Longwall Caving Process in Different Geological Environments
Better Understanding through the Combination of Modern Assessment Methods

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Abstract: Longwall geomechanical research being carried out by CSIRO’s Exploration and Mining and Strata Control Technology has resulted in a better understanding of rock failure mechanisms around longwall extraction. Shear, rather than tensile failure, has been the predominant failure mechanism in the Australian environments monitored. Failure has occurred further ahead of the retreating face than predicted by conventional longwall geomechanics theory. In some cases, significant failure has been detected several hundred metres ahead of the face position with demonstrated influences of minor geological discontinuities. Major structural features have been shown to have a dominant control on failure mechanisms. Layout geometry, the previous goafing mechanics and pore water pressure have also been shown to influence failure. Validating technologies of microseismic monitoring and new face monitoring techniques have assisted the development of predictive 2D computational modelling tools. The demonstrated 3D consequences of failure has assisted in the ongoing direction of the project to further investigate these effects.

Key Words: Longwall geomechanics, Failure mechanisms, Microseismic monitoring, Numerical modelling, Caving behaviour.

Introduction

Despite the impressive growth in Australia’s longwall production, many longwall mines have experienced major geotechnical problems. Unexpected geological intrusions and fault zones have resulted in loss of production over extended periods in some mines. Stress concentration in goateroads is another a major problem. In some mines, high gas emissions have resulted in production delays up to 20%, leading to lower production and productivity. Water ingress from overlying aquifers or watercourses has also been an issue. In the past five years, cyclic loading under massive strata and the associated problems with face stability and windblasts has also occurred. Subsidence of surface features, roads, water bodies, dams are some of the other problems which have restricted longwall operations.

These types of problems are not just confined to Australia and are common in many countries, restricting the production potential of modern longwall faces. In addition, longwall panels have been trending both wider and longer to increase productivity. To support these larger capacity longwalls and to reduce the risk of occurrences that limit productivity, there needs to be an improvement in the understanding of longwall fracturing processes.

In order to improve understanding of longwall fracturing and caving, research into caving processes across a broad range of underground environments is being undertaken by CSIRO Exploration and Mining and Strata Control Technology (SCT). In this paper there is a brief review of the current understanding, a description of the methods used in this work, and a discussion of the results and insights into longwall caving process that have been obtained.
Review of Current Understanding

There have been many studies into the geomechanical behaviour of longwall faces, and there is considerable variation in both the approach and underlying assumptions. Attempts have been made to analyse the caving mechanism using numerical models, empirical models, physical models and various forms of field measurement techniques. Most researchers link the extent of fracturing to extraction thickness and a number of relationships have been proposed to predict fracturing extent (Wilson, 1964, 1983; Peng and Chiang, 1984; Kidybinski & Babcock, 1973; Zhu, Qian & Peng 1989; Whittaker, Gaskell and Reddish, 1990). These studies suggest that front abutment pressure reaches a peak value approximately 3 to 5 metres in front of the face and is about 4 to 6 times the overburden pressure.

Most studies suggest that there is vertical fracturing due to tensile failure ahead of the face, because the peak front abutment stress is thought to be very close to the face. However, such models are contradicted by time domain reflectometry (TDR) studies (Dowding, Su and O’Connor 1989; Haramy and Fejes, 1992), which suggest shear rather than tensile failures in the roof rock 15 to 20 m ahead of the face. This suggestion also indicates a different type of stress distribution around a longwall face and raises questions about many of the assumptions in current longwall design methods. In addition, knowledge of actual fracture zones and failure mechanisms ahead of the face and in the floor is limited.

Conventional field investigations (Wilson, 1964; Wagner and Steijn, 1979; Christiaens, 1982; Freeman and O’Grady, 1992) using stress cells, extensometers and convergence measurements often refer to the region very close to the face, and are insufficient to understand the rock mass behaviour further ahead of the face. Investigations involving surface boreholes and extensometers, such as camera surveys of borehole walls before and after mining, give some idea on the vertical extent of fracture zones. However, they are difficult to undertake, time consuming and expensive. In addition, the amount of data that can be obtained from such field studies, including TDR monitoring, is limited and is insufficient to characterise the complete caving process.

