making flow chart as shown in Figure 8.3, identifies the necessary elements which are required for the final determination as part of the Authority to Mine, giving the recognition that conditions are appropriate for normal mining.

The outburst management plan includes other necessary and essential components particularly training (i.e. training on the plan itself, outburst awareness, duties and responsibilities under the plan and gas drainage tasks); auditing (both internal and external auditing); plan review (to be undertaken at least every 12 months by the Outburst Risk Review Team); monitoring; corrective action; goods and services acquisitions; information storage and process control. These being required elements as outlined in the outburst management plan guidelines, prepared by the Department of Mineral Resources.

A recent addition to the Appin outburst management plan is a specially developed procedure to mine safely through long (>200 m) methane drainage holes. This relates to a particular incident at Appin Colliery, where mining operations intersected an exploratory in-seam drainage hole. The hole was in excess of 800 metres in length and had become blocked, allowing the gas pressure to build up and concentrate within the drill hole.
Sampling Procedure: The method used to determine the location and frequency of core sampling for gas content determination.

Sample type 1 - Outburst Prone area, minimum of four samples within 5m of structure. Two inbye and two outbye the structure, located within 5m of both ribs. More if required.

Sample type 2 - Area with potential to outburst, minimum of two samples within 5m of structure. One sample inbye and one outbye of the structure.

Sample type 3 - Area of low outburst potential such as the absence of drilling anomalies in the vicinity of a projected or inferred structure. Minimum of one sample in the vicinity of the projected or inferred structure. More if required.

Sample type 4 - Area of no outburst potential. Sample as per management plan under reference 7.3.

Figure 8.2 Sampling location and procedure
(Appin Colliery Outburst Management Plan)
Figure 8.3 Decision Making Flow Chart
(Appin Colliery Outburst Management Plan)
Consequently when the mine development intersected the hole an incident closely resembling an outburst occurred unexpectedly, flooding the immediate face area with methane. The need to effectively manage this type of event has been recognised and a procedure and process to mine through gas drainage holes has been developed. The key elements of the procedure are indicated in the process flow chart (Figure 8.4) which focuses on identifying the potential risk and drilling in advance of mining and where possible intersect the hole or at least relieve any accumulation of gas or gas pressure.

In summary the Appin outburst management plan has all the necessary components as recommended by the Department of Mineral Resources Guidelines. The plan focuses on in-seam drilling and gas drainage, which are considered to be two fundamental components for the prediction and prevention of outbursts. Outburst mining is not considered as an option within the plan. It is the intent of the plan to drain the gas in advance of the development headings to a level below the gas threshold values.

The various components within the plan logically reflect the mining conditions and the seam gas levels at the mine (averaging between 12-15 m³/tonne of predominantly CH₄). In this regard the outburst management plan is only one of a number of safety management systems utilised at the mine to control and manage risks relating to mining operations. Of particular note is a ventilation and gas management plan, which also focuses on in-seam gas drainage but includes post drainage, both in-seam (targeting the seams below the Bulli seam) and from the surface (targeting gases within the Bulgo sandstone, above the Bulli seam). The reliance on gas drainage as a control mechanism leads to a certain amount of synergy between the two plans.
Will the roadway to be driven come within the Safety Zone?

- **N** No Action
- **Y**

Is the Methane Hole determined as being gassy, blocked or inefficiently draining?

- **Y**
  - Flow readings to be shifty while mining through safety zone.
  - Details how to drill into Methane hole prior to entering Safety Zone
  - Write details on the “A to M”

- **N**
  - Write details on the “A to M”
  - Issue the “A to M”

