Comparison of Ground Conditions and Ground Control Practices in the United States and Australia

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ABSTRACT

Australia and the United States both have large, modern underground coal mining industries. Many companies have invested in both countries, and there is growing awareness that technological developments in one country can rapidly affect the other. Yet the ability of technology to pass between the countries depends on comparability of ground conditions. Many Australian observers believe that their ground conditions are significantly poorer than typical U.S. conditions, but some U.S. professionals are not convinced.

The author recently visited 10 Australian longwall mines and two room-and-pillar mines. Each mine visit included determination of the Coal Mine Roof Rating, roof support installed, pillar design, and an in-depth discussion of ground control experience. The Australian conditions observed are compared with an extensive data base from U.S. mines. The paper also offers observations on geotechnical data collection, monitoring, and the roles of the mine inspectorate and research community.

Acknowledgments

I would like to express my sincere appreciation to Mark Colwell and Russell Frith for arranging all the longwall mine visits, and to Ian Anderson, Steve Mathews, and John Shepherd for arranging other portions of the trip.

INTRODUCTION

Early in 1998 the author visited Australia to gather information on the Australian state-of-the-art in mine safety technology. The focus was on ground control and disaster prevention and response. A secondary goal of the trip was to assist an Australian Coal Association Research Program (ACARP) project that is evaluating the applicability of the Analysis of Longwall Pillar Stability (ALPS) and the Coal Mine Roof Rating (CMRR) to Australian mines (Colwell and Frith, 1997).

A total of 12 mines were studied in the course of the trip. On week was devoted to five longwall mines in the newest Australian coalfield, central Queensland (figure 1).

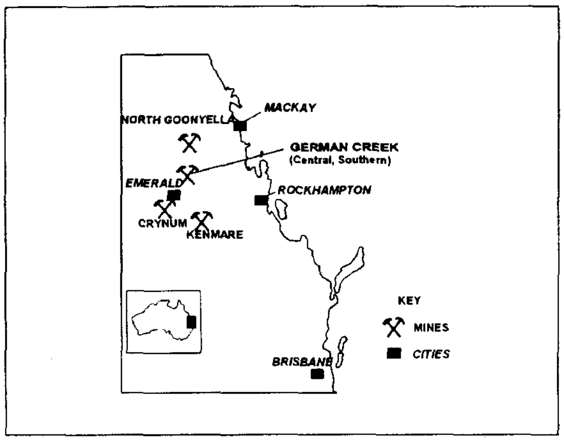

Figure 1. Coal mines visited in Queensland.

Two of the mines were only on their second longwall panel. The second week of the trip included visits to Mining Engineering departments at three universities and meetings with other ground control specialists. Two room-and-pillar mines were also studied, one a deep-cover, full-extraction operation, and the other a shallow, partial-extraction operation beneath massive conglomerate roof. During the final week of the trip, five longwall mines were studied in New South Wales (NSW). Two were in the Lake Macquarie/Newcastle district, and one each in the Hunter Valley, Western (Lithgow), and Southern (Wollongong) coalfields (figure 2).

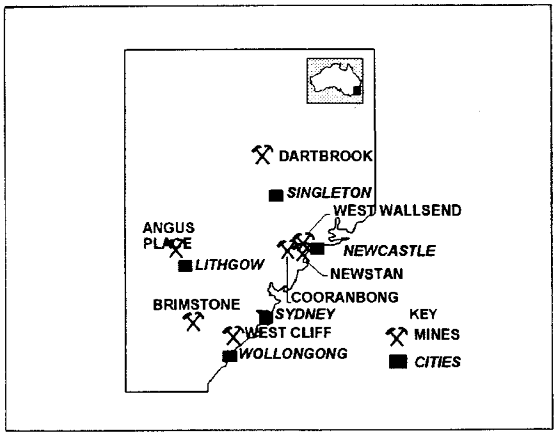

Figure 2. Coal mines visited in New South Wales.