It would therefore seem that there is no clear understanding of the stress distribution and failure mechanism ahead of a longwall face, and that more comprehensive and thorough investigations are necessary to achieve such an understanding. However, this now appears to be possible with investigations by Sato and Fuji (1988), Styles, Bishop and Toon (1992) in Britain and by Hatherly et al (1995) at Gordonstone Mine showing that microseismic monitoring can provide large sets of three dimensional and dynamic data on stresses and failure mechanisms at minimal cost. Such data provide validation for the numerical simulations, which can now be produced with increasing sophistication and accuracy.

The Current Project

The current longwall investigations are aimed at improving face design and control methods by better defining strata failure mechanisms around the face. It will allow design and predictive tools to be developed for a broad range of underground environments. Specific Australian mines have been studied to allow a rational understanding of the caving process and in turn its relevance to fluid flow, stress distribution and support interaction. The mines have been chosen with a view to covering a broad base of environments so that the results may be widely applicable. Microseismic monitoring, 2D and 3D computational modelling, longwall face monitoring and new soft rock testing procedures are being used.
Microseismic monitoring

Most microseismic monitoring is mainly undertaken for the forecast and control of rockbursts, mine bumps and failures (Young, 1993; Coughlin and Rowell, 1993; Miller and Descour, 1996). This is an important application but represents only one aspect of its geotechnical uses. The potential of microseismic monitoring in understanding the longwall caving processes has been largely unexplored until recently.

The microseismic monitoring of longwall mining is utilising arrays of three-component geophones grouted within boreholes drilled from the surface to the working seam. Microseismic activity is monitored continuously as mining progresses. The number of boreholes and location of geophones depends on the geology and geometry of the area being monitored. The system includes a monitoring unit and computer data storage devices installed on the surface in a modified shipping container. The system is self-contained with diesel generators providing power and a mobile phone with modem providing remote phone-in access. Geophone orientations and seismic wave velocities are established by firing of shots at known locations.

Numerical modelling of longwall caving

The program FLAC (Itasca, 1995) is used as the basic numerical modelling program with additional proprietary rock failure and goaf consolidation subroutines which simulate the longwall caving process and allow more rational prediction of stress distributions and displacements occurring around longwall faces. The code can handle the wide range rock mass failure conditions that exist around a forming goaf and complex fluid and ground deformation capabilities.

The rock failure routines define the orientation and properties of fractures created in the rock mass from various failure models. In addition, the orientation of pre-existing joints and the failure planes generated are analysed to assess stability under conditions of tension and shear, as the ground moves backwards into the extracted void. The goaf consolidation routine assesses stiffness of the caved material as a function of load and void space. The type of fracture and its orientation are displayed in the output.

The approach used in modelling is to excavate an approximately one metre wide 'web' (shear slice), calculate the ground response and then to repeat the process. The simulations also include coupled fluid pressure as part of the rock failure process. To date, the simulations have been two-dimensional simulations of the central part of a longwall panel where the panel is of supercritical width and the out-of-plane third dimension has least effect.

The question of 3D modelling versus the 2D used in the study needs comment. The level of detail required to adequately represent failure development using a discrete web width of one metre is such that the 2D model requires a three week continuous run on a fast work station. A 3D model of the same detail is therefore not practical. However, we have commenced to model a broader, less detailed situation using several 3D codes (ABAQUS, FLAC3D, 3DEC and some particle codes) to understand the influence of structure and adjacent longwalls on the failure mechanisms of the current block.

Face monitoring

The longwall face monitoring component of this work has involved the monitoring of chock leg pressures, face convergence and goaf pressure. A new longwall powered support closure
measurement system, which does not depend upon potted wires, has been developed for convergence monitoring. This system has several advantages over current closure measurement such as spring tensioned wire transducers. By utilising robust transducers mounted in relatively protected areas on the longwall support, the system has greater reliability. The system also provides additional information on the reaction of the base and canopy to loading, which can be used to help analyse support performance. This system is being used in conjunction with support manufacturer’s monitoring packages for the monitoring of both leg pressures and convergence on each longwall face during the microseismic monitoring.