Figure 8.4 Decision flow chart for mining through methane holes

(Appin Colliery Outburst Management Plan)
8.3 DARTBROOK COLLIERY

It is significant to note that Dartbrook Colliery or any of the neighbouring mines within the Newcastle/Singleton/Muswellbrook coalfields do not have a history of outbursts. Ellalong Colliery came close with one potential outburst type incident. However, given that the mine workings for Dartbrook are located within the middle 4 metres of the Wynn Seam, which has an average thickness of 20 metres, a depth of cover of approximately 330 metres and a seam gas content averaging 8 m³/tonne of approximately 85% CO₂, outbursts can be regarded as a possibility. Hence the mine management have identified (based upon experience with underground operations in the Illawarra coalfields, namely South Bulli Colliery) that under certain conditions outbursts and resultant mining problems associated with outbursts could occur. Working on the principle that it is only possible to control and subsequently manage mining problems, which have been considered and are subsequently recognised (conversely a problem cannot be managed if its existence is not considered), Dartbrook Colliery have developed an “Outburst Risk Control Plan”.

This plan tends not to be as elaborate and comprehensive as the outburst management plans developed for Bulli seam mines and as such could be considered as a preliminary and basic risk assessment rather than a risk management plan, which is the case for Bulli seam mines. As such the scope of the plan is limited to all development roadways and more specifically it applies to known and projected faults, dykes and zones of geological structure, in association with high seam gas content. Consequently the assessment of the outburst risk relies upon known seam structures, gas content and any conditions likely to reflect changes within the seam, as identified by in-seam drilling and the measurement of the gas content.

Exploratory drilling is identified as the initial activity or action and is used to locate geological structures and take core samples in advance of mine development, to determine seam gas content. The plan requires at least one
cored (and surveyed hole if it is longer than 110 m) exploratory drill hole to be maintained a minimum of 10 m in advance of the developing face. The Gas/Ventilation Engineer then compares the gas analysis and content results from the core samples and drilling reports with the criteria for mining. The limiting gas content and the manner in which it determines the criteria for mining is represented diagrammatically in Figure 8.5 and is based upon gas threshold values used to control the outburst risk for Bulli seam mines.

<table>
<thead>
<tr>
<th>Methane %</th>
<th>Normal drilling</th>
<th>Without structure</th>
<th>normal drilling</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>9</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>6</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

Figure 8.5 Limiting seam gas contents
(Dartbrook Outburst Risk Control Plan)

The Action Plan Team, being comprised of the Mine Manager, Development Co-ordinator and the Gas/Ventilation Engineer (as a minimum) will assess and determine the limits of mining in accordance with the decision making flow chart as shown in Figure 8.6. As a direct consequence of this process no development can proceed without an "Approval to Mine" form signed by
the Mine Manager or the development Co-ordinator. More specifically the limits on mining are identified as:

**Normal Mining** ---- Where gas contents fall below the lower limit and drilling is normal, mining can continue with approval of the Mine Manager or Development Co-ordinator. If gas content falls below the lower limit and unusual hole behaviour or mining hazard conditions are noted, then mining is to stop until the Action Plan Team assesses the situation.

**Low Risk Area** ---- If gas contents are above the lower limit and below the upper limit with no structure present, mining can only proceed with the approval of the Mine Manager, Development Co-ordinator, Geologist and Gas/Ventilation Engineer.

**High Risk Area** ---- If gas contents are above the upper limit, mining can only continue after the Action Plan Team (with the District Check Inspector and the District Inspector of Coal Mines) has considered all options to reduce the risk to mining and fully documented the decision.

Once a situation (i.e. above the gas content limits an/or identification of an outburst prone structure) has triggered action under the outburst risk control plan, approval to mine can only be granted under the following conditions:

- Gas contents have been drained to within the limits and drilling is normal
- Gas contents are above limits and:
  a) Drilling is normal and,
  b) Gas contents on both sides of the structure are within 1 m³/tonne and
  c) Previous history on structure indicates no abnormal events.
- Mining shall only commence with the approval of the Mine Manager or Development Co-ordinator after the required data has been documented and criteria for mining met.
Figure 8.6 Decision flow chart for mining through structures
(Dartbrook Outburst Risk Control Plan)
### Table 8.1 Hazardous mining conditions: guide for identification and actions

