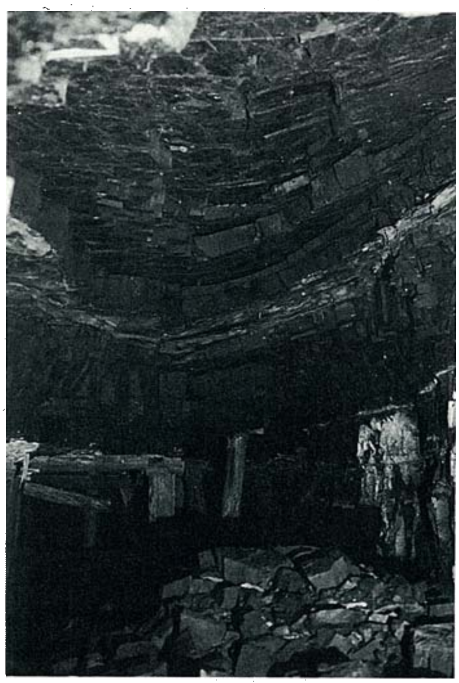
Winning more coal from underground mines

As the miners put it, coal irretrievably lost to recovery is 'sterilized'. It has been left in the mine perhaps because it would have been difficult to extract, because extraction would have destabilized the mine, or because roof falls or outbursts cut off access to it. The result is that, from the time underground coal-mining began in Australia in the early 1800s, more coal has been sterilized than has been brought to the surface.



A roof fall in a colliery in the Western Coalfield. The normal roof line is shown by the remaining roof supports at the lower left.

In round figures, that means more than 1000 million tonnes of this valuable resource have been rendered inaccessible to further mining. After examining old mine plans, a former member of the Joint Coal Board, Mr John Smith, now a company mining engineer, believes that the amount could well exceed 2000 million tonnes. The higher figure acknowledges the limited technology available in what was virtually a hand-worked industry until less than 40 years ago, and takes into consideration the losses due to fires, flooded workings, and other causes.

Today, Australian underground miners generally recover about 50% of a seam. A variety of geological, technical, and economic factors determine a particular mine's recovery percentage. Much of the coal, for example, must, for safety reasons, be left in supporting pillars. The Australian performance probably matches or exceeds that experienced in other mining countries.

Yet, whichever way we look at it, the loss is real and, in terms of national resources, regrettable. Australia has vast coal resources — estimated at about 200 000 million tonnes — but, increasingly, coal will be called upon to supply our expanding energy needs as oil becomes scarce.

In 1975–76 this country extracted 40 million tonnes of underground coal, about the same quantity as recovered from open cuts. By the year 2000 we will probably need to produce some 200 million tonnes annually. If oil-from-coal plants become established, that figure would rise considerably.

To satisfy demand, underground mining will, in the long term, remain a major source of supply, despite large new open-cut mines. Most of our high-quality coal lies at depths that are beyond the reach of open-cut techniques.

To keep the coal pouring out of the ground, voracious mining machines eat into the coal seam. Whereas in 1948, only 37% was won by machine, in 1977 the figure was 98·7%. Mechanization has meant that, during that time interval, production has more than trebled, the number of mines has halved, and the average scale of operations in each mine has therefore increased at least six-fold. However, mechanization does not necessarily avoid large proportions of coal seams becoming sterilized.

In a study by the Joint Coal Board, 48 of the 71 underground mines operating in New South Wales were examined in 1976 to determine the proportion of the coal seam they were recovering. (The survey did not include any mines that had been worked out, abandoned, or closed for any reason.)

The following significant conclusions emerged from the study:

- ▶ 24 mines (half of those examined) are mining less than the full height of the seam, the proportion of seam height worked going as low as 30%.
- ▶ Of the seam height worked, mining recovery varies between 30 and 80%.
- ▶ Considering all the coal in all the working seams studied, mining recovers between 17 and 80%, with the mean at 47%.
- ▶ After washing out rock and other impurities from the coal, the saleable recovery of the seams worked varies between 12 and 75%, with a mean of 40%.