Other technologies

A sophisticated triaxial testing facility at CSIRO is being used to quantify rock and coal strength parameters at field sites. The soft rock triaxial testing facility consists of an automated cell pressure control, measurement and data acquisition system. The system can accommodate samples up to 300 mm in diameter. Pre- and post-failure characteristics and volumetric strain response are typically recorded to within 1% accuracy.

In addition, ‘Goafmon’, an instrument system designed to measure the load exerted by the caved strata in a goaf, has been used. Goafmon comprises a 400 mm diameter flatjack with associated electronics installed in the floor of a goaf, and connected by robust cables to the controller module located in an adjacent roadway. The frequency with which the pressure is monitored is user selectable, and to maintain the integrity of the data there is a full suite of real time synchronisation and error checking routines.

Caving Behaviour Under Weak Roof Conditions
Gordonstone Colliery

The Gordonstone Mine is located in the Bowen Basin in Central Queensland. The geology is described by Kelly, Lawrence and Davy, (1994). In the area of the study the 3 m thick German Creek seam is being mined at a depth of about 235 m. Mining is by the longwall method, with a face width of 250 m. The immediate roof and floor are particularly weak, with UCS values of only 5 - 15 MPa. Stronger bands (UCS of about 50 MPa) occur above the Corvus Seam, some 25 metres above the worked seam. The dominant horizontal stress is NNE, parallel to the panel direction and sub-parallel to the dominant coal cleat and strata joint directions. The thickness of the Tertiary sediments and volcanics is about 70 m.

Microseismic monitoring results

In 1994 a microseismic study was undertaken with the objective of determining whether caving from longwall mining extended to overlying unconsolidated Tertiary sediments and volcanics Hatherly et al (1995). Three boreholes were drilled, and nine triaxial geophones were installed in each. Piezometer readings to supplement the microseismic data were also made. The microseismic activity was monitored for a longwall retreat distance of 5000 m. The activity was closely correlated with mining, and in all 1200 events were detected. Of these, 629 with sharp P-wave onsets were located. The remaining events were of lesser magnitude, with indistinct onsets; these are thought to have been from within the goaf and to have occurred after initial failure.
The locations of the microseismic events are summarised in Figs 1 and 2. They are estimated to have accuracy generally better than 5 m within the microseismic network and 10 m outside. In plan view (Fig. 1) it is apparent that the majority of the events occurred within and above the panel (LW 103) which was being mined. There is a tendency for events to occur on the sides of the panel, and in cross section (Fig. 2) it can be seen that they generally lie within an envelope at some 15° from the vertical above the gateroads. Fig. 2 also shows that the events extend to a height of about 120 metres above the German Creek Seam, and to a depth of about 30 metres into the floor.

Fig. 3 shows the locations of the events relative to a fixed face position. This figure shows that the events tend to occur up to 100 m ahead of the face and that this seismically active zone extends upwards at an angle of about 50° from the horizontal. It has also been possible to determine source mechanisms for a number of the events. The nodal planes are approximately parallel to the longwall face and a compressive shear fracture pattern is indicated with fault planes dipping at an angle of approximately 50°(±10°).
Picrometer data confirm these microseismic results. In the upper piezometers, increases in pore pressures occurred over 200 m ahead of the face and varied according to mining activity. In one case (Fig. 4), a pressure increase of 800 Pa occurred, demonstrating undrained behaviour that would influence rock failure. The piezometer cables were also sheared progressively up the hole at distances of 73 m, 53 m, and 25 m ahead of the face respectively. These distances coincide with the onset of the microseismic activity (Fig 3).

