AN ANALYSIS OF THE GEOLOGICAL FACTORS LEADING TO OUTBURST-PRONE CONDITIONS AT COLLINSVILLE, QUEENSLAND

By

R.J. WILLIAMS[1] AND J. ROGIS[2]

ABSTRACT

The basic parameters causing outbursts are rock pressure, gas characteristics and the physico-mechanical properties of the coal. The three sets of factors are to some degree interdependent.

At Collinsville, the gas characteristics coupled with the physico-mechanical properties of the coal appear to be the major factors contributing to outbursts. The relative importance of rock pressure is uncertain.

The following geological parameters appear to be necessary before outbursts can occur.

1. A coal rank greater than 1.2% vitrinite reflectance.
2. Thrust faults with throws greater than 3.0m or strike-slip faults with coal gouge wider than 0.3m.
3. Seam gas emission values greater than 1.1 cm^3/g.

Igneous intrusions are the likely source of the carbon dioxide seam gas.

Outbursts have occurred at depths ranging from 215m to 265m. They occur at these relatively shallow depths due to:

1. the high rank of coal at the present topographic surface and the high coalification gradient;
2. the relatively high degree of tectonic deformation of the strata;
3. the seam gas characteristics; and
4. the extent of igneous intrusions.

INTRODUCTION

Instantaneous outbursts of coal and gas in the Collinsville district have been confined to the Bowen Seam and occurred in two separate areas (Fig. 1). The first outburst occurred in the State Mine in October, 1954. Seven men were asphyxiated when approximately 14 000m^3 of carbon dioxide and 500 tonnes of coal were ejected. A Royal Commission was appointed by the Queensland Government during December, 1954 to enquire into events preceding the outburst. Details of the outburst were also published by Hargraves (1958, 1967). After the recommencement of mining in this area, eleven more outbursts were induced by shot-firing over a twelve month period to March, 1961. At that time, mining ceased in the State Mine in favour of developing the shallower non-outburst-prone coal reserves in No. 3 Mine.

Development continued in No. 3 Mine until April 1972 when two small outbursts occurred. The workings had been developed using continuous miners and were within 150m of the outburst area in the State Mine.

During the period from September to November 1978, four minor outbursts and a number of "gas incidents" were reported in No. 2 Mine. Details of selected occurrences are given by Biggam, Robinson and Ham (1980).

In anticipation of outburst-prone conditions increasing with depth the Collinsville Coal Company Pty. Ltd. (CCP) in early 1979 began an extensive research program. A significant part of the program incorporates geological studies. The aim is to determine and predict the geological factors contributing to outbursts and to provide basic data with which a gas drainage and gas monitoring program can be designed and interpreted.

---

[1] Research Officer — Rock Mechanics, and

[2] Geologist, Collinsville Coal Company Pty. Ltd., Collinsville.

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

GENERAL GEOLOGY

GEOLOGICAL SETTING

The Collinsville Coal Measures have been described by Reid (1929), Webb and Crapp (1960), and Mengel (1975). They have been placed in a regional context by Staines and Koppe (1979).

The measures are confined to, and crop out around the northern rim of the Bowen Basin (Fig. 1). Their location on the orogenic margin of the basin has resulted in a relatively high degree of tectonic deformation. Deformation is manifested in the nature and frequency of faulting, the high rank of coal at the present topographic surface, the attitude of the strata and the widespread occurrence of igneous intrusions.

The dominant fault type is low angle reverse (thrust), but bedding-plane and strike-slip faults are also common. Normal faults are uncommon. The western limit to mining in No. 2 Mine is formed by a thrust fault with a maximum throw of 40m (the Three Mile Creek Fault).

