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THE UNIVERSITY OF NEW SOUTH WALES SCHOOL OF MINES

THE DYNAMICS OF WIND BLASTS IN UNDERGROUND COAL MINES
Phase 3

Final Project Report

by

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ABSTRACT

The aim of the Wind Blast Project is to develop a fundamental understanding of the wind blast phenomenon resulting from massive roof failure in underground coal mines and thus provide a basis on which to develop strategies to mitigate the hazard. Individual objectives are to define the fluid mechanics of wind blasts and to minimise the hazards associated with wind blasts by optimising mine layout and by developing safe working practices.

A system to record air overpressures and velocities during wind blasts has been developed and successfully demonstrated at several mine sites. A physical laboratory model has also been constructed and has been used to help provide insight into the dynamics of the interaction between the roof elements and the air during a roof fall. A computer program which employs finite element modelling and time stepping procedures to numerically simulate fluid compression and flow arising from a roof fall is also under development.

Further field work and modelling will provide the data necessary for the development of work practices designed to minimise the risk of injury to mine personnel. It is also envisaged that the computer program will be further developed into a form which will be suitable for use at the mine site to optimise panel design and layout in order to minimise the hazards associated with wind blasts.

EXECUTIVE SUMMARY

S1 INTRODUCTION

In some underground coal mines where the roof comprises strong and massive rock, the roof strata do not cave regularly as extraction progresses but 'hang up', leading to extensive areas of unsupported roof. These areas can collapse, suddenly and often without warning, compressing the air beneath and forcing it out of the goaf through surrounding openings giving rise to a phenomenon known as *wind blast*. The force of the wind can and sometimes does cause injury to mine personnel, disruption to the ventilation system and damage to plant and equipment. It can also increase the hazard of explosion by expelling methane from the goaf and mixing it with raised coal dust.

S2 PROJECT OBJECTIVES AND OUTLINE

The aim of the Wind Blast Project is to develop a fundamental understanding of the wind blast phenomenon resulting from massive roof failure in underground coal mines and thus provide a basis on which to develop strategies to mitigate the hazard.

The initial phase of the Wind Blast Project was funded by a grant under the National Energy Research, Development and Demonstration (NERD&D) Programme, together with financial contributions from each of the three participating coal companies, namely Newcom Collieries Pty Limited and Elcom Collieries Pty Ltd (now amalgamated as Powercoal Pty Ltd) and Coal & Allied Operations Pty Limited.

The second phase was funded by a grant from the Joint Coal Board Health & Safety Trust while the third phase utilised the resources of The University of New South Wales Department of Mining Engineering, supplemented by additional funding from the Joint Coal Board Health & Safety Trust and from Powercoal Pty Ltd.

The first interim report (Project Report No. 1[1]) was issued in April 1994 and covered the first phase of the work, i.e. the period from January 1991 to March 1993. The second interim report (Project Report No. 2[2]), issued in July 1994, covered the second phase, from April 1993 to June 1994. This report, Project Report No. 3, covers the third phase of the study, the period between July 1994 and March 1997.

During phase one, the overall direction of the project was determined by a steering committee drawn from the coal mining industry and representing the companies, unions & inspectorate.

S3 MAIN FINDINGS AND CONCLUSIONS

S3.1 What is a wind blast?

The available evidence indicates that a wind blast is a sudden mass movement of air displaced by a goaf fall and caused to flow through adjacent openings. A wind blast event may exhibit three distinct phases.

1. A *primary phase*, characterised by a high velocity flow of air (away from the fall) which exhibits a peak and corresponds to the period during which the falling roof is accelerating.
2. A *secondary phase*, characterised by a residual air flow (away from the fall) of a lesser velocity than in the primary phase and corresponding to the period during which the roof is falling at its *terminal velocity*.
3. A *tertiary phase*, characterised by a flow of air towards the fall (the 'suck back') and corresponding to the period immediately after the roof strikes the floor.

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[1] Fowler, JCW 1994, The dynamics of wind blasts in underground coal mines (Project Report No. 1, The University of New South Wales School of Mines), Australian Coal Association Research Program Final Report, Project No. C1595, available Melbourne: The Australian Mineral Industry Research Association.

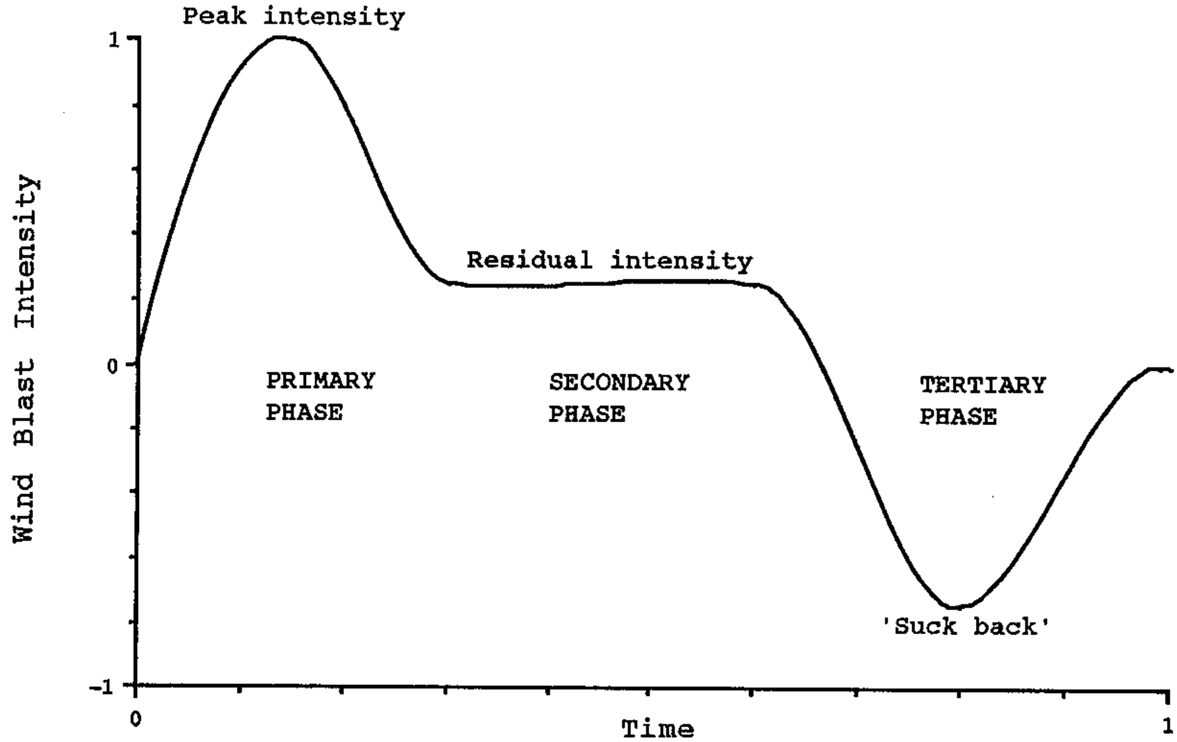
[2] Fowler, JCW & Torabi, SR 1994, The dynamics of wind blasts in underground coal mines (Project Report No. 2, The University of New South Wales School of Mines), Joint Coal Board Health and Safety Trust End of Grant Report, Project No. 19822, available Sydney: The University of New South Wales Department of Mining Engineering.

The three phases of a wind blast are illustrated in figure S1(a) which is a synthesis of theoretical considerations with the results of field monitoring and laboratory modelling. While the primary phase is always present in a wind blast, the secondary and tertiary phases may be absent.

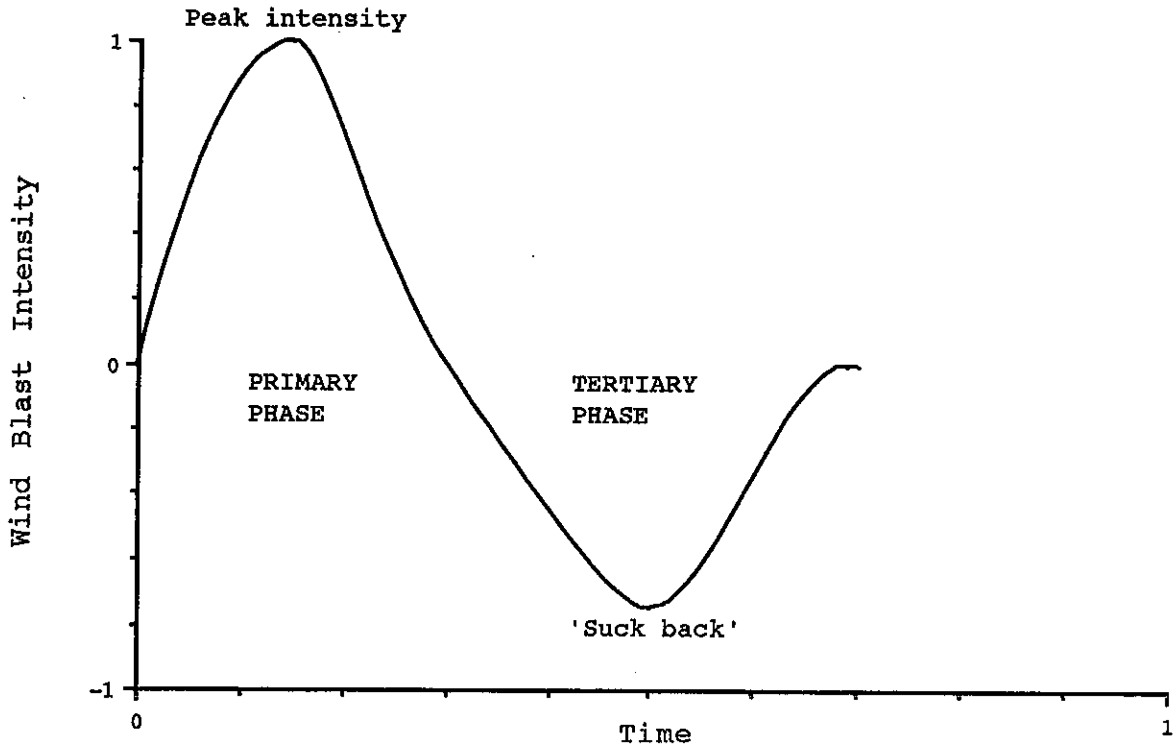
Evidence of the secondary phase has yet to be clearly observed in the mine situation and it may be that the conditions of a real roof fall in a coal mine are such that the primary phase is always prematurely terminated by the falling roof element hitting the floor with the result that the secondary phase (corresponding to the roof element achieving its *terminal velocity*) does not develop (fig. S1(b)).

The absence of the tertiary ('suck-back') phase in some of the field recordings is believed to be due to changes in the resistance to air flow in some of the entries caused by the presence of the bulked goaf material. The distribution of the return flow between the various openings adjacent to the goaf may well be different from the distribution of the initial flow away from the goaf.

A wind blast is a mass movement of air. It is not a shock wave (like that emanating from an explosion) and there is no evidence that, as the wind blast event propagates through the workings, shock wave conditions develop, although the possibility of such an eventuality cannot be excluded. Measured wind blast velocities are an order of magnitude less than the speed of sound. It must be understood, however, that the *celerity* or rate at which the wind blast event is propagated through the mine is equal to the speed of sound. Consequently, personnel subjected to a wind blast will not hear the event before they are struck by the force of the air, i.e. they will receive no audible precursor to the actual roof fall although, of course, 'roof talk' prior to the fall may be evident.



(a) Primary, secondary and tertiary phases



(b) Primary and tertiary phases only

Fig. S1 Synthesised time histories of wind blasts

S3.1.1 The magnitude of a wind blast

The *magnitude* of a wind blast is related to the amount of air displaced from beneath the falling roof element and caused to flow from the goaf area into the surrounding workings. Factors which affect the magnitude of a wind blast include, but are not necessarily restricted to, the following.

1. Geological factors which affect the way in which the roof falls.

2. Geometrical factors such as the thickness & plan area of the falling roof element and the distance through which it falls.

S3.1.2 The intensity of a wind blast

The *intensity* of a wind blast relates to the effect of a wind blast upon the working place. In assessing the intensity of a wind blast the following factors are considered to be of importance.

1. Air velocity (and differential pressure) for *drag-sensitive* elements.

2. Air overpressure for *overpressure-sensitive* elements.

Some elements of the mine may be both drag & overpressure sensitive.

S3.2 The characteristics of a wind blast

Wind velocity time histories recorded in the maingate and travelling road of longwall panels during three significant wind blasts are illustrated in figure S2. Both the differential pressure and overpressure curves are also of this same general shape.

The maximum peak roadway air velocity so far recorded is 40 m/s (144 km/hr) while the greatest peak suck back velocity is of the same order of magnitude. To put this value into perspective, it is well into the *hurricane range*, Force 12 on the Beaufort Scale, for which the lower bound is 33 m/s (118 km/hr). In addition, the highest recorded rate of rise of velocity is 50 m/s/s while the greatest measured flow distance is 142 metres.

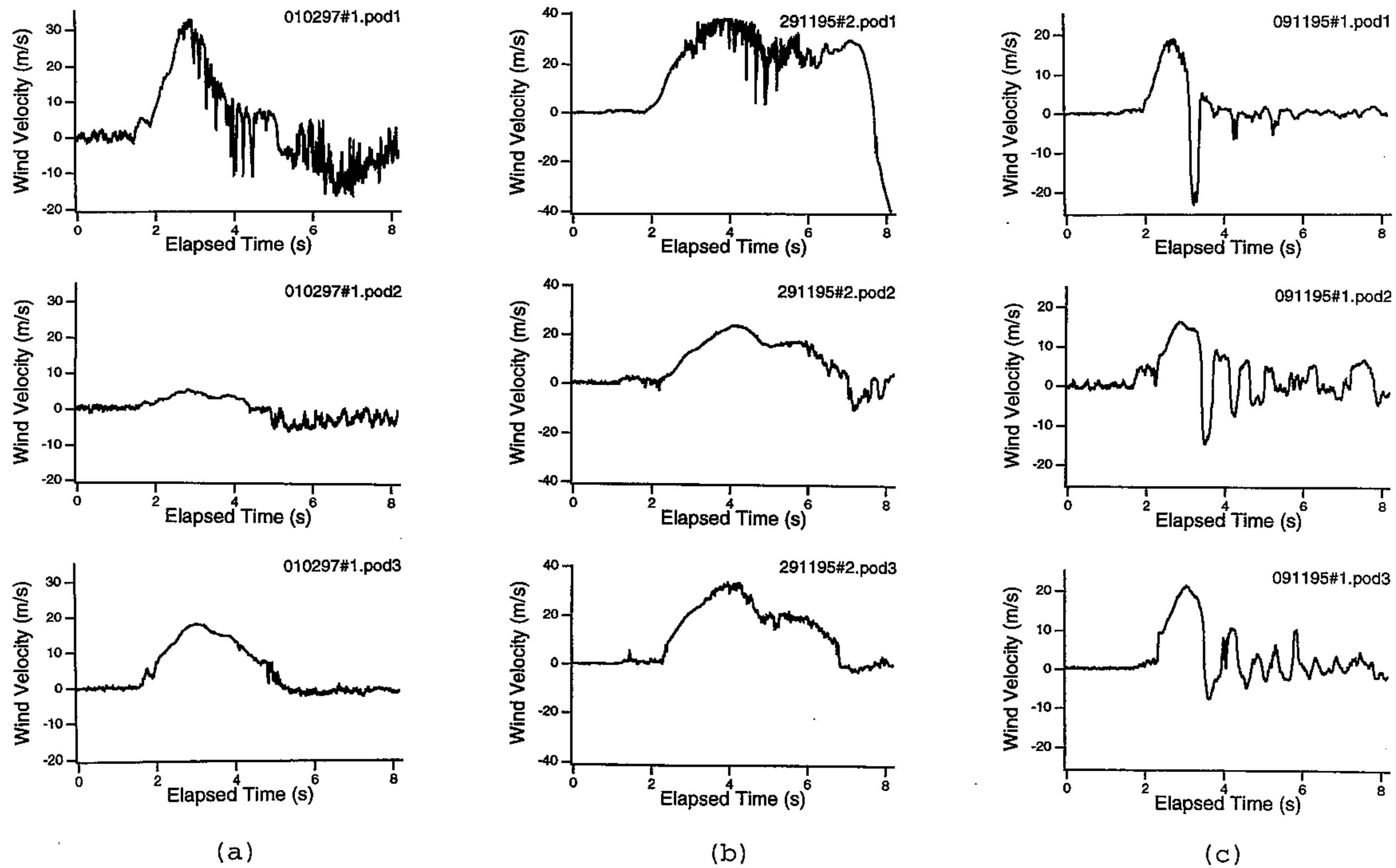


Fig. S2 Roadway air velocity time histories recorded during three significant wind blasts

The maximum recorded peak overpressure is 100 hPa (10% of standard atmospheric pressure), the highest rate of rise of pressure is 50 hPa/s and the maximum impulse is of the order of 200 hPa.s.

There is no reason to assume, however, that wind blasts of greater intensity, i.e. exhibiting higher wind velocities and overpressures, do not occur.

S3.3 The direct effects of a wind blast

It is considered that the 'elements' in a coal mine most sensitive to wind blast are the personnel themselves and the ventilation system. Wind blasts of an intensity below that which causes injury to personnel or damage to elements of the ventilation system are considered unlikely to cause damage to drag-sensitive elements of the mine such as plant and equipment.

S3.3.1 Effect on mine personnel

Mine personnel are considered to be both overpressure and drag sensitive.

Direct blast injury may result from air overpressure and there are at least three parameters which may be relevant in this context: peak overpressure, pressure rise time and impulse. The element of the human body most sensitive to damage by rapid pressure change is reported to be the eardrum and published data for the threshold overpressure value for eardrum rupture is of the order of 340 hPa. This is more than three times the maximum overpressure of 100 hPa recorded to date during a wind blast.

Indirect injuries may result from displacement due to the drag force occasioned by a wind blast. It is tentatively assumed that the sudden application of a force equal to, or more than, 15% of self-weight would give rise to the possibility of an individual in an upright mode being knocked over. Such a drag force would be occasioned by an air speed of the order of 20 m/s and, consequently, one of the necessary conditions for a wind blast event to be considered *significant* is taken to be an air velocity of 20 m/s or greater.

S3.3.2 Effect on elements of the mine ventilation system

The maximum peak overpressure so far recorded (100 hPa) is far less than the generally accepted design pressure loading of 3500 hPa (50 psi) adopted for explosion-proof stoppings. However, it corresponds to the lower limit of published values for the shattering of large wall panels constructed of 300 mm thick concrete or cinder blocks and, consequently, may be sufficient to cause failure in this form of stopping. Clearly, it is more than sufficient to destroy a plasterboard stopping.

S3.4 Factors which influence magnitude and intensity

S3.4.1 Density and thickness of the falling roof

Gravitational force obviously controls the acceleration and velocity of a falling roof element. However, interaction with the air significantly moderates its fall and, consequently, the density and thickness of the roof element are important parameters which influence its acceleration & terminal velocity.

There are distinct differences, however, in the way 'thin' and 'thick' falling roof elements interact with the air and, consequently, they are discussed separately below.

S3.4.2 The collapse of a 'thin' roof element

The extensive programme of testing using the Laboratory Wind Blast Model (described below) indicated that during the fall of a roof element which may be classified as 'thin', i.e. one whose weight per unit area is significantly less than standard atmospheric pressure (1013 hPa), the creation of a zone of reduced air pressure above the element significantly modulates its acceleration and terminal velocity and, consequently, determines the rate at which air is expelled from the goaf area and, hence, controls the roadway air velocity.

The vacuum gauge pressure in the zone of reduced air pressure above the falling roof element is influenced by two factors.

1. The presence of a pre-existing void above the roof element before it begins to fall. Failures where such a void is present will involve higher rates of acceleration of the roof element and, hence, generate potentially higher peak air velocities in the openings.

2. The presence of flow paths through the falling roof element occasioned by open discontinuities such as joints, fractures and bedding planes. Failures where such flow paths are present will involve higher roof element terminal velocities and, hence, generate potentially higher residual air velocities in the openings.

The plan area of the falling roof element may also influence the magnitude and intensity of potential wind blasts. The collapse of larger areas of roof will result in larger quantities of air being expelled in unit time and, hence, increased roadway air velocities.