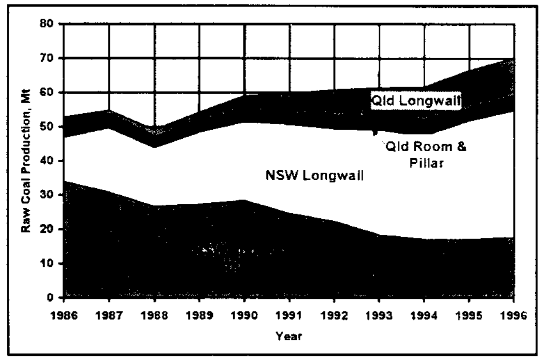

Figure 3. Trends in Australian underground coal production.

BACKGROUND

Australia is the world's leading exporter of coal. Although Australia's total production of about 250 million raw tonnes of bituminous coal is considerably less than China, Russia, or India, Australia's mining technology is extremely modern. It is fair to say that the Australian coal industry has more in common with the U.S. coal industry than any other in the world. Indeed, in recent years the same coal producing companies have made large investments in both countries.

Underground mining currently accounts for about 28% of Australian bituminous coal production. Almost all underground production (and 96% of all coal production of black coal) comes from the two states of Queensland (Qld) and New South Wales (NSW). The last decade has seen rapid growth and technological change in the Australian industry. Underground production in NSW expanded by nearly 20% (to 55 million tonnes) between 1986 and 1996, and it nearly tripled during the same period in Queensland (from 6 to 16 million tonnes). The decade also saw a pronounced shift to longwall technology. Longwall mines produced about 13 million tons in 1986, and that figure has grown to 48 million tons a decade later. Longwalls now account for nearly 80% of underground production in NSW and almost 100% in Queensland (figure 3).

On the whole, Australia maintains a mine safety record that is similar to the U.S. The Australian lost time injury frequency rate (LTIFR) in 1994 was 16 per 200,000 hours worked, compared to an LTIFR of 11 for the U.S. (Muncton, 1995). There have been two major mine disasters in Australia during the last five years. Eleven miners perished in the Moura mine explosion in 1994, and four miners were killed at Gretly Colliery by an inundation in 1996. There were a total of 12 other fatalities during the period, 4 of which were attributed to roof or rib falls (Doyle, 1997).

Today, the Australian coal mining industry seems to be at a crossroads. The optimism based on several decades of sustained growth seems to have given way to uncertainty. Just a year ago the trade magazines were filled with plans for major new projects, but now layoffs and mine rationalizations seem to be the order of the day. Labor strife has also increased, with major confrontations at Arco's Gordonstone mine and the Rio Tinto operations. Low coal prices, competition from Indonesia and South Africa, and concern about the economic slowdown in Asia (the primary market for Australian coal) underlie the uncertainty.

The Australian coal industry is now struggling to increase productivity, while continuing to improve its safety record. Ground control is a serious hazard throughout the industry, along with spontaneous combustion and control of mine gasses. The Australian mining community is meeting the challenge with a vibrant, cooperative research effort that is on the cutting edge of many mine safety technologies. The remainder of this paper will describe the state-of-the-art in Australian ground control, and compare it with the U.S.

ROOF GEOLOGY

The Coal Mine Roof Rating (CMRR; Molinda and Mark, 1994) was determined at all 12 underground operations that were visited. The range of CMRR values is shown in figure 4a. The two strongest roofs were a massive conglomerate (CMRR=90) and an interbedded shale and sandstone (CMRR=60). The weakest top (CMRR<45) included four mines with thick coal roofs and a sandstone laminated with igneous tuff layers. The intermediate roofs included one thick coal roof, two Bulli seam "laminites" (interbedded shales and sandstones), a sandy shale, and a stackrock sandstone. On the whole, the roof in Queensland seemed somewhat more competent than that in NSW.