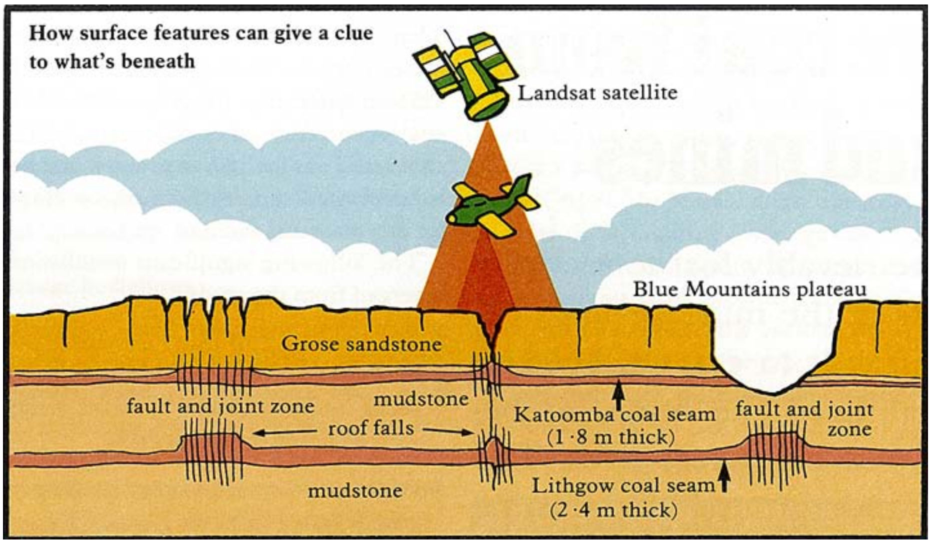
Most of our high-quality coal lies at depths that are beyond the reach of open-cut techniques.

The survey also showed that, in possibly five cases, workable virgin seams had been sterilized by nearby underground mining activities.

To date, miners have naturally attacked the easy stuff — coal seams at shallow depths in good stable environments. When that coal has been recovered, mining companies have to tackle the more difficult deposits, which are generally deeper and hence subject to greater pressure and likelihood of roof failure. This will make it difficult to improve coal recovery rates.

What's going on?

The earth hundreds of metres below the surface is under considerable stress. When a miner extracts the coal, he leaves a cavity around which these stresses must be redistributed. To help keep the roof up, he gives it support in the form of wooden posts and steel beams. Rock bolts driven into the roof overhead often help in poor roof conditions, and wire



In the Western Coalfield near Lithgow, N.S.W., the scientists have correlated numerous surface features with bad roof conditions in the mine.

mesh is also employed. A problem is that it takes some time to erect these supports. Often a weak roof will collapse before it can be trussed up, and gas outbursts usually give no time at all to act — they blast straight out from the working face.

A supported roof can collapse too, but then the warning signs are often there to be observed: the roof will crack and groan, the supporting posts will begin to bend, and their bottom ends, deliberately sharpened, will begin to splay.

Miners have their own terms to describe bad roof conditions, and the novice soon learns to correctly identify scaly roof, heavy roof, very heavy roof, gutter falls, dome falls, and other manifestations of deteriorated roof conditions.

Even with today's mechanized mining techniques, bad roof conditions are to be avoided whenever possible. Unstable roofs demand that miners make more effort to support the roof, and rates of advance can slump from a standard 10 m per shift to 1 or 2 metres. Costs in lost production and extra work can be severe.

To date, miners have naturally attacked the easy stuff.

In most collieries, it is very expensive to abandon one working face and drive a new heading. If bad roof zones are unexpectedly encountered, the mine layout may have to be changed, involving the withdrawal of the big mechanized miners from the face, re-laying tracks and services, and opening up a new line of development.

If roof conditions deteriorate sufficiently, mining becomes unprofitable and the workings may need to be abandoned.

Research to help

Against this backdrop, research is helping to improve the efficiency of extraction of coal and to make the job safer and easier. Scientists are assisting the mining engineer to predict the location of bad roof conditions (and hence avoid them), to predict imminent roof failures and gas outbursts, and to develop new mining methods. Among the researchers involved in this work are scientists from the CSIRO Institute of Earth Resources, and descriptions of some of their studies follow. Some of the research receives funding support from the National Energy Research Development and Demonstration Council, as it is recognized that an increased level of research into coal extraction is a way of making better use of our energy resources.

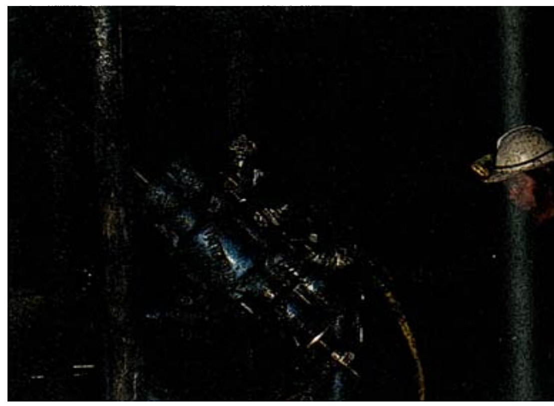
The CSIRO Division of Applied Geomechanics has been involved in the study of mining problems for a decade, but only in the last few years has the Division, in addition to its research in metalliferous mines, directed its efforts to the difficulties peculiar to underground coal-mines. Many of the geomechanical factors involved are similar; others differ considerably. As coal is much softer and more elastic than ore and can contain methane or carbon dioxide, the pressure underground imparts more energy to it. As a result, outbursts are likely to be more dangerous to miners than rock bursts in metal-mines.