**Fig. 4:** Results of piezometer monitoring at Gordonstone.

### Numerical modelling results

The numerical model for Gordonstone, extends from the seam to the surface and 500 m below the seam. The results of simulated longwall mining at Gordonstone are presented in Fig. 5. A number of key features are indicated:

- Failure of roof strata occurs at a substantial distance in front of the face. The model indicates that this takes place at least 10-15 m ahead of the face, and that it extends up to the Corvus Seam (20-25 m above the worked seam). The fractures are pervasive but have no pattern. The expected microseismic characteristics would therefore be many low intensity energy releases, rather than a (periodic) high-energy release of lesser frequency.
- Failure of the immediate floor strata occurs at regular intervals.
- The nature of rock failure ahead of the face is shear fracture through intact material, and bedding plane shear.
This simulation for Gordonstone does not have coupled fluid pressure as part of the rock failure process as more recent models now have. As a result, it is probable that shear fractures form even further ahead of the face than indicated from this study. At Gordonstone, the outcomes of subsidence, stress measurement and microseismic data are all consistent with the results of the simulation.

Caving Behaviour Near Fault Area
North Goonyella Colliery

General description including Geology

The North Goonyella Mine is located on the western margin of the Bowen Basin in Central Queensland approximately 150km inland of Mackay. In the area of the study the 6 m thick Goonyella Middle Seam is being mined at a depth of about 180 m in the Moranbah Coal Measures.

Mining is by the longwall method, with a face width of 250 m. The roof and floor conditions are weak. The seam floor consists of over 10 m of cross-laminated fine-grained sandstone and siltstone. The upward succession of roof strata consist of 30 m of claystone and siltstone, then a thin couplet of coal and tuff (P-tuff), followed by 10 m of sandstone up to a height of 55 metres. Stronger bands (UCS 50 MPa) occur above the P-Tuff marker unit, which is some 32 metres above the worked seam. The dominant horizontal stress is NNE, parallel to the panel direction and sub-parallel to the dominant coal cleat and strata joint directions. The Moranbah Coal Measures geology is described by Esterle et al, 1997.

Structural elements occurring in the Longwall 3 South study area are shown in Fig. 7. In this area a multiple fault intersection occurred between two diverging and westerly trending normal faults and a northerly trending thrust fault that is associated with flexure-rolls. These elements and their interrelationships are presented schematically in a block model in Fig. 6. The two principal vertical faults diverge to west-northwest and the intervening zone is around 120 m wide where they penetrate the tailgate. Mapping in the tailgate shows this zone contains numerous blocks separated by a maze of small 0.1-1.3m throw conjugate faults.
The principal structures in the study area include:

- Bedding-plane shears
- Weak flexures/rolls with a northerly orientation
- Lateral faults & joint-shears
- Thrust faults; NNE trending
- Flexed-normal faults
- Down-thrown and hinged blocks

Where the larger faults intersected one another, substantially weaker ground conditions were experienced. This, combined with the present NS stress regime, created blocks of roof bounded by vertically converging faults with a tendency to "pop out" as stress was released by mining.

Microseismic monitoring results.

The microseismic monitoring system installed at North Goonyella consisted of three holes drilled up to 30 metres below the working seam with 4 triaxial geophones in each hole. The microseismic activity was monitored in two periods from December 1996 to May 1997 and then from July to December 1997. During this time the face retreated a total of 670m, with significant delays on the face due to roof falls.
More than 3,000 microseismic events were recorded during these periods. Most of the events were very weak in energy and only triggered geophones in one borehole. This coupled with indistinct P wave onsets resulted in only 54 larger events being located accurately. All of these larger events that were able to be located occurred in the vicinity of the fault (Fig. 7 & Fig. 8). Source fracture mechanisms for most of these large 54 seismic events was found to be predominantly shear. The seismicity generally occurred before the occurrence of the major roof falls.

