KEYNOTE ADDRESS

A REVIEW OF INSTANTANEOUS OUTBURST DATA

by

ALAN J. HARGRAVES[1]

ABSTRACT

The problem of instantaneous outbursts remains unsolved after over a century of events and the investigation of the mechanism of the phenomenon and means of treating it. Outbursts have occurred of up to 5,000 tonnes with perhaps up to 500,000 m^3 of accompanying gas, either methane (CH_4) or carbon dioxide (CO_2) or mixtures. The low density of CH_4 and the high density of CO_2 give particular problems. Australia with both gases has experienced outbursts for 85 years with fatalities as recent as 1978.

The Bulli Seam of the Illawarra area of the Sydney Basin is affected and outbursts with both CH_4 and CO_2 occur. The Northern and Central Bowen Basin also experiences outbursts with both gases. Proneness of affected mines is related to the high rank of the coal and the proneness of the seams is localised according to depth, gassiness, structure and development geometry. Proneness may be reduced by appropriate choice of mining methods. In addition to outbursting mines other mines have symptomatic phenomena. Traditional preventive methods have been used and control by inducement has been practised. A method of local prediction for widespread use has not been achieved although locally successful prediction is claimed - methods based on prediction of structure, assessment of gassiness and analysis of microseismic events.

The large amount of world research achieved over the last century and in the past 25 years in Australia particularly has reinforced the complexity of the problem and the need for the strongest research efforts to solve it whilst mining becomes deeper and more mines are expected to become prone. Past work has so far not ruled out any of the visible lines of research into this problem and much remains to be done

[1]Superintendent Rock Mechanics and Strata Control, The Broken Hill Proprietary Company Limited, Steel Division Collieries, Wollongong, N.S.W.

INTRODUCTORY

Perhaps after 25 years of studying the problem of instantaneous outbursts of coal and gas, one way of reviewing this period would be to present a bibliography. But, apart from some case histories and a little original work, it would largely be a list of potboilers for there has been no real breakthrough in this period. In fact a bibliography recording the past 100 years of study of instantaneous outbursts would be similarly disappointing. With a century of progress in coal production techniques, including intensive mechanisation, instantaneous outbursts still occur. There is no simple litmus test to identify with certainty that a coal is outburst prone. There is no simple alarm device to give adequate warning time of an impending outburst in a place. The understanding of the mechanics of

The Aus. I.M.M. Southern Queensland Branch, The Occurrence, Prediction and Control of Outbursts in Coal Mines Symposium September, 1980

the phenomenon is lacking. Theories abound. The uncertainty still exists. But to say more than that an instantaneous outburst is a gas and stress phenomenon is going too far without risk of challenge. We are still learning, but disappointingly slowly.

In 1960 an international mining magazine, under the heading of "Safety Device for Coal Mines" reported 'An apparatus making it possible to forecast, at least six hours in advance, any sudden eruption of coal and gas, always a danger to miners, has been designed by a Moscow scientist, Mikhail Antsiferov. The build-up of this phenomenon causes crackle in the coal layer, which becomes stronger as the moment of eruption approaches, when the accumulated CH_4 gas in the layer forces the coal towards the face. This crackling is accompanied by the radiation of microseismic waves - and it is on the registration of these that the apparatus is based. Antsiferov's "geophone", if placed in the layer, is able to detect the slightest sound oscillations in the rock. In registering them, the geophone produces electric impulses which are passed through an electronic amplifier to a tape recorder. The operator watches the intensity of the crackles. If their number exceeds the norm, it indicates an impending eruption. It is therefore possible to evacuate the miners from the face in good time.'(Anon., 1960). Unfortunately the U.S.S.R. enthusiasm for this principle was premature, and many instantaneous outbursts with fatalities have occurred in U.S.S.R. since 1960.

In Australia in 1978 it was published that "scientists have gained an understanding of the mechanisms that cause outbursting. They are using a range of monitoring techniques to provide warning of impending outbursts". Unfortunately, two months after that publication two men died in an Australian instantaneous outburst and other, non-fatal outbursts have occurred without warning since.

In this problem which has defied understanding and prediction sufficient for safety over the past century there is no room for immodesty. There is no room for false security deriving from the enthusiasm of journalists. There is an urgent need for modest and diligent work, aided by present sophisticated scientific developments. By modesty, frame of mind is implied, not extent of work which, to judge from the amount done already without great success, could well be enormous.

The tendency to regard the maximum size of previous outbursts as the maximum size of future outbursts is an attitude fraught with danger. Likewise even outbursts regarded as small may involve hazards seemingly out of proportion to their size.

Perhaps the most spectacular outburst recorded was of 1,270 tonnes, at the Ricard Colliery in the Cevennes Basin, France at a depth of 800 m in 1938 (Chaineaux, 1947). Shotfiring comprising eight 1.8 m holes with a total of 2.25 kg of permitted explosive was thought to have caused an outburst (heard in the surface shotfiring station through a telephone off-the-hook near the face shot). About five minutes later at the collar of the downcast shaft there was a violent rush of air, quickly followed by fume or dust and a greater flame. About 30 minutes after the shots, the upcast fan was stopped and the shutter in the upcast was closed. Figure 1 shows the height of the flame (which burnt for seven hours) with the passage of time. The outburst initially reduced the depression at the Gouffre (upcast) shaft from 160 mm to 125 mm.

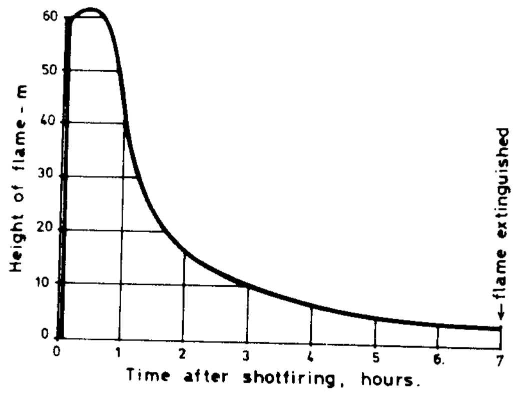

Fig.1 Ricard Shaft-1938 - height of flame above collar

The cause, and location of the subsequent ignition is uncertain. Altogether, a total emission of 400,000 m^3 of CH_4 was estimated. Apparently the seam gas composition was approximately 9% CO_2, 91% CH_4.