<table>
<thead>
<tr>
<th>SIGN</th>
<th>INDICATION</th>
<th>WHAT TO DO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coking of coal</td>
<td>Igneous activity – dyke</td>
<td>Stop mining if not expected – inform Coordinator</td>
</tr>
<tr>
<td>Colouration of calcite (browns – blues)</td>
<td>Igneous activity – dyke</td>
<td>Stop mining if not expected – inform Coordinator</td>
</tr>
<tr>
<td>Highly stressed coal/slickensides, mylonite</td>
<td>Faulting and broken ground</td>
<td>Stop mining if not expected – inform Coordinator</td>
</tr>
<tr>
<td>Gas Blowers from bolt holes</td>
<td>Pressure close to rib line</td>
<td>Monitor progress of bolting.</td>
</tr>
<tr>
<td>(More unusual in ribs)</td>
<td>Low permeability</td>
<td>If gas blowers worsen or coal fragments ejected from hole then stop mining – inform Coordinator.</td>
</tr>
<tr>
<td>Deterioration in mining conditions (blocky,</td>
<td>Faulting</td>
<td>Monitor gas concentrations.</td>
</tr>
<tr>
<td>drummy or fragmented ground)</td>
<td>May be associated with stress</td>
<td>If significant increase or decrease in gas levels – stop mining – inform Coordinator.</td>
</tr>
<tr>
<td></td>
<td>build up, highly permeable ground or gas pockets</td>
<td></td>
</tr>
<tr>
<td>Decrease in gas concentrations</td>
<td>Stress build up near structure.</td>
<td>Check for normal bubbles on cleat line.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If no gas emissions apparent on rib and gas concentrations continue to fall, stop mining – inform Coordinator.</td>
</tr>
</tbody>
</table>

When any of the following signs are noted:
- Proceed with extreme caution
- Monitor gas level constantly
- Report situation to shift coordinator
- Use your local knowledge and experience to assess conditions
- If in doubt stop mining and inform shift coordinator
The plan does include its own version of outburst awareness for warning signs and appropriate response (as shown in Table 8.1). This could be seen as the final barrier or protection to the mine workers in recognising that something has changed, the conditions are different hence, stop mining and seek clarification.

As with a majority of the coal mines in New South Wales this plan is only one of a number of safety management plans or systems used by the colliery. In the specific case of Dartbrook, gas and ventilation control are important mining issues given the overall thickness of the seam (20 metres) with the middle four metres being mined. Having such a large amount of coal being left behind in the immediate goaf, spontaneous combustion is a major concern hence gas drainage is used primarily to support the gas and ventilation management plans for the colliery.

8.4 TAHMOOR COLLIERY

The outburst management plan for Tahmoor colliery is a comprehensive systems management approach to effectively manage the outburst risk, as it relates to that particular mine. It is made up of a number of standard procedures, which cover the following aspects:

- Authority to mine
- Outburst mining procedures
- First response rescue
- Reaction to plan failure
- Outburst training
- Pre-mining in-seam drilling
- In-seam gas content sampling
- Pre-mining data
- Appointment of officers and delegates
- Maintenance and amendments to the outburst management plan
- Audit
- Corrective action request
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- Recording of outburst incident
- Failed gas content samples
- Outburst precautions – longwall mining
- Grunching through coal with gas content above the outburst threshold limit values

The various components, which make up the outburst management plan, reflect the geological conditions and the need to manage outburst within a modern day mining/production environment.

The Authority to Mine, like all the other Bulli seam operations can be regarded as the primary determinant for safe mining operations, in respect of the outburst risk. The Authority to Mine Team, being comprised of the Manager Mining, Development Superintendent, the Gas Drainage Superintendent and the Geologist, ensure that that all the necessary information is provided to the Manager Mining, to authorise mining and under what conditions this mining must be undertaken. The requirements for safe or normal mining are the defined gas content threshold limit values as indicated in Figure 5.2 and were imposed by the Inspector of Coal Mines in 1994. The various responsibilities of each member of the team are clearly defined within the plan, all in support of developing the Authority to Mine.