![Graph showing microseismic events location in cross section – near fault area.](image)

**Fig. 8:** Microseismic events location in cross section – near fault area.

**Numerical modelling results**

A model of the strata section at North Goonyella was developed on the basis of a bore program and from past geophysical logging. The modelled section includes the Permian strata, tertiary basalts and the poorly consolidated tertiary sediments. Fluid flow and pore pressure within the strata was coupled within the model. Permeability for the strata was determined on the basis of regional data from borehole testing. A clay rich zone was included toward the base of the tertiary section.

Two models were run; one with a vertical fault plane and one with no structural defects. The results of both models indicate that ground failure occurs in the strata above the coal in front of the face. Sub vertical zones of ground fracturing could occur in front of the longwall supports if the top coal and rib integrity were lost.

![Image showing results of modelling showing zones of rock failure – near fault area.](image)

**Fig. 9:** Results of modelling showing zones of rock failure – near fault area.
The effect of a vertical fault structure was also assessed. The fault plane has a friction angle of 10 degrees to simulate a clay infilled structural zone. The fault was within the Permian strata only. The effect of the fault was initially noted approximately 20 m from the fault and subsequently localised failure as the longwall approached. The fault structure caused a significant and increasing severity of ground failure and displacement in the region of 5 m from the fault (Fig. 9). The model indicated that the increased severity of roof deformation about the fault structure would require control of rib stability and the immediate roof to limit the potential for roof cavities to form as the fault was approached.

The fluid flow data from the models indicated the potential for increased pore pressure zones ahead of the face influencing rock failure and also the potential for recharge of aquifers in the tertiary where the clay layers at the base of the tertiary isolated the flow systems.

**Caving Behaviour Under Medium Strong Roof Conditions**

**Appin Colliery**

Appin Colliery is located in the Southern Coalfield of the Sydney Basin. The longwall panel at Appin is 200 m wide and extracts the 2.3 m thick Bulli Seam at a depth of about 500 m. The strata below the Bulli seam typically consists of interbedded strong sandstone, coal, carbonaceous material and inter laminated sandstone and shale. A study was made of longwall panel 28a to determine the nature of the fracturing to the underlying Wongawilli seam and to determine whether the fractures extended to the Tongarra seam. These seams are significant potential sources of goaf gas emissions. Within the panel numerous strike slip joint structures intersect the maingate particularly between 5 and 7 cut-throughs.

**Microseismic monitoring results**

At Appin Colliery 17 triaxial geophones were installed with nine geophones in a borehole drilled from the ground surface to the Bulli Seam and two perpendicular surface strings of four geophones each. The microseismic activity was monitored during August to November 1996 during which time there was 700 m of face retreat. Distinctive seismic events with low and high frequencies were observed.

The microseismic events locations in plan view, Fig. 10, indicate three broad areas of failure (i) cyclic failure of strata from mid face across to the tailgate (ii) reactivation of the strata under the pillars of the previous gateroad and (iii) activation of a strike slip structure in the maingate well outbye of the face position. All of the high frequency events are located in the fault structure zone and activation of the structure started far ahead, more than 300 m, of the face.

The event locations in section, Fig. 11, show that the majority of fracturing (the low frequency events) extends to a height of about 50 to 70 m above the Bulli seam and to a depth of 80 to 90 m into the floor, often extending down to the Tongarra seam. They tend to occur up to 30 - 50 m ahead of the face in cyclic pattern. The microseismic events location in space-time context within a 4D virtual reality visual model that includes mine workings and geology are shown in Fig. 12 (LeBlanc Smith, Caris and Soole, 1998). The events around the previous gateroad pillars may also be up to 300 metres away from the face position. This mechanism under the gateroad pillars has also reactivated surface subsidence (Fig. 13).
Fig. 10: Microseismic events location in plan view – medium strong roof.

Fig. 11: Microseismic events locations in cross section – medium strong roof.

Fig. 12: Microseismic events location in virtual world view of longwall panel in relation to fault structures.
Fig. 13: Reactivation of surface subsidence due to failure under the previous gate road pillars.

Numerical modelling results

The Appin longwall caving model has been developed using the geological and geotechnical data collected from the mine. The section considered for detailed investigations extends from 50 m below the seam to 150 m above the working seam. The model simulations also included coupled fluid pressure as part of the rock failure process. The results of the simulations are presented in Fig. 14.