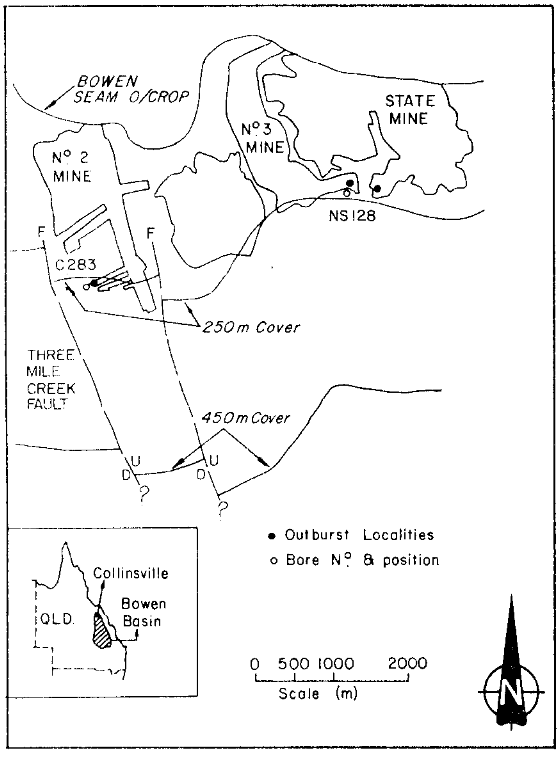


Fig 1 — Locality Map

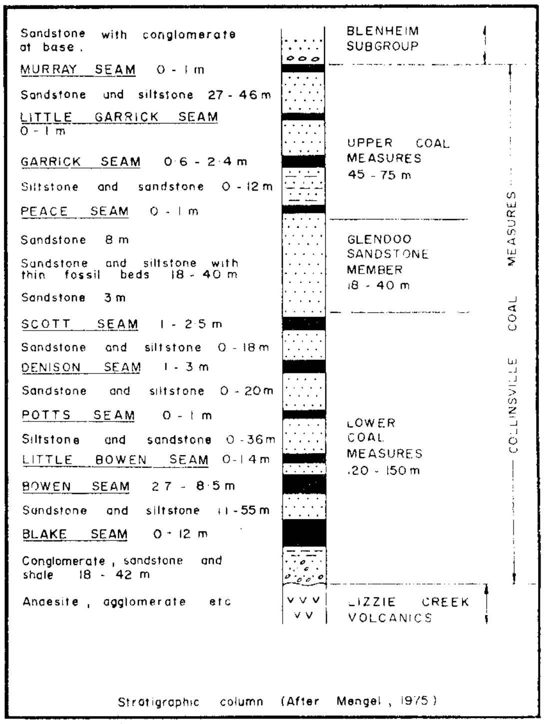
The stratigraphic positions and names of coal seams in the Collinsville Coal Measures are shown in Fig. 2. Extensive underground reserves only exist for the Garrick, Bowen and Blake Seams. The Garrick and Blake seams have been developed to a minor degree by underground methods.

THE BOWEN SEAM

The Bowen Seam is the most extensively mined seam at Collinsville. The seam has highly variable physical and chemical properties, and is therefore difficult to typify.

Over the CCP leases the mineable seam thickness averages 4.5m. Around the current mining areas in No. 2 Mine, the total seam thickness averages 6.1m. The seam dips to the south at approximately 7° and has been mined from outcrop to a maximum depth of 280m in the No. 2 Mine. The maxiumum depth of cover over the CCP leases is 480m.

Coal analyses from the two outburst areas (State/No. 3 Mine and No. 2 Mine) are listed in Table 1. Petrographic and ultimate analyses are only available for the mining



Stratigraphic column (After Mengel, 1975)

Fig. 2 — Collinsville Coal Measures

Table 1 — Comparison of Bowen Seam analytical data in the vicinity of outburst areas.

Bore	CS283	NS128
Location	No. 2 Mine	No. 3 Mine
Thickness (metres)	* 5.03	4.37
Ash %	23.0	19.2
Inherent Moisture %	1.2	1.0
Volatile Matter % (a.a.)	21.0	20.6
(d.a.f.)	28.3	26.0
Fixed Carbon % (a.a.)	54.8	59.1
(d.a.f.)	71.7	74.0
Specific Energy MJ/Kg (a.a.)	25.31	27.90
(d.a.f.)	33.9	34.95
Swell Index	5½	2½
Sulphur %	1.90	0.94

* Excluding 0.74m siltstone band;
a.a. = as analysed; d.a.f. = dry, ash-free.

section in the outburst area of No. 2 Mine. These are listed in Table 2.

The seam gas consists predominantly of carbon dioxide with minor amounts of methane. A seam gas analysis for the No. 2 Mine outburst area is listed in Table 3. Some seam gas analyses in the deep areas of No. 2 Mine workings show apparently anomalous nitrogen contents of up to 80%. The methane content appears to increase with depth and Hargraves (1967) has estimated a 90% methane content of seam gases at 400m depth.

Desorbable gas contents of the coal as determined from core samples vary from 2cm^3/g to as high as 24cm^3/g. These values are only an approximation due to the difficulty in estimating the volume of lost gas (McCulloch and Diamond, 1976).