Whereas outburst CH_4 has the added danger of ignition, as exemplified in the Ricard and other experiences, it is virtually physiologically inert. CO_2 on the other hand is debilitating in air at concentration below the minimum explosive percentage of CH_4, added to which, because of higher sorptive capacities, more CO_2 appears to be outburst. With destruction of ventilation structures near the site of a major outburst, with slower diffusion characteristics of CO_2 relative to CH_4, the heavier CO_2 tends to move towards and remain in the bottom of the mine or in a dip place. This was the experience at 200 m depth at Collinsville in 1954 when seven miners and two horses perished (Queensland Govt., 1956). Had it been CH_4 without ignition, some or all could have survived.

A similar circumstance in the Isere, France, of an outburst with CO_2 at 400 m depth trapped eight miners in the bottom of the mine. The ventilation fan could not cope with the dense, almost pure CO_2, and special extractors were needed to progressively remove it from the mine and cope with the continuing make of CO_2. A 300 m column of CO_2 was equivalent to a depression of 200mm of water (Cognet, 1946). The 1,000 tonnes of coal were accompanied by 10,000 m^3 of CO_2 and the continuing CO_2 make with time is shown in Figure 2.

To go in this vein and to detail the various outburst disasters might be construed as discouragement to the mining of outburst prone seams, but this is not the intent. The intent is to dispel any oversimplification of the problem and to encourage the broadest research, particularly as the most apparent lines of research are already under continuing

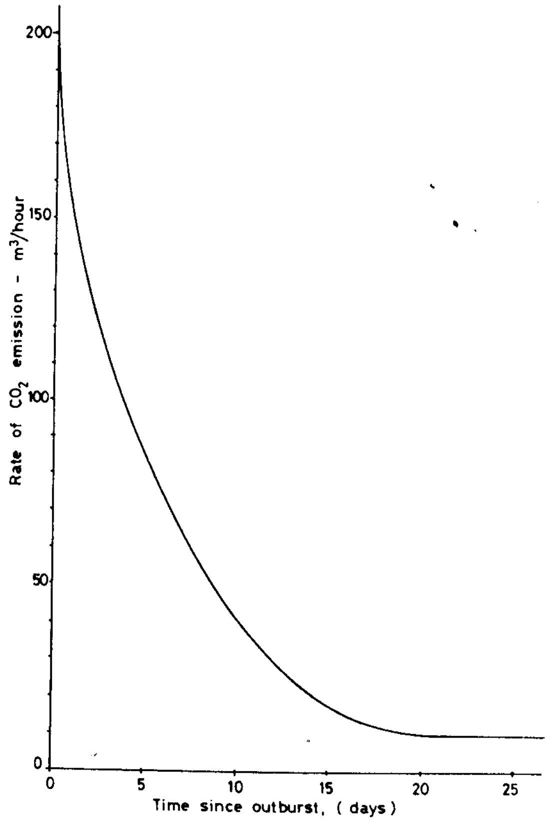

Fig. 2 Make of CO_2 following outburst, Rioux Shaft, Isere. 1946.

study. An instantaneous outburst is a phenomenon during active face advance, and hence the best conditions for field research are only provided when mining is actively going on. To give up because of outbursting problems is virtually to close an outburst research laboratory. This was the situation at the Collinsville No. 1 Tunnel throughout the 1960's and 1970's.

In summary, some large outburst disasters are shown in Table 1.

AUSTRALIAN EXPERIENCES

Australia has documented experiences of instantaneous outbursts commencing at Metropolitan Colliery (Sydney Basin) in 1895. Until 1954, when both Metropolitan Colliery and Collinsville State Colliery (Bowen Basin) experienced fatal outbursts, Metropolitan had been the only colliery affected, except a single reported occurrence at North Bulli Colliery in 1911 (Hargraves, 1965a). In retrospect it appears possible that, in the period to 1954 other deep and gassy mines have been affected with marginal phenomena, unrecognised at the time. 1954 marked the beginnings of promotion of research into the phenomenon by Hebburn Ltd., operators of Metropolitan, and by the Department of Mines, Queensland. In subsequent years promotion of research was taken up by The Joint Coal Board, The Queensland Coal Board, The Broken Hill Proprietary Co. Ltd., Bowen Consolidated Coal Mines, etc. and was conducted by The University of Sydney, Australian Coal Association (Research) Ltd. and the Department of Mines, N.S.W. With the passage of years other mines in the Sydney and Bowen Basins have been affected, and the present state of outburst experience in Australia is summarised in Table 2. The Coalcliff and North Bulli occurrences, all on dyke intersections, are regarded as marginal. Other marginal and suspect occurrences more remote from established occurrences have been excluded. Without exception, all outbursts have occurred in heading work.

Additionally, some apparent outbursts have occurred in surface exploration rotary boreholes; in 1958-1959 in the Sydney Basin Mulgoa No. 2 Bore at depth 790 m in the Middle River Seam and 1080 m in the Tomago Seam, with coal and firedamp, and in 1960 in the Bowen Basin, NS 275 Collinsville Bore in the Murray Seam at 305 m with coal and firedamp (Hargraves. 1965a).

The initial major impetus of Australian research was to mine safely as an immediate

TABLE 1

Some large outburst disasters

Mine	Country	Date	Gas	Tonnes coal	Estimated m^3 gas	Fatalities	Remarks
Agrappe	Belgium	1879	CH_4	?	340,000	141	Explosion and fire
No. 1 Morrissey	Canada	1904	CH_4	3500	140,000	14	Suffocated
Wenceslaus	Poland	1930	CO_2	5000	28,000	151	Suffocated
Ricard	France	1938	CH_4	1270	400,000	2	Explosion and fire
Istvan	Hungary	1957	CH_4	1400	273,000	?	Ventilation reversed