Fig. 14: Results of modelling showing zones of rock failure - medium strong roof.

Key features of the results include:

- Cyclic fracturing through to the base of the Wongawilli seam and occasional permeability increase down to the Tongarra seam.
- Bedding plane shear in the Stanwell park claystone unit approximately 100 m above the Bulli seam and extending 50 - 100 m in front of the working face.

The model predictions are consistent with microseismic monitoring measurements with respect to the cyclic loading but do not represent the extraordinary three dimensional nature of failure in this environment.
Face monitoring

In addition to the above studies, face-monitoring investigations were conducted at Appin Colliery. The new convergence monitoring system was used in conjunction with support manufacturer's monitoring packages for the monitoring of both leg pressures and convergence. The results agree with those from a conventional potted wire convergence system also used on the face. With the additional information on canopy angle, it is possible to determine whether there is tip loading or goaf loading occurring. Preliminary analyses of the face monitoring data show a correlation between convergence rate, microseismic events and subsequent gas emissions.

New Insights Into Longwall Caving

As described earlier, most traditional studies while recognising that abutment loads can be detected significant distances away from the longwall, still predict that the maximum abutment loads occur close to the longwall excavation. They further predict that these abutments are 4 to 6 times the overburden pressure. Most studies also predict either explicitly or implicitly that the failure mechanism is tensile. This tensile mechanism is caused by an indirect tensile stress due to an essentially unconfined large abutment load close to the face.

In contrast, the vertical stress profile, Fig. 15, developed from the simulation, shows that the maximum abutment load is only twice the overburden stress and occurs 10 metres ahead of the face. This difference may be from two main causes:

- Firstly, many Australian mines are in a high horizontal stress regime with the major principal stress being horizontal, and about 2.5 times the overburden stress and typically designed to be parallel to the gateroads. The horizontal relief into the goaf is quite significant and through lateral relaxation will have a decreasing influence on the vertical stress.
- Secondly, bedding plane shear and shear through intact rock will result in a reduction in the load carrying capacity of the rock adjacent to the longwall zone. This will effectively transfer the abutment peak away from the longwall and reduce its magnitude.

![Graph showing vertical stress profile](image)

**Fig. 15:** Vertical abutment stress relative to the goaf edge developed in the model.

The microseismic events at Gordonstone have shown that the initial failure occurs 50-70m ahead of the face and that the dominant failure mechanism of all events is a shear failure with a failure plane oriented at an average angle of 50° to the horizontal thrusting up into the goaf direction. This failure is further validated by piezometric evidence. Our modelling has also indicated that the initial failure occurs a substantial distance ahead of the face with the dominant failure mechanism being shear through intact rock with some bedding plane shear.
The main difference between the model and actual field microseismic measurements are not the modes of failure but the predicted distance ahead of the face where failure occurred, being 15 m for the model and a mean of 30 - 40 m for the field measurements. The roof sequences at Gordonstone have a high moisture content that was not modelled as part of the failure criteria. It is postulated that pore water pressure has an influence on the intact rock failure by reducing the effective stress. This will cause failure to be initiated at lower stress levels and may explain the differences between the model and field measurements.

At North Goonyella, the study area was chosen to monitor the effect of the fault on the geomechanics in front of the retreating longwall. It is clear from the results that the fault played an overwhelmingly dominant role with all of the recorded larger events concentrated in the fault zone. The subsequent difficult mining conditions reinforced this dominance from this type of structure. Both modelling and microseismic results support a failure mechanism around the fault that initiates above and well ahead of the face and propagates to seam level just ahead of the advancing chocks. The fault structure caused a significant and increasing severity of ground failure and displacement in the fault region.

At Appin, the failure mechanisms recorded were of three main types:

1. A cyclic failure in the Tailgate side of the face with an interval of slightly more than 100 m. These events occurred about 50-60 m ahead of the face and with the majority from 80 m above the seam to 100 m below the seam. This mechanism was expected, although the depth below the seam was surprising. This depth demonstrated consistent breakage of the Tongarra seam for gas release.