Rank of the seam in No. 2 Mine as determined from vitrinite reflectance measurements (vitrinite A, non-polarised light) has been increased in the upper sections of the mine by the effects of igneous intrusions (Fig. 3). In areas unaffected by intrusions, coal rank ranges from 1.07% in the shallow parts of the mine to 1.27% in the deepest areas.

Table 2 — Bowen Seam petrographic and ultimate analyses, 53 Level West, panel mining section.

Ultimate %

Carbon (d.a.f.)	88.6
Hydrogen (d.a.f.)	4.5 - 4.9
Nitrogen (d.a.f.)	1.9 - 2.0
Sulphur (d.a.f.)	2.0 - 3.0
Oxygen (d.a.f.)	1.7 - 2.5
Carbonates (a.a.)	0.04 - 0.06

Petrographic %

Vitrinite	24 - 48	Sclerotinite	0
Exinite	0	Micrinite	2 - 4
Fusinite	0	Inertodetrinite	5 - 8
Semi-fusinite	30 - 49	Mineral Matter	4 - 8
Macrinite	5 - 10	Total Inertinite	46 - 49

Table 3 — Bowen seam, gas composition at Outburst No. 16 (Reference, Table 4)

	%
Carbon Dioxide	92.09
Carbon Monoxide	0.0001
Nitrogen	1.2
Methane	6.54
Hydrogen	0.01
Ethane	0.067

Mining induced strain analyses are in general agreement with stress measurements by Hall (unpublished data, 1978). The axis of maximum principal stress is horizontal, trends in an east-west direction and has an average value of 15mPa at 240m depth. This is approximately 2.2 times greater than the vertically directed minimum principal stress.

GEOLOGICAL CONDITIONS AT THE OUTBURST SITES

Details of strata surrounding and including the Bowen Seam are given in Fig. 4. Analytical data are listed in Tables 1 and 2 with additional geological information in Table 4.

THE STATE MINE

The Bowen Seam is approximately 4.7m thick and there are two thin coal seams in the immediate roof strata

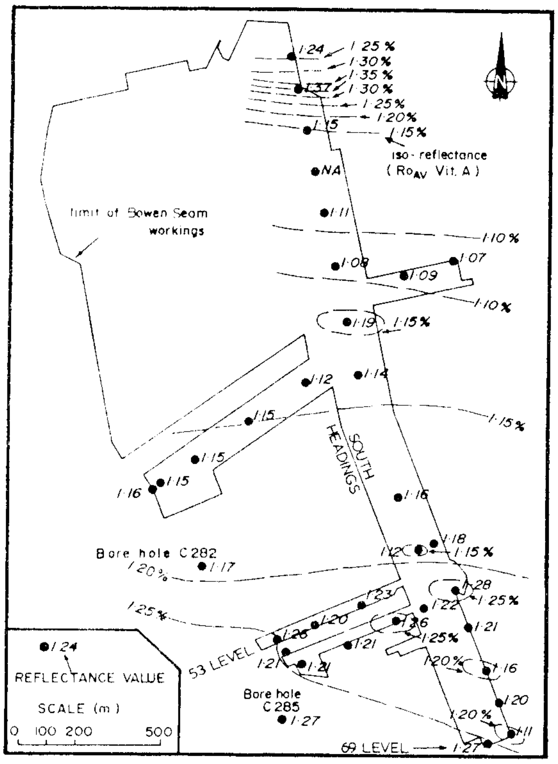


Fig. 3 – Variation in Vitrinite Reflectance, Bowen Seam,No. 2 Mine

(Fig. 4.1).

The outbursts have occurred on the northwestern margin of an extensive area of partially coked Bowen Seam. The effects of this intruded area were noticeable in the southeasterly corner of the State Mine workings (Fig. 5) where a 0.3 m thick sill was encountered.

A bedding-plane fault is located in the middle of the seam and consists of 0.1 m of mylonitised coal.

The depth of cover in the outburst areas range from 215m to 235m. The strata dip to the south at 7°.