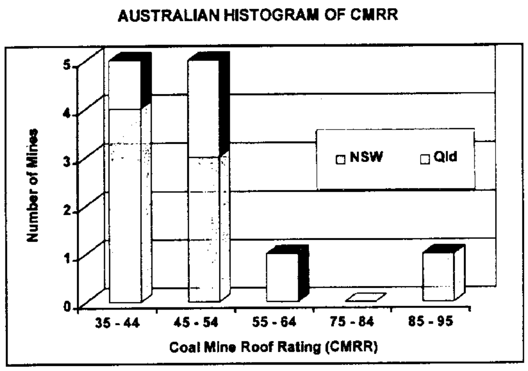

Figure 4a. Range of Coal Mine Roof Rating (CMRR) values observed in Australia.

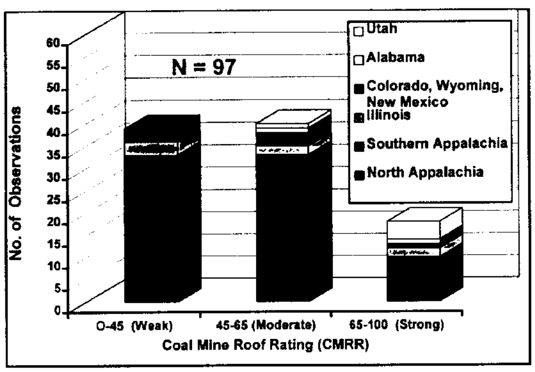

Figure 4b. Range of Coal Mine Roof Rating (CMRR) values observed in the U.S.

Figure 4b shows the range of CMRRs found in U.S. coal mines. On average, it appears that the roof in NSW may be roughly equivalent to that found in the Northern Appalachian coalfields, while Queensland roof may be closer to that in the Central Appalachians. Overall, the range of roof quality was similar to that found in the U.S.

Large-scale geologic features had an important effect on longwall performance at a number of mines. Igneous dikes seemed to be the most common feature, followed by faults. Massive roof, as discussed below, was another important issue.

The depth of cover varies significantly from coalfield to coalfield. Most of the Queensland mines gain access to seam from the highwalls of surface mines, and the cover is relatively light. Mines in Southern NSW have the deepest cover because the coalfields are relatively mature and the terrain is mountainous. Cover is moderate in the Northern and Western NSW coalfields.

The presence of horizontal stress was not very noticeable at most of the mines visited. Active mines in the Queensland coalfields particularly seem to have low stress levels, though some deeper operations there have had problems in the past. Horizontal stress appears to be most important in the Western and Southern NSW coalfields. In the Western coalfields, where the coal seams are only a few meters above the basement rock, "structural zones" have been associated with some of the most difficult ground conditions in the country.

It seemed that the Australian mines were well supplied with geotechnical information from core logs and laboratory testing. For example, Dartbrook mine has a coverage of 18 holes per square km, or one hole every 235 m. About half these holes were fully cored, and many samples were tested for uniaxial, triaxial, and bedding plane shear strength (Hayward, 1998). Many mines estimate rock strength from geophysical logs, often using relationships that have been derived from their own testing. Measurement of horizontal stress also seems routine and nearly universal.

The geologic characteristics of the visited mines are summarized in Table 1.

Table 1
Geologic Characteristics of 12 Representative Australian Coal Mines

Coalfield	CMRR	Depth (m)	Horizontal Stress
Queensland	40-60	<250	5-15 MPa
NSW - Northern	40-90[1]	100-300	5-10 MPa
NSW - Western	35	100-350	20 MPa
NSW - Southern	45-55	300-500	20-35 MPa

[1]CMRR=90 with massive conglomerate roof.

LONGWALL LAYOUT AND MINING METHODS

All of the longwall mines employed two-entry gates. The crosscut spacing was almost universally 100 m. Pillar widths varied between 28 and 40 m, and entry widths were 4.5 to 5.3 m. One striking feature was the thickness of the coal seams. In the mines visited, the pillar heights ranged from 2.5 to 4 m.