Table 2

Summary of Australian Outburst Experience

Date	Colliery	Basin	Seam	VM%/ afd	Depth, m	Number	Max Size Tons	Gas	Work Phase
1895+	Metropolitan	Sydney	Bulli	18	400 -450	15	200?	Firedamp	Pick
1925	Metropolitan	Sydney	Bulli	22	400	1	140	Blackdamp	Single Shot
1949	Metropolitan	Sydney	Bulli	22	425	1	5	Blackdamp	Undercutting
1954	Metropolitan	Sydney	Bulli	22	425	1	90	CO_2	Undercutting
1961+	Metropolitan	Sydney	Bulli	22	425	many	300?	CO_2+mixed	Inducer Shotfiring
1911	North Bulli	Sydney	Bulli	25	370	1	1	Firedamp	Pick-delayed
1961	Coal Cliff	Sydney	Bulli	22	450	2	2	Mixed	Continuous Miner
1967	Corrimal	Sydney	Bulli	24	400	3	50	Mixed	Continuous Miner
1969	Appin	Sydney	Bulli	23	520	3	60	Methane	Continuous Miner
1972	Bulli	Sydney	Bulli	12	380	1	100	Mixed	Continuous Miner
1977+	West Cliff	Sydney	Bulli	23	460	100+	130	Methane	Continuous Miner
1954	Collinsville State	Bowen	Bowen	22	180	1	400	Blackdamp	Single Shot?
1960	Collinsville State	Bowen	Bowen	22	180-200	6+	360	Blackdamp	Inducer Shotfiring
1978	C.C.C.P.	Bowen	Bowen	23	280	1	25	Blackdamp	Continuous Miner
1975+	Leichhardt	Bowen	Gemini	23	370	many	500	Methane	Continuous Miner Inducer Shotfiring

requirement and to develop safe means of continuous mining as the long term objective. Thus inducer shotfiring was introduced (Hargraves et al., 1964) (Hardie and Hargraves, 1960). Then experiments with large diameter holes with inducer shotfiring to establish preventive effects were undertaken. In the absence of overseas criteria of patterns of large diameter boreholes for prevention in headings extensive experiments were conducted at Metropolitan Colliery with holes of progressively greater diameter - ultimately to 600 mm - with concurrent monitoring for degassing (by gas pressure and by emission testing) and destressing (by stress change measurement) ahead of the heading faces (Figs. 3 and 4). Then after establishing that the gas pressure in the centre of a large pillar was low compared with virgin gas pressure the pillar was split by continuous mining (Fig. 5). As a result of this work the following conclusions were drawn:-

1. Two 300 mm diameter holes drilled adjacent to the rib line prevented explosive inducement of instantaneous outbursts in an area regarded as highly outbursting.

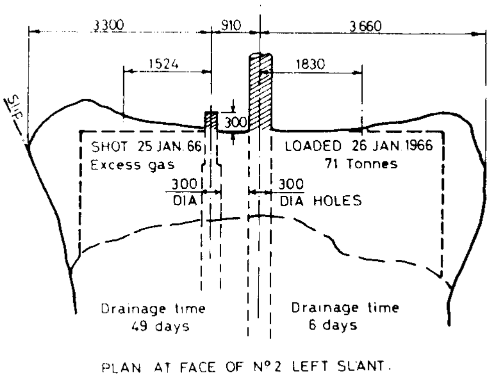

Fig.3 Example of inducement with insufficient 300mm dia. preventive holes.

2. Small outbursts were induced in sides of faces containing central single 300 mm and central single 450 mm diameter holes.

3. Considerable gas drainage was indicated by the fall of gas pressure with time at a point between 10-14 m depth, which was remote from the 300 mm diameter hole and not in the same plane in the seam. For example, at 2.7 m from a 300 mm diameter hole the gas pressure may be reduced from at least 25 kg/cm^2 to 5 kg/cm^2 with 60 days drainage.

4. Although the experimental results show the 300 mm diameter holes to have an immediate though small stress-relieving effect, at present they do not allow accurate specification of this stress relief.

5. Occasional bumping and crackling within the hole and its occasional substantial enlargement (300 mm to 750 mm diameter) during drilling confirm qualitatively that stress relief takes place. Considerable hole collapse and audible stress relief

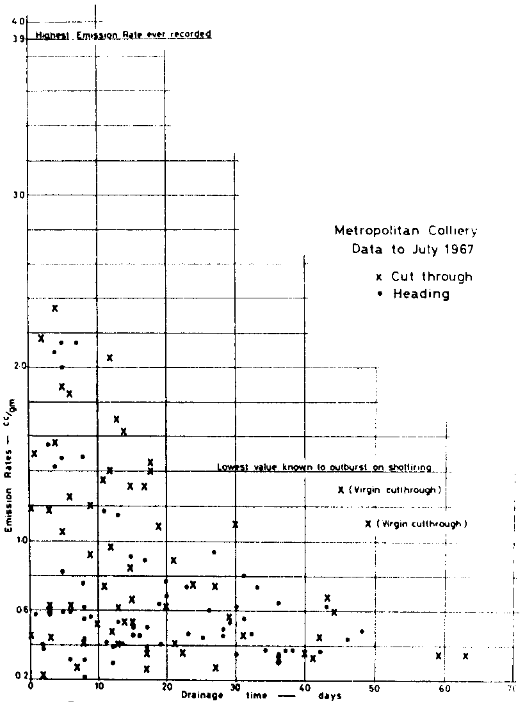

Fig.4 Emission Rates relative to Drainage time in face with two 300mm dia. ribline holes.

would be more likely in outburst-prone zones weakened by slips, faults and dykes.

6. While it has been possible to locate the face abutment between 3-9 m, lesser abutments parallel to the 300 mm diameter holes are assumed without knowing their distance from the holes. The 2.7 m drainage range mentioned above indicates that this assumed abutment is insufficient to prevent effective lateral drainage.

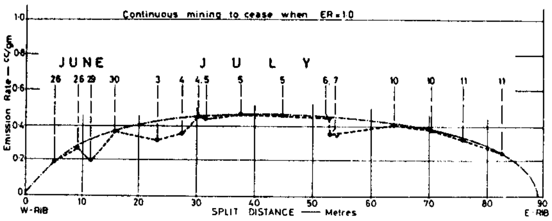

Fig.5 First use of Continuous miner in development (pillar split) at Metropolitan Colliery
(Pillar dimensions 88 m × 250m. West rib exposed 6 years; East " " 23 ")

7. Empirical results suggest that single 300 mm diameter holes have an immediate 1.5 m range of preventive effect, and hence this parallel abutment may be at this range.