Then, of course, coal-mines work in generally horizontal seams, whereas metalliferous mines tend to the vertical. The geophysicist therefore must exercise his scientific principles in significantly different ways. Results to date have been encouraging, and we will look at some of them below.

Under we go

One of the Division's high-priority areas is study of the causes of outbursts, because the difficulty of predicting them makes them particularly troublesome. Fortunately, gas outbursts do not affect every coal-mine, but as mining progresses to greater depth, overseas experience indicates that the problem will worsen.

Outbursts currently occur in two main areas: the Southern Coalfield in the Sydney basin of New South Wales, and the Bowen basin in Queensland. In the Southern Coalfield, new mines are presently being developed at depths of 500 m. In the Bowen basin, underground mines are encountering outbursts at depths as little as 200 m.

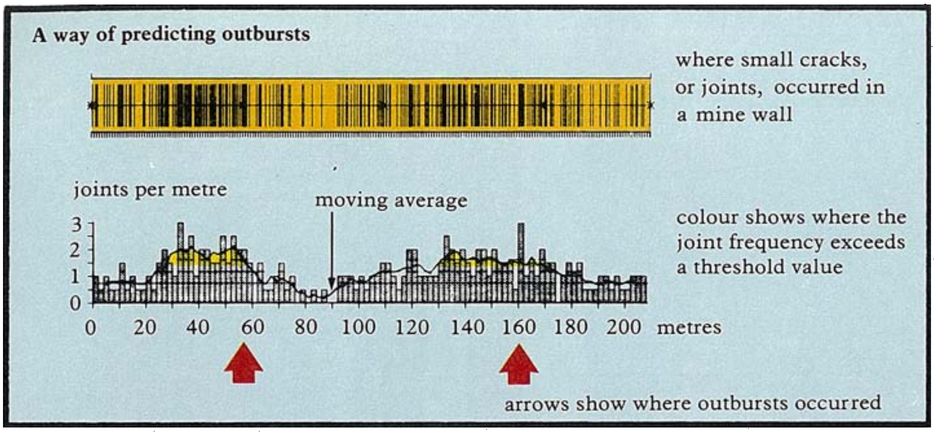


To measure stress in the rock above a coal seam, a mining engineer from CSIRO, Mr Jim McKay, uses a pneumatic drill to make a hole in which he will locate stress gauges.

Some mines that experience outbursts have adopted the precaution of measuring the flow of gas from holes drilled into the work face. If the amount of gas becomes excessive, extra holes may be drilled or a charge detonated to relieve stress and diminish the gas pressure. The drawback to this approach is that it interrupts production.

Mechanization adds to the difficulty of detecting imminent outbursts. Continuous miners — wheeled machines with a rotating array of teeth at the front that bite into the coal seam — provide rapid coal extraction, but their noise swamps the warning sounds that old-time miners could listen for.

Mr Byron McKavanagh (now at the University of Queensland) and Mr Jim



If, as mining progresses, a constant check is made on the number of small cracks, or joints, encountered in the coal, outbursts can be anticipated. If the number of joints exposed per metre exceeds a certain threshold, an outburst can be expected ahead.

Scientists are assisting the mining engineer to predict the location of bad roof conditions (and hence avoid them).

Enever of the Division have developed a 'microseismic' warning system that becomes the 'ears' for the modern miner. Using a microphone embedded in the coal face, the system constantly listens for the low-level high-frequency sounds (between 8 and 50 kilohertz) that signal coal under stress. Mining noises, generally between 0·1 and 2 kHz, are ignored.

A similar method has been used in Poland, Russia, and the United States for warning of rock bursts and roof falls. Taking their equipment to a colliery in the Southern Coalfield of New South Wales, Mr McKavanagh and Mr Enever wanted to see what it could do in an Australian coal-mine.

Mining there is conducted at a depth of nearly 500 metres in a 2·5-m seam of bituminous coking coal. Although the mine has only been operating 3 years, it has experienced many instantaneous outbursts during its short history. An average outburst displaces about 40 tonnes of coal into the workings. The main dangers are the sudden movement of the continuous miner and burial in the powdered coal. However, substantial quantities of gas are emitted, and this may pose a ventilation problem in some enclosed areas.