Most of the gates were driven by a single machine, typically an ABM20 with mounted roof drills. Often only a single shuttle car was used. The typical procedure was to mine 1-1.5 m, and then install a row of bolts. The machine will drive crosscut-to-crosscut before moving to the other heading. There is currently quite a bit of interest in American-style "place-changing," using a separate roof bolting machine. At least four of the mines that I visited have tried place changing, with satisfactory roof stability at only two of them. In the U.S., it has been found that "extended cuts" are more likely to be successful when the CMRR exceeds 40-50 (Mark, 1998), and the Australian experience seems to fit the same pattern. Also, the large Australian mining machines (like the ABM20) are usually slow to tram, and two-entry gates with long crosscuts are far from optimal for rapid place-change cycle times.

ALPS Stability Factors (SF) have been determined at a number of mines that are involved in the ACARP project. The preliminary data show similar trends to those found in U.S. studies. Figure 5 shows of that when the case histories are plotted against the U.S. design equation (Mark et al., 1994), there are only four misclassifications. Three of the misclassifications fall near the line, and the fourth may be successful because of an extremely high density of primary support. The very worst tailgate conditions in the data base were encountered at a mine where the ALPS SF was 0.8, well below the suggested value for a CMRR of 35. In contrast, at other operations where the ALPS SF was well above the suggested value, it was possible to drive a vehicle all the way up to the tailgate corner of the longwall.

A variety of techniques are used to design pillars in Australia. The University of New South Wales (UNSW) recently developed a pillar strength formula from back-analysis of room-and-pillar case histories (School of Mines, 1994; Hebblewhite and Galvin, 1996) which has been widely applied. Numerous mines have employed stress measurements to evaluate pillar behavior, and sophisticated computer simulations are available (Gale, 1998). However, the relative lack of variation in longwall pillar size indicates that there may be room for more innovation.

ROOF SUPPORT

One immediate and obvious difference between the two industries is their tolerance for roof falls. In the U.S., approximately 2000 falls of supported roof occur each year, which is approximately one for every 120,000 tons mined underground on advance. In Australia, none of the large mines I visited had experienced more than a handful of roof falls. Indeed, I was told on several occasions that their unwritten goal was "no outby roof falls." The intolerance of roof falls even extends to inby roof failures during mining.

The universal primary support in Australia is what would be called a torque-tension bolt in the U.S. These are fully-grouted with a two stage resin (a fast set for the anchor at the back of the hole, and a slow set around the tensioned portion of the bolt). Australian roof bolts tend to be of larger diameter and made from higher strength steel, with a typical yield load of about 20-25 tonnes. The bolt length was 1.8-2.4 m almost everywhere. At the mines I visitied, all the bolts were installed with drill rigs mounted on the continuous miner, or with hand-held drills. It seems that it might be difficult to obtain consistent quality installations with the hand-held units.