8. One hole along each rib in a normal width place has a progressive drainage effect on the intervening coal and apparently has some modifying effect on the (assumed) parallel abutments between the holes.

9. There is a relation between the emission rate of coal and subsequent induced outbursting. There exists a limiting emission rate of 1.4 cc/g below which outbursts have not been induced.

10. No relation has been established between maximum gas pressure measured under standard conditions and subsequent induced outbursting.

11. Holes 300 mm diameter reduce the emission rate of the surrounding coal with time. In the gassiest circumstance, after a period of approximately 60 days, the emission rate of coal in the working place appears to be reduced below 1.0 cc/g.

12. The empirical results suggest that it may be possible to commence continuous mining in development immediately after places are drilled with two 300 mm diameter holes. This is normally the case when the large-hole system is used overseas, i.e. there is no elapse of waiting time.

The successful introduction of continuous mining in development at Metropolitan Colliery followed, with prevention by 300 mm holes. The beginning of this practice is chosen as the end of early Australian experiences, and subsequent specific mining developments are largely left to other authors.

PRONENESS OF SEAMS

It is apparent that the higher the rank of coal the more prone it is to outbursting. It seems that this proneness lies in the higher capability of a coal to sorb gas with increase of chemical rank as defined by V.M.% a.f.d. Possible differences in the parameters of physical rank at any one chemical rank may explain variations in proneness within the one chemical rank. Some workers have referred to coal type as a basis for proneness (Hargraves, 1958) but there appears to be no substantiation of this in Australian experience. The higher sorptive capacity of coal for CO_2 than for CH_4, no doubt explains the greater violence and the greater apparent proneness of outburst with CO_2. Accepting than an outburst is a gas and stress phenomenon the strength and elastic moduli of the coal are no doubt involved in the fracture mechanics. Physical rank and strength are related. In general, rank increases with depth of cover. Stress increases with depth due to greater confinement and superincumbent load and hence proneness is related to depth. Some seams are badly damaged by prior geological history and an entire seam virtually may become a structural anomaly; to this extent structure affects the proneness of whole seams. Whereas it is generally accepted that only seams of high rank are prone to outbursts, there are exceptions where seams of lower rank are subject not only locally, where the rank is increased by intrusion (Ettinger and Lao-Tchi, 1959), but inexplicably in the case of some very low rank coals (Jovanovik et al., 1979).

The ΔP index, determined by laboratory test, indicates the proneness of a coal to outburst. It has been found to be particularly useful in European coal environments where sometimes 20 or more seams may be worked or considered for working in the one area. Under these circumstances, foreknowledge of seam proneness is not only useful to decide whether the precautions against outbursts are to be adopted in working the seam, but also particularly in selecting a non or less-prone seam as a protective seam for prior working, even to the extent of giving consideration to working underlying seams first, because of their greater range of protection (Hargraves, 1973), despite the general mining disadvantages.

Table 3
Instantaneous outburst proneness relative to nature of mining - a comparison with rockbursts

Nature of work	Instantaneous outbursts		Rockbursts
	Proneness	World Events	Proneness
Exposure of seam (shaft, cross-measure)	1 (greatest)	Many	5
Drivage in seam	2	Very Many	4
Longwall advancing	3	Some	3
Longwall retreating	4	Almost none	2
Pillar extraction	5 (lowest)	Almost none	1

PRONENESS OF PLACES

Whilst the most prone circumstance is cross-measuring or sinking into a seam (Table 3) there are in Australia no records of such occurrences. The generally flat deposits with a minimum of faulting limit the number of seam intersections under Australian conditions. The only Australian instantaneous outburst occurrences have been in heading development, the second most prone circumstance. The next prone circumstance, advancing longwall, has not been practiced in Australia due to the general thickness of the seams and to the unavailability in thick seam mining of material for packwall building. The recent innovation of concrete slurry pumping for rapid production of pack-walls now makes the consideration of longwall advancing a possibility (Hargraves, 1977) as a means of reducing the amount of higher proneness heading work.

Instantaneous outbursts are virtually absent in pillar extraction (Table 3). Panel pillars are virtually winded of gas within six months of formation (Hargraves, 1973). Gas occurring with bumps during pillar extraction (Talman, 1954) derives from relieved adjoining seams (Hargraves, 1973).

The proneness of places is markedly increased by intersection of geological structure particularly faults and, for instance, the only examples of outburst inducement at the Collinsville State Colliery (Table 2) were on fault intersections, whereas a similar method of inducement at Metropolitan Colliery, admittedly at greater depth, resulted in frequent inducement of outbursts even where faulting was sparse (Hargraves et al., 1964). The marginal examples in Table 2 of North Bulli and of Coalcliff were on dyke intersections, also effective in increasing proneness. The relationship between proneness of heading work and of longwall advancing work (Table 3) is an extension of the increase in proneness with the decrease of width of heading places. This may be related also to the increase in proneness from working only the partial thickness of a seam. The gassiness of a place has been shown to increase as the place advances and the greater the rate of advance the greater the increase in gassiness of face coal. Further it has been shown that the occurrence of outbursts has increased in probability in later days of the working week whereas there has been a decrease on a Monday following two days of non-production (Hargraves, et al., 1964). A corollary to this is that rate of advance increases proneness and this has been recognised in overseas outbursting mines by limiting daily rate of face advance (Hargraves, 1965b). Overall geometry has an effect on proneness and development in the abutment of adjoining workings, whether in the working seam or an adjoining seam, creates an increase in proneness. Extension of gateroads ahead of an advancing longwall face traverses the front abutment of the longwall. Hence the extension should be very short, or should extend beyond the highly stressed front abutment to avoid significant increases in proneness in gateroad advance.

The practice of prior protective seam working - especially if it can be done in a benign seam - gives security from outbursts in the working seam as discussed above. Working an underlying protective seam first should only be considered when the problems of outbursting are judged to outweigh the problems of working in a seam previously undermined.

Although rockbursts, or bumps are also a stress phenomenon, the gas component of instantaneous outbursts entirely changes their character, especially proneness (Fig. 3), so that rockbursts and instantaneous outbursts are quite separate phenomena (Rice, 1918) (Coeuillet, 1954).