S3.4.3 The collapse of a 'thick' roof element

During the fall of a roof element which may be classified as 'thick', i.e. one whose weight per unit area is significantly more than standard atmospheric pressure (1013 hPa), the comparative influence of the partial vacuum above the element is much reduced and it is the increased air pressure generated below the element which significantly modulates its acceleration and terminal velocity. This pressure, together with the resistance to air flow in the openings, controls the rate at which air is expelled from the goaf area and, consequently, determines roadway air velocity.

S3.4.4 'Plug type' collapse

A particularly hazardous situation occurs in the case of a roof failure which extends to the ground surface, i.e. a 'plug type' collapse. In this circumstance, the zone of reduced air pressure which would moderate its fall does not form. Consequently, an important distinction must be drawn between roof failures which extend to the surface and those which do not as the former will potentially generate the highest peak velocities during wind blasts.

S3.5 Can wind blast magnitude be reduced at source?

S3.5.1 Restricting mining height

The *critical distance* is the potential distance through which the roof element would fall before achieving its *terminal velocity*. If the height of the standing goaf, and hence the distance through which the roof element falls, is equal to the critical distance, the primary phase of the wind blast will be fully developed and the potential peak air velocity generated as indicated in figure S1(b).

A height of standing goaf which is greater than the critical distance will not lead to a higher peak air velocity but will permit the development of the secondary wind blast phase, characterised by a lower velocity residual air flow, leading to an increased duration for the overall event (fig. S1(a)). It may be of significance, however, that the secondary phase has not yet been observed in the real mine situation.

Conversely, a height of standing goaf which is less than the critical distance will cause the primary wind blast phase to be truncated and the peak air velocity to be reduced. The extent of the reduction depends on the relationship between the peak air velocity and the acceleration of the falling roof element, a relationship which has yet to be fully defined.

Whether or not restricting the design mining height in a total extraction panel would have any significant effect upon the magnitude of a wind blast (and, consequently, upon its intensity) depends, therefore, on the relationship between the mining height and the critical distance.

The problem of whether reducing mining height would lead to a reduction in the magnitude of a potential wind blast in a total extraction panel which is already partially mined-out and includes an area of standing goaf is more complex. This situation is one of those which it is intended to simulate using the Numerical Wind Blast Model (see below).

S3.5.2 Artificially promoting caving

As outlined above, the magnitude of a wind blast may be affected by factors which include the plan area & thickness of the falling roof element and the rock mass properties of the roof strata including flow paths occasioned by open discontinuities such as joints, fractures and bedding planes. Consequently, techniques which could influence some or all of these factors might be used to reduce wind blast magnitude and those which might be applicable include blasting and water infusion / hydrofracturing.

S3.6 Can wind blast intensity at the workplace be reduced?

S3.6.1 Increasing the total area of openings

A possible strategy to reduce wind blast intensity at the workplace might be to increase the total cross-sectional area of workings open to the goaf. The results of a programme of investigations using the Laboratory Wind Blast Model indicated that during the fall of a 'thin' element of immediate roof roadway air velocity could be reduced in this way.

Increasing roadway and cut-through width is not generally practicable and mining height is often determined by geomechanical factors and considerations of coal quality. Consequently, the only practicable way of attempting to reduce the intensity at the working place of a wind blast of a given magnitude may be by increasing the number of openings which intersect the goaf area.

While this strategy would probably be effective for falls of 'thin' roof, it may not work for 'thick' roof falls for the reason given above, i.e. that pressure below a falling element of 'thick' roof, together with the resistance to air flow in the openings, controls the rate at which air is expelled from the goaf area. Increasing the number of openings which intersect the goaf area would merely have the effect of decreasing the total resistance to flow and, consequently, increasing the rate at which air was expelled from the goaf. The pressure time history within the goaf area and the velocity time history of air in the openings would be unaffected. The duration of the wind blast would, however, be shortened and this might indirectly affect the maximum air velocity.

S3.6.2 'Protecting' an opening

'Protecting' a single opening could be achieved, in theory, by introducing a wind blast regulator into the opening. Such a regulator would be analogous to those used to direct the flow of air for purposes of ventilation. Practical problems to be overcome would include selecting a suitable location for the regulator and designing and constructing it so as to withstand the overpressures generated by wind blasts.

The effect on air velocities in the 'non-protected' openings would again depend on whether the falling roof element were 'thin' or 'thick', the effect being the reverse of that resulting from increasing the area of openings as discussed above.

S3.7 A note of caution

The preceding observations and conclusions relating to the wind blast phenomenon are based upon the results of extensive laboratory physical modelling but rely on only a limited number of field measurements. They remain provisional until confirmed or modified by the results of numerical computer modelling and further field monitoring.

S4 WORK PROGRAMME DESCRIPTION

The methodology employed to study the wind blast phenomenon comprised the following four main elements.

An *Interview Programme* which sought to identify any factors common to significant wind blasts.

A *Wind Blast Monitoring System* which was developed and deployed to record air overpressures and velocities during wind blasts in openings near to the goaf.

A *Laboratory Wind Blast Model* which was used to help provide insight into the dynamics of the interaction between the roof elements and the air during a roof fall and into the ensuing flow of air through the adjacent openings.

A *Numerical Wind Blast Model*, a computer program with which to numerically simulate the fluid compression and flow arising from a roof fall and which it is hoped will be able to be used to predict the magnitude and intensity of wind blasts.

S4.1 The interview programme

As the result of an interview programme, which included many personnel in the coal mining industry, it was possible to identify five factors most of which are considered necessary in order for a significant wind blast to occur.

1. A strong roof, such as massive sandstone or conglomerate, which does not cave readily. (A weak roof such as mudstone does not present a wind blast problem.)
2. Little coal left in the standing goaf in the form of stooks or pillar remnants.
3. An extensive area of roof 'hanging up' (but the intensity of the wind blast does not seem to be directly related to the area).
4. Initial total extraction in a previously unworked area.
5. Few roadways into an area, which seems to concentrate the effect.

The geometry of the goaf area was also considered to be of importance.

S4.2 The Wind Blast Monitoring System

During the first phase of the project, a *Wind Blast Monitoring System* was developed to record air overpressures and velocities during wind blasts occasioned by massive falls of roof in underground coal mines. Features of the System include monitoring equipment, data processing software, field procedures and interpretation know-how.

The Wind Blast Monitoring Equipment is certified and approved for use in hazardous locations in coal mines in New South Wales and Queensland. It comprises the following elements.

1. An intrinsically safe Wind Blast Data Logger, built into a flameproof enclosure, which includes a switching power supply with battery backup, intrinsic safety barriers and a data acquisition unit which affords millisecond acquisition.
2. Four transducer (sensor) 'pods' each containing two differential pressure transducers and one direct pressure transducer, together with associated electronics capable of continuously monitoring overpressures, differential pressures and wind velocities and of supplying data to the logger via two DC current loop circuits.
3. A hand held data transfer unit, the Hand Held Interface, used to download data from the Wind Blast Data Logger and to transfer it in ASCII file format to a personal computer for storage and analysis.

The data acquisition unit is the 'heart' of the system and monitors each of the current loop circuits at a sampling frequency of 1000 scans per second. However, data is only stored when a significant signal is detected on one or more of the current loop circuits. The levels of the parameters which define a significant signal are selected by the user. Upon such an event occurring, the data acquisition unit stores information from all four pods in binary format for the two seconds preceding triggering and for the following six seconds. The unit can store data from up to fifteen eight-second periods.

Subsequent to the successful demonstration of the Wind Blast Monitoring Equipment during the first phase of the project at Wallarah and Cooranbong Collieries in NSW where it captured and recorded nine wind blast events arising from roof falls (although these events were not generally of a intensity to be classified as 'significant'), it was deployed at Oakey Creek Mine in Queensland and Wyee Colliery in NSW. Neither site, however, afforded a wind blast.

During subsequent monitoring at Newstan Colliery in NSW, 23 wind blast events were recorded of which eight were classified as significant, i.e. of sufficient intensity to pose a risk of personal injury or of damage to the mine ventilation system.

S4.3 The Laboratory Wind Blast Model

The design and construction of a physical laboratory model to generate, monitor and record air overpressures and velocities arising from simulated roof falls was completed during the second phase of the project.

The *Laboratory Wind Blast Model* comprises representations of solid coal, pillars and goaf areas sandwiched between a 'table top' and a 'lid' of perspex. The goaf fall is represented by a group of four square pistons contained within a piston box. The abutting pistons are suspended electromagnetically and released in computer-controlled time sequences.

The model is instrumented with displacement transducers and accelerometers, which respond to changes in relative vertical position and acceleration of the pistons, with gauge pressure transducers, which detect changes in pressure above and below the pistons, and with Pitot tubes and differential pressure transducers, which respond to the flow of air in the model openings.

S4.4 The Numerical Wind Blast Model

A computer program which numerically simulates fluid compression and flow arising from roof falls was further developed during phase 3 of the Wind Blast Project. The *Numerical Wind Blast Model* employs finite element modelling and time stepping procedures and takes into account the dimensions of the goaf, the layout of panel and the mechanics of roof collapse. The falling roof element is modelled as a 'leaky piston' and the user of the program must specify a roof fall mass per unit plan area and a parameter defining the extent to which air leaks through the roof element as it falls.

It is envisaged that the computer program will be further developed into a form that will run on a moderate sized computer system and be sufficiently user-friendly for routine use by mine personnel.

S4.5 Work 'in hand'

Further work on the Wind Blast Project is currently underway, funded by a grant from Australian Coal Research Limited under the Australian Coal Association Research Program (ACARP). Tasks include the refurbishment of, and modifications to, the Wind Blast Monitoring System; further field monitoring; further development and verification of the Numerical Wind Blast Model and development of a 'user-friendly' computer interface; the development of guidelines for panel design and layout; and the development and definition of safe working practices.

On completion of this work a fundamental understanding will have been gained of the wind blast phenomenon resulting from massive roof failure in underground coal mines and a sound foundation provided for developing strategies to mitigate the hazard.

S5 TECHNOLOGY TRANSFER

Technology transfer has been effected both formally, via technical publications, conferences, workshops & seminars, and informally, through the involvement of personnel at the five 'host' collieries and through the membership of the project steering committee who represent organisations drawn from the underground coal mining industry.

S6 RECOMMENDATIONS FOR FURTHER WORK

It is recommended that research be instituted, as a matter of urgency, into the issue of the expulsion of methane from the goaf into the working place during wind blasts. Of particular concern is evidence that air/methane from the goaf can *reverse* the ventilation flow on the intake side of a longwall panel and may penetrate beyond the 'hazardous zone' defined by statute into areas where non-intrinsically-safe and non-flameproof equipment may be located. It is also of concern that such equipment may be in process of being shut down by safety devices designed to 'trip' the electrical power supply in the event of a wind blast and, hence, be at their most hazardous at the very time that they are inundated by an air/methane mixture displaced from the goaf.

It is further recommended that a project be initiated as an extension of the present research with the specific aim of better understanding the caving mechanism during 'initial' goaf falls in total extraction panels, particularly in areas of massive sandstone or conglomerate roof.

Finally, it is recommended that a project be undertaken with the specific aim of establishing and demonstrating appropriate techniques to 'artificially' induce goaf falls with particular emphasis on the problem of initial goaf falls in total extraction panels in previously unworked areas. The application of such a strategy would not only reduce the incidence and severity of wind blasts but would also reduce 'weighting' problems such as pillar crushing, rib spall and excessive support yield associated with goaf hang-up.

CHAPTER ONE

INTRODUCTION

In some underground coal mines where the roof comprises strong and massive rock, the roof strata do not cave regularly as extraction progresses but 'hang up', leading to extensive areas of unsupported roof. These areas can collapse, suddenly and often without warning, compressing the air beneath and forcing it out of the goaf through surrounding openings giving rise to a phenomenon known as *wind blast*. The force of the wind can and sometimes does cause injury to mine personnel, disruption to the ventilation system and damage to plant and equipment. It can also increase the hazard of explosion by expelling methane from the goaf and mixing it with raised coal dust.

1.1 BACKGROUND

The impetus to undertake research on wind blast arising from roof falls came about as the result of incidents at the Wallarah Colliery of Coal & Allied Operations Pty Limited, in November 1989, when a deputy was so seriously injured by being thrown against a continuous miner by the force of a wind blast that he will probably never be able to work again, and at the Myuna Colliery of Newcom Collieries Pty Limited (now incorporated into Powercoal Pty Ltd), in February 1990, when eleven miners who had taken shelter, perceiving a fall to be imminent, were knocked to the ground and peppered with coal and debris during a wind blast.

Previous wind blasts resulting in injury or death had been reported from both New South Wales and Queensland, as well as from the United States of America, South Africa and China.

In the case of New South Wales, the last fatal incident had occurred in 1976 at Eastern Main Colliery when a miner had died from massive head injuries caused by his being thrown into the ribside by the force of a wind blast. Subsequently, several other personal injury accidents had been reported as having been occasioned by wind blasts including one at Cooranbong Colliery, in 1983, where eight persons had been injured including an electrician who had received severe facial injuries believed to have been caused by impact with a trickle duster.

Several of the incidents referred to above are described in detail in Project Report No. 1.

It is of particular concern that methane may be expelled from the goaf into the working place as a consequence of wind blast. At Moura No. 4 Mine in Queensland, twelve miners were killed in 1986 in an explosion which was considered to have been preceded by a wind blast. The 1995 explosion at Endeavour Colliery in NSW, described in detail in section 1.6, is also believed to have involved just such an occurrence.

The incidence of wind blasts is likely to increase as a result of the trend away from pillar extraction to longwall mining. Moreover, the risk of personal injury and of damage to the mine infrastructure will become greater owing to the restricted number of openings through which the wind blast can be dissipated and, perhaps, to increased extraction height. Mining under strong, massive roof, such as some sandstones and conglomerates, increases the risk, particularly where longwall face length is restricted because of strata control or subsidence considerations. Face lengths which are less than what is known as 'critical width' often do not cave regularly and are notoriously prone to 'hang up'.

For example, wind blast is already a serious issue for collieries mining the West Borehole Seam under massive channel conglomerates to the north west of Lake Macquarie. It is also likely to pose a problem for those collieries in the south of Lake Macquarie which are proposing to mine the Great Northern Seam under the Teralba Conglomerate by the longwall method.

The initial phase of the Wind Blast Project was funded by a grant under the National Energy Research, Development and Demonstration (NERD&D) Programme, administered by the Department of Primary Industries and Energy, together with financial contributions from each of the three participating coal companies, namely Newcom Collieries Pty Limited and Elcom Collieries Pty Ltd (now amalgamated as Powercoal Pty Ltd) and Coal & Allied Operations Pty Limited.

The project also received the support of the Coal Mining Inspectorate and Engineering Branch of the New South Wales Department of Minerals and Energy (now Mineral Resources) and of the United Mineworkers' Federation of Australia.

The second phase was funded by a grant from the Joint Coal Board Health & Safety Trust while the third phase utilised the resources of The University of New South Wales Department of Mining Engineering, supplemented by additional funding from the Joint Coal Board Health & Safety Trust and from Powercoal Pty Ltd.

During phase one, the overall direction of the project was determined by a steering committee drawn from the coal mining industry and representing the following organisations.

- Capricorn Coal Management Pty Ltd
- Coal & Allied Operations Pty Limited
- Elcom Collieries Pty Ltd & Newcom Collieries Pty Limited
  (now amalgamated as Powercoal Pty Ltd)
- The NSW Coal Mining Inspectorate
- The Queensland Safety in Mines Testing and Research Station
- The United Mineworkers' Federation of Australia
- The UNSW Department of Mining Engineering

1.2 OBJECTIVES

The aim of the Wind Blast Project is to develop a fundamental understanding of the wind blast phenomenon resulting from massive roof failure in underground coal mines and thus provide a basis on which to develop strategies to mitigate the hazard. Individual objectives are to define the fluid mechanics involved in the compression and distribution of air during wind blasts; to optimise mine design and layout in order to minimise the hazards associated with wind blasts; and to minimise the risk of injury to mine workers as a result of wind blasts, by defining and developing safe working practices.

1.3 LIMITATIONS

Wind blast phenomena occur in both coal mines and metalliferous mines but only the former fall within the terms of the present study.

Some of the most severe wind blasts, for example those at Muswellbrook No. 2 Colliery, NSW, and at Coalbrook North Colliery, South Africa, have been associated with violent pillar failure. The occurrence of this type of wind blast would be obviated by addressing the problem of pillar design and lies outside the terms of the present study which is confined to those wind blasts associated with the failure of the roof element alone. Improved pillar design has been addressed as part of the Strata Control for Coal Mine Design Project recently completed at The University of New South Wales.

1.4 PROJECT REPORTS

The first interim report (Project Report No. 1) was issued in April 1994 and covered the first phase of the work, i.e. the period from January 1991 to March 1993. The second interim report (Project Report No. 2), issued in July 1994, covered the second phase, from April 1993 to June 1994. This report, Project Report No. 3, covers the third phase of the study, the period between July 1994 and March 1997.

1.5 THE INTERVIEW PROGRAMME

Visits were made to the following eight collieries, all of which were situated within the Lake Macquarie district of the Newcastle Coalfield, New South Wales (see chapter 3, figures 3.1 & 3.2), mined the Great Northern seam and employed pillar extraction.

1. Awaba
2. Cooranbong
3. Myuna
4. Munmorah
5. Newvale
6. Endeavour (Newvale No. 2)
7. Wyee
8. Wallarah

The visits had the twin objectives of collecting eye-witness accounts of wind blasts (with particular emphasis on how the goaf fell) and identifying those factors which were considered necessary for a wind blast to occur.

Discussions were held with miners, deputies, under-mangers and managers but it was found that there were no observations as to how goafs had fallen as, when the roof was heard to be 'working' and a fall judged to be imminent, the universal tendency was, not surprisingly, to retire to a place of safety. Observations from the edge of the goaf after the roof had fallen had indicated that the conglomerate (the Teralba Conglomerate Member often overlies the Great Northern Coal) had broken into pieces that were often said to be 'as big as this office'.

Many observers reported three apparently distinct phenomena.

1. A feeling of 'pressure' typically evidenced by 'popping' in the ears.
2. A mass movement of air away from the area of the fall which they referred to as a 'wind blast'. This was sometimes, but not always, accompanied by a secondary wind blast.

3. A mass movement of air towards the goaf which they referred to as a 'suck back'.

Also reported was a perceived variation in the intensity of the wind blast phenomenon amongst different roadways leading away from the goaf area.

As the result of the interviews it was possible to identify five factors most of which are considered necessary in order for a significant wind blast to occur.

1. A strong roof, such as massive sandstone or conglomerate, which does not cave readily. (A weak roof such as mudstone does not present a wind blast problem.)
2. Little coal left in the standing goaf in the form of stooks or pillar remnants.
3. An extensive area of roof 'hanging up' (but the intensity of the wind blast does not seem to be directly related to the area).
4. Initial total extraction in a previously unworked area.
5. Few roadways into an area, which seems to concentrate the effect.

The geometry of the goaf area was also considered to be of importance, although opinions differed as to which particular geometrical configurations were of significance.

The possibility remains, however, that there are further factors as yet unidentified.

1.6 CASE HISTORIES

1.6.1 Introduction

Cases of personal injury and physical damage occasioned by wind blast have been reported from Australia, the United States of America, South Africa and China. Some of those which occurred prior to 1994 were reported in detail in Project Report No. 1 while a more recent occurrence is discussed below.

1.6.2 Endeavour (Newvale No. 2) Colliery

A significant wind blast associated with a major goaf fall preceded the explosion which occurred during partial extraction operations in 300 Panel at Endeavour (Newvale No. 2) Colliery on 28 June 1995 (Coal Mining Inspectorate and Engineering Branch 1996; Anderson 1997).

Endeavour Colliery is one of eight underground mines owned and operated by Powercoal Pty Ltd, a wholly owned subsidiary of Pacific Power. It is situated about 100 km north of Sydney, New South Wales, within the Lake Macquarie district of the Newcastle Coalfield (figs 3.1 & 3.2). It currently mines the Great Northern seam and produces a bituminous steaming coal. 300 Panel was situated at the western extremity of the workings adjacent to the Munmorah Colliery lease in an area of predominantly first workings and under a massive conglomerate roof.