The Tahmoor outburst management plan requires as part of the authority to mine, the general criterion that normal mining shall only occur if the in-seam gas content has been drained below the defined gas threshold limit value at the specific gas composition. It stipulates that a potential outburst zone shall only be mined using outburst mining methods where the seam gas content has been drained to below the threshold limits. The exact nature of the drilling and the gas sampling is further defined within the plan under procedures for pre-mining in-seam drilling and procedures for in-seam gas content sampling.
Furthermore the plan identifies that in the event it is not physically possible to
drain the in situ gas, or to confirm that the gas has been drained, mining shall
not proceed unless with approval by the Steering Committee (comprised of
the Managing Director, General Manager, Manager Mining, the local Check
Inspector, a relevant Superintendent and an external expert appointed by the
Managing Director). This committee also has the responsibility for the
overview of standards relating to outburst management at Tahmoor colliery.

As an ultimate safety barrier or fallback position the plan identifies that should
a workman or mine official consider in the course of normal mining that a
workplace displays the signs and symptoms of outburst potential mining
should stop. These signs are defined as:

- Stretch marks in the roof
- Joints – increase in frequency and/or change in the direction; “greasy”
surfaces on the joint faces
- Calcite bands (white crystalline/powdery bands) especially in mid-
seam or the base of seam
- Coal changing colour
- Mylonite (bands of crushed coal) in mid seam – it is common at the top
or bottom of the seam
- Coal softening
- Changes in gas levels – especially an increase in pre-drained coal
- Gas blowers
- Dyke stringers in the face
- Faulting in the coal
- Cindered coal

The workman or mining official shall cause mining to cease and report the
changed conditions to the Panel Supervisor. Mining activities in the
workplace will not resume until the Manager Mining has provided a new
Authority to Mine.
The Tahmoor outburst management plan includes procedures for outburst mining and this does entail specific requirements such as:

- Clearly identifying the location and nature of the potential outburst structure, using additional in-seam drilling.
- Use of auxiliary fan ventilation within any panel that is operating under outburst mining conditions.
- The Panel Supervisor shall control all mining operations and activities within the district, from the Fresh Air Base. During the cutting cycle no other operation shall be conducted within the district.
- The Fresh Air Base shall be established on the intake side of the first intersection at the first completed cut through, outbye of the face and shall not be closer than 50 metres from the face at any time.
- All persons at the Fresh Air Base shall wear oxygen rescue or escape equipment during the mining cycle. A minimum of two persons wearing oxygen rescue equipment are to be at the fresh Air Base at all times during the mining cycle.
- No person shall enter the panel and proceed beyond the Fresh Air Base without the authorisation of the Panel Supervisor.
- During the cutting cycle the only person to be in the vicinity of the face is the miner driver. The driver shall remain in the cabin until the end of the mining cycle, wearing a face mask connected to the appropriate air supply at all times.
- Radio communications must be maintained and operational between the driver and the fresh Air Base at all times during the mining cycle.
- Continuous mining operations must not undercut the face; the sequence of cutting is to be from roof to floor; the side of the face most likely to outburst shall be driven forward up to 1 metre in 300 mm increments.
- Following completion of coal cutting, the driver shall "bump" the face with the head of the miner and a period of five (5) minutes shall elapse before any workman are permitted to enter the face area. The head of the continuous miner shall be left up at the roof level whenever possible to afford protection to workmen from possible outburst material.
Chapter 8  CASE STUDIES OF OUTBURST MANAGEMENT

The plan also includes detailed requirements for the use of a full face ABM20 mining machine, hand held roof and rib bolting and access to the return side of the face area. Training is covered, particularly training in the outburst management plan itself, training for gas drainage drillers, training for normal mining along with retraining where and when required.

A particular component of the Tahmoor outburst management plan includes a procedure in the event of a failed seam gas sample. This procedure provides guidance for a particular situation, where the potential advancement of a development panel is halted due to a failed gas content sample. Under this particular situation it is considered that the pre-mining in-seam drilling and the gas drainage has been unsuccessful in reducing in situ seam gas content to a level below that defined by the gas threshold limit values, which determine normal mining conditions. The decision-making flow chart shown in Figure 8.7 (a) & (b) identifies the steps within the procedure and the nature of the information which is required at each stage of the procedure.