Another erroneous association with instantaneous outbursts is the occurrence of outbursts or blowers of gas such as in the intersection in development of fissures providing ready permeation paths, and in the strata fissures deriving from irregular fracturing of floor in longwall or pillar extraction (Arscott and Hackett, 1969).

THE AUSTRALIAN SITUATION

The Australian situation statistically appears to be of mild outbursting proneness under conditions of more than average CO_2. The standard Australian method is bord and pillar but with the recent generally promising innovation of mechanised longwall retreating, it means that in the future at least a significant proportion of Australian coal will be mined by the longwall method. The relative sparseness of faulting in the measures, generally uniform thickness, and generally uniform dip give a situation which lends itself to rapid development into virgin areas and rapid mining out of large blocks only impeded by roof problems and by gas encountered in development and in extraction. However, the experience of sporadic outbursting both on structures and without structures provides an uncertainty. This uncertainty creates the situation of the necessity to undertake prediction, precautions, preventive measures and/or controls for a most inconsistent problem. As a result there is always the feeling that precautions are being overdone. For the immediate future all that can be seen in deep mining in the Sydney and Bowen Basins is an increasing gassiness and an increasing proneness to instantaneous outburst with increasing depth of working. There will be a continuing compromise between rate of advance and outburst proneness. As for seams other than the Bulli, the Bowen and the Gemini known to be outbursting, in the deeper mined areas the adjoining seams, some yet to be mined and seams in other areas have coal compositions and seam gas contents seen to be close to those of the working seams. Already from the exploration boreholes instanced above proneness of some seams other than working seams is suggested. There appears to be no other future in the Australian situation than finding continuing and increasing proneness to outbursting with deeper mining in the present working seams and with suspicion of outburst proneness in seams yet to be mined. In marginal instances not quoted in Table 2 there are examples of lower rank coals exhibiting gas and stress phenomena symptomatic of outbursts (Hargraves, 1980) and so even in presently working seams presumed non-prone there is the possibility of development of a clear proneness to instantaneous outbursts.

PREVENTION

MINING METHOD AND GEOMETRY

Instantaneous outbursts can be reduced by avoiding use of methods which give high proneness.

In the flat disposition of Australian seams, if seams could be extracted totally, prevention in adjoining seams could be simple. But incomplete extraction, by creating abutment loadings in the working seam created by unmined pillars and by face ends in the "protective" seam will locally increase proneness in the working seam. An instantaneous outburst with CO_2 on a longwall face at Nova Ruda Colliery, Poland in 1978 is thought to be due to this cause.

The number of cross measure intersections of seams, the most prone situation (Table 3) is small and cannot be minimised.

The avoidance of narrow work is dependent somewhat on mining method. To employ longwall retreating in preference to bord and pillar for extraction perhaps halves the amount of heading work. To reduce width of roadways to improve roof conditions may involve more roadways for ventilation requirements and not only increase proneness, but also the number of roadways in which the increased proneness applies. To mine the full thickness of the seam is to reduce proneness rather than to mine portion of the seam, whether by leaving coal at the roof to improve a roof problem, or because seam thickness is too great to mine in one pass or both. Because of gravity, effects leaving coal at roof appears more serious than leaving coal at floor (Daval, 1936).

Longwall advancing, especially where gateroads are not extended ahead of the longwall face, is the method minimising narrow work and is therefore partially preventive. The lack of pack-building material in the mining of the thick Australian seams has dispelled all thought of longwall advancing in the past, but recent developments in monolithic concrete packing now warrant further consideration (Hargraves, 1977).

SEAM DE-STRESSING

To prevent a stress phenomenon in the course of mining it is necessary to destress the zone to be mined sufficiently to reduce the stress below the burst point. At this stage of knowledge, this point is uncertain, as is the stress in the coal ahead of the face on a day to day basis. Thus destressing techniques are arbitrary. Undercutting is known to have induced outbursts (Hargraves, 1958) and a row of large diameter holes for prevention, if the holes were sufficient in number, would approach a horizontal cut condition. A pattern of holes should fall short of this condition. Large diameter holes, however, are themselves seen to create stress anomalies until in sufficient number to relax the face coal generally. There may be some analogy between effective large diameter hole patterns and a yielding pillar technique. In some instances overseas, outbursts have been induced in holes during drilling (Willett and Thomas, 1965), sometimes so serious as to decide to reduce hole diameter.

High pressure water infusion through boreholes as used on longwall faces in U.S.S.R. has the first effect of imposing higher stress on the coal, and when infusion has finished the coal, if cracked, will have higher macropermeability and will tend to degass more readily. In that coal shrinks with degassing, such an effect of high pressure infusion will involve stress relaxation. But in some cases water infusion has initiated instantaneous outbursts (Hargraves, 1965b).

SEAM GAS PRE-DRAINAGE

To prevent a gas phenomenon in the course of mining, it is necessary to degass the zone to be mined sufficiently to reduce the gas content below the content for proneness. Outbursting coals are almost invariably high rank which involves high sorptive capacity (Hargraves, 1966) and low permeability, making degassing of virgin coal more difficult. The degree of gassiness equivalent to the beginning of proneness is not known. The onset of outbursts in dipping seams at a particular depth almost nowhere is less than 200 m and the relationship of gassiness to depth may be a helpful approach. (Virgin gas pressure is of the order of hydrostatic head from the surface.) In the absence of this knowledge an empirical index to face gassiness is helpful in assessment of local proneness in day to day work (Hargraves et al., 1964). Testing in various coal basins indicates its greater usefulness under CO_2 than CH_4 conditions. Such a proneness index identifies the need for degassing for prevention.

As stated above, high pressure infusion will tend to increase permeability and degassing, and hence can be regarded, with time, as preventive.

CONTROL

TIME

Of the two methods of control, the control of time of outburst is the more general. The method is by inducer shotfiring, devised by Marsault in France in 1892 (Lange, 1892). It involves a simultaneous round of shots to advance the entire heading face or at least a large section of the longwall face by overboring, over-charging, and firing from a safe or remote distance. In general the experience with prior outbursting gives some guidance to the degree of remoteness and often shotfiring is from a central shotfiring station on the surface. There may be other monitoring controls used to identify outburst conditions such as an audible control, gas monitoring, vibration monitoring etc. (Hargraves, 1965b). It is the first resort treatment used when outbursts occur for the first time and if prediction and prevention cannot be achieved it is often the last resort also. Certainly the number of inducements is significantly greater than the number of outbursts which would occur spontaneously. (Inducer shotfiring increases proneness at least by some fraction of a category.) This disadvantage is preferred to random outbursts during the course of mining with men at the face or returning to the face after single or gentler shotfiring.