Owing to limitations imposed by the overlying Lake Budgewoi and its foreshores, 300 Panel employed partial extraction using the panel and pillar method. A series of 90 metre wide goafs was being developed, separated by 33 by 40 metre abutment pillars.

The extent of the workings in 300 Panel at the time of the incident is shown in figure 1.1. The Panel was bounded on one side by unmined coal, on the second by the main 'buff' headings and flanking barrier pillars, and on the third by the barrier pillar of the adjoining Munmorah Colliery. It was linked to the rest of the workings by a five heading development.

Goaf areas had been formed at the time of the incident in the sequence marked 1 to 6. The immediate roof of zones 1 to 4 is reported as having collapsed but the falls had been noted as 'irregular and shallow'. An area of 30 metres by 100 metres was still standing immediately adjacent to the face within zones 5 & 6.

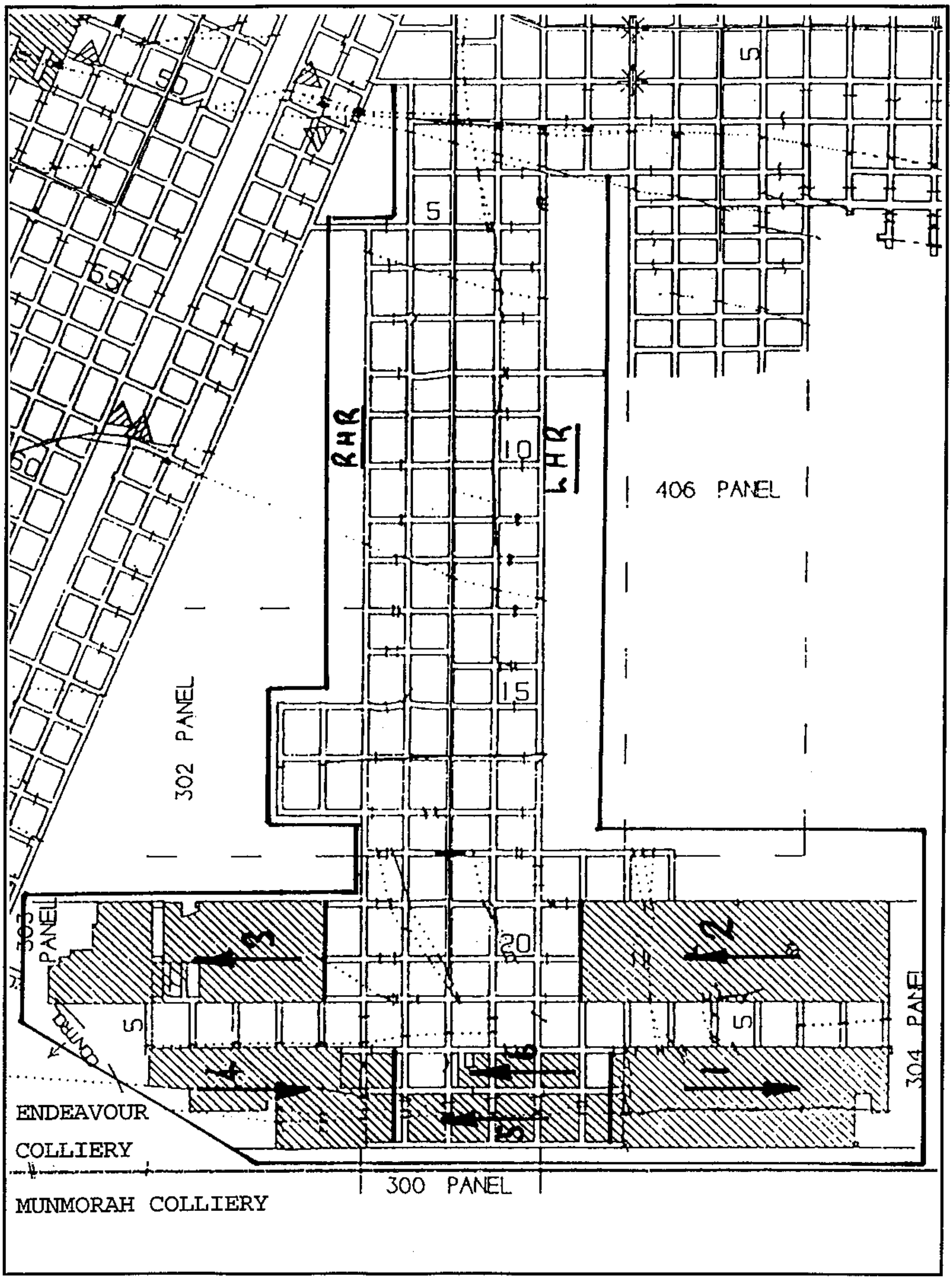


Fig. 1.1 Location plan, significant wind blast and explosion, Endeavour (Newvale No. 2) Colliery (adapted from Coal Mining Inspectorate and Engineering Branch 1996)

A plan of the immediate site of the incident is given in figure 1.2. Mining operations had been temporarily suspended while a minor repair to the continuous miner was underway. Fortunately, no other machinery was running and so there was little background noise.

Four of the eight persons present in the section were in the vicinity of the miner, and all heard noises from the goaf area and judged a large fall to be imminent. One of the crew took shelter behind the miner while three others ran outbye. All three were in the vicinity of the intersection of 22 cut-through and 3 heading when they were knocked to the ground by a wind blast generated by the fall.

Both shuttle car drivers had remained in their seats: one was knocked from his machine while the other was 'peppered' with coal particles and had his helmet blown away. (The cap lamp bracket was reported as being torn off.) The two remaining crew members were further outbye, in 20 cut-through, and were unaffected by the wind blast.

Within seconds of the wind blast an explosion occurred. The intensity of the explosion was reported as being an order of magnitude greater than that of the wind blast. Fortunately, all eight personnel were able to make their way unaided to fresh air and to the panel entry to await help.

From the available evidence it appears that the fuel for the explosion was methane gas expelled from the goaf during the wind blast and that the area of ignition was in 21 cut-through which is one pillar outbye the general goaf line. The most likely source of ignition has been identified as the shuttle car cable.

Damage to 'elements' of the mine itself was restricted to stoppings but was not confined to just 300 Panel and the few roadways leading to its entry. Significant damage also occurred to plasterboard stoppings in 8 West Panel, some 2 km inbye. Unfortunately, it is impossible in this regard to differentiate the effects of the wind blast from those of the explosion.

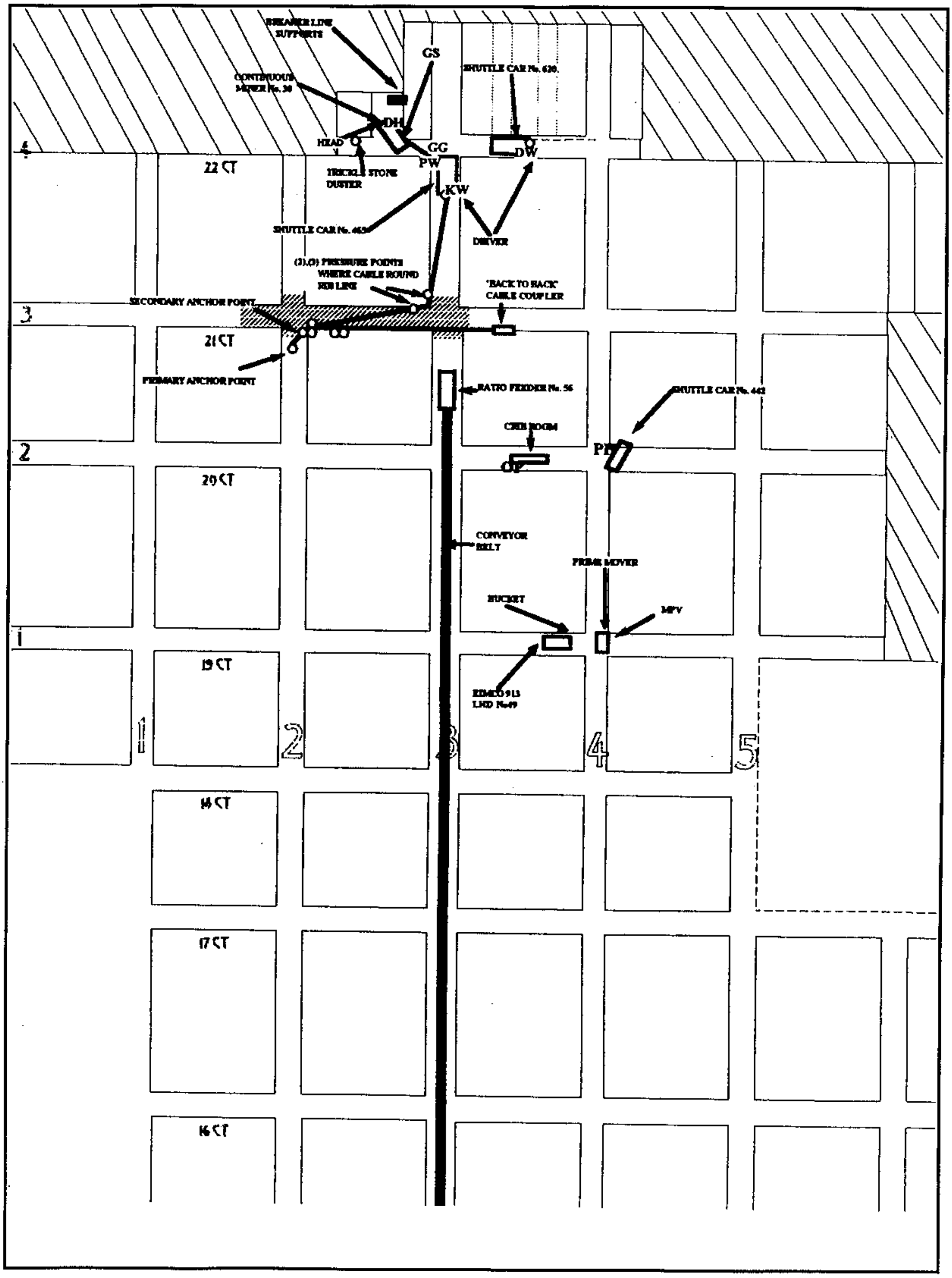


Fig. 1.2 Plan of site of significant wind blast and explosion, Endeavour (Newvale No. 2) Colliery (adapted from Coal Mining Inspectorate and Engineering Branch 1996)

CHAPTER TWO

HARDWARE AND SOFTWARE DEVELOPMENT PROGRAMME

2.1 INTRODUCTION

The hardware and software development programme comprised the following three main elements.

A *Wind Blast Monitoring System* which was developed and deployed to record air overpressures and velocities during wind blasts in openings near to the goaf.

A *Laboratory Wind Blast Model* which was used to help provide insight into the dynamics of the interaction between the roof elements and the air during a roof fall and into the ensuing flow of air through the adjacent openings.

A *Numerical Wind Blast Model*, a computer program with which to numerically simulate the fluid compression and flow arising from a roof fall and which it is hoped will be able to be used to predict the magnitude and intensity of wind blasts.

2.2 THE WIND BLAST MONITORING SYSTEM

The Wind Blast Monitoring System, developed to record air over-pressures and velocities during wind blasts occasioned by massive falls of roof in underground coal mines, was described in detail in Project Report No. 1.

2.3 THE LABORATORY WIND BLAST MODEL

Although the features of the Laboratory Wind Blast Model were outlined in Project Reports Nos. 1 and 2, several modifications have been made to improve its functionality and performance and the latest version is described in detail below.

2.3.1 Base model

The model, at a scale of 1:125, comprises representations of solid coal, pillars and goaf area 'sandwiched' between a 1.5 x 0.75 metre aluminium base plate, which simulates the floor of the seam, and a perspex lid, which simulates its roof. The model represents 12.5 metre square pillars (between rib lines) and 4.75 metre wide by 2.5 metre high headings and cut-throughs. A larger scale might have been desirable in order to reduce the effect on air flow of the presence of intrusive Pitot tubes but physical space requirement and cost considerations precluded it.

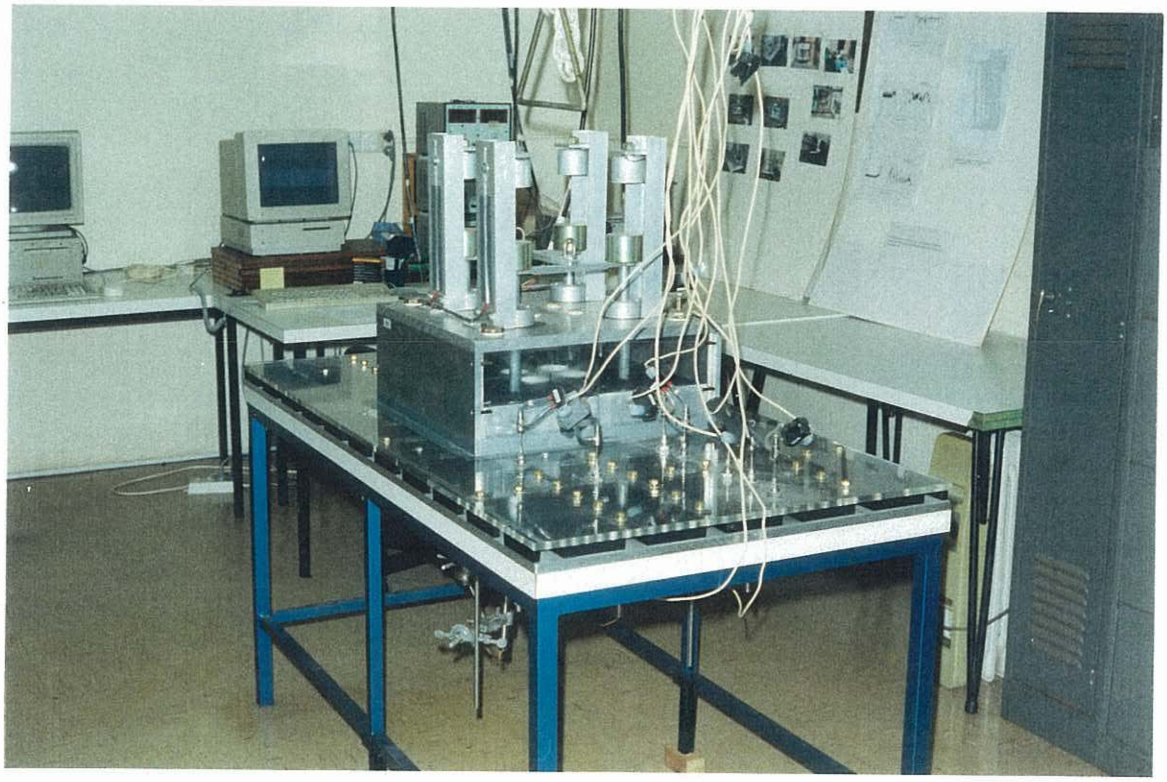


Photo. 2.1 Laboratory Wind Blast Model

Goaf falls are simulated by a group of four square abutting pistons arranged so that they are able to slide vertically within a piston box representing an area 56.5 metres square. The head of each piston is a hollow aluminium box of plan dimensions 226 x 226 mm (representing an area 28.25 metres square). Each piston face plate is provided with a valve which incorporates an occlusion disk containing three pressure relief holes each 12.5 mm in diameter. The holes can be partially or totally occluded from outside the piston box by means of a special tool. The stainless steel piston rods are of circular cross section and pass through sealing rings in holes in the lid of the piston box. Each piston rod is terminated by a cylindrical cadmium-plated mild-steel keeper block. The pistons are each capable of being loaded internally with lead inserts and lead shot ballast and externally with steel weights up to a maximum 'all up' weight of 49.25 kg which is capable of exerting a maximum pressure of 94.6 hPa.

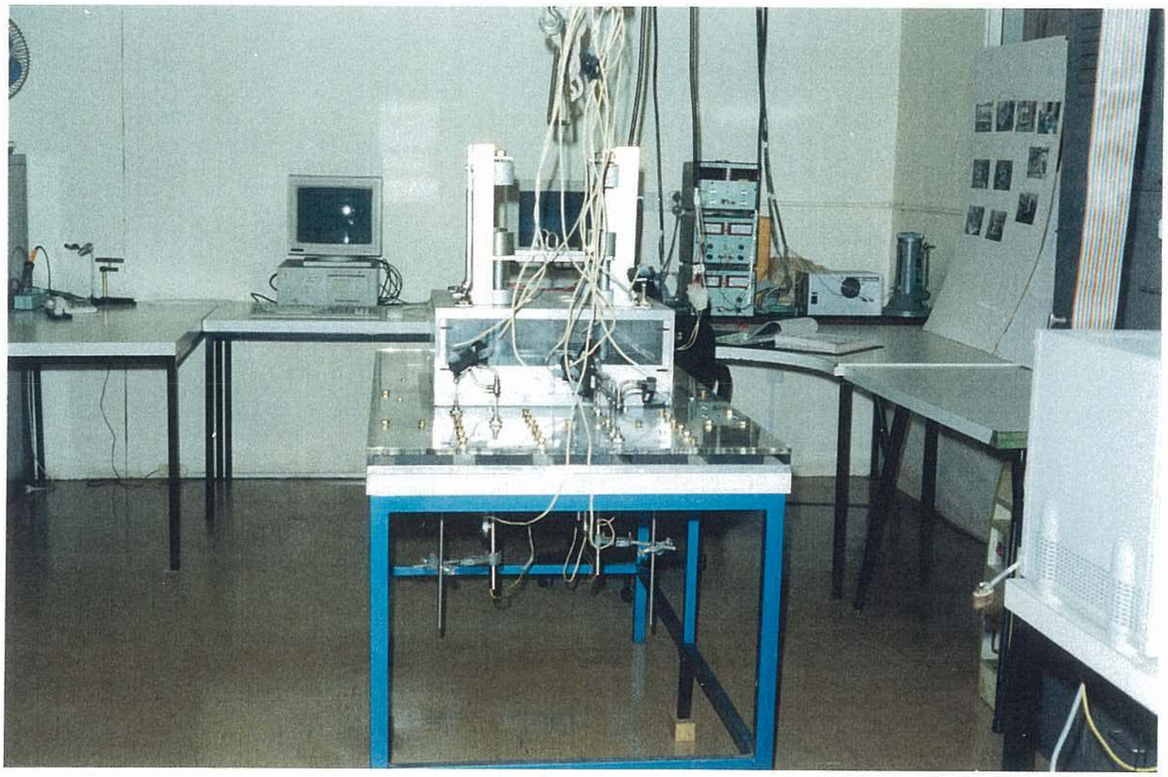


Photo. 2.2 Laboratory Wind Blast Model

Large ports in the lid of the piston box permit the passage of the special tool used to occlude the pressure relief holes, while other ports permit the amount of lead shot ballast in each piston head to be individually adjusted and may also be adapted to act as pressure tappings. The base plate which forms the underside of the box is equipped with four ports which function as pressure tappings and four others through which extension rods can pass in order to transfer the vertical motion of the pistons to displacement transducers or accelerometers. When all the ports are closed, the piston box is hermetically sealed except for rectangular openings which connect with the immediately adjacent model headings and cut-throughs.

The pistons are suspended by their keepers from Serpent and Dove 'Stubby' electromagnets each rated at up to 50 kg force and are released in computer-controlled time sequences. Power to energise the electromagnets at up to 18 V DC is supplied by a Good Will Instrument Co. GPS-1810H regulated DC power supply via a National Instruments SC-2062 signal conditioning board which is equipped with electromechanical relays. Each relay has a set of single-pole contacts. When a digital line to the relay is in the low (0) state, the contact is closed and current in an external circuit may flow through the relay. When the state of the digital line is changed to high (1), the contact opens and current ceases to flow.

Hewlett Packard type 7DCTD-3000 displacement transducers (linear variable differential transformers or LVDTs), with a maximum stroke of 152.4 mm, are mounted below two of the pistons and respond, via extension rods, to changes in the vertical position of the pistons. Power to energise the LVDTs at 6 V DC is supplied by a Good Will Instrument Co. GPS-1810H regulated DC power supply.