Outburst No. 1 (Table 4) was the most severe in the coalfield and occurred in a tectonically complex area. Hargraves (unpublished data, 1954) determined the presence of a thrust fault with a 5m throw occurring in association with a normal fault of 1m throw. Drilling by

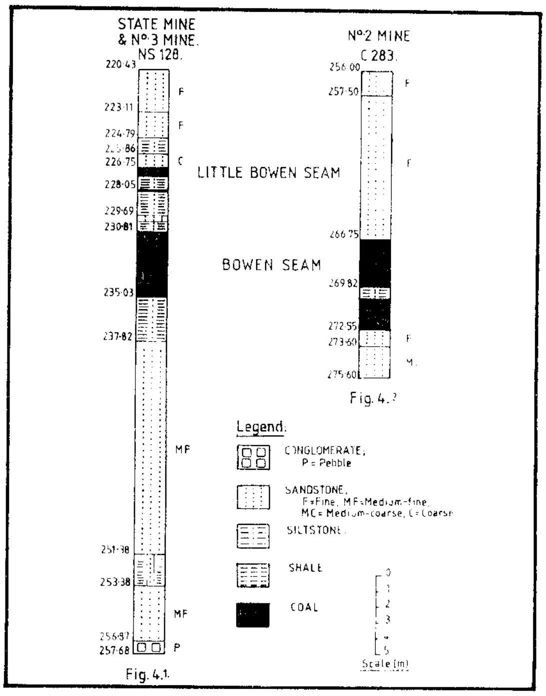


Fig. 4 – Roof and floor strata near outburst areas

Cribb (1956) delineated an irregular igneous intrusion of up to 3m thickness, causing partial coking of the seam.

Outburst No. 2 occurred on the same thrust fault which had increased in throw to 10.5m (Fig. 5). The fault zone consisted of two almost parallel fault planes approximately 1m apart. The material between the planes consisted of highly-sheared coal. Associated with this structure was a normal fault of 0.6m throw and a 3m thick dyke (Fig. 5). Both the normal fault and the dyke have been displaced by the reverse fault. A maximum seam gas pressure of 300kPa was recorded in the vicinity of the outburst.

Outburst No's 3 to 7, 9 and 10 all occurred at different points along a fault which has a throw ranging from 0.1m to 0.6m. A description by Crapp (unpublished data, 1960) together with observations at other intersections strongly suggests that it is a strike-slip fault with a 0.5m width coal

TABLE 4 - OUTBURST DETAILS FOR THE COLLINSVILLE COALFIELD

Locality	No.	Date	Size of Outburst (t)		Faulting		Other Structures	Seam Thickness	*Rank of Coal	Emission Value	Gas Composition %			Depth of Cover
			Coal	Stone	Type	Throw (m)		(m)	%	cc/g	CO_2	CH_4	N_2	(m)
State Mine	1	13/10/54	500	500	Thrust, Normal	5	3m Dyke	4.6			98			220
State Mine	2	4/ 3/60	360	450	Thrust, Normal	10.5,0.6	3m Dyke	4.8						225
State Mine	3	19/ 4/60	90	Nil	Strike-slip	0.4		4.6						225
State Mine	4	13/ 5/60	100	Nil	Strike-slip	0.7		4.6						225
State Mine	5	27/ 5/60	60	Nil	Strike-slip	0.7		4.6						225
State Mine	6	7/ 6/60	0.5	Nil	Strike-slip	0.3		4.6						220
State Mine	7	21/ 6/60	15	Nil	Strike-slip	0.1		4.6						220
State Mine	8	5/ 8/60	70	Nil	Thrust	3.2		4.6						220
State Mine	9	9/11/60	60	Nil	Strike-slip	0.5		4.8						215
State Mine	10	17/11/60	100	280	Strike-slip	0.3		4.8						215
State Mine	11	7/ 2/61	60	Nil	Strike-slip	0.1		4.4						230
State Mine	12	6/ 3/61	1	Nil	Strike-slip	0.2	0.3m sill	4.4						235
State Mine	13	21/ 3/61	5	Nil			0.3m sill	4.4						235
No. 3 Mine	14	30/ 3/72	1	Nil	Strike-slip	0.1		4.3	1.29	1.23				230
No. 3 Mine	15	14/ 4/72	1	Nil	Strike-slip	0.1		4.3	1.29	1.10				230
No. 2 Mine	16	6/ 9/79	25	Nil	Thrust	6.0		5.8	1.26	1.28	92.1	6.5	1.2	260
No. 2 Mine	17	27/10/78	1	Nil	Thrust	6.0		5.8	1.26	1.28				260
No. 2 Mine	18	22/11/78	0.14	Nil	Thrust	6.0		5.8	1.26	1.28				265
No. 2 Mine	19	23/11/78	19.2	Nil	Thrust, strike-slip	6.0,0.5		6.8	1.26	1.28				265