MAGNITUDE

Where inducer shotfiring is used as a controlling measure the damage from the violence of the ensuing outburst may be reduced by the use of a barricade. This applies only to cross measure work and to heading work and was used mostly in France (Hargraves, 1965b). The normal mechanism of an outburst dying out is for the burst coal heaped up in front of the face to provide only a narrow escape channel for subsequent bursting coal and gas and presumably the back pressure created by the resistance in this channel adds to the constraint on the bursting face sufficiently to arrest the burst. The barricade, providing a strong obstruction over the major cross section of the roadway provides resistance through it to passage of coal and gas from the beginning and allows the outbursts to be choked off before choking off in the normal uncontrolled process.

Presumably relaxation hole boring if not adequate for prevention could have some reducing effect on any outburst occurring.

PREDICTION OF EVENTS

GENERAL

Having established seam proneness, whether by prognostic ΔP or other laboratory methods or by virtue of having had a smaller symptomatic or a full scale outburst event, the day to day proneness will depend on stress condition and gas condition, and perhaps geological structural domain, and, perhaps, also coal strength condition. For forecast of such proneness some monitoring of one or more of these contributory factors must be undertaken, particularly gas and stress. Sometimes the whole seam could be regarded as a weakened geological structure. Induced outbursts clearly required only the first two factors. Spontaneous outbursts have occurred with just these two. For day to day prognosis a gas or stress parameter or both is needed.

FROM STRESS

The state of stress measurement and particularly stress measurement in coal plus the lack of knowledge of specific stress values giving rise to proneness are all insufficient upon which to base a method of prediction of specific outburst events. In a stress and gas phenomenon it requires the relief of only one for prevention but at this stage it is not possible to predict on the basis of stress.

FROM GAS

There have been a number of attempts to use gassiness as a predictive measure. This has been mentioned above. The earliest attempts at gassiness assessment derived from gassiness of ventilation as a result of emission of gas in the working place. It has long been recognised (Hargraves, 1958) that a forerunner to a local outburst situation may be an increase or a decrease of gassiness. At this stage any positive prediction method depends on such fluctuation. The fact that there is no agreement about increase or decrease retards the development of any such method. The gassiness of the coal can be determined by attempting measurements in a standard borehole into the advancing face. This is more suitable for incremental advance with shotfiring than with continuous miner advance because of the necessity to drill the hole at the face and the need to support right at the face to protect personnel. In the mid

1950's at Collinsville a whistle was attached to a seal on a standard borehole and the note of the whistle gave an indication of the amount of gas issuing. Experiments with gas pressures in standard holes (Hargraves et al., 1964) were tested but were not particularly promising and subsequently a method of determining an empirical gassiness index from cuttings of standard granulometry from a standard hole was used with success. The gas emission from the cuttings was related to the incidence of outbursts during inducer shotfiring and this in turn was used as the basis with a safety factor for safe mining during continuous mining. The ΔP index used widely overseas in determining the proneness of seams rather than working places has been modified into an express method for determining proneness in the working place and is used under some circumstances (Paul, 1977).

The differing permeation rates of the component gases of mixed seam gas - mainly CH_4 and CO_2 but with other minor constituents such as C_2H_6, He, etc.- is a possible basis for prediction. Currently in U.S.S.R. and elsewhere the amount of He issuing is taken as some indication for prediction. The much readier permeation of He through coal presumably results in a higher than normal He content in the ventilation air when the nature of the coal changes allowing freer escape of gas with He in the forefront. (Small proportions of He occur in CO_2 rich seam gas in the Bulli Seam.)

FROM FAILURES

In the days of hand working when operating machinery did not obscure noises issuing from the coal the first signs to the hand miner of an imminent outburst were of knocks within the coal of the face. The knocks occurred with increasing frequency until the noise became continuous representing the culmination of the outburst. Interpretation of the beginnings of such noise sequences allowed many miners to be saved. These individual knocks are individual failures in the coal (and perhaps the roof and floor) as the face re-adjusts to finally fail completely in the outburst. Modern methods making use of such snowballing failures involve the use of geophones or accelerometers set in the coal with a complex electronic device for interpretation and warning. These methods are used not only for outburst prediction but also for rock burst prediction and have been used for this purpose in both problems for at least three decades. There have been instances in the rock burst phenomenon at least where mining has been arrested deliberately and no rock burst has ensued. As the occurrence of the stress phenomena rock bursts and instantaneous outbursts are related to rate of advance, the stopping of the face, if in early enough stages of snowballing failures, may be sufficient for the problem to disappear. Researches in U.S.S.R. into this problem have been intense (Antsiferov et al., 1960). The only proven usefulness of geophones in outburst occurrence to this time appears to be the identification in retrospect of outbursts having occurred such as in the Cevennes Basin in France where inspections after inducer shots were delayed if outbursts had been detected at the time point of shotfiring by microseismics (Hargraves, 1965b). With the very rapid advances in electronic techniques and equipments in recent years there is promise that the presently unheard and unnoticed premonitory noises of imminent outbursts can be identified in sufficient time to allow employees to retreat and maybe to allow the immediate proneness to die away and to allow local preventive measures to be undertaken.

FROM STRUCTURE

Shepherd and Creasey (1979) advocate a roof joint density basis for forecasting tectonic disturbance in the form of strike slip faults, the common structural location of all instantaneous outbursts at Westcliff Colliery. This becomes the basis of assessing general local proneness, to be substantiated by some other local and more specific proneness index such as microseismics. However, at Metropolitan Colliery about 15 km away all historic outburst structures are roughly at right angles to those at Westcliff, and certainly the fatal outbursts of 1925 and 1954 were on faults of significant vertical movement. Outburst structures to the south in Metropolitan trend more towards the Westcliff orientation. It is clear that the Southern Coalfield of N.S.W. is not strongly tectonically affected by comparison with many other instantaneous outbursting regions and the mild tectonics there are related more to local structures rather than to regional influences. The transposition of any structural predictive basis from one part of the Coalfield to another may not be possible because of lack of similarity. Figure 6 shows the orientation of outburst related structures in the Bulli Seam.