Environmental Equipments type AV100 piezoelectric accelerometers, with a maximum peak acceleration level of 50 g, are mounted below two of the pistons and respond, via extension rods, to the vertical acceleration of the pistons. Power to energise the accelerometers at 12 V DC is supplied by a Powermaster 12 V DC precision power supply.

Air pressure changes above the pistons are detected by a Honeywell Micro Switch type 163PC01D48 differential pressure transducer. One port is vented to atmospheric pressure while the other is connected to one of the pressure tappings in the lid of the piston box in order to respond to vacuum gauge pressure. While excited by an 8 V DC supply voltage, the transducer provides a change in output of +4.0 V DC when subjected to a change in gauge pressure from -20 to +120 cm water gauge (-1.96 to +11.77 kPa).

Changes in air pressure below two of the pistons are detected by Honeywell Micro Switch type 163PC01D36 differential pressure transducers. One port of each is vented to atmospheric pressure while the other is connected to one of the pressure tappings in the base plate, which forms the floor of the piston box, in order to respond to gauge pressure. While excited by an 8 V DC supply voltage, the transducers generate a change in output of +5.0 V DC when subjected to a change in gauge pressure from -5.0 to +5.0 inches water gauge (-1.245 to +1.245 kPa).

Power to energise the gauge pressure transducers is supplied by a Good Will Instrument Co. GPS-3000D regulated DC power supply.

Air flow in the model headings is detected by Airflow Developments miniature Pitot tubes. Each of these is fitted with a BSP gland, through which the stem of the tube passes, and with an adapter which may be screwed into holes drilled and tapped into the perspex lid on the centrelines of the model headings. Sliding the stem through the gland enables the position of the head of the Pitot tube to be adjusted in a vertical plane and hence traverse model the heading between 'floor' and 'roof'.

Tubes from the stagnation and static pressure ports of each Pitot tube are connected to the pressure ports of a Honeywell Micro Switch series 160PC differential pressure transducer. The standard transducer, employed in most of the series of tests, was the type 163PC01D75. When excited by a 12 V DC supply voltage, this provides a change in output of +7.5 V DC when subjected to a change in differential pressure from -2.5 to +2.5 inches water gauge (-623 to +623 Pa). When, on occasion, the range of this type of transducer was exceeded, it was replaced by a type with half the sensitivity, the 163PC01D36.

Power to energise the pressure transducers is supplied by the same Powermaster 12 V DC power supply that is used to energise the accelerometers.

2.3.2 Computerised control and data acquisition

Control of the Laboratory Wind Blast Model and acquisition of data is afforded by an Apple Macintosh IIsi computer with a National Instruments NB-MIO-16XL-18 input/output board installed in the NuBus slot. Software comprises National Instruments LabVIEW version 2.2 running under Macintosh System Software version 7.5.5.

The NB-MIO-16XL-18 is a multifunction analogue, digital and timing input/output board. It includes a 16-bit analogue to digital converter, 16 multiplexed inputs, two 12-bit digital to analogue converters, 8 digital input/output lines and three 16-bit counters/timers.

LabVIEW software is based on the concept of the *virtual instrument* or *VI*, a software emulation of test equipment that creates, analyses, and displays data much as physical instruments do. It facilitates data capture and analysis without requiring access to dedicated test equipment. Its programming language, called *G*, is a graphics language where the manipulation of objects replaces the more conventional writing of code. It is used to create applications for data acquisition and management, signal and transient analysis, and process control.

A LabVIEW data acquisition and control VI has been created to release the pistons, which simulate the goaf fall, in controlled time sequences and to acquire the subsequent output from the LVDTs, which respond to the changes in vertical position of the pistons, from the accelerometers, which respond to the acceleration of the pistons, from the gauge pressure transducers, which detect changes in pressure above and below the pistons, and from the differential pressure transducers, which respond to the flow of air in the model roadways. This is done by sending timed signals from the VI, via four of the digital input/output lines on the NB-MIO-16XL-18 board, to change the state of the electromechanical relays on the SC-2062 signal conditioning board and, hence, switch off the current to each of the electromagnets. Just prior to the above, the VI starts to acquire data from the pressure transducers, LVDTs and accelerometers via fifteen of the analogue inputs on the NB-MIO-16XL-18 board and its analogue to digital converter.

The data acquisition and control VI subsequently displays on the computer screen the changing values, over an eight second period, of binary output corresponding to vertical displacement for two pistons, acceleration for two pistons and to differential pressure at each of the eight Pitot tubes and the three gauge pressure transducers, and saves the raw binary output data to disk.

A suite of VIs has also been created to manipulate and display the binary data facilitating the study of the detailed histories of piston displacement & acceleration and air pressure & velocity in both the time and frequency domains.

2.4 THE NUMERICAL WIND BLAST MODEL

There is need for a numerical model capable of predicting air velocities and overpressures in roadways, resulting from the collapse of a given area of goaf. The intention is that the development process will result in a computer program which is sufficiently 'user-friendly' for routine use by mine personnel, and which can be run on a moderate sized computer system.

In the analysis under development, account is being taken of the dimensions of the goaf, the mine layout in the vicinity of the goaf and the mechanics of roof collapse.

Account is also being taken of the inertia and viscosity of the air which is expelled from the goaf. In view of the brief duration of a wind blast, pressure changes are taken to be adiabatic. In addition, air is taken to be an ideal gas. The falling roof is modelled as a leaky piston and the user of the software must specify a roof fall mass per unit plan area, and a parameter defining the extent to which air leaks through the roof as it falls. It is expected that whereas *a priori* estimates of the roof mass may be possible, values of the leakage parameter (which depends upon the degree to which the roof breaks up as it falls) will have to be determined by the correlation of numerical predictions with field data.

In mathematical terms, the problem amounts to the solution of the transient Navier-Stokes equations for compressible flow, in conjunction with a conservation of mass condition, which simply states that there are no sources or sinks within the air mass, and Newton's second law of motion for the falling roof. Once account is taken of the assumption of an ideal gas under adiabatic conditions, the unknown functions of position and time to be computed reduce to the air velocity vector, air density, roof height above the floor of the goaf, roof fall velocity, and density of the air in the void above the falling roof. No matter what numerical method is employed, a full three dimensional solution would be possible only on a supercomputer. The analysis under development is, therefore, necessarily two dimensional in plan, it being supposed that air velocity and density depend upon time and plan position only. This is reasonable, provided mining height is small compared with plan dimensions of the goaf and roadways. That condition is easily satisfied in the goaf but less well so in roadways.

The available methods of analysis, for an arbitrary mine layout, are the finite difference method and the finite element method. The Navier-Stokes equations are remarkably similar to the governing differential equations of elasticity, and there already exist within The University of New South Wales Department of Mining Engineering finite element programs for elastic analysis and considerable experience in the development of such programs. It was therefore decided to use a finite element approximation to the spatial variation for the unknown functions referred to above. In the procedure under development, time is divided into a large number of small steps. The basic operation consists of computing what is happening at the end of a time step from the situation at the beginning, starting of course with the first time step at the beginning of which all velocities are zero and pressure is atmospheric pressure.

The role of the finite element analysis carried out at each time step is to take account of the spatial interdependence of air velocities. This spatial interdependence is the result of inertial and viscous effects.

The peculiar difficulty of the time stepping procedure is that the values of the unknown functions at the end of a time step depend not only upon the known values at the beginning but also upon themselves. Any method of computation must be iterative. At each iteration, the values of the unknown functions are recomputed from their previously computed values and from the known values at the beginning of the time step. For the first iteration, an arbitrary choice of the values of the unknown functions at the end of the time step must be made. For each time step, the iteration is continued until successive changes in the computed values of the unknown functions are negligible, and the iteration is then said to have converged. It is of course essential to success of the time stepping procedure that convergence is achieved at every time step.

In a first version of the computer program the Crank-Nicholson iterative procedure was used. This procedure has proved successful in time stepping solutions of elastoviscoplasticity, but for compressible flow it did not converge. Extensive testing and a further literature survey revealed that this was the consequence not of an error of programming but of a fundamental characteristic of the equations of gas flow, whether compressible or incompressible.

A second version of the program, based on the Peaceman-Rachford operator splitting technique, has now been developed and has been shown to model adequately a simple geometry. Further evaluation remains to be carried out including, in particular, the leaky piston model of the falling roof in a realistic panel geometry.

The program in its present form takes too long to run for reasonably accurate analysis of realistic panel geometries to be carried out, because the finite element meshes have to be finer than had been envisaged at the outset. Although the rate at which computers are being made to run faster is impressive, it is not such that hardware improvements can be relied upon to solve the problem of long run times within a reasonable time frame. There is considerable cope for improvement of the analysis upon which the numerical model is based. Insight is being gained by further study of weighted residual and finite element methods applied to fluid flow, and it is likely that the existing program can be improved sufficiently for realistic analyses to be carried out on a PC with Pentium central processor. Since Project Report No. 2, about 40 working days have been spent on improvement and testing of the program. The further improvements advocated above are likely to require another 90 days of specialised personnel time, whereas the 30 to 60 days of work required to develop user friendly graphical input and output could be done by personnel experience in software development but not necessarily conversant with the theory of finite elements.

Upon its completion the Numerical Wind Blast Model will be employed to simulate complex roof falls and help provide insight into the dynamics of the interaction between the roof elements and the air during a roof fall with the objective of confirming or modifying the findings resulting from the operation of the Laboratory Wind Blast Model.

It will then be used to compare different detailed panel layouts by computing the distribution of air overpressures and velocities in the roadways and cut-throughs.

CHAPTER THREE

FIELD MONITORING

3.1 INTRODUCTION

Subsequent to the successful demonstration of the Wind Blast Monitoring Equipment at Wallarah and Cooranbong Collieries in NSW (Project Report No. 1), where it captured and recorded small wind blasts arising from roof falls (although these events were not generally of an intensity to be classified as *significant* [sec. 5.3.1]), it was deployed at Oaky Creek Mine in Queensland and Wyee Colliery in NSW. Neither site, however, afforded a wind blast (Project Report No. 2).

On 8 August 1995, however, a significant wind blast occurred at Newstan Colliery during the mining of longwall panel no. 6 (LW 6). During this event, three persons were knocked over and injured, stoppings were blown down and an overcast was damaged. As a result of this incident, a decision was taken to deploy the Wind Blast Monitoring Equipment in LW 6 and the monitoring programme was subsequently extended to include the next three longwall panels (LW 7 to LW 9).

Newstan Colliery is situated within the Lake Macquarie district of the Newcastle Coalfield (figs 3.1 & 3.2) and currently mines the Young Wallsend / West Borehole seams. Production began over 100 years ago and the Great Northern, Fassifern & Borehole seams have all been worked in addition to the above. Continuous miners have been employed for both development and pillar extraction since 1963, and longwall mining was introduced into the Fassifern seam in 1984 and into the Young Wallsend / West Borehole seams in 1990. The four longwall panels (LW 6 to LW 9), where wind blast monitoring has been undertaken and which are the subject of this report, are situated in the West Borehole seam towards the south-western side of the workings (fig. 3.3) with the panel centrelines orientated approximately south-east.

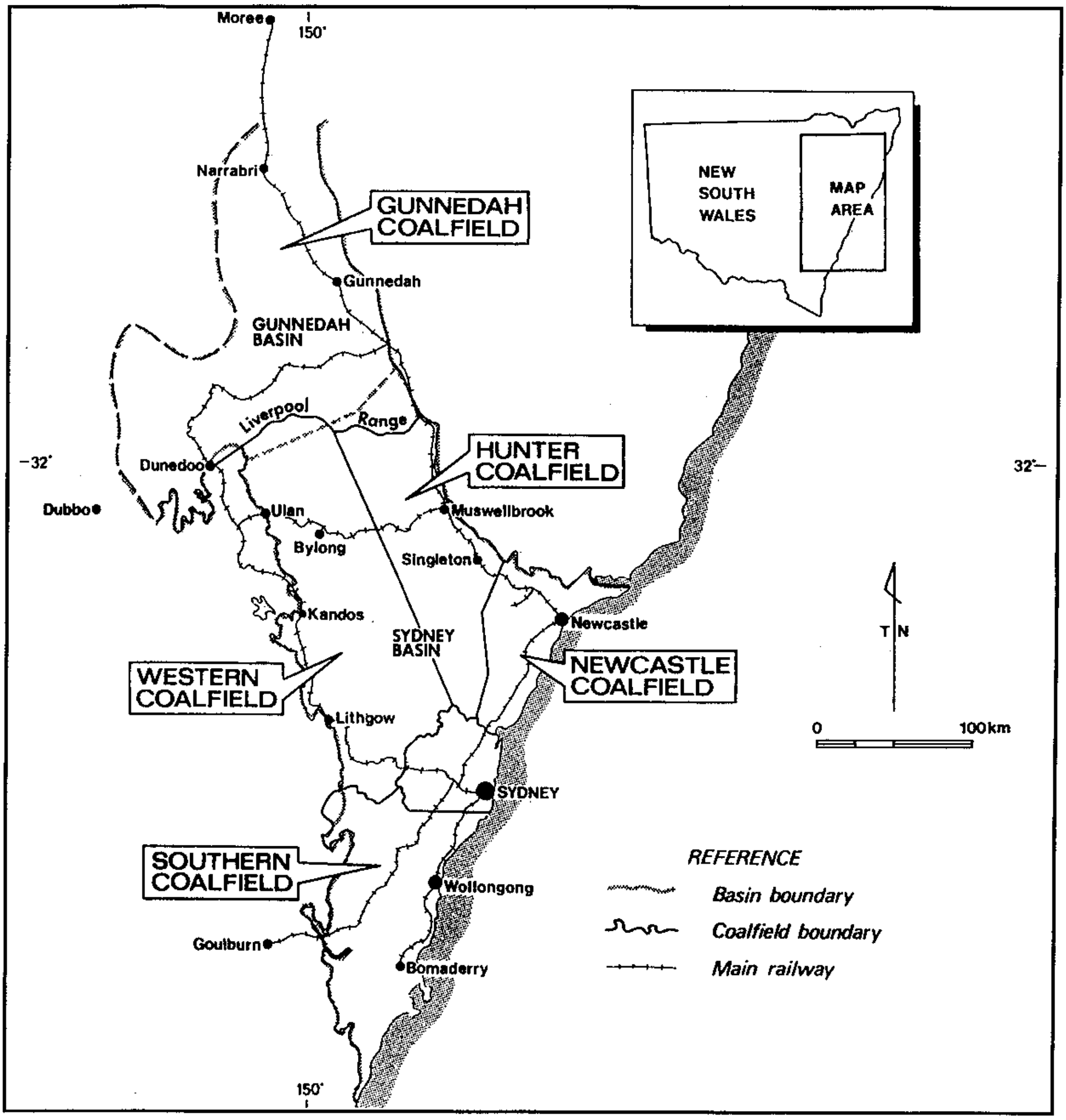


Fig. 3.1 Boundaries of the coalfields within the Sydney and Gunnedah Basins (adapted from Standing Committee on Coalfield Geology of New South Wales 1986)

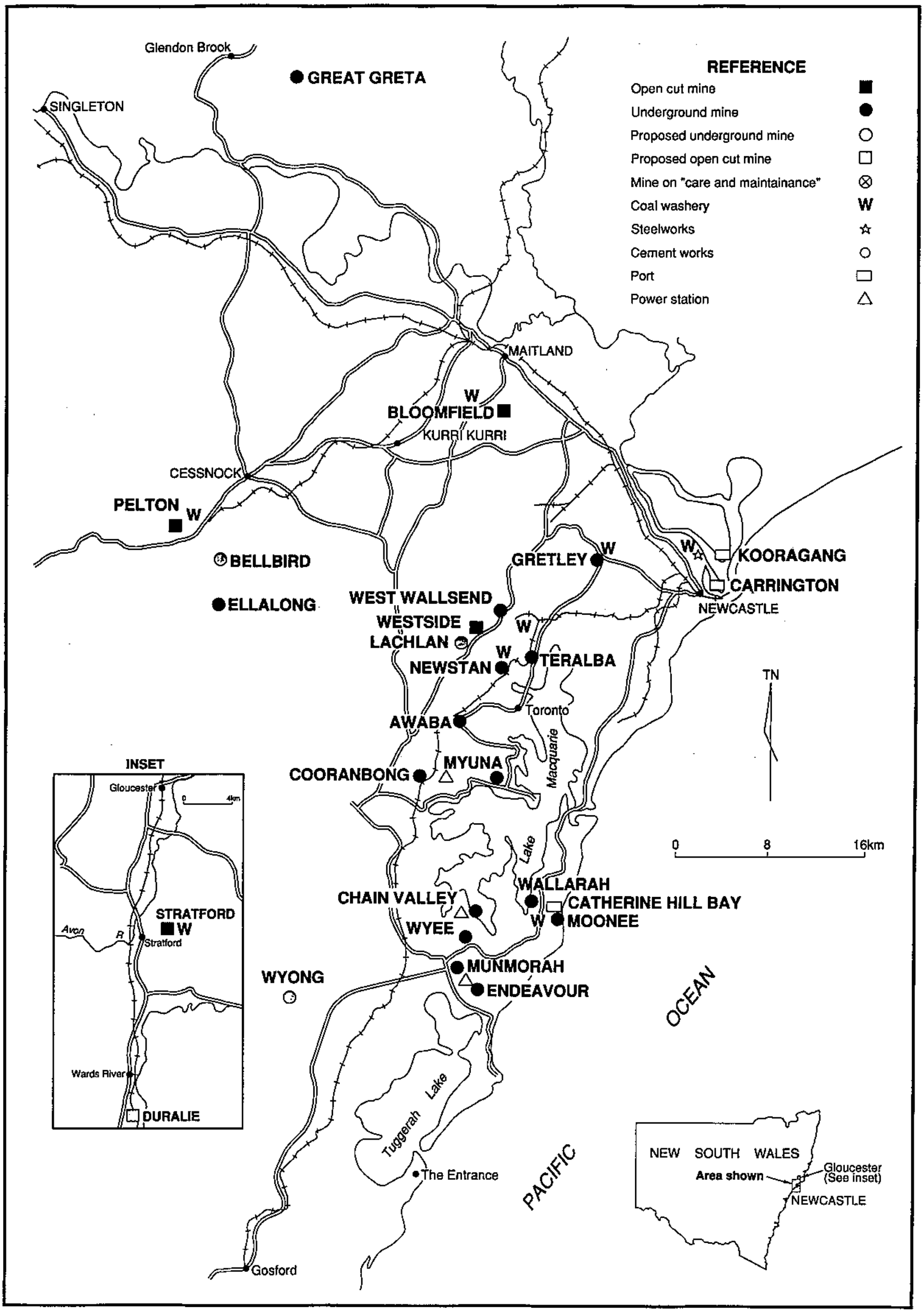


Fig. 3.2 The Newcastle Coalfield, New South Wales
(adapted from Armstrong & Mische 1997)

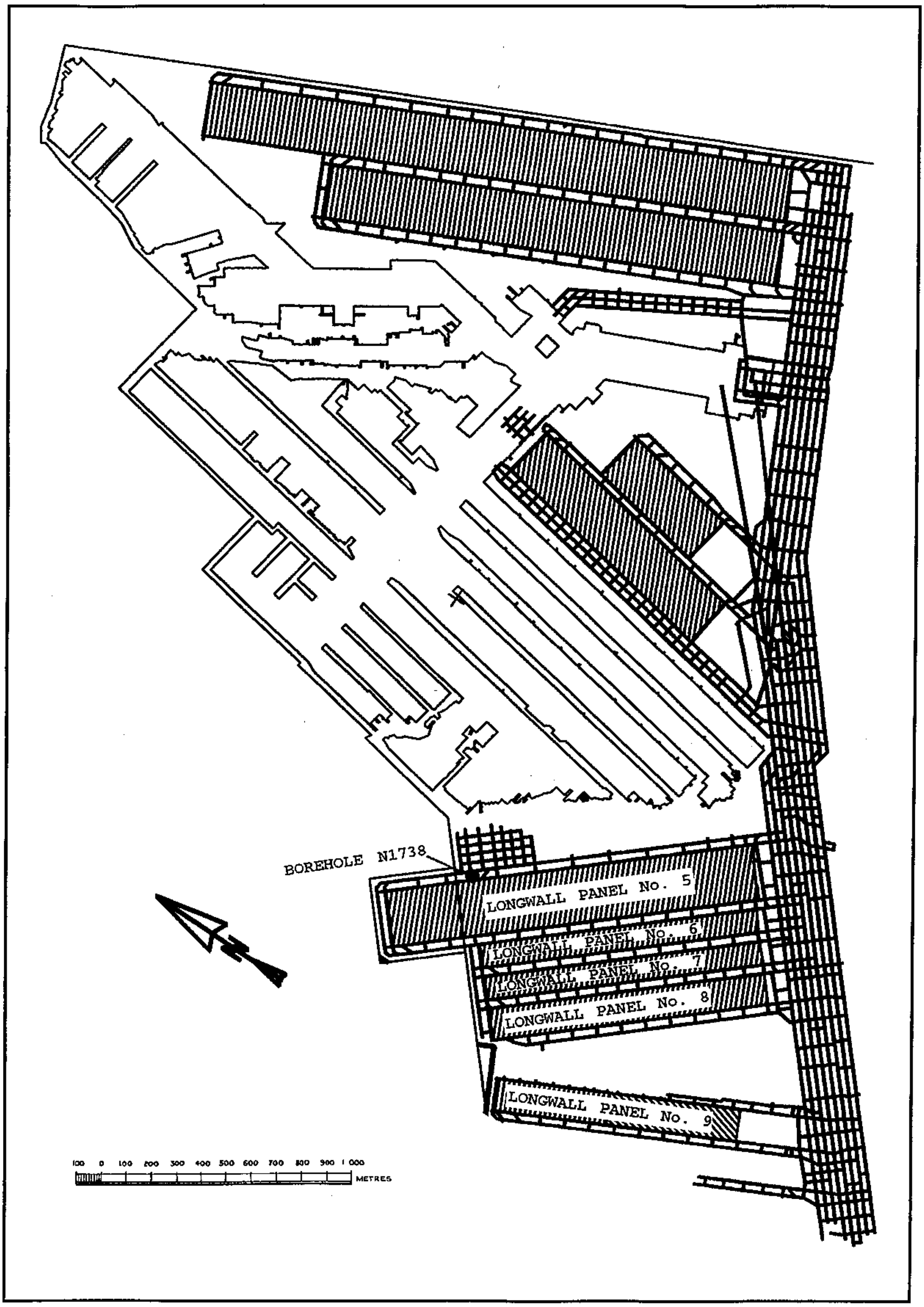


Fig. 3.3 Extent of workings in the Borehole, Young Wallsend and West Borehole seams at Newstan Colliery

3.2 GEOLOGICAL AND TECTONIC SETTING

3.2.1 Regional geology

The geological setting of the Newcastle Coalfield is presented in detail in Project Report No. 1 but a brief description of the Young Wallsend / West Borehole coals, which are mined by Newstan Colliery, amongst others, and of the overlying strata is given below.