* Vitrinite reflectance

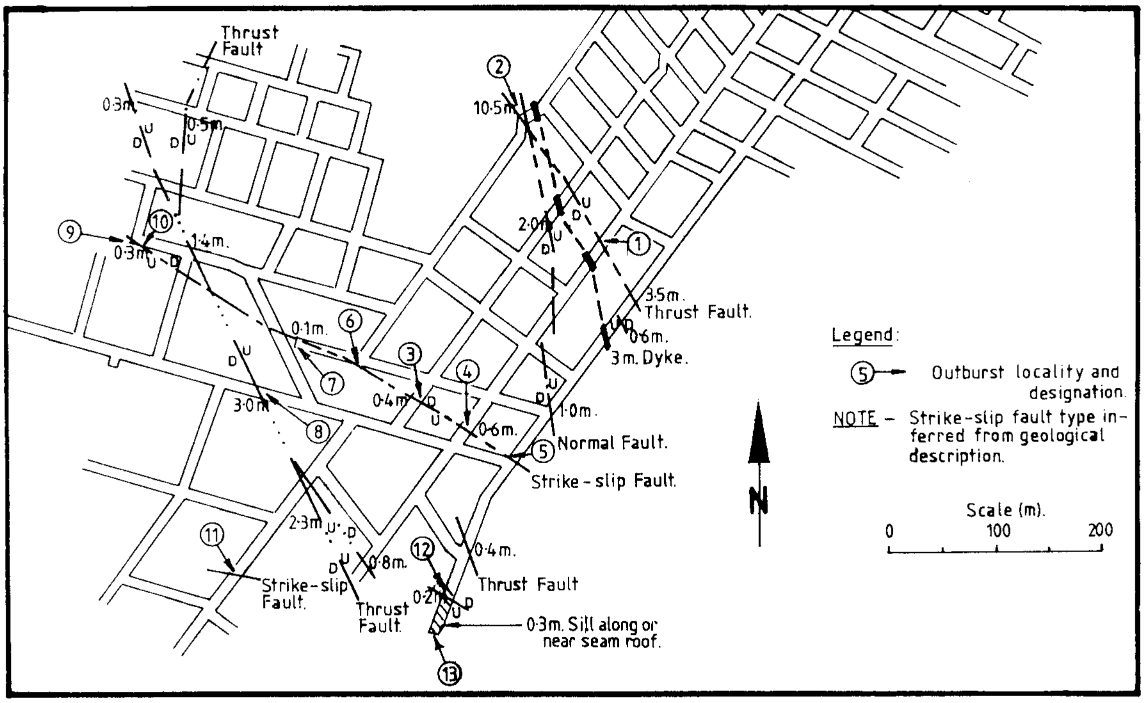


Fig. 5 — Fault and outburst localities, Bowen Seam, State Mine

gouge. With the exception of Outburst No. 10, the roof conditions were not adversely affected at the outburst sites along this fault. A seam gas pressure of 310kPa was measured in the vicinity of Outburst No. 4.

Outburst No. 8 occurred on a thrust fault with a 3.2m throw. Northwest and southeast of this point, the fault decreased in throw and no further outbursts were recorded along it.

Outburst No's 11 and 12 occurred on structures interpreted as strike-slip faults. Outburst No. 12 was of minor intensity (Table 4).

Outburst No. 13, also of minor intensity occurred in association with an intrusive igneous body. Apart from the ubiquitous bedding-plane fault no other faulting was present.

NO. 3 MINE

The two outbursts (No's 14 and 15, Fig. 6, Table 4) occurred on the same strike-slip fault as Outburst No. 11 in the State Mine. The outbursts were minor and occurred at a depth of 220m. The coal has a rank of 1.29% vitrinite reflectance near the outburst sites.

Gas emission measurements (method by Hargraves, 1962) show an increase in "gassiness" towards the outburst area (Fig. 6). Gas emission values in the vicinity of the outbursts were in excess of $1 cm^3/g$ (Table 4).

The strike-slip fault was previously intersected on many occasions in less gassy areas and no outbursts were experienced. At the outburst sites, the fault has virtually no throw, but is indicated by a 0.46m band of mylonitised coal.

The occurrence of outbursts, together with roof control problems and the experiences in the State Mine were sufficient to halt further development in No. 3 Mine.