Tahmoor colliery has experienced particular problems with what has been termed as “tight coal”. Within certain parts of the colliery gas drainage has proven to be ineffective in lowering the total gas content to a level, which enables normal mining. For some particular reason the coal does not drain even with gas drainage holes at 2 metre spacings. As referenced in section 6.5.3 a mechanism or procedure using remote control mining was developed especially to permit mining through these tight coal areas. However, the use of this process was discarded in favour of grunching (grunching being defined as the process of shot-firing coal off the solid) and a detailed risk assessment was undertaken with the subsequent development of procedures for “grunching through coal with gas content above the outburst threshold limit value". To date (Wynne, 2001) Tahmoor colliery has used grunching under these procedures to develop 1,600 metres of roadway through coal that was above the defined gas threshold limits, with no outburst incidents and no injury or endangerment to mine workers.
Figure 8.7 (a) Decision making flow chart for failed gas sample
(Tarboro Colliery outburst management plan)
Figure 8.7 (b) Decision making flow chart for failed gas sample
(Tahmoor Colliery outburst management plan)
8.5  SUMMARY

The three outburst management plans as reviewed, are representative of the systems safety management approach, which has been promoted within the New South Wales coal mining industry. The benefits of this type of approach being;

- The safety of mine workers is the focus of the management system, over and above production or the various technical aspects that tend to go with mining.
- Mining activities are designed and co-ordinated for that particular mining operation to reflect the underlying geological conditions, hence they are purpose built with safety being the focus.
- The process by which any particular mining or mining related activity is undertaken is fully documented, so that the safest and most appropriate method of achieving any particular outcome is clearly delineated.
- The major benefit is that the ownership of safety and or safe mining operations rests with the mine management in providing leadership, guidance and consistency in all mining activities.

As identified, the outburst management plans do work, in that the number of outburst incidents has been dramatically reduced and safety is now the number one consideration. In addition the management of the outburst risk is regarded and considered along with all other mining related risks. The safety management system uses a fail-safe approach, even if this does ultimately depend upon the mine workers identifying that conditions have changed and further review and assessment is required. A hundred or more false alarms are preferred to one injury and or fatality.
CHAPTER NINE

CONCLUSIONS AND RECOMMENDATIONS
CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

As a consequence of the research the following conclusions have been developed:

- Outbursts throughout the world are a significant obstacle to safe mining with the following parameters being of relevance in determining outburst risk:
  - Gas content, especially desorbable gas and the desorption rate.
  - Correlation with structures, especially those which are compressive in nature, e.g. thrust faults, shear zones, reverse faults.
  - Coal characteristics, especially permeability, strength and rank.
  - Inherent tectonic stresses both within the seam and induced by mining operations.

These factors while being characteristic of outbursts throughout the world are relevant for Bulli seam outbursts.

- Throughout the years, with all the research and study, which has been undertaken, no one particular method has been developed for determining the potential for an outburst to occur. There is no one universal predictive tool. Similarly there is no one mechanism for the prevention of outbursts. Gas drainage has been the most successful outburst prevention technique, especially for the Bulli seam; though this is not universally the case and most probably would not have been of assistance in the case of coal with very low permeability (such as at Mt. Davy, NZ) and high in situ stress.
• Gas drainage has clearly been identified as the single most effective mine safety mechanism not only in the prevention of outbursts but for many other mining related matters. This technology, while reducing the gas content within the coal seam and thereby taking the energy out of outburst prone areas has a number of other beneficial "spin offs" such as providing greater ventilation control and identifying geological structures in advance of mining which have the potential to create roof support problems.