A generalised stratigraphic sequence of the basal sub-group of the Newcastle Coal Measures, the Lambton, together with the immediately overlying Kotara Formation of the Adamstown Sub-Group, is given in figure 3.4. The constituent components comprise coal, conglomerate, sandstone, shale and rocks of pyroclastic origin which are of variable grain size up to coarse sand and are termed 'tuff'.

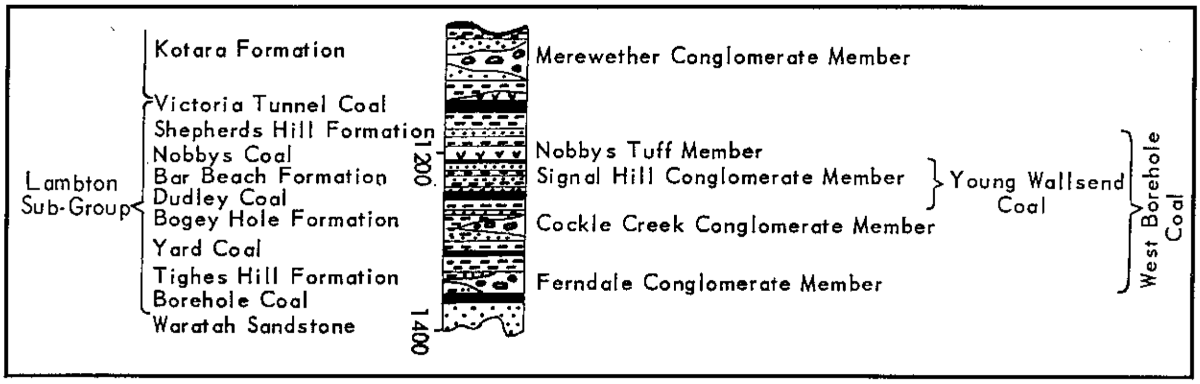


Fig. 3.4 Generalised stratigraphic sequence, Lambton Sub-Group and overlying Kotara Formation, Newcastle Coal Measures (adapted from Standing Committee on Coalfield Geology of New South Wales 1974)

The West Borehole coal splits within the Newstan Colliery holding into the Young Wallsend, Yard and Borehole coals (fig. 3.5). The split will be seen to be one of a set believed to have been caused by tectonically induced differential settlement on the flank of the Lochinvar Anticline (Warbrooke & Roach 1986). The latter is located on an old basement high and forms the western limit of the Newcastle Coalfield (Project Report No. 1).

A section through the coalesced West Borehole coal together with the overlying stratigraphic sequence at borehole N1738 (fig. 3.3) is given in figure 3.6.

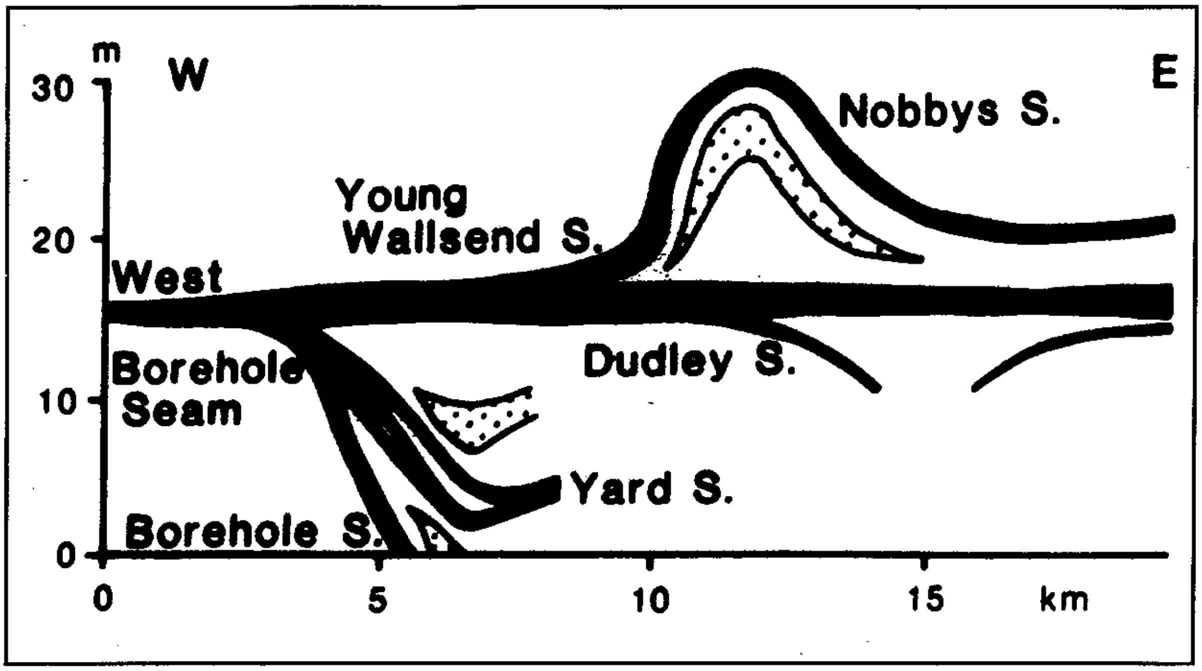


Fig. 3.5 Section through the Young Wallsend / West Borehole coals passing near to Newstan Colliery (after Warbrooke & Roach 1986)

The Young Wallsend / West Borehole coals retain the individual physical characteristics of their constituent coal seams and comprise high-volatile bituminous coal with medium to high ash and low sulphur contents. They contain minor, occasional shale or tonstein bands up to 150 millimetres in thickness, and some deterioration in coal quality occurs in those 'plies' which comprise the uppermost elements of the constituent coal seams. The maximum thickness of the West Borehole Coal within the Newstan Colliery holding occurs at the line of convergence and is approximately six metres. The extracted seam height during the mining of the project panels was either 4.3 or 3.3 metres.

Immediately overlying the Young Wallsend / West Borehole coals is the Shepherds Hill Formation, the basal member of which is the Nobbys Tuff. The latter, readily identified by its micaceous basal section, is the most persistent marker horizon throughout the Newcastle Coalfield. The Nobby's Tuff Member is generally overlain by the unnamed sandstones and shales which constitute the remainder of the Shepherds Hill Formation.

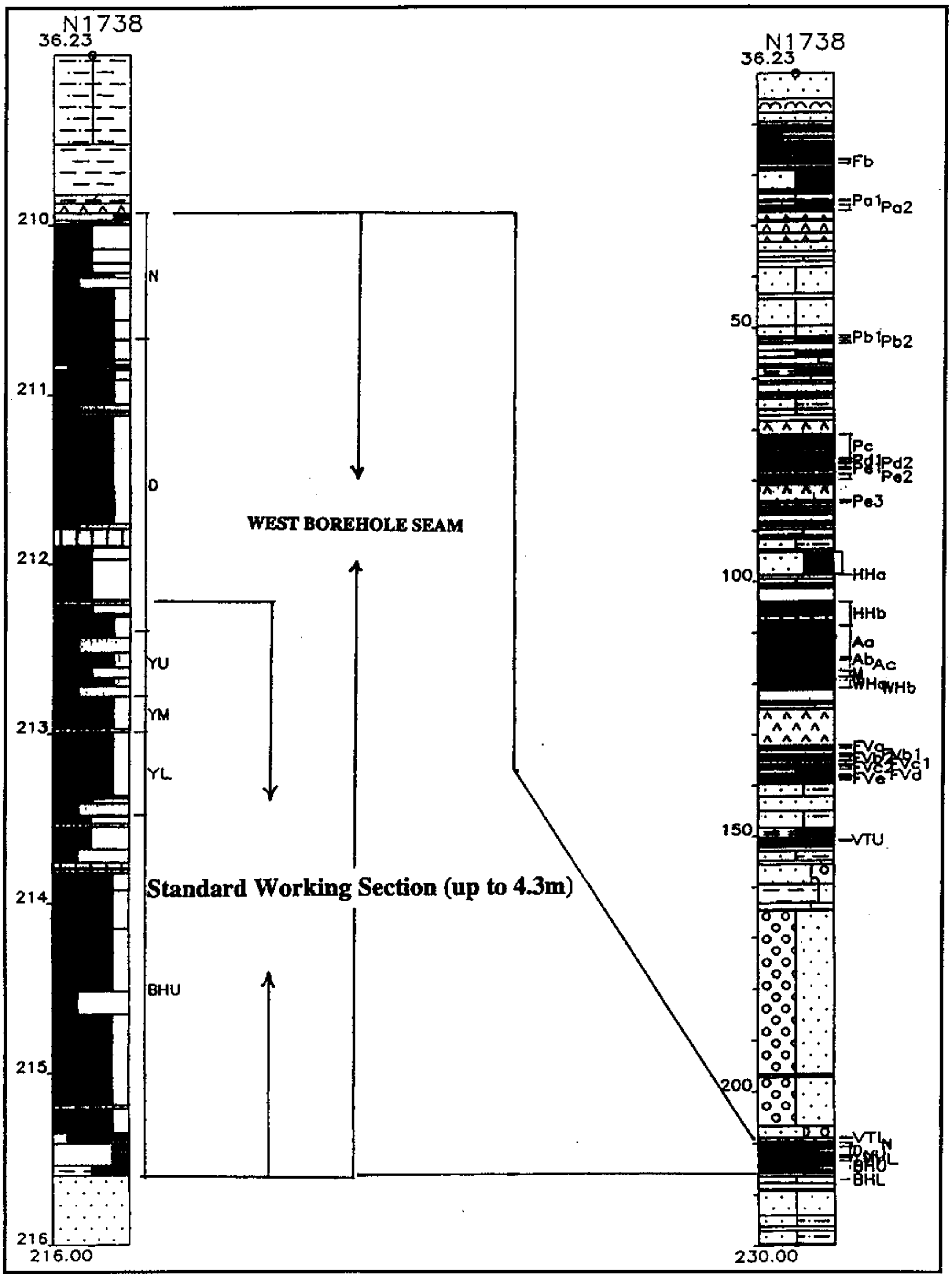


Fig. 3.6 Standard working section, West Borehole Coal, and stratigraphic sequence, Newstan Colliery (after Creech 1996)

In the generalised stratigraphic sequence, the Shepherds Hill Formation is immediately overlain by the Victoria Tunnel Coal, the roof of which forms the upper limit of the Lambton Sub-Group (fig. 3.4). However, the Victoria Tunnel Coal deteriorates to the west and is difficult to identify on the western side of Lake Macquarie.

Overlying the Lampton Sub-Group is the Adamstowm Sub-Group at the base of which is the Kotara Formation. Considerable variation in the lithology of the latter is evident from borehole logs but the Merewether Conglomerate Member is particularly well developed and forms the basal member in an area to the north-west of Lake Macquarie which includes part of the Newstan Colliery holding. The main body of the Merewether Conglomerate exhibits a wide variation in particle size ranging from pebbly gravel to silt. Large cross-beds alternate with massive conglomerate sheets in combinations which are up to 50 metres in thickness. The various particle sizes are concentrated in thin, discontinuous lenses with abrupt transitions. Both clast-supported and matrix-supported beds occur. The latter are thicker and contain the largest pebbles, up to 60 mm in diameter.

3.2.2 Regional stress field

Several earthquakes which have occurred beneath the Sydney Basin have generated sufficient seismological data for *focal mechanism* studies to be carried out and these are described in Project Report No. 1, together with details of *in-situ* absolute stress determinations carried out at several collieries within the Lake Macquarie district of the Newcastle Coalfield.

While neither the seismological evidence nor that from direct stress measurements yield an unequivocal direction for the regional stress field within the Newcastle Coal Measures, the similarities in the computed directions of major principal stress are striking, and all the more so because there is no reason to suppose that the stress field in the basement rocks at depths greater than 10 kilometres is related to that in the Newcastle Coal Measures at depths of less than 200 metres.

It is, therefore, assumed, as a working hypothesis, that the stress field is homogeneous and that the major secondary principal stress in the horizontal plane acts in a direction between north and north-east over the Lake Macquarie district of the Newcastle Coalfield.

3.2.3 Geology of the project panels at Newstan Colliery

The extent of the workings of Newstan Colliery at the time of the wind blast investigations is indicated in figure 3.3 which also indicates the location of the project panels.

Over much of the area of the project panels the Nobbys Tuff Member (sec. 3.2.1) forms the immediate roof to the Young Wallsend / West Borehole coals. In some localities, however, the Victoria Tunnel Coal (and, perhaps, other elements of the Shepherds Hill Formation) appears to be absent (washed out?) with the result that the main roof comprises the Merewether Conglomerate Member. This has been intersected in up-holes drilled alongside all of the project panels and shown to be up to 45 metres thick and to include massive conglomerate lenses which vary in thickness from 0 to 25 metres. The distance from the West Borehole Coal to the overlying Merewether Conglomerate Member varies across the project panels from 3 to 15 metres. A longitudinal section through the set of up-holes drilled from alternate cut-throughs on the maingate side of LW 7 is shown in figure 3.7.

Within the project panels, a set of closed, widely spaced roof joints trends in a north-north-westerly direction, subparallel to the predominant cleat. Faulting is commonly of a normal type with subvertical fault planes and vertical displacements of less than 0.75 metres although, just outside the project panels, a throw of 7 metres has been recorded. Most faults strike approximately north-north-west. Dolerite dykes are subvertical to vertical and usually strike in a similar direction to that of the faults.

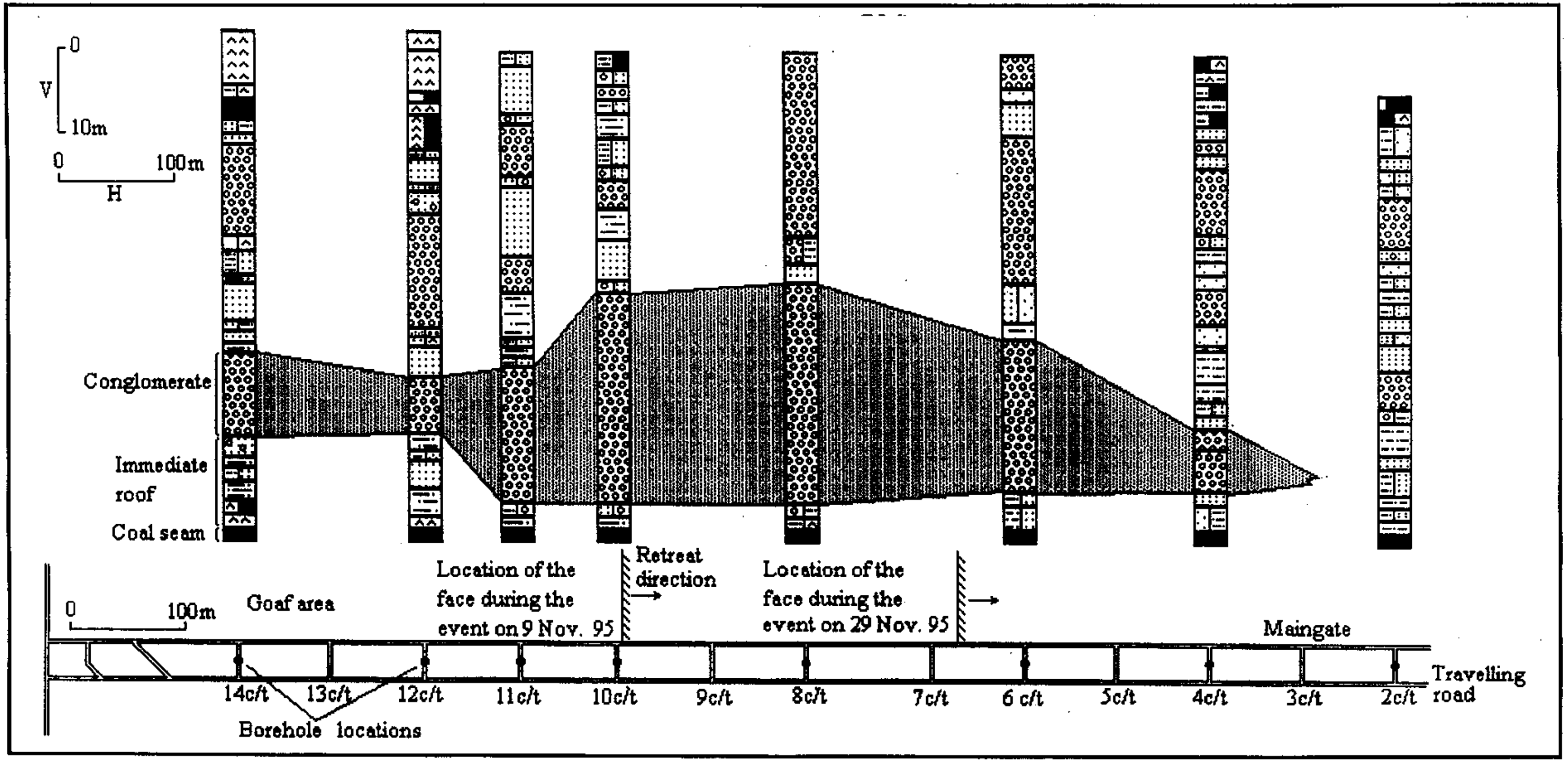


Fig. 3.7 Longitudinal section through the roof strata of maingate 7 at Newstan Colliery

3.2.4 The stress field at Newstan Colliery

Measurements of absolute in situ stress have been carried out at the nearby West Wallsend No. 2 Colliery (Project Report No. 1). They indicate a northerly direction for the major secondary principal stress in the horizontal plane which is not inconsistent with the seismological evidence (sec. 3.2.2).