On the two other Australian affected fields there is no clear similarity to the Westcliff tectonic situation as described by Shepherd and Creasey (1979). At Collinsville all recorded outbursts occurred on faults (Hargraves, 1958) (Hardie and Hargraves, 1960) with clear vertical movement; at Leichhardt outbursts occurred both without faulting and with - the largest, 1978 outburst with two fatalities was on a fault with a vertical displacement. All that can be said about faulting, whether strike or dip slip or both is that it increases proneness to instantaneous

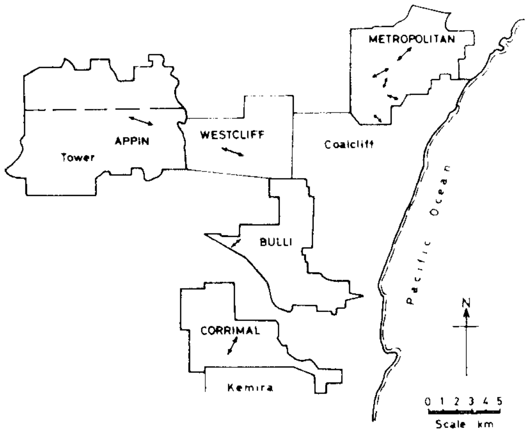

Fig 6. Southern Coalfield - direction of outburst related structures

outburst by one category (Hargraves, 1980). Mines with marginal gas and stress phenomena in undisturbed seam are candidates for more significant phenomena at seam dislocations.

Geological, although not visibly structural, is the local increase in rank (presumably due to intrusion in adjoining roof or floor) which increased proneness at Bulli Colliery - Table 2. Such local analysis changes in the seam ahead would be difficult to predict.

PROGRESS IN PREDICTION

Nearly a century ago seam prediction followed an instantaneous outburst event and local prediction was made when frequency of noises within the coal increased and approached a high frequency. In extreme instances, prevention was achieved by closing the mine down, when no other system was considered appropriate. Otherwise prevention was by limiting face advance, by brisk ventilation of face coal (Carpov and Artemov, 1958) and by constraining the face until the coal settled down. These measures did not completely remove hazards. Control was obtained by preventing an imminent outburst by manually constraining the face, then constraining it with shoring, then drilling and blasting the face out inducing the outburst. Control by other inducements involved striking the place with a pick, or reducing the ventilation of the place, causing bursting.

Modern treatments do not differ markedly from the time honoured ones, with a trend towards methods allowing faster face advance.

ACTION FOLLOWING PREDICTION

If prediction is possible then the courses open are control by shotfiring as used at Metropolitan Colliery, prevention by large hole boring as used at Leichhardt and Collinsville Collieries, and by other methods including employing a more experienced work party as used at Westcliff Colliery.

If the seam gas is CO_2, then hazards of inducer shotfiring are reduced. Inducer shotfiring involves control of instantaneous outbursts by a method - shotfiring - so traditionally well disciplined in the coal mining industry that human error and human discretion are minimised, whereas more newly developed preventive techniques may be more subject to human error, discretion, and personal opinion.

RESEARCH

With 100 years of the problems and with outbursts still occurring, some unfortunately with fatal results, there is continuing and great need for research into the problem. Research is all the more necessary because not only are there affected mines but there are mines also with minor gas and stress phenomena symptomatic of the major phenomena. Research is in two forms:

1. Research aimed at understanding the phenomenon - an understanding which will rationalise methods of prediction, prevention and control.

2. Research of a more empirical nature based on intuitive attempts and trials of methods of prediction, prevention and control.

The nature of research generally divides into stress research, gas research and the relationship of one to the other. The physical natures of the coals are much less understood than their chemical natures. There have been some very exotic aspects of instantaneous outburst research not necessarily related directly to gas and stress aspects such as the occurrence of outbursts relative to the phases of the moon, earthquakes, earth emanations, etc.

One might say that reproduction of instantaneous outbursts in the laboratory (Quentin, 1952) (Famin, 1959) implied an understanding of the mechanism of the phenomenon. But they seem to represent a phenomenon from a complex set of arbitrary conditions, some possibly unrealistic, adding another diverse experience in the history of a complex perplexing phenomenon.

ANALOGOUS PHENOMENA

In the mining and tunnelling of other rocks, instantaneous outbursts may occur. Particularly, outbursts of salt and gas resemble outbursts of coal and gas (Eckart et al., 1966) and occur in various bedded and domed salt deposits in Poland, Germany, France, U.K., U.S.A. etc. with seam gases as in coal, CH_4, CO_2, N_2 and H_2S. Outbursts have occurred with shotfiring, inducer shotfiring and with continuous mining. The largest outbursts in salt have been about 50,000 tonnes.

In mining in porous rocks, outbursts of rock and gas may be a problem, such as in the A.A. Skochinsky Colliery, Don Basin, U.S.S.R. where outbursts of sandstone and gas occur.

There should be some benefits in relating the research and experiences associated with these occurrences to aspects of coal and gas outbursts.

CONCLUSON

This paper commenced with some rather dampening remarks relating to the lack of progress in handling the phenomenon of instantaneous outbursts after a century of concerted work into gas and stress by many diverse approaches. These dampening remarks were intended to discount the association of enthusiasm and immodesty in the approach to outburst research and certainly not to dampen any research efforts. It has been stated that whilst plagued with the outburst phenomenon in several mines, Australia has other mining areas where symptomatic phenomena are occurring and it may only be necessary for these mines to deepen or for rates of advance to increase or for mining methods to change somewhat before proneness appears more positively. Instantaneous outbursts are a problem being experienced and which will be experienced more and more as time goes by. The limitation of outbursting to high rank coals which has been assumed in the past need not necessarily be so exclusive in the future based on occurrences elsewhere in the world, although the highest rank coals will always be those most prone. Presently in Australia there is a great impetus to instantaneous outburst research and fortunately the increasing gassiness of coal measures generally has also given impetus to more general seam gas drainage research, a research specifically useful to outburst research. Within the general mining tendency to concentration of production, high productivity units, fast rates of advance, and to reducing number of roadways thereby increasing rate of frontal advance, all these present aspects of mining should lead to greater day to day proneness of work. The present move towards longwall retreating is a move towards reduction of number of roadways and to concentration of mining production on long faces in large pillars - a much less prone situation. Even better, from an outburst prevention or modification point of view, would be practice of longwall advancing. However, the serious disadvantages seen in this by most operators in the Australian context appear to be a real bar to its serious consideration at present. An example of longwall advancing in the U.S.A. in a thick flat outbursting seam is being watched with interest and evidence there may have progressive influence on the Australian view point. Finally, the great volume of research done without satisfactory solution to the problem should be no deterrent to continuation of the work but rather should spur workers on to greater efforts to get on top of this perplexing problem.