NO. 2 MINE

Compared to the State Mine, the outbursts in No. 2 Mine have been minor with the largest outburst ejecting

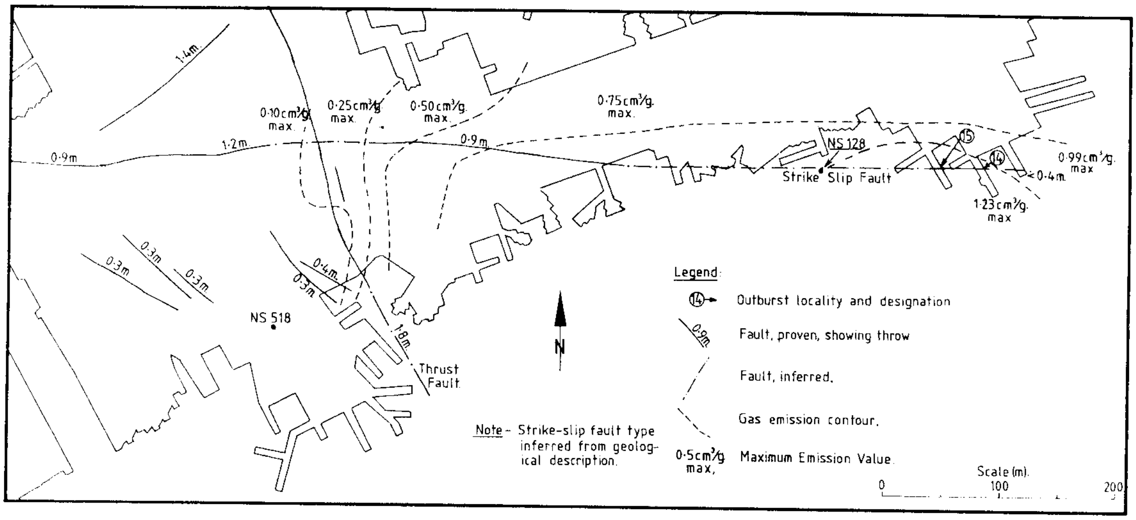


Fig. 6 — Gas emission values, fault and outburst localities, Bowen Seam, No. 3 Mine

only 25 tonnes of coal (Table 4). Four outbursts (No's. 16, 17, 18 and 19, Fig. 7, Table 4) occurred in the 53 Level West Panel and were associated with a 6m-throw, thrust fault. A strike-slip fault with 0.5m throw was also associated with Outburst No. 19.

A number of gas "incidents" were also reported, the most notable occurring in the South Headings. These are described by Biggam, Robinson and Ham (1980).

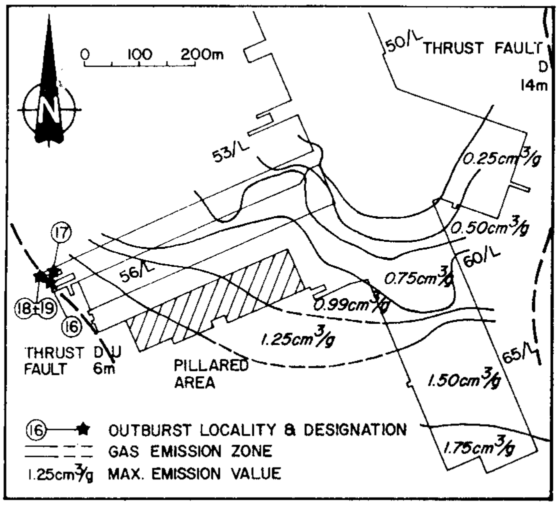


Fig. 7 — Gas emission values, major faulting and outburst localities, Bowen Seam No. 2 Mine

Outburst No's. 16 and 17 (Table 4) occurred at 260m depth, while No's. 18 and 19 were at 265m depth, on the downthrown side of the thrust fault.

Details of the geological structures associated with the thrust fault are presented by Shepherd, Rixon and Creasey (1980).

Gas emission values increased progressively along 53 Level West Panel up to a maximum of 1.28cm^3/g in the vicinity of the outbursts at the 6m-throw, thrust fault (Fig. 7). This rise in emission values is part of a regional trend and was also experienced in the 56 Level West Panel and the South Headings. Here, the maximum recorded gas emission value was 1.73cm^3/g.

The increase in emission values corresponds to an increase in coal rank to above 1.20% vitrinite reflectance (Fig. 3). At the western extremity of 53 Level West Panel and at the deepest point in the South Headings, the vitrinite reflectance is around 1.27%.