3.3 WIND BLAST MONITORING

3.3.1 Location of instrumentation

The configuration of the project panels and nearby workings at the time of installation in LW 9 of the Wind Blast Monitoring Equipment is shown in figure 3.8.

The project panels at Newstan Colliery (LW 6 to LW 9, fig. 3.3) were all 'total extraction' panels and employed the longwall system of mining. The longwall blocks were generally bounded on both sides by pairs of development headings, an exception being LW 9 which employed a single entry tailgate. Panel widths, between gateroad centrelines, were 96 metres for LW 6 and LW 7 and 128 metres for LW 8 and LW 9 while chain pillar width was 38 metres (between centrelines). The depth of overburden varied across the project panels from 150 to 200 metres and, consequently, the ratio of the widths of the longwall blocks to depth ranged between 0.5:1.0 and 0.8:1.0.

From figures 3.3 and 3.8 it will be seen that there were several openings through which air overpressure induced by a massive goaf fall might be relieved. As it was impracticable to monitor all of these openings, a decision was taken to concentrate the wind blast monitoring instrumentation in one area relative to the face. In addition, it was decided to forgo the opportunities to measure wind blast intensity within the area of the longwall face or in the tailgate as this would have necessitated running cables through the area of the face-ends, locations where maintaining cables had proved difficult during previous monitoring at other sites.

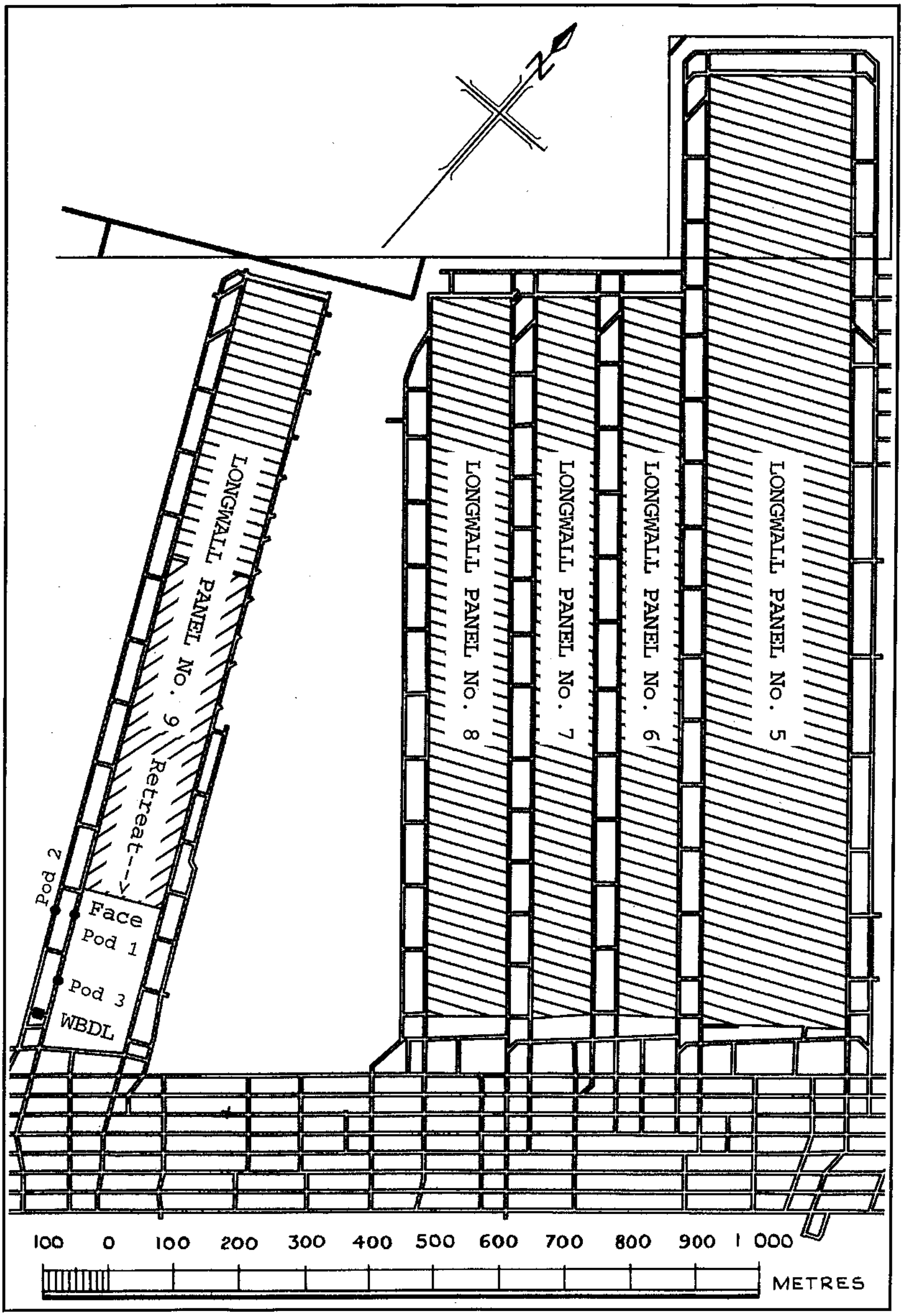


Fig. 3.8 Project panels and nearby workings, Newstan Colliery

It was considered important, however, to position transducer pods as close as practicable to the working face in order to be able to measure the overpressure and velocity of the potential wind blast events in the near field, i.e. before they were much attenuated with distance. In addition, in order to measure the attenuation with distance and the *celerity*, or rate of propagation, of the potential events, it was necessary to place a transducer pod as far outbye as possible. It was also thought desirable to obtain a comparison of wind blast velocities and overpressures between headings.

In view of the above, monitoring locations were selected in the maingate and companion roadway (travelling road) and a typical installation is that indicated in figure 3.8. For convenience, the Wind Blast Data Logger was positioned in a cut-through immediately adjacent to the longwall transformers which provided its external power source.

Owing of the rapid rate of retreat of the longwall faces it was considered impracticable to mount the maingate pods at fixed locations as had been the previous practice (Project Report No. 1). An alternative arrangement was devised whereby they were mounted on elements of the longwall equipment and, consequently, moved outbye as the longwall face retreated. Pod no. 1 was located on the 'pantec' while pod no. 3 was positioned 116 metres further outbye on the 'turning circle'.

The disadvantages of this arrangement were the necessity to 'reel in' the cables between the transducer pods and the Wind Blast Data Logger as the face retreated, the possibility of the pods being affected by zones of water ingress and the need to traverse intersections which might induce additional turbulence during a wind blast.

The location in the maingate companion (travelling road) for pod no. 2 was chosen so that during the retreat it remained at a distance from the extended face line which lay between those of pod no. 1 and pod no. 3. In practice, the precise location in the travelling road was selected to be away from intersections and near the mid-pillar position, but adjusted so as to avoid areas of poor roof or rib or of water ingress.

3.3.2 Installation

The Wind Blast Monitoring Equipment was installed by the Authors with the assistance of Newstan Colliery personnel. It was considered desirable to rigidly mount the transducer pods as close to the centroid of the roadways as possible but, in order to effect this, differing arrangements had to be made in the maingate and travelling road.

For the former, four-leg towers were fabricated and securely bolted to the pantec and turning circle. Provision was made for adjusting the height and the altitude and azimuth of the transducer pod so as to align its major axis with that of the roadway. In practice, the positions of the transducer pods had to be offset laterally from the roadway centroid in order to accommodate the belt structure and vertically upwards to avoid turbulence occasioned by the bulky maingate equipment.

For the latter roadway, an inverted tripod, similar to those previously employed (Project Report No. 1), was fabricated and secured to the roof with a single central roof bolt, adjustable length legs allowing for roof irregularities. Provision was again made for aligning the transducer pod with the roadway. An offset of two metres towards the rib and 0.5 metre vertically upwards was necessary to maintain safe vehicular passage.

In order to control mining, an orthogonal system of setting-out lines had been established by the Colliery surveying department on the theoretical centrelines of headings and cut-throughs, and intersections of the setting-out lines had been marked by semipermanent survey pins in the roof. In addition, 'chainage markers' denoting the distance from the face start line had been set out on the chain pillar ribs in the maingate.

After the transducer pods had been installed, the distances from the extended face line to the maingate locations were measured with a steel tape. In order to facilitate the determination of the 'face distance' of the transducer pod in the travelling road, the orthogonal distances from the pod to the nearest survey pin was also measured.

3.3.3 Wind blast monitoring - LW 6

The Wind Blast Monitoring Equipment installed in panel LW 6 at Newstan Colliery was powered up on 2 September 1995. To maximise the probability that all of the events associated with a wind blast would be recorded but that events associated with other environmental factors, such as variations in ventilation air flow, would not, the operating mode and trigger levels (Project Report No. 1) were set as follows.

1. Operating mode: roll-over
2. Velocity trigger level (all pods): 9 metres per second
3. Pressure trigger level (all pods): 1095 mB
4. Delay time (all pods): 100 milliseconds
5. Pressure integration time: 1 minute

The standardised procedure (Project Report No. 1) developed for downloading data from the Wind Blast Data Logger to the Hand Held Interface at Wallarah Colliery was used again at Newstan Colliery. The task of downloading data was carried out by the Authors and, on each occasion, data was downloaded when up to ten events had been recorded.

Statutory safety inspections were carried out in accordance with the prescribed schedules by Newstan Colliery personnel.

On 9 September 1995 those items of longwall equipment that did not retreat with the face were moved two pillar lengths outbye. Included in the move were the longwall transformers and, of necessity, the Wind Blast Data Logger. Pod no. 3 was also moved to a new location in the travelling road two pillar lengths outbye.

It proved impracticable to maintain the Wind Blast Monitoring Equipment in LW 6 after 18 September 1995 as the longwall was nearing the face finish line and modified procedures for 'retreating' the equipment had been implemented. These included the removal of the turning circle and the relocation of the transformers further outbye. Consequently, the equipment was withdrawn and the transducer pods returned to the laboratory for recalibration.

3.3.4 Wind blast monitoring - LW 7

The Wind Blast Monitoring Equipment was operated in LW 7 at Newstan Colliery between 1 November and 14 December 1995. The locations of the Wind Blast Data Logger and of the transducer pods relative to the longwall face were as described in section 3.3.1.

The operating mode and trigger levels were revised as follows.

1. Operating mode: fixed
2. Velocity trigger level (all pods): 5 metres per second
3. Pressure trigger level (all pods): 1095 mB
4. Delay time (all pods): 100 milliseconds
5. Pressure integration time: 1 minute

The reduction in the velocity trigger level compared with that for LW 6 (5 cf. 9 metres per second) was implemented in order to increase the probability of detecting small events. The reduction was made in conjunction with a change in operating mode from 'roll-over' to 'fixed' in order to obviate the possibility of significant wind blast records being overwritten by subsequent small events.

3.3.5 Wind blast monitoring - LW 8

The Wind Blast Monitoring Equipment was deployed in LW 8 at Newstan Colliery between 27 February and 30 June 1996. The locations of the Wind Blast Data Logger and of the transducer pods relative to the longwall face were again as described above.

The operating mode and trigger levels were initially set as follows.

1. Operating mode: fixed
2. Velocity trigger level (all pods): 7 metres per second
3. Pressure trigger level (all pods): 1095 mB
4. Delay time (all pods): 100 milliseconds
5. Pressure integration time: 1 minute

The increase in velocity trigger level from 5 to 7 metres per second was made in order to reduce the possibility of triggering by spurious events.

However, pod no. 1 on the pantec continued to be a source of spurious triggering owing to cable handling problems and, consequently, on 13 March the triggering function was discontinued for pod no. 1 but maintained for the other two pods. On 29 March the velocity trigger level for pods nos 2 & 3 was reduced to 4 metres per second in order to increase the probability of detecting small but real events.

3.3.6 Wind blast monitoring - LW 9

The Wind Blast Monitoring Equipment was operated in LW 9 at Newstan Colliery between 30 December 1996 and 15 March 1997. In order to obviate the cable problems which had affected previous installations at Newstan Colliery, all the cables and connectors were replaced. The type of connector was also changed: Ausdac replacing the Davies of Derby / Bramco.

The locations of the Wind Blast Data Logger and of the transducer pods relative to the longwall face were as described previously. The operating mode and trigger levels adopted were the same as the initial values used for LW 7.

It was considered appropriate to continue monitoring after the completion of the mining of LW 9 and, consequently, the pods which had been mounted on the turning circle and pantec were relocated upon the withdrawal of these items. They were attached to the roof of the maingate using inverted tripods similar to that employed in the travelling road (sec. 3.3.2).

3.4 ANALYSIS OF FIELD DATA

Data which had been downloaded to the Hand Held Interface was transcribed on to floppy disks using the hardware and software described in Project Report No. 1. After each data file had been 'cleaned up' and reformatted it was displayed (and printed, if required) in tabular mode. Files which were obviously not the result of spurious triggering were then further processed and graphical output produced as previously described (Project Report No. 1).

3.5 RESULTS OF FIELD MONITORING

A schedule of wind blasts recorded at Wallarah, Cooranbong and Newstan collieries between 1992 and 1997, a total of 32 events, is given in table 3.1. Of the 23 events recorded at Newstan Colliery, the eight wind blasts indicated by a bold font are considered *significant* (sect. 5.3.1).

Wind velocity time histories recorded in the maingate and travelling road at Newstan Colliery during three of the recorded significant wind blast events are illustrated in figure 3.9. Both the differential pressure and overpressure curves are of this same general shape.

The maximum values of the various key parameters recorded during the significant events are as follows.

Peak air velocity	40 m/s (144 km/hr)
Rate of rise of velocity	50 m/s/s
Flow distance	142 metres
Peak differential pressure	10 hPa
Peak overpressure	100 hPa
Rate of rise of pressure	50 hPa/s
Impulse	200 hPa.s (approx.)

The significance of many of the above values is discussed in chapter 5.

Site	Event number	Day	Date	Time	Maximum wind velocity (uncorrected) m/sec
Wallarah Colliery	170792#1	Fri	17 Jul 1992	16:41:27 EST	13
	240792#1	Fri	24 Jul 1992	04:18:26 EST	12
	240792#2	Fri	24 Jul 1992	04:18:33 EST	6
	240792#3	Fri	24 Jul 1992	21:49:56 EST	10
	240792#4	Fri	24 Jul 1992	21:50:30 EST	11
	240792#5	Fri	24 Jul 1992	21:52:54 EST	9
	240792#6	Fri	24 Jul 1992	21:53:01 EST	6
Cooranbong Colliery	171192#1	Tue	17 Nov 1992	14:20:05 DST	11
	231192#2	**Mon**	**23 Nov 1992**	**19:26:47 DST**	**28**
	241192#1	Tue	24 Nov 1992	18:52:24 DST	6
	251192#1	**Wed**	**25 Nov 1992**	**02:12:38 DST**	**21**
Newstan Colliery (LW 7)	021195#1	Thu	02 Nov 1995	14:33:13 DST	3
	061195#1	Mon	06 Nov 1995	01:54:54 DST	8
	091195#1	**Thu**	**09 Nov 1995**	**05:17:05 DST**	**22**
	091195#2	Thu	09 Nov 1995	05:18:00 DST	4
	271195#1	Mon	27 Nov 1995	16:37:58 DST	9
	291195#1	Wed	29 Nov 1995	11:41:16 DST	13
	291195#2	**Wed**	**29 Nov 1995**	**11:41:45 DST**	**40**
	291195#5	Wed	29 Nov 1995	19:22:19 DST	12
	021295#1	Sat	02 Dec 1995	10:01:40 DST	9
	031295#1	Sun	03 Dec 1995	21:22:05 DST	14
	041295#2	Mon	04 Dec 1995	06:47:17 DST	12
	051295#1	Tue	05 Dec 1995	04:58:46 DST	11
Newstan Colliery (LW 8)	110496#1	Thu	11 Apr 1996	21:44:59 EST	14
	170496#1	**Wed**	**17 Apr 1996**	**18:47:50 EST**	**39**
	190496#1	Fri	19 Apr 1996	19:31:15 EST	8
	280496#1	**Sun**	**28 Apr 1996**	**15:55:21 EST**	**40**
	280496#2	**Sun**	**28 Apr 1996**	**16:07:57 EST**	**39**
	300596#1	**Thu**	**30 May 1996**	**20:37:33 EST**	**32**
	040696#1	Tue	04 Jun 1996	08:14:16 EST	16
	120696#1	**Wed**	**12 Jun 1996**	**13:29:58 EST**	**23**
	160696#1	Sun	16 Jun 1996	13:55:11 EST	10
Newstan Colliery (LW 9)	**010297#1**	**Sat**	**01 Feb 1997**	**09:22:09 DST**	**33**
	010297#2	Sat	01 Feb 1997	11:42:43 DST	18

Table 3.1 Schedule of wind blasts, 1992-97

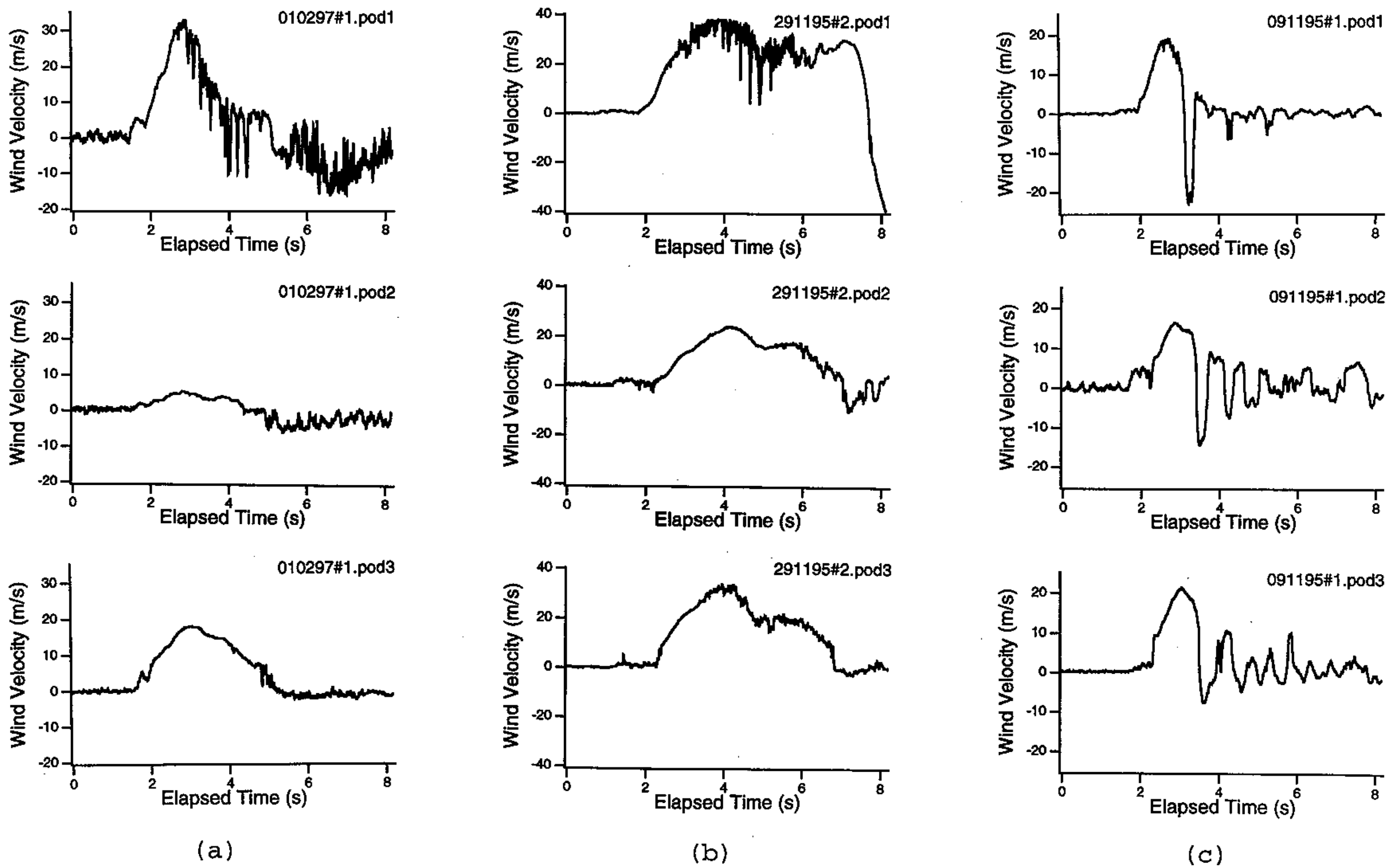


Fig. 3.9 Roadway air velocity time histories recorded at Newstan Colliery during three significant wind blasts

CHAPTER FOUR

LABORATORY MODELLING

4.1 INTRODUCTION

One of the functions of the Laboratory Wind Blast Model is to help provide insight into the dynamics of the interaction between the roof elements and the air during a fall. A comprehensive series of investigations was devised to investigate the relationships between variations in gauge pressure above and below the falling roof elements, the accelerations and terminal velocities of the latter, and the flow of air out of and into the goaf area. During the investigations the following parameters were studied.