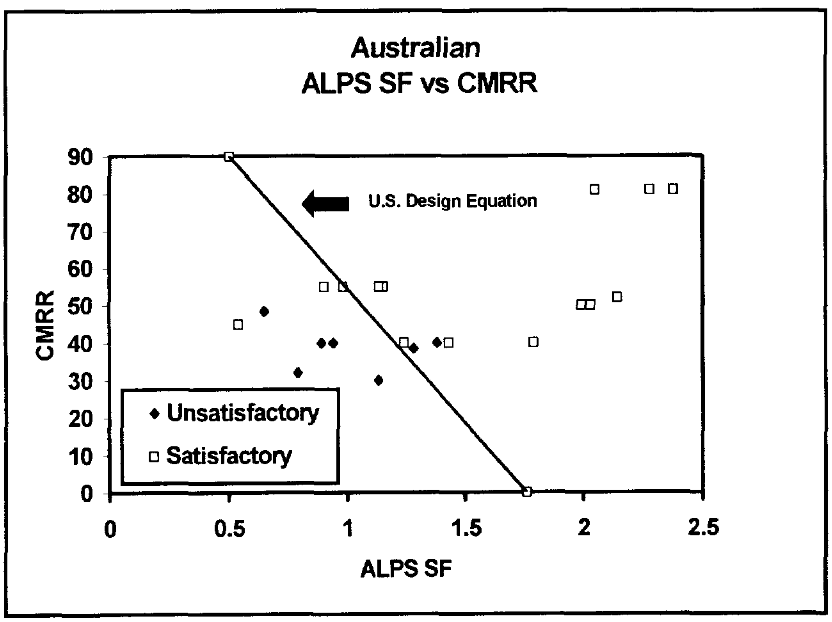

Figure 5. Preliminary data showing Analysis of Longwall Pillar Stability (ALPS) stability factors from Australian mines.

There has been some controversy in the Australian ground control community over the importance of the installed tension. There are devices available that allow torque-tension bolts to be installed with more than 10 tons of load, twice the usual amount.

The bolt density varied considerably in the mines studied. Six mines used four bolts on 1.2-1.5 m centers, a pattern that would be considered typical in the U.S. Another four mines used more intensive patterns, with six bolts on 1-1.2 m centers. Figure 6 compares Australian with U.S. bolt densities.

The trend towards reduced roof bolt densities seems to be relatively recent. At one mine I visited near Newcastle, the bolt density has been decreased by 56% (from 6 per meter to 4 per 1.5 meter) over the last three panels, apparently without negative effect.

Rib bolting is almost universal in Australia, due to the high seams. Two or four rib bolts are usually installed per row of roof bolts, and additional rib bolts may be installed later. Several mines expressed disappointment in fiberglass bolts, which often fail at low load or even during installation. Some plastic bolts are currently being trialed.

In the U.S., secondary tailgate support is usually installed nearly simultaneously with the headgate pass. In Australia, most mines try to leave the tailgate open for access and ventilation. About half the longwalls visited used no regular tailgate secondary support, and most of the rest installed it only within 100 m of the tailgate corner. Burrell cans seemed to be the most common standing support, followed by Link-N-Lock cribs. No tailgate I observed was supported by wood cribs (or "chocks," to use the Australian terminology). Cable bolts and flexi-bolts were also used for supplemental support.

In general, it seems that Australian longwalls may have traditionally relied upon primary roof bolts for tailgate support, which may partially explain their higher bolt density. The disadvantage is that intensive primary support patterns slow down gate road drivage rates. The current trend towards reducing the number of primary bolts speeds up drivage, but requires that mines make more use of cable bolts and standing supports in tailgates.

One notable contrast with U.S. longwalls is that more than 60% of Australian faces are using four-leg supports. Many of these are relatively new supports, with capacities of up to 900 tonnes. In the U.S., only 2 of 65 longwalls use four-legged supports.

Retreat Mining: Pillar recovery operations have historically accounted for the lion's share of ground control fatalities in Australian coal mines. In 1991, seven miners were killed on NSW pillar lines. Following a major research, education, and regulatory effort undertaken by the entire mining community (School of Mines, University of New South Wales, 1994; Coal Mining Inspectorate and Engineering Branch, 1992; Shepherd, 1997), no fatalities have occurred during the last five years.