The Bowen Seam in the deeper areas of the mine contains an irregular siltstone band which varies markedly in its position within the seam. At the outburst area, the band is located 1.4m from the seam roof. To the east the band irregularly diverges from the roof and at 180m from the outburst area, it is 4.5m from the seam roof. This variation is accompanied by a rapid change in coal

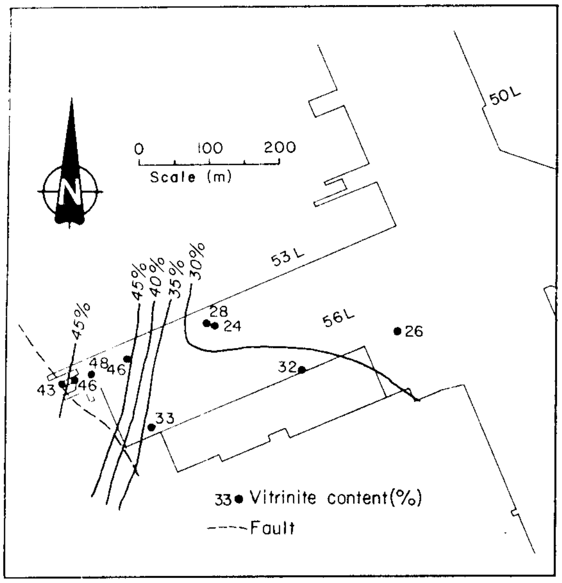


Fig. 8 – Vitrinite Content of the top 1.8 to 2.5 metres of Bowen Seam, No. 2 Mine

type. At 200m east of the 6-m throw, thrust fault, the vitrinite content of the mining section (the top 2.5m to 2.8m of the seam) is 28% and increases to a maximum of 48% near the fault (Fig. 8). The increase in vitrinite content is confned to the lower half of the mining section. In the vicinity of the fault, it is 63% compared to 26% in the top section. A bedding plane fault separates the two sections. The vitrinite-rich lower section is highly sheared.

INTERPRETATIONS

Coal rank and type, seam "gassiness", virgin and mining-induced rock stresses, the nature of faulting and igneous intrustions all appear to contribute to outburst proness in varying degrees.

COAL RANK AND TYPE

The level of coal rank was shown by Ettinger (1952) and Ettinger et al (1966) to be an important parameter in determining the potential gassiness of a coal seam. Ettinger et al (1966) showed that for carbon dioxide the gas sorbtion capacity depended only upon rank. The rate of gas desorbtion was shown to be dependent upon coal type and rank and the gas composition.

The mechanical strength of coal has been shown by a number of authors to be closely related to coal rank. The Hardgrove Grindability Index was correlated with rank by Van Krevelen (1961). He showed that the grindability of coal increases with rank up to a maximum of 90% carbon. An analysis of data listed in Edwards (1975) showed a clear relationship between Hardgrove Grindability and rank for Australian coals (Williams, unpublished data, 1980).

In the Soviet Union and Czechoslovakia it is an "established fact" that the degree of outburst proneness varies smoothly with increasing rank (Nikolin, 1974). A quantitative relationship has been determined between outburst potential and coal rank. This relationship is regarded as the basis for a method of regional forecasting.

Outbursts have only occurred in the Bowen Seam when the rank of the coal has exceeded 1.2% vitrinite reflectance. The relationship between a gas dynamic parameter (emission value) and coal rank is shown by comparing Fig. 3 and 7. The sudden increase in gas emission values in the lower area of No. 2 Mine occurs at the point where the coal rank exceeds 1.2% vitrinite reflectance. A similar relationship was shown for No. 3 Mine (Williams, unpublished data, 1980).

The effect of coal type on mechanical strength was demonstrated in No. 2 Mine where intense fracturing was mostly confined to the high vitrinite coal. It is possible that Outburst No. 16 may not have occurred without the rapid increase in vitrinite content and concomitant fracturing towards the outburst site (Fig. 8).

ROCK STRESS

Rock stress is generally cited as an important outbursting parameter, but it is often difficult to evaluate in outburst analysis. Ground conditions in No. 2 Mine are generally very good and signs of high stress in the form of roadway failure are uncommon. Low stress levels are also indicated by a lack of rock noise during microseismic monitoring trials. The outbursts in No. 2 Mine appear to be more of a gas-burst as opposed to the wholly stress-initiated rock-burst.

Roof failures in the outbursting areas of the No. 3 and State Mines were much more common than in No. 2 Mine. It is likely that rock pressures were higher and did contribute to the more frequent and intense outbursts.