1. The rock mass properties of the failing roof including flow paths occasioned by open discontinuities, such as joints, fractures and bedding planes, and the presence of a void occasioned by pre-existing bed separation above the roof element before it begins to fall.
2. The geometry of the falling roof element, including its thickness, area and weight, and the type of collapse (whether partial or total).
3. The geometry of the standing goaf area, including its height, and whether or not the fall extends to the ground surface as in a 'plug type' collapse.
4. The effect of time, i.e. simultaneous or sequential collapse of adjacent roof elements.
5. The effect of panel layout.

In addition to the flow of air away from the fall (the wind blast) the model also simulated the flow of air towards the fall (the 'suck back').

4.2 DESCRIPTION OF INVESTIGATIONS

The series of investigations, in which the Laboratory Wind Blast Model was utilised to examine the dynamics of the interaction between the roof elements and the air during a roof fall, are described below. The findings are particular to the fall of 'thin' elements of immediate roof, i.e. elements whose weight per unit area is significantly less than standard atmospheric pressure (1013 hPa), and extreme caution must be exercised in applying the findings to falls of thicker roof strata. The findings also remain provisional until confirmed or modified by the results to be obtained from the Numerical Wind Blast Model.

It was found that wind blasts occasioned by a fall of roof may exhibit three distinct phases.

1. A *primary phase*, characterised by a high velocity flow of air (away from the fall) which exhibits a peak and corresponds to the period during which the roof element is accelerating. The peak air velocity is related to the acceleration of the roof element.
2. A *secondary phase*, characterised by a residual air flow (away from the fall) of a lesser velocity than in the primary phase and corresponding to the period during which the roof element is falling at its *terminal velocity*. The velocity of the residual air flow is directly proportional to the terminal velocity of the falling roof element.
3. A *tertiary phase*, characterised by a flow of air towards the fall (the 'suck back') and corresponding to the period immediately after the roof element strikes the floor. The velocity of suck back is influenced by the flow paths formed as a result of the fragmentation of the roof element.

While the primary phase is always present in a wind blast, the secondary and tertiary phases may be absent.

4.2.1 Flow paths occasioned by open discontinuities

The effect of the presence of flow paths through 'thin' roof elements occasioned by open discontinuities, such as joints, fractures and bedding planes, was simulated in a series of model tests during which the pressure relief holes in the piston valves (sec. 2.3.1) were occluded to varying degrees. The permeability of the roof elements (pistons), i.e. the total open area of all the holes divided by the total plan area of the roof elements, expressed as a percentage, was varied between 0.02% and 0.74%.

It was found that, during the failure of a 'thin' roof element, a zone of reduced air pressure is created above the element and significantly modulates its acceleration and terminal velocity and, hence, determines the rate at which air is expelled from the goaf and, consequently, the wind blast air velocity.

However, the presence of flow paths through the falling roof element, occasioned by open discontinuities such as joints, fractures and bedding planes, allows a supply of air into the zone of reduced air pressure above the falling roof element, permitting the latter to attain a higher terminal velocity. Such discontinuities may be present prior to the commencement of collapse or may form as a consequence of collapse. Failures where such flow paths were present were found, over most of the range of permeability cited above, to generate higher residual velocities during simulated wind blasts.

At permeabilities up to 0.55%, the increase in the residual air velocity in the roadway was in direct proportion to the increase in permeability of the roof element while the increase in peak velocity was less marked. At permeabilities above 0.55%, however, the roof element struck the floor of the piston box before achieving terminal velocity. Under these conditions, the primary phase of the simulated wind blast was truncated and the secondary phase absent.

4.2.2 Bed separation

The effect of pre-existing bed separation above 'thin' roof elements, which implies the presence of a void even before the fall begins, was simulated by varying the distance between the top of the pistons and the underside of the lid of the piston box. The notional void ratio of the roof elements (pistons), i.e. the volume of the void divided by the volume of the roof elements, normalised to a standard specific gravity, was varied between 0.03 and 0.20. The actual void ratio exceeded these notional values by a constant amount owing to the presence of additional air spaces between the individual grains of lead shot ballast and within the fittings which connected to the lid of the piston box.

The normalisation consisted of computing notional volumes for the roof elements equal to their actual volumes multiplied by the quotient of a standard specific gravity of 2.5 and their actual effective density. This was necessary because, as it was not possible to alter the thickness of the pistons in the model, their overall weight and, hence, effective density was varied by altering the amount of lead shot ballast which they contained.

The presence of a void above a 'thin' roof element before it began to fall led to a reduction in the peak vacuum gauge pressure in the zone of reduced air pressure above the falling roof element and, consequently, to an increase in its acceleration.

It was demonstrated that failures where such a void was present generated higher peak rates of air displacement out of the goaf area and higher peak air velocities in the roadway during simulated wind blasts. The increase in the peak air velocity in the roadway was in almost direct proportion to the increase in the notional void ratio of the roof element whereas there was little or no change in the residual air velocity. The overall duration of the wind blast was, however, reduced.

4.2.3 Thickness, plan area and weight

The effect of variations in thickness and weight of 'thin' roof elements was simulated during a series of tests. The ratio of maximum to minimum piston weight employed was 1.61:1.00.

In the laboratory model the weight of the falling roof element was found to be a factor which exerted a major influence on its acceleration and a somewhat lesser influence on its terminal velocity. The peak air velocity in the roadway was found to be directly proportional to the weight of the roof element while the effect of the latter on residual velocity was less marked.

Extrapolating the results obtained from the operation of the laboratory model to the field situation, it is to be expected that failures of thicker, denser strata will generate potentially higher peak velocities during wind blasts. During the failure of 'thin' roof elements, the factors discussed in sections 4.2.1 and 4.2.2, where present, will exert a strong influence upon the magnitude and intensity of any resultant wind blast. During the failure of 'thick' roof elements, however, those factors are expected to be of less relative importance.

When considering the influence of the plan area of the falling roof element upon the magnitude and intensity of potential wind blasts there are two distinct cases.

In the first case, that of *complete collapse* where the falling roof element occupies the whole of the standing goaf area, it is considered that plan area will exert little influence upon acceleration and terminal velocity. Where such a condition obtains, however, failures of larger areas of standing goaf will result in larger quantities of air being expelled in unit time and, hence, increased roadway air velocities.

The second case is that of *partial collapse* where the falling roof element occupies only part of the standing goaf area. This is discussed below in section 4.2.6.

4.2.4 Height of workings

The *critical distance*, i.e. the distance through which the roof element falls before it achieves terminal velocity, is influenced by the factors cited in sections 4.2.1 to 4.2.3 above. If the fall height is equal to the critical distance, the primary phase of the wind blast will be fully developed and the potential peak air velocity generated.

Any increase in the fall height will not lead to a greater peak velocity but will permit the development of the secondary wind blast phase, characterised by a lower velocity residual air flow. Conversely, a decrease in the fall height will truncate the primary wind blast phase so that the potential peak air velocity will not be generated.

4.2.5 Sequential collapse

Sequential collapse refers to the situation where contiguous roof elements do not all begin to fall at the same instant. The effect of sequential collapse was simulated in the model during a series of tests in which pistons were released in delayed sequences. A range of delay periods between consecutive piston releases was employed. The delay varied from zero to periods that provided sufficient time for the previously released piston to strike the base of the piston box before the succeeding one was released.

It was demonstrated that sequential collapse may lead to a peak air velocity which differs considerably from that arising from the simultaneous collapse of an equivalent area. When the delay period is so short that the succeeding element begins to fall before the preceding one has struck the floor, the peak air velocity may be reduced. For example, when four roof elements were allowed to fall in a 'short' delayed sequence, the peak air velocity was approximately halved compared with that arising from the simultaneous collapse of all four.

4.2.6 Partial collapse

Partial collapse refers to the situation where not all of the roof elements fall. The effect of partial collapse was simulated in the model during a series of tests in which groups of pistons were released simultaneously while the remainder were restrained in the raised position. Groups of 1, 2, 3 and 4 pistons were employed in these tests corresponding to the collapse of 25%, 50%, 75% and 100% of the simulated standing goaf area respectively.

It was found that, in the case of partial collapse, the plan area of the falling roof element did not exert a significant effect upon its acceleration and terminal velocity. However, failures of larger areas of roof will still generate potentially higher peak velocities during wind blasts owing to the larger volumes of air displaced. For example, the effect of increasing the area involved in the failure from 25% to 100% of the simulated standing goaf area was to increase the peak air velocity by a factor of 1.8 during the primary phase of the wind blast.

4.2.7 'Plug type' collapse

As discussed in section 4.2.1, the presence of a zone of reduced air pressure above a falling roof element was shown to modulate its acceleration and terminal velocity and, consequently, to influence the intensity of any potential wind blast. Consequently, in order to simulate a 'plug type' collapse, where the fall extends to the ground surface, a series of tests was carried out in which the potential space above the pistons in the Laboratory Wind Blast Model was vented to the atmosphere by opening one of the 32 mm diameter holes in the lid of the piston box.

The resulting peak air velocity was more than 3.5 times the highest peak air velocity recorded during any of the series of tests described in sections 4.2.1 to 4.2.6. It will be seen that an important distinction must, therefore, be drawn between roof failures which extend to the surface and those which do not as the former will potentially generate much higher peak air velocities during wind blasts.

4.2.8 Panel layout

The Laboratory Wind Blast Model was used to compare different panel layouts by measuring the distribution of air velocities in openings occasioned by the fall of a 'thin' element of immediate roof. Both peak and residual air velocity decreased as the result of an increase in the total cross-sectional area of workings open to the goaf.

CHAPTER FIVE

MAIN FINDINGS AND CONCLUSIONS

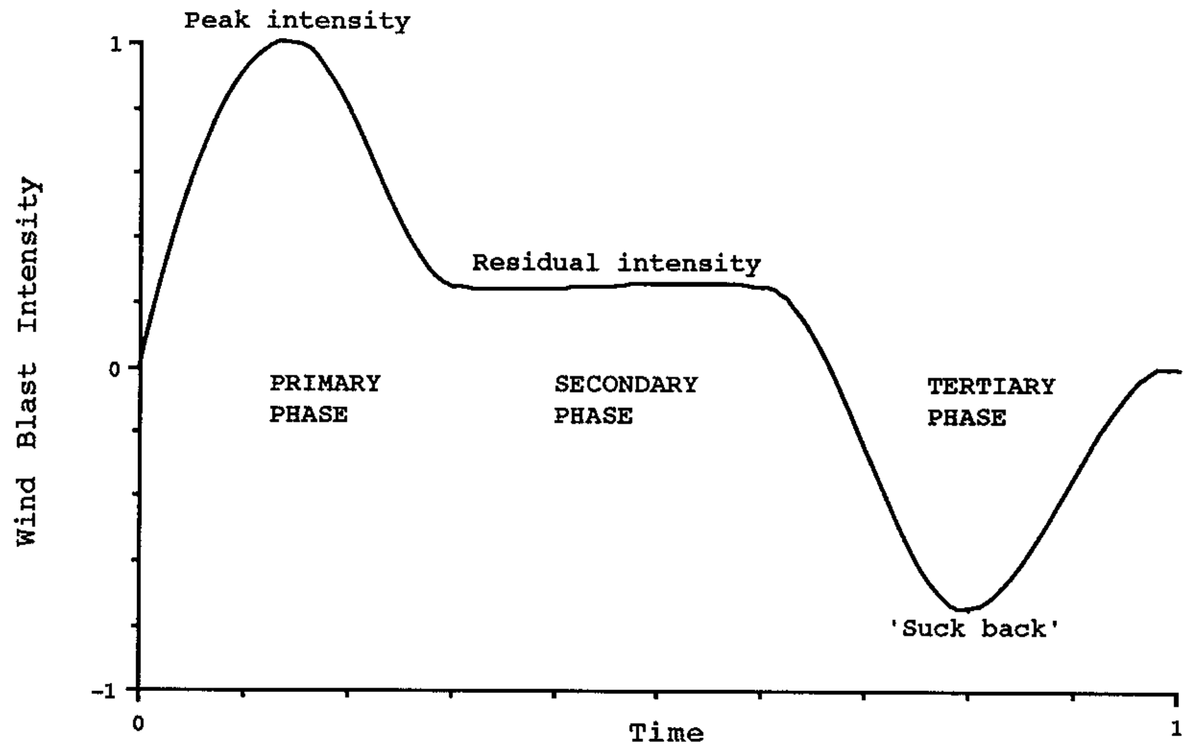
5.1 What is a wind blast?

The available evidence indicates that a wind blast is a sudden mass movement of air displaced by a goaf fall and caused to flow through adjacent openings. The results of a comprehensive series of investigations using the Laboratory Wind Blast Model (chapt. 4) indicated that a wind blast event may exhibit three distinct phases.

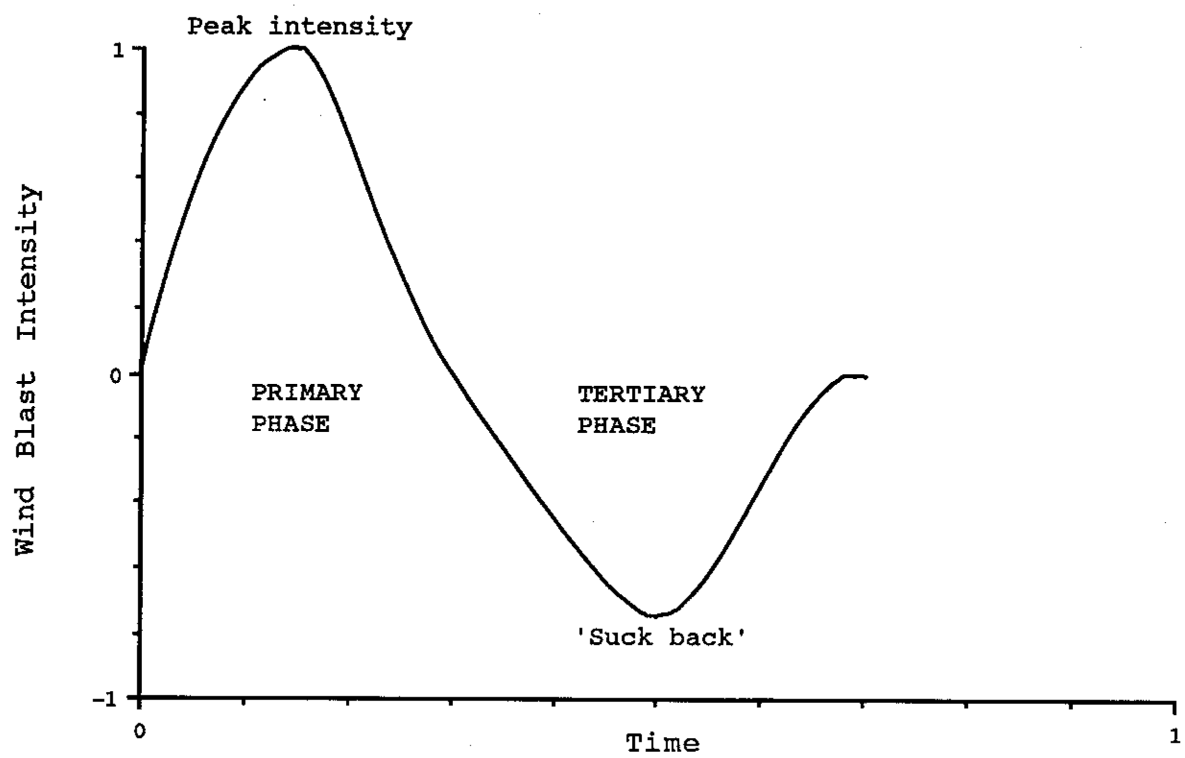
1. A *primary phase*, characterised by a high velocity flow of air (away from the fall) which exhibits a peak and corresponds to the period during which the roof element is accelerating.
2. A *secondary phase*, characterised by a residual air flow (away from the fall) of a lesser velocity than in the primary phase and corresponding to the period during which the roof element is falling at its *terminal velocity*.
3. A *tertiary phase*, characterised by a flow of air towards the fall (the 'suck back') and corresponding to the period immediately after the roof element strikes the floor.

The three phases of a wind blast are illustrated in figure 5.1(a) which is a synthesis of theoretical considerations with the results of field monitoring and laboratory modelling. While the primary phase is always present in a wind blast, the secondary and tertiary phases may be absent.

Evidence of the secondary phase has yet to be clearly observed in the mine situation and it may be that the conditions of a real roof fall in a coal mine are such that the primary phase is always prematurely terminated by the falling roof element hitting the floor with the result that the secondary phase (corresponding to the roof element achieving its *terminal velocity*) does not develop (fig. 5.1(b)).



(a) Primary, secondary and tertiary phases



(b) Primary and tertiary phases only

Fig. 5.1 Synthesised time histories of wind blasts

The absence of the tertiary ('suck-back') phase in some of the field recordings is believed to be due to changes in the resistance to air flow in some of the entries caused by the presence of the bulked goaf material. Indeed, some openings may be completely choked by fallen material. Because of changes in geometry occasioned by such fallen material, the distribution of the return flow between the various openings adjacent to the goaf may well be different from the distribution of the initial flow away from the goaf.

A wind blast is a mass movement of air. It is not a shock wave (like that emanating from an explosion) and there is no evidence that, as the wind blast event propagates through the workings, shock wave conditions develop, although the possibility of such an eventuality cannot be excluded. Measured wind blast velocities are an order of magnitude less than the speed of sound. It must be understood, however, that the *celerity* or rate at which the wind blast event is propagated through the mine is equal to the speed of sound. Consequently, personnel subjected to a wind blast will not hear the event before they are struck by the force of the air, i.e. they will receive no audible precursor to the actual roof fall although, of course, 'roof talk' prior to the fall may be evident.

5.1.1 The magnitude of a wind blast

The *magnitude* of a wind blast is related to the amount of air displaced from beneath the falling roof element and caused to flow from the goaf area into the surrounding workings. Both the total mass of the displaced air and the rate of displacement are considered to be of importance. Factors which affect the magnitude of a wind blast include, but are not necessarily restricted to, the following.

1. Geological factors which affect the way in which the roof falls. The geological structure of the roof strata and the mechanical properties of both the rock fabric and of the discontinuities (in particular, their strength properties) are, *a priori*, significant in this regard.

2. Geometrical factors such as the thickness of the falling roof element and the distance through which it falls, together with both its plan area and the total plan area of the standing goaf.

5.1.2 The intensity of a wind blast

The *intensity* of a wind blast relates to the effect of a wind blast upon the working place. In assessing the intensity of a wind blast the following factors are considered to be of importance.

1. Air velocity (and differential pressure) for *drag-sensitive* elements. Parameters which may be relevant include peak air velocity, rate of rise of velocity (or *velocity rise time*) and *flow distance* (the total area under the graph of variation of air velocity with time).

2. Air overpressure for *overpressure-sensitive* elements. Parameters which may be of relevance include peak overpressure, rate of pressure rise (or *pressure rise time*) and *impulse* (the total positive area under the graph of variation of overpressure with time).

Some elements of the mine may be both drag & overpressure sensitive.