ACKNOWLEDGEMENTS

The Broken Hill Proprietary Company Limited is thanked for permission to prepare and present this paper. The comments expressed are not necessarily those of the Company. The late Mr. A.E.R.(Mac) McCoy for his own research and promotion of research of others, including that of the author, is gratefully acknowledged.

REFERENCES

Anon., 1960. Engineering Digest - Safety device for coal Mines, The South African Mining and Engng. Jour. Johannesburg, Aug. 12.

Antsiferov, M.S. et al., 1960. Seismoacoustic investigations in coal mines, Paper of Mining Institute, Academy of Sciences, Moscow.

Arscott, R.L. and Hackett, P., 1969. The effect of geological features on the occurrence of gas outburst fractures in the East Midland Coalfield. Auarterly Jour. Engng. Geol., Vol. 2, pp. 89-101.

Carpov, A.M. and Artemov, A.B., 1958. Influence of the intensity of ventilation on the hardness of coal, and the means of using this phenomenon as measures against instantaneous outbursts of gas and coal, Ugol - No. 3 - 58, pp. 25-29.

Chaineaux, M.L., 1947. Quelques Accidents et Incidents Remarquables, Technical Note No. 47/6, Cerchar, Paris.

Coeuillet, R., 1954. Ground pressure and dynamic incidents (Instantaneous outbursts and roof bumps) Revue de L'Industrie Minerale.

Cognet, M., 1946. Pompage du Gas. Carbonique d'un Degagement Instante, Mines No. 4, Paris.

Daval, G.J., 1936. Principes a Consulter Pour L'exploitation des Mines Sujettes Aux Degagements Instantanes, Revue de L'Industrie Minerale

Eckart, D. et al., 1966. Instantaneous outbursts of rock and gas in mining industry (in German) (VEB Deutscher Verlag: Leipzig).

Ettinger, I.L. and Lao-Tchi, 1959. Tendency to instantaneous outbursts of coals in the Popular Republic of China and several peculiarities of their physico-chemical properties, C.R. (Izvestia) Academy of Sciences U.S.S.R. Metallurgy - Comb. No. 5, pp. 187-191.

Famin, 1959. Instantaneous outbursts of coal and gas in a laboratory experiment, Problems of mine ventilation, Mining Institute, Academy of Sciences, Moscow, pp. 219-224.

Hardie, R.N. and Hargraves, A.J., 1960 The introduction of full face multiple shot-firing at Collinsville State Coal Mine, Proc. Australas. Inst. Min. Metall., No. 196, pp. 9-27.

Hargraves, A.J., 1958. Instantaneous outbursts of coal and gas, Proc. Australas. Inst. Min. Metall., No. 186, pp. 21-72.

Hargraves, A.J., et al., 1964. The control of instantaneous outbursts at Metropolitan Colliery, N.S.W., Proc. Australas. Inst. Min. Metall., No. 209, pp. 133-166.

Hargraves, A.J., 1965a. Instantaneous outbursts of coal and gas in Australia, Proc. Eighth Commonwealth Min. Metall., Cong., Vol. 6 - General., pp. 871-885.

Hargraves, A.J., 1965b. Instantaneous outbursts, overseas investigations 1964, The University of Sydney.

Hargraves, A.J., 1966. Gas emission into mine workings, Proc. Symp. on Seam Gases in Coal Mines, Dept. of Mining Engng., The Univ. of Sydney, Paper 4b, pp. 1-16.

Hargraves, A.J., 1973. Planning and operation of gaseous mines. 75th Ann. Gen. Meeting of C.I.M. Vancouver, C.I.M. Bulletin Vol. 66, No. 731, pp. 119-128.

Hargraves, A.J., 1977. A novel approach to longwall mining. Proc. of Third Symp. on underground mining, National Coal Assoc. Bituminous Coal Research, Coal Conf. and Expo IV, Louisville, Kentucky pp. 281-296.

Hargraves, A.J., 1980. Seam gas problems and drainage in Australia. Fifth Int. Cong. on Coal Research, Dusseldorf, (in press).

Jovanovik, et al., 1979. The energy of free gas spreading in oligomiocenic coal beds and its outbursting capacity, Proc. XVIII Int. Conf. on Scientific Research in the field of safety at work in mining industry, Dubrovnik, pp. 19-31.

Lange, C., 1892. Outbursts of carbon dioxide at the Rochbelle Mines, Bulletin Soc. L'Industrie Minerale, Paris, Series, 3,6.

Paul, R., 1977. Early recognition and prevention of gas outbursts, Gluckauf, 113, No. 13.

Queensland Government, 1956. Report of Royal Commission relating to State Coal Mine Collinsville (Qld. Govt. Printer Brisb.)

Quentin, M., 1952. Reflections on instantaneous outbursts, Revue de L'Industrie Minerale, Vol. 6.

Rice, G.S., 1918. Bumps and outbursts of gas in the mines of Crowsnest Pass Coalfield, Brit. Col., Dept. of Mines Bulletin No.2.

Shepherd, J.R. and Creasey, J.W., 1979. Forewarning of faults and outbursts of coal and gas at Westcliff Colliery, Australia, Coll. Guardian Coal Int., 227 (4) pp. 13-22.

Talman, W.G., 1954. Auger drilling to control mountain bumps, U.S. Steel Corporation Coal Division - Gary-Lynch, W. Va.

Willett, H.L. and Thomas, D.A., 1965. Outbursts of gas and of coal and gas, Proc. Eighth Commonwealth Mining and Metall., Cong., Vol. 6 - General, pp. 861-869.