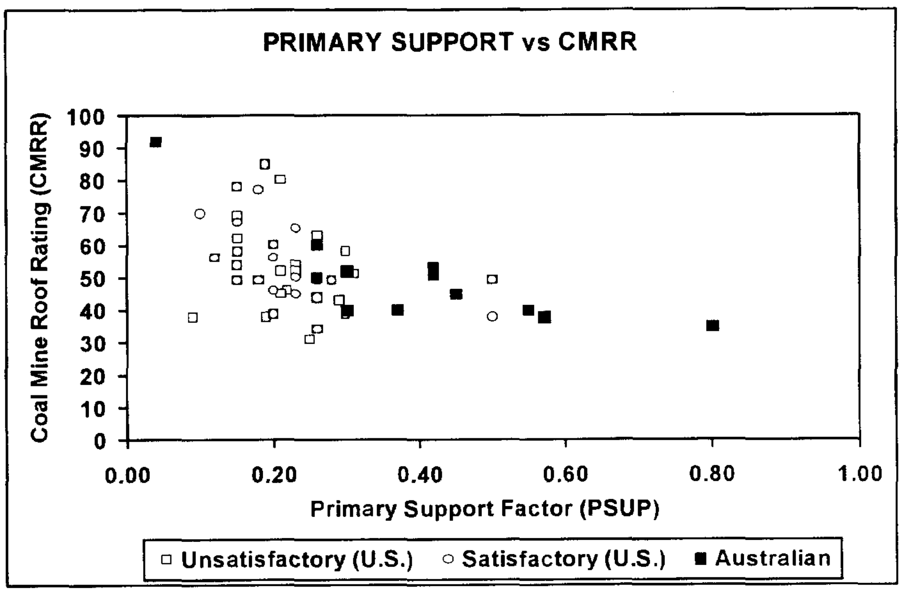

Figure 6. Primary bolt densities observed in U.S. and Australian coal mines. PSUP = (Bolt length * bolt diameter * number of bolts/row)/(Entry width * Spacing between rows of bolts) (see Mark et al., 1994).

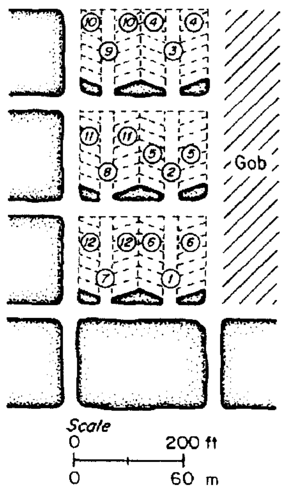

Figure 7. Modified Wonga-willi pillar extraction sequence used at Brimstone Colliery.

One reason for the improvement is better support. Breaker line supports (BLS) were introduced in the mid-80's, and are now standard. One typical application is at Brimstone Colliery, under 400 m of cover. Here pillars are developed on 40 m centers. On retreat, the pillars are split, and then lifted using a Christmas-tree sequence (figure 7). Three BLS are walked down the split as it is recovered. Large "stooks" (pushouts) are left to support the intersections, but they are engineered to crush out at this depth of cover.

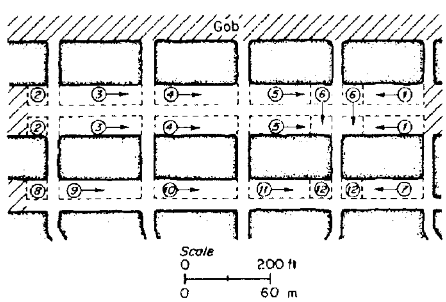

Figure 8. Partial pillar extraction sequence used beneath massive conglomerate roof at Cooranbong Colliery.

At Cooranbong Colliery, the roof is a massive conglomerate under only 100 m of cover beneath a residential area. They also develop large pillars (45 m centers), but then only Christmas tree down the entries, leaving 20x40 m pillars for permanent overburden support (figure 8). Again, three BLS are used in the lift. The major change here has been to support the roof with a standard bolt pattern, together with a scaling program. Previously, much of the mine was only spot-bolted.

Roof Monitoring: Australian coal mines make far more extensive use of roof monitoring than U.S. mines. Indeed, it seemed that several individual mines probably had more geotechnical monitoring installed than the entire U.S. industry. For example, one of the Queensland mines I visited installs a two-point tell-tale in every intersection. The stations are initially read daily by a shift boss, and plotted up in the mine office. If a station is observed to be still moving rapidly when the deformation reaches 40 mm, then cables or trusses will be installed. Reportedly, approximately 25% of all intersections at this mine require supplemental support. The same mine currently has two pillar stress measurement sites installed. On the other hand, about half of the mines visited only use geotechnical monitoring for "special projects" like longwall recovery rooms or driving through faults.