It is doubtful whether the Little Bowen Seam (Fig. 4.1) contributed to the outburst proneness in the No. 3 and State Mines. Accounts of high gas flows from this seam probably reflect a sudden increase in roof strata permeability brought about by progressive upward fracturing (and destressing) under high lateral stress. The gas flows are more an effect than a cause of roof instability.

FAULTING

The association of zones of sheared coal and outbursts testifies to the importance of faulting as a major contributing factor to outbursts at Collinsville.

Empirical data indicate that for an outburst to occur on a fault, the gas conditions of the faulted coal must be above a certain threshold. An outburst will not occur if there is insufficient gas trapped in the coal gouge. Faults on which outbursts have occurred in gassy areas have been negotiated without incident in low gas areas. This is exemplified in No. 3 Mine where outbursts have only occurred on the strike-slip fault where the gas emission values have exceeded $1.1 cm^3/g$ (Fig. 6). The thrust fault in the State Mine on which Outburst No's. 1 and 2 occurred, was repeatedly intersected in the shallower workings without incident.

While the degree of coal mylonitization requisite to outbursting requires seam dislocations, not all faults produce outbursts, even in outburst-prone areas. It appears that on some faults, the intensity and regularity of outbursting is greater than on others. This variation is partly due to differences in the way mining is carried out and to fundamental geological differences. Outbursts have occurred in 65% of the roadways intersecting strike-slip faults in outburst-prone areas. In comparison, there is only a 30% outburst incidence in roadways intersecting thrust faults. Lateral displacement was probably of considerable magnitude to produce the 0.5 to 0.6m wide coal gouge zones associated with the strike-slip faults in No. 3 and the State Mines. Strike-slip faults have been encountered in the high gas areas of No. 2 Mine and were not outburst-prone. The coal gouge associated with these faults was only 0.05m thick.

The higher frequency of outbursting on strike-slip faults may be largely explained by the generation of coal gouge within the plane of the seam. It could be argued, that for a displacement in excess of the seam thickness, more coal gouge would be generated by a strike-slip fault than by a thrust fault. A thrust fault would generate more coal gouge than a normal fault for the same mechanical properties and stress difference. Mapping by Shepherd, Rixon and Creasey (1980), revealed the high complexity of shearing associated with thrust faults. In view of this, it is not surprising that large variations in outburst intensity and frequency occur on thrust faults. Strike-slip faults, with a more even fault gouge distribution are more consistent in their outburst proneness. This is demonstrated by the outburst-prone, strike-slip faults at Westcliff Colliery (Marshall, Griffiths and Lama, 1980) and the regular incidence of outbursts along the strike-slip fault in the State Mine.

While strike-slip faults are associated with a high frequency of outbursting, the largest outbursts occurred on a thrust fault (Outburst No's. 1 and 2, Table 4, Fig. 5). The two thrust faults in the State Mine were apparently mined across from the up-thrown to the down-thrown side except for Outburst No. 2. The intensity of this outburst was probably increased by mining through it from the down-thrown side resulting in the outburst being gravity assisted. No outbursts have been recorded on thrust faults in outburst-prone areas where the fault throw is less than 3.0m.

The fault designated as "normal" in the State Mine experienced no outbursts despite a maximum throw of 2.0m. The lack of outburst-proneness may be accounted for by a smaller displacement compared with the strike-slip and thrust faults.

IGNEOUS INTRUSIONS

The State Mine has experienced by far the most intense and frequent outbursts and is located on the western margin of an extensive area of igneous intrusion. Intrusions were associated with Outburst No's 1, 2, 12 and 13.

There are indications in No. 2 Mine, that high gas areas may be associated with igneous intrusions. In the No. 2

Mine area, the gas content of the intruded Blake Seam is always higher than that of the overlying Bowen Seam.

Igneous intrusions possibly affect outburst proneness in the following ways.

1. Gas contents and desorbtion rates are increased because of the higher rank coal.
2. Carbon isotope work by the Commonwealth Scientific and Industrial Research Organisation (Smith and Gould, unpublished data, 1979) indicates a likely igneous origin for the carbon dioxide. If this deduction is correct then depending upon permeability characteristics, greater volumes of carbon dioxide would be stored in the coal surrounding these bodies. Coal has a greater sorbtion capacity and desorbtion rate for carbon dioxide than for methane.

CONCLUSIONS

The natural conditions leading to outbursts at Collinsville form a complex