• The systematic safety management approach has been extremely successful, particularly for Bulli seam operations. The key benefits being the collection of data such as seam geology, gas content, gas composition, potential geological structures, lead time for gas drainage and correlation against gas threshold values. All these components are successfully combined to give a total image/picture of the coal seam immediately before it is mined. The most suitable mining method is then selected in the interests of safety and the mine manager or appropriate senior mining official then signs off on the collected information and the mining method. This approach is supported by a fully documented system and training for all mine workers, so that the responsibilities of each person are fully understood. Given that there is no one answer to predicting and preventing outbursts this is a logical approach.

• Outburst mining, either with the use of purpose built/designed equipment (with a specially equipped driver's cabin), or the use of remote control mining techniques or shot firing (such as grunching) are considered as the last resort when all other attempts to prevent or control outbursts have failed. Similarly the ongoing training in outburst awareness must continue as the ultimate and fundamental protection for all face workers. The ability to identify key outburst warning signs and related changes in mining conditions can save lives. It is better to have had one hundred false alarms than one fatality.
• It would appear that over and above the effectiveness of the current outburst management plans for Bulli seam mines, there is an undue reliance on one outburst indicator, namely seam gas content, as the primary standard or determinant for outburst risk. For the plans to become more adaptive and comprehensive, other factors need to be considered (such as seam gas pressure, coal strength and permeability) and incorporated within the outburst management plans. This reflects the overall belief and following assumption that outbursts in the Bulli seam are largely a “gas-dynamic” phenomenon and as such, this does not easily accommodate variations within the seam and the mining environment that could cause Bulli seam outbursts to become a “geo-

dynamic” phenomenon.

9.2 RECOMMENDATIONS

Based upon the research work and the above conclusions the following recommendations are proffered.

• Further research and/or investigation should be directed to the use of the Radio Imaging Method (RIM), as an adjunct to in-seam drilling and gas drainage. The potential for this technology to locate small geological structures and potential outburst zones along with “pockets” or concentrations of seam gas in advance of mining, has not been fully realised. This technology could be used to assess the overall effectiveness of gas drainage and identify or target areas for further drilling or investigation. The equipment and subsequent interpretation of the image (tomograph) needs to be more “user” (mine) friendly.

• Further research needs to be directed to the use and adaptation of the real time mud logging system, to verify its potential and integrate the overall process within current underground drilling operations. The potential exists for this process to take the guesswork and subjective assessment out of borehole drilling and make this a more reliable and consistent tool for the identification of structures and potential outbursts.
• Further research needs to be directed to a quick and easy method for determining seam gas pressure in advance of the development face and this should be undertaken as a component of regular total gas content determination. The rate of desorption may act as an indicator of gas pressure.

• Further research needs to be directed to determining in a comprehensive and scientific manner, the direct interaction and correlation of the primary outburst causal factors. For example with any given gas content level, to what degree is the outburst risk either increased or reduced, with changes in coal strength or variations in seam gas pressure or variations of in situ stress levels?

• It is strongly recommended that an "Expert Outburst Steering Committee" be formed to focus on the effective management of outbursts, as a potentially life threatening coal mining phenomenon. In particular this committee should:
  • Determine the particular seam and mining characteristics which render a coalfield, a coal seam and or a coal mine to have outburst potential or to be outburst prone.
  • Initiate and or direct research into mining and coal seam conditions, which contribute to the outburst risk.
  • Provide technical advice and auditing/review support for all mines in the formulation and maintenance of outburst mining plan.
  • Provide a separation of powers between setting statutory standards and the enforcement of these standards.
  • Provide advice and where necessary determine statutory standards for each mine and or coal field in New South Wales or Australia.
  • Provide a regular forum for the dissemination of information relating to outbursts and the effective management of the outburst risk.
• Regularly benchmark the management of the outburst risk for New South Wales or Australian mines with considered industry leaders throughout the world. This should include various outburst prediction, prevention and protection strategies and technologies.

• Provide a uniform standard for outburst awareness training for all mine workers and contract workers. This should focus on both an understanding of outburst management and outburst warning signs.

• Develop and provide literature and guidance material on outburst, and outburst management plans. Such literature must be regularly updated so that it represents the current conditions and techniques use to determine and manage the outburst risk.
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