Table 2 lists roof monitoring "triggers" used by different mines. It is interesting that three of these triggers are based on the rate of roof sag, while the other two use a total sag criterion. Moreover, the trigger rates vary by an order of magnitude. Clearly, there is room for research to relate critical roof movements to geology and other factors. In the U.S., a typical trigger rate is about 5 mm/wk (Mark et. al., 1994).

Table 2
Roof Monitoring Action Points for Five Australian Mines

Coalfield	CMRR	Type of Criterion	Magnitude
Queensland	40	Total movement	40 mm
Queensland	50	Rate of movement	5 mm/wk
NSW - Northern	40	Rate of movement	10 mm/wk
NSW - Northern	40	Rate of movement	1 mm/wk
NSW - Western	35	Total movement	25-50 mm[1]

[1]Additional actions at 100 mm and 150 mm of total movement.

A number of different devices were used for roof monitoring, including an electrical system that uses a rheostats and was read by a tiny, hand-held LCD. Sonic probes are losing favor in some circles because of their price ($12,000 US), but they are still widely used for research and to determine trigger levels for tell-tales.

A most impressive monitoring system is being developed by Strata Control Technologies and Angus Place Collieries. It is an entirely permissible system that can be easily installed by the bolting crew. Each new station "daisy chains" to the previous one, and automatically identifies and initializes itself. The entire system can be tied into a computerized mine-wide monitoring system. The goal is to eliminate the need for specialists to install, read, and plot the data.

Microseismic Monitoring: Microseismics are being used for a number of issues in Australia. In the Lake Macquarie area, massive conglomerate main roof is a major concern for at least three longwall mines. At Newstan Colliery, extreme periodic weighting two years ago caused face falls that cost more than 6 months of production. Longwall panels at Newstan have since been limited to less than 150 m in width. The problems with periodic weighting at Newstan have already been mentioned. At the nearby Moonie Colliery, wind velocities of 40 m/sec were measured during a windblast event. Both mines are now using a South African microseismic monitoring system to warn workers of impending airblasts.

A 1998 paper by Kelly, et. al., describes microseismic studies at Appin and Gordonstone Collieries aimed at predicting water and gas inflows resulting from overburden response to longwall mining.

MINES INSPECTORATE AND SAFETY MANAGEMENT

According to Ian Anderson, Senior Mine Inspector in NSW, the basic qualification for an Inspector is actual experience as a Mine Manager. A degree in Mining Engineering is preferred, as is experience in mine rescue. The high level of training is necessary because Australian mining law gives the Inspectorate much more discretion than in the U.S.

There are few statutory safety requirements in either Queensland or NSW. Instead, the Coal Mines Regulation Act requires each Mine Manager to develop a set of rules that are appropriate for his operation. For example, Manager's Rules on roof bolting would include criteria as to when and where different bolt patterns are required. The Manager's Rules must be approved by the District Coal Mines Inspector. In addition, the plans for each new panel are submitted for approval.

In recent years, the trend has been to upgrade the Manager's Rules into Safety Management Plans (SMPs). SMPs were one of the recommendations that came out of the Moura disaster. The SMPs are Quality Assurance-type documents that are typically prepared for Spontaneous Combustion, Gas, Ventilation, Strata Control, Evacuation, Outburst, and Water (Reece, 1998). The SMPs define the range of hazards associated with each issue, and the necessary controls and procedures for management of the hazards. SMPs are very detailed. For example, the Strata Hazard Management Plan for the North Goonyella mine is 44 pages long. A typical format is:

- Hazard Identification and Control Procedure
- Monitoring Scheme
- Roles and Responsibilities
- Action Response Planning
- Training Requirements
- Corrective Action
- Review Procedures

The SMPs provide auditable procedures that allow stakeholders (workforce, mine management, shareholders, and Inspectorate) to scrutinize whether the objectives are being met. Of particular interest is that the SMP clearly defines the roles of every individual at the mine, when monitoring is to be used, and what the action triggers will be (Byrnes and Doyle, 1997).