2. Failure along a joint-shear in the Maingate/blockside of the face. This joint had been mapped as a minor feature underground. Failure along this joint commenced while the face was still 450 m inbye of it and this mechanism controlled the stress relief along the entire maingate side. This mechanism is outside all conventional longwall geomechanics theory and was a surprise to both the research team and site staff.

3. Failure of the gateroad pillars between the previous longwalls 26 and 27. Conventional pillar theory revolves around empirical coal strength formula. However the majority of the failure observed in this case occurred from in the surrounding strata, predominantly in the floor below the pillar up to a depth of 130m below the seam. Again this is outside conventional longwall geomechanics theory.

![Graph](image)

**Fig. 16:** Gas flow in LW28a and previous panels during longwall extraction.
The correlations with gas release at Appin are also worthy of comment. The initial gas levels for LW28a were much higher than previous blocks while subsequent levels were significantly lower (Fig 16). It should be noted that LW28a commenced opposite the middle of LW27 block and was not subject to the same end constraints. Hence, a quicker transition to mature goafing and higher gas levels can be easily explained. It is suspected that the lower subsequent gas levels were due to the correlating stress relief from slippage on the joint shear. As discussed this mechanism was a major influence on maingate geomechanics and could explain the reduction of gas release to 25% less than normal total gas make expected.

Conclusions

The power of combining accurate microseismic monitoring and detailed numerical simulation has been demonstrated in this study. It has been shown that the traditional models of tensile failure mechanisms and abutment loads of 4-6 times the overburden pressure are not appropriate for the Australian test sites. The effect of shear failure, reduction of horizontal stresses and perhaps pore fluid pressure has resulted in a much lower abutment load which peaks further away from the longwall face than traditional models indicate. This has a major implication in understanding longwall geomechanics generally and will influence issues of face control,巷道 abutments and fluid flow (both gas and water).

At Appin, the results have been more dramatic and in contradiction to traditional longwall geomechanics theory. The essence of the 3D nature of failure in medium strength environments has been depicted, especially underlying the effect of minor structure in influencing failure mechanisms and questioning the relevance of conventional pillar design theory which relies principally on empirical coal strength formula. The 3D nature and effect of structure have also been demonstrated at North Goonyella. Fracture mechanisms of the microseismic events located at all the three sites was found to be predominantly shear. The value of detailed site studies, especially structural analyses, has been demonstrated at all of the sites.

The effectiveness of the combination of technologies has been the most potent outcome of the work to date. Validation of results through several independent technologies increases confidence in the findings and dismisses the academic controversies, which tend to cloud new findings such as these. This confidence assists implementation into minesite and graphically demonstrates the narrow vision of past assessment methods. The future requires a better understanding of the 3D nature of some of these mechanisms and the development of effective numerical modelling that can translate results into studies of mining alternatives. Also required is the further development of the microseismic monitoring system. Current analyses, although accurate, are slow and tedious.

Finally, although not discussed throughout the paper, the safety implications of better defining longwall mechanics demand a comment. A better understanding of longwall geomechanics has profound safety implications. Issues such as face control, wind blasts,巷道 support and high level gas emissions can all be better addressed with the knowledge that this project will provide.
Acknowledgements

This work was conducted with support and cooperation from ACARP, Gordonstone Coal Management, BHP Australia Coal, The Shell Company of Australia, North Goonyella Coal Mines Ltd, Macquarie Coal Joint Venture, Cyprus Australia Coal Company and Joy Manufacturing. All the organisations are gratefully acknowledged. Thanks are also due to Dr Stephen Matthews of SCT for his invaluable suggestions & assistance during project investigations. The support and cooperation of Mr Ian Hutchinson, Mr Ron McPhee, Mr Don Flynn, Mr Robert Dixon, Mr Zak Jecny and Damian Carvolth of CSIRO are gratefully acknowledged.

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