The research pair monitored a total of 30 mining shifts, during which they were lucky enough to record five separate outbursts, of varying intensity. Analysing the records, it seemed that four of the five outbursts could have been predicted. Apparently, following a short period of high noise level, the coal goes quiet just before an outburst, so the researchers suggest that a practical automatic warning device could watch out for this phenomenon. The device could be mounted on the continuous miner and give the operator a warning light or sound whenever the noise count dropped to a low level.

Mr John Smith of the CSIRO Fuel Geoscience Unit has also been involved over recent years in examining this problem at the same mine. Mr Smith has concentrated his efforts on analysing the gas from different parts of the mine, and has come up with another distinguishing feature that he suggests may warn of a potential outburst.

How underground coal-mining has changed in New South Wales

	1948	1977–78
production, raw tonnes	10·5 million	37·9 million
number of employees	17 283	15 131
number of mines	138	73
raw tonnes per man-shift	2·97	10·4
percentage won by mechanization	36·7	98·7
percentage won by continuous miners	nil	92·1
percentage won by mechanized long-wall	nil	4·2
percentage won by other mechanization	nil	2·4

Mechanization has increased production, but the proportion of coal 'sterilized' (irretrievably lost to recovery) still stands at about 50% of a seam.

Mr Smith recognized that gas from outburst-prone zones is, compared with that in more stable parts of the mine, relatively rich in carbon dioxide (more than 2% and up to 70% by volume) and correspondingly depleted in methane. This is a good pointer, but by itself it is too broad a criterion on which to base a prediction. A further pointer derives from the isotopic composition of the gas. It seems that the amount of carbon-13 in carbon dioxide from outburst-prone sections is less than elsewhere. Taken together, these two indicators could give useful warning signs.

Faults and outbursts

On another front, this time the geological, the mine has been surrendering more of its secrets to Dr John Shepherd and Mr John Creasey, of the CSIRO Division of Mineral Physics. They have found that outbursts generally occur when mining reaches within 4–5 m of certain types of faults. Once an 'outburst zone' has been uncovered, the approximate location of similar zones in adjacent workings can be estimated by noting the direction of the fault. The scientists have also uncovered geological features that allow them to forecast the appearance of an outburst zone up to 45 m away.

The faults near which outbursts occur are always 'strike-slip' ones, in which material on one side of the fault has slipped, usually less than half a metre, relative to the other.

The tell-tale features that spread much further from the outburst zone are numerous natural cracks called joints. Dr Shepherd and Mr Creasey discovered that the spacing of these joints becomes markedly reduced near strike-slip faults. Sometimes the joint spacing is 6–8 times less when a strike-slip fault is coming up.

The various lines of research therefore point to a broad set of guidelines. If all the warning signs are heeded and one or two monitoring techniques employed, it should be possible to considerably reduce surprise outbursts.

Dr Shepherd and Mr Creasey have also investigated mines around Lithgow, which were having problems — not with outbursts, but with bad roof collapses. Here in the Western Coalfield of New

The nether world of a coal-mine.

South Wales, some workings have been abandoned because reserves could not be reached across bad roof zones. Could such areas be predicted so that mine management could avoid them when laying out the design of the mine?

Indeed, once again the researchers were able to associate areas of many small joints and faults (a 'swarm') with bad roof conditions. They found that underground mapping of these joints could give a short-range prediction that, if the frequency of the joints rises above 4–5 per m, potential mining difficulties are likely.

Better still, a technique allowing long-range prediction of bad mining conditions was developed. It depends on aerial photography and Landsat satellite pictures, to find surface fracture traces that can be projected down into a virgin coal seam.

In this work, a colleague, Dr John Huntington, contributed his expertise in enhancement and interpretation of aerial images. He found one trace of a fracture 25 km long, which crossed old coal-mines that had been forced to skirt around its zone of influence. In one case, a mine was abandoned because of the influence of a fracture. When opening up a new mine or heading, then, the scientists suggest that mining companies should not venture into areas beneath surface features that indicate a severe fault.

To give odds on the strength of their advice, the researchers note that, of all those examined, 73% of the bad roof zones coincided with fault and joint swarms, and 60% with individual large faults that could be detected on aerial and satellite photographs.

Rocking the rock

One of the earliest methods miners used to gauge the integrity of a roof — and one commonly used by miners today — is tapping the roof with a bar or hammer. Miners know that intact rock responds with a high-frequency sound and detached rock gives a dull response. The difference resembles that between a good bell and a cracked one.

The aim of work being done by Mr Tony Siggins of the Division of Applied Geomechanics is to extend the method and to make it less subjective and more scientific. The technique calls for a vibration generator and a detector implanted in the mine's roof (either coal- or any other sort of mine for that matter).