MINING RESEARCH

Australia has an extremely vibrant, successful, and confident mining research community. In part, this may derive from the rapid growth of the industry over the past 30 years. The structure of mining research funding also facilitates the success of mining research.

The primary source of research funding since 1978 has been a $0.05/tonne levy on all black coal production. Under a Memorandum of Understanding with the Australian Commonwealth, the levy is administered by the Australian Coal Association through ACARP. ACARP identifies high-priority problems, and solicits research proposals in those areas. The proposals may come from government agencies, consulting groups, Universities, or mining companies. Cooperative efforts, with cost sharing from the private sector, are looked upon most favorably. Cost-sharing leverages the funding for a typical research project by a factor of 2.5 (Graham, 1998).

The ACARP approach has a number of significant advantages. The research is customer driven, not researcher driven. It helps researchers stay focused on real problems, and it helps keep consultants and company staff abreast of the latest technology. Currently, 68 mine sites are involved in research projects, and 114 company staff are involved in ACARP, either by participating in the project selection process, or as Project Monitors. It has been highly successful in breaking down barriers between government researchers, academics, and mining staff. The breadth of knowledge about mining research at all levels in the industry is truly admirable.

Probably the most significant advantage of the ACARP system is technology transfer. Because the ultimate customers are intimately involved with the entire research process, technology transfer begins almost with the inception of the project. Technology transfer is also built into every project. The result is a large number of successful products, and a dramatically reduced time lag between research and implementation.

Approximately 40% of ACARP's research budget is spent on underground mining (the rest is split between surface mining, preparation, and utilization). Strata control is the biggest single research area, with an annual funding in excess of $500,000. Current research areas include rib support techniques, roof monitoring, windblasts, and replacing primary support with secondary support.

One criticism of ACARP could be that the miner's union and the regulatory agencies do not have direct input into the project selection process. However, it seems that safety is still the primary research driver. Perhaps the reliance on self-policing through "manager's rules" has carried over into the industry-sponsored research program.

CONCLUSIONS

The first, obvious conclusion is that there are no unique "Australian" ground conditions, any more than there are unique "U.S." conditions. A wide variety of conditions are found in both countries. The mines under deep cover and high horizontal stress in the Southern NSW coalfield do seem to suffer more severe problems than are typical in the U.S., but U.S. counterparts come to mind for most of the other Australian mines.

The typical Australian mine uses a higher density of primary support than is common in the U.S. Three factors may explain this:

- Australian mines are less tolerant of roof falls;
- Australian mines have traditionally relied less on supplemental support in the tailgate; and,
- in Southern NSW, lower pillar stability factors may require more entry support.

It seems that there is currently some trend in Australia towards reducing primary support in favor of secondary support.

Another trend in Australia is towards experimentation with place-changing systems. However, the combination of low CMRR roof, two-entry mine layouts, inappropriate equipment, and a low tolerance for roof falls may limit the applicability of place changing. In many instances, the miner-bolter development system used in a number of Pittsburgh seam longwall mines may be a better U.S. benchmark.

There is also quite a bit that we in the U.S. might learn from Australia. Roof monitoring technology is far more advanced in Australia, for example. The Australian approach to safety management and integrating mining research into the industry also have a lot to commend themselves.

Finally, there are many areas in which we can learn from each other. Both countries have recently made valuable contributions in roof support technology, pillar design, and numerical modeling that are readily transferable across the Pacific. More interactions like this Conference could greatly benefit both countries.

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