5.2 The characteristics of a wind blast

Wind velocity time histories recorded in the maingate and travelling road of LW 7 and LW 8 at Newstan Colliery during two significant wind blast events are illustrated in figure 3.9 (chapt. 3). Both the differential pressure and overpressure curves are of this same general shape.

The maximum peak roadway air velocity so far recorded is 40 m/s (144 km/hr) while the greatest peak suck back velocity is of the same order of magnitude. To put this value into perspective, it will be observed from table 5.1 that it is well into the *hurricane range*, Force 12 on the Beaufort Scale, for which the lower bound is 33 m/s (118 km/hr). In addition, the highest recorded rate of rise of velocity is 50 m/s/s while the greatest measured flow distance is 142 metres.

The maximum peak differential pressure, corresponding to a velocity of 40 m/s, is 10 hPa. However, the maximum recorded peak overpressure is one order of magnitude higher (100 hPa or 10% of standard atmospheric pressure), while the highest rate of rise of pressure is 50 hPa/s and the maximum impulse is of the order of 200 hPa.s.

Beaufort Scale number	Description	Nautical observation	Land-based observation	Equivalent windspeeds at 10 m knots	km/h	m/s
0	calm	flat sea	smoke vertical	0	0	0
1	light air	ripples form	smoke drifts	2	4	1
2	light breeze	wavelets	leaves rustle	6	11	3
3	gentle breeze	breaking wavelets	wind felt on face	9	17	4.5
4	moderate breeze	white horses	thin branches move	14	26	7
5	fresh breeze	moderate waves	small, leafy trees sway	17	31	9
6	strong breeze	white foam, spray	large branches sway	23	43	12
7	moderate gale	heaped sea	whole trees move	29	54	15
8	gale	long crests, blown foam	twigs break off, progress impeded	37	68	19
9	strong gale	10 m waves, reduced visibility	removes tiles	43	80	22
10	storm	heavy rolling sea, over-hanging crests	trees blown down	50	93	26
11	—	spray impedes visibility	widespread damage	58	107	30
12	hurricane	sea white with foam	extreme damage	64	118	33

Table 5.1 The Beaufort Scale of wind speeds (after Linacre & Hobbs 1977)

There is no reason to assume, however, that wind blasts of greater intensity, i.e. exhibiting higher wind velocities and overpressures, do not occur.

5.2.1 How much roof falls?

It is of interest to note that the total volume of air forced down the maingate and travelling road during one of the seven significant events recorded at Newstan Colliery was in excess of 3000 cubic metres. Taking the fall height to have been two metres and making the somewhat conservative assumptions that

1. no air was expelled through the other entries open to the goaf and
2. the falling roof acted as a 'non-leaky piston' and was 100% efficient in expelling air from below it into the maingate and travelling road,

then the corresponding roof fall area may be calculated to have been in excess of 1500 square metres.

5.2.2 How far does the air penetrate into the working place?

It is of particular concern that, during one of the significant events recorded at Newstan Colliery, the flow of air over the pod mounted in the maingate on the pantec exceeded 140 metres, i.e. air from the goaf penetrated beyond the 'hazardous zone' defined by statute. In a gassy or poorly ventilated panel such expelled air could contain a significant methane content, although there is no evidence that such was the case during the wind blasts at Newstan Colliery. In addition, non-flameproof equipment such as the panel transformers was located off the intakes at a distance from the longwall face which far exceeded the statutory minimum.

5.3 The direct effects of a wind blast

It is considered that the 'elements' in a coal mine most sensitive to wind blast are the personnel themselves and the ventilation system. Wind blasts of an intensity below that which causes injury to personnel or damage to elements of the ventilation system are considered unlikely to cause damage to drag-sensitive elements of the mine such as plant and equipment.

5.3.1 Effect on mine personnel

Mine personnel are considered to be both overpressure and drag sensitive.

Direct blast injury may result from air overpressure and there are at least three parameters which may be relevant in this context: peak overpressure, pressure rise time and impulse. The element of the human body most sensitive to damage by rapid pressure change is reported to be the eardrum and published data for the threshold overpressure value for eardrum rupture is of the order of 340 hPa. This is more than three times the maximum overpressure of 100 hPa recorded to date during a wind blast. Moreover, this threshold value is based upon military data and is specific to overpressure time histories which exhibit the fast rise times associated with the arrival of a shock wave following an explosion. It may, therefore, be unduly conservative if applied to wind blasts which exhibit a much slower rise time.

Indirect injuries may result from displacement due to the drag force occasioned by a wind blast. It is tentatively assumed that the sudden application of a force equal to, or more than, 15% of self-weight would give rise to the possibility of an individual in an upright mode being knocked over.

The air velocity which would result in such a drag force is difficult to assess as it depends upon stance. However, as a first approximation, the *terminal velocity* of a 'skydiver' in his or her 'diving' mode is considered. At this velocity the force exerted by the relative motion of the air exactly balances the force due to gravity, i.e. his or her weight. The terminal velocity is of the order of 50 m/s and the force due to wind drag varies in proportion to the square of velocity. It follows, therefore, that a drag force equal to 15% of self-weight would be occasioned by an air speed of the order of 20 m/s and, consequently, the necessary condition for a wind blast event to be considered *significant* is taken to be an air velocity of 20 m/s or greater.

Another source of indirect injury is impact by missiles entrained in the air and it is considered that laceration of uncovered skin is the mode of injury which would occur at the lowest velocity. Published values for the threshold of skin laceration are of the order of 15 m/s for a missile weighing 10 gram.

5.3.2 *Effect on elements of the mine ventilation system*

The maximum peak overpressure so far recorded (100 hPa) is far less than the generally accepted design pressure loading of 3500 hPa (50 psi) adopted for explosion-proof stoppings. However, it corresponds to the lower limit of published values for the shattering of large wall panels constructed of 300 mm thick concrete or cinder blocks and, consequently, may be sufficient to cause failure in this form of stopping.

An overpressure of 100 hPa is equivalent to a loading of one tonne per square metre and, consequently, the total force imposed on a stopping in a roadway of width 5.5 metres and height 3.0 metres would be 16.5 tonnes. Clearly, this would be more than sufficient to destroy a plasterboard stopping.

5.4 Factors which influence magnitude and intensity

5.4.1 *Density and thickness of the falling roof*

Gravitational force obviously controls the acceleration and velocity of a falling roof element. However, interaction with the air significantly moderates its fall and, consequently, the density and thickness of the roof element are important parameters which influence its acceleration and terminal velocity. Failures of thick, dense strata, for example, will cause more air to be expelled from the goaf area in unit time and, hence, generate potentially higher roadway air velocities during wind blasts.

There are distinct differences, however, in the way 'thin' and 'thick' falling roof elements interact with the air and, consequently, they are discussed separately below.

5.4.2 *The collapse of a 'thin' roof element*

The extensive programme of testing using the Laboratory Wind Blast Model (chapt. 4) indicated that during the fall of a roof element which may be classified as 'thin', i.e. one whose weight per unit area is significantly less than standard atmospheric pressure (1013 hPa), the creation of a zone of reduced air pressure above the element significantly modulates its acceleration and terminal velocity and, consequently, determines the rate at which air is expelled from the goaf area and, hence, controls the roadway air velocity.

The vacuum gauge pressure in the zone of reduced air pressure above the falling roof element was shown to be influenced by any pre-existing void above the roof element, before it begins to fall, and by any flow paths through the falling roof element occasioned by open discontinuities such as joints, fractures and bedding planes.

The plan area of the falling roof element was also shown to influence the magnitude and intensity of potential wind blasts, the collapse of larger areas of roof resulting in larger quantities of air being expelled in unit time and, hence, increased roadway air velocities.

5.4.3 The collapse of a 'thick' roof element

During the fall of a roof element which may be classified as 'thick', i.e. one whose weight per unit area is significantly more than standard atmospheric pressure (1013 hPa), the comparative influence of the partial vacuum above the element is much reduced and it is the increased air pressure generated below the element which significantly modulates its acceleration and terminal velocity. This pressure, together with the resistance to air flow in the openings, controls the rate at which air is expelled from the goaf area and, consequently, determines roadway air velocity.

5.4.4 'Plug type' collapse

A particularly hazardous situation occurs in the case of a roof failure which extends to the ground surface, i.e. a 'plug type' collapse. In this circumstance, the zone of reduced air pressure which would moderate its fall does not form. Consequently, an important distinction must be drawn between roof failures which extend to the surface and those which do not as the former will potentially generate the highest peak velocities during wind blasts.

5.5 Can wind blasts be predicted?

There are two aspects to the prediction problem: predicting when a fall will occur and predicting whether the fall will generate a significant wind blast. One of the tasks of the Wind Blast Project is the identification of factors which affect the probability of a wind blast and this may well lead, in conjunction with the Numerical Wind Blast Model, to a prediction of wind blast magnitude for any given goaf fall.

However, the propensity for major goaf falls, particularly initial falls in total extraction panels, to occur suddenly and without warning is notorious. Another of the tasks of the Wind Blast Project has been to look for velocity or overpressure precursors but, unfortunately, if they do exist they are at a level which is below that of the ambient variations and, hence, undetectable.

In addition, velocity and overpressure data during the time period immediately preceding triggering of the Wind Blast Data Logger has been recorded for each event (Project Report No. 1) but no immediate precursors have been detected in the time histories. Rise times are short and as the *celerity* is equal to the speed of sound (sec. 5.1) persons subjected to a wind blast will not hear the event before they are struck by the force of the air.

The possibility exists, however, that microseismic monitoring techniques may afford a prediction tool and, to this end, a microseismic array was installed, by others, over LW 8 and LW 9 at Newstan Colliery. Prior to the commissioning of the microseismic array, two large wind blasts which occurred during the mining of LW 8 had resulted in injury to three miners. After commissioning, the longwall crews were withdrawn using a criteria based upon the release of seismic energy. This resulted in the loss of 30 per cent of production time during the remainder of the mining of LW 8. However, the further significant wind blasts which occurred all took place while the crews were withdrawn from the face and further injuries due to wind blast were avoided during this time and during the subsequent mining of LW 9.

5.6 Can wind blast magnitude be reduced at source?

5.6.1 Restricting mining height

The *critical distance* is the potential distance through which the roof element would fall before achieving its *terminal velocity*. It may be affected by factors which include, but are not necessarily restricted to, the rock mass properties of the falling roof and the geometry of the both the latter and of the standing goaf. If the height of the standing goaf, and hence the distance through which the roof element falls, is equal to the critical distance, the primary phase of the wind blast will be fully developed and the potential peak air velocity generated as indicated in figure 5.1(b).

A height of standing goaf which is greater than the critical distance will not lead to a higher peak air velocity but will permit the development of the secondary wind blast phase, characterised by a lower velocity residual air flow, leading to an increased duration for the overall event (fig. 5.1(a)). It may be of significance, however, that the secondary phase has not yet been observed in the real mine situation.

Conversely, a height of standing goaf which is less than the critical distance will cause the primary wind blast phase to be truncated and the peak air velocity to be reduced. The extent of the reduction depends on the relationship between the peak air velocity and the acceleration of the falling roof element, a relationship which has yet to be fully defined.

Whether or not restricting the design mining height in a total extraction panel would have any significant effect upon the magnitude of a wind blast (and, consequently, upon its intensity) depends, therefore, on the relationship between the mining height and the critical distance.

The problem of whether reducing mining height would lead to a reduction in the magnitude of a potential wind blast in a total extraction panel which is already partially mined-out and includes an area of standing goaf is more complex. This situation is one of those which it is intended to simulate using the Numerical Wind Blast Model.

5.6.2 Artificially promoting caving

As outlined above, the magnitude of a wind blast may be affected by factors which include the plan area & thickness of the falling roof element and the rock mass properties of the roof strata including flow paths occasioned by open discontinuities such as joints, fractures and bedding planes. Consequently, techniques which could influence some or all of these factors might be used to reduce wind blast magnitude and those which might be applicable include blasting and water infusion / hydrofracturing.

The techniques could be applied in one of two ways: either as a method of pretreatment prior to the commencement of total extraction in a panel or, alternatively, as a method of post-treatment where an extensive area of roof is already 'hanging up'.

Both blasting and water infusion / hydrofracturing have the potential to be utilised as a method of pretreatment with the aim of opening up existing discontinuities in the roof strata or of creating new fracture surfaces. The latter might also be employed, where appropriate, to reduce the strength of roof rocks. A difficulty, however, would be to ensure that the pretreatment did not adversely affect roof control at the face during mining.

Niu and Gu (1982) report the successful application of water injection to promote caving at a mine in the Datong Coal Mining Administration area in China, an area with a history of wind blasts, some of them leading to fatalities (Song & Xu 1992; see also Project Report No. 1.) The mineralogy of the sandstone roof rock was such that it was susceptible to loss of strength on immersion in water and, hence, infusion rather than hydrofracturing may have been the most significant factor in the failure process.

Two water injection trials were undertaken during 1988-89 at Newstan Colliery (Holt 1989). The target strata were the roof rocks of the Great Northern seam which predominantly comprised conglomerate and sandstone, together with some shale. It was reported that, during the second trial, roof caving behaviour was successfully modified, as evidenced by reduced longwall chock pressures, and that the main process whereby roof strata were weakened was water infusion rather than hydrofracturing.

5.7 Can wind blast intensity at the workplace be reduced?

5.7.1 Increasing the total area of openings

A possible strategy to reduce wind blast intensity at the workplace might be to increase the total cross-sectional area of workings open to the goaf. The results of a programme of investigations using the Laboratory Wind Blast Model indicated that roadway air velocity could be reduced in just this way. In the laboratory model, however, the fall of the piston, representing a 'thin' element of immediate roof, is only moderated by the zone of reduced air pressure above it and not by the air below. Consequently, the amount of air leaving the goaf in unit time will be a constant and the effect of increasing the cross-sectional area of workings open to the goaf will be to reduce air velocity.

Increasing roadway and cut-through width is not generally practicable and mining height is often determined by geomechanical factors and considerations of coal quality. Consequently, the only practicable way of attempting to reduce the intensity at the working place of a wind blast of a given magnitude may be by increasing the number of openings which intersect the goaf area.

While this strategy would probably be effective for falls of 'thin' roof, it may not work for 'thick' roof falls for the reason given above, i.e. that pressure below a falling element of 'thick' roof, together with the resistance to air flow in the openings, controls the rate at which air is expelled from the goaf area. Increasing the number of openings which intersect the goaf area would merely have the effect of decreasing the total resistance to flow and, consequently, increasing the rate at which air was expelled from the goaf. The pressure time history within the goaf area and the velocity time history of air in the openings would be unaffected. The duration of the wind blast would, however, be shortened and this might indirectly affect the maximum air velocity.

5.7.2 'Protecting' an opening

'Protecting' a single opening could be achieved, in theory, by introducing a wind blast regulator into the opening. Such a regulator would be analogous to those used to direct the flow of air for purposes of ventilation. Practical problems to be overcome would include selecting a suitable location for the regulator and designing & constructing it so as to withstand the overpressures generated by wind blasts.

The effect on air velocities in the 'non-protected' openings would again depend on whether the falling roof is classified as 'thin' or 'thick'.

In the case of a fall of 'thick' roof, where the increase in pressure below the falling roof element, together with the resistance to air flow in the openings, influences the rate at which air is expelled from the goaf area, protecting an opening with a regulator would merely have the effect of increasing the total resistance to flow and, consequently, decreasing the rate at which air was expelled from the goaf. The pressure time history within the goaf area and the velocity time history of air in the 'non-protected' openings would be unaffected but the duration of the wind blast would be increased. This might indirectly affect the maximum air velocity.

In the case of the collapse of a 'thin' roof element, however, where the zone of reduced air pressure above the element influences the rate at which it falls and, hence, the rate at which air is expelled from the goaf area, regulating an opening would lead to a compensatory increase in the velocity of air in the 'non-protected' openings. The duration of the wind blast would, however, be unaffected.

5.8 Further work

5.8.1 Work 'in hand'

Further work on the Wind Blast Project is currently underway, funded by a grant from Australian Coal Research Limited under the Australian Coal Association Research Program (ACARP). The following tasks are to be undertaken.

1. Refurbishment of, and modifications to, the Wind Blast Monitoring System.
2. Further field monitoring.
3. Further development and verification of the Numerical Wind Blast Model and development of a 'user-friendly' computer interface.
4. A comparison of different detailed panel layouts using both the Numerical and the Laboratory Wind Blast Models.
5. The design of a miniaturised wind blast monitoring apparatus.
6. A review of personal protective wear and equipment.
7. The development of guidelines for panel design and layout.
8. The development and definition of safe working practices.
9. Further technology transfer.

On completion of this work a fundamental understanding will have been gained of the wind blast phenomenon resulting from massive roof failure in underground coal mines and a sound foundation provided for developing strategies to mitigate the hazard.

5.8.2 Recommendations for further initiatives

It is recommended that research be instituted, as a matter of urgency, into the issue of the expulsion of methane from the goaf into the working place during wind blasts. Of particular concern is evidence that air/methane from the goaf can *reverse* the ventilation flow on the intake side of a longwall panel and may penetrate beyond the 'hazardous zone' defined by statute into areas where non-intrinsically-safe and non-flameproof equipment may be located. It is also of concern that such equipment may be in process of being shut down by safety devices designed to 'trip' the electrical power supply in the event of a wind blast and, hence, be at their most hazardous at the very time that they are inundated by an air/methane mixture displaced from the goaf.

It is further recommended that a project be initiated as an extension of the present research with the specific aim of better understanding the caving mechanism during 'initial' goaf falls in total extraction panels, particularly in areas of massive sandstone or conglomerate roof.

Finally, it is recommended that a project be undertaken with the specific aim of establishing and demonstrating appropriate techniques to 'artificially' induce goaf falls with particular emphasis on the problem of initial goaf falls in total extraction panels in previously unworked areas. The application of such a strategy would not only reduce the incidence and severity of wind blasts but would also reduce 'weighting' problems such as pillar crushing, rib spall and excessive support yield associated with goaf hang-up.

5.9 A note of caution

The preceding observations and conclusions relating to the wind blast phenomenon are based upon the results of extensive laboratory physical modelling but rely on only a limited number of field measurements. They remain provisional until confirmed or modified by the results of numerical computer modelling and further field monitoring.

CHAPTER SIX

TECHNOLOGY TRANSFER ACTIVITIES

The first interim report (Project Report No. 1), issued in April 1994, is available as an ACARP (Australian Coal Association Research Program) Publication from the Australian Mineral Industries Research Association Limited (Fowler 1994). The second interim report (Project Report No. 2), issued in July 1994, is available from The University of New South Wales Department of Mining Engineering (Fowler & Torabi 1994).

An article on the wind blast phenomenon was published in January 1996 in Research Technology Transfer Bulletin - No. 8 (The University of New South Wales School of Mines 1996).

A technical paper, on the laboratory study, was published in the proceedings of the 1995 Underground Operators' Conference (Fowler, Torabi & Daly 1995) and another, on the field investigations, in the proceedings of the '96 International Symposium on Mining Science & Technology (Fowler, Torabi & Daly 1996). A paper on the field investigations at Newstan Colliery is to be presented at the First International Underground Coal Conference to be held in Sydney in June 1997.

A module on the wind blast phenomenon has been included in the series of workshops on Risk Management run by The UNSW Department of Safety Science for personnel from the NSW Mines Rescue Service and seminars have been given for students from the Departments of both Safety Science and Mining Engineering.

The Wind Blast Project was assisted by the active involvement on the steering committee of representatives of the participating coal mining companies, the United Mineworkers' Federation of Australia, the Coal Mining Inspectorate and Engineering Branch of the New South Wales Department of Mineral Resources and The UNSW Department of Mining Engineering. Representatives of these organisations met from time to time to review progress and provide appropriate advice on matters pertaining to the project. This involvement enabled the members of the steering committee to acquire a clearer understanding of the phenomenon and to pass on this knowledge to other members of their organisations.

In addition, many people from within the coal mining industry have been actively involved in preparing the Wind Blast Monitoring Equipment for field deployment and in the use of the equipment at mine sites. Their involvement has resulted in the dissemination of information on the topic to a broad cross section of the underground coal mining community. This form of involvement is ongoing with further field monitoring planned.

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