He at first considered using an ultrasonic technique, which relies on reflection of the ultrasonic vibrations from cracks and joints to define a potential failure zone. However, high-frequency vibrations are absorbed quickly with distance, and, as most rock contains imperfections on both a small and a large scale, interpreting the results is difficult.

The alternative is to use sounding frequencies in the audible range. Vibrations of these frequencies penetrate deeply and it is possible to characterize a particular region of the mine environment by its resonances and damping behaviour.

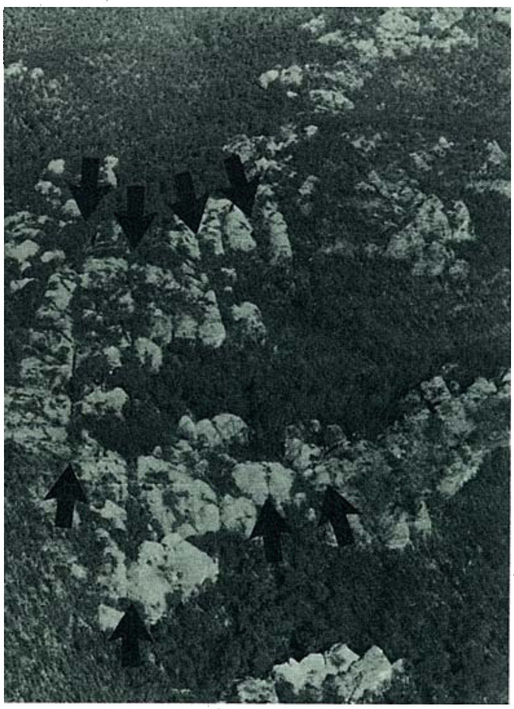
A mathematical analysis showed Mr Siggins that, as cracks develop in rock due to stresses on joints and bedding planes, the natural frequencies of the rock mass become lower. Thus, the idea is that detection of a decrease in a rock mass's resonant frequency will indicate that failure is imminent. Trials in mines are now under way.

Alternative mining methods

The most common mining technique is known as bord-and-pillar mining, wherein a criss-cross pattern of tunnels (bords) is driven to leave a regular pattern of pillars. Coal in the pillars may be recovered during a second extraction. The roof material is then allowed to subside in a controlled manner. The Wongawilli system, a modification of the bord-and-pillar system, was developed in Australia in the 1960s. The system has resulted in higher seam recovery and the successful extraction of coal at depths as great as 550 m.

However, both these techniques and others now in use can lead to significant amounts of coal being left behind, particularly in difficult mining conditions, and alternative techniques offer possibilities of higher total recoveries. 'Long-wall' mining, in which continuous thin slices are extracted from coal faces up to 130 m long, is not common in Australia, but is gradually being introduced. The greater coal recovery can repay the high initial cost.

Yet, even with long-wall mining — in certain situations, such as with thick, deep, or irregular seams — significant losses can occur. There is a need to in-



The arrows point to surface fractures in this low-level aerial shot of an area in the Western Coalfield. The fractures relate to bad roof zones in the mine beneath.

troduce new methods and to improve existing ones. Mr Jim Enever and Mr Chris Rawlings, of the Division of Applied Geomechanics, are conducting studies aimed at assisting the industry to choose the most suitable methods for specific areas.

Their research involves modelling of new or modified systems, and collecting data from the field with which to compare the information obtained from the models. Mathematical models are being used, for example, to evaluate the stability of pillars used in long-wall mining. They can give valuable guides to mine planners.

Members of the Division have built a large test frame in which they can place a model of part of a mine, built with synthesized coal-mine materials. Numerous hydraulic rams on the edge of the frame can subject the model to a force of 6 meganewtons. The team is currently studying the loads that could occur at the coal face in long-wall mining. The actual loads during mining will be monitored for comparison.

Some workings have been abandoned because reserves could not be reached across bad roof zones.

The future

In the short term we can expect to see much more reliance put on open-cut mining, since this method is cheaper and total recovery can be about 90%. However, in the long term this is not the answer to low underground recovery factors. There will be more open cuts and they will go deeper (China proposes to mine an 85-m thick seam at Fushun, presently being open-cut mined at a depth of 280 m, down to a depth of 500 m by the same method).

Nevertheless, the fact remains that the great majority of our coal resources, perhaps 85%, lie at depths that can only be worked by underground methods, even allowing for advances in open-cut technology.

For a long time to come we will continue to rely on the underground miner, and his expertise, for the winning of our black coal inheritance.

Andrew Bell

More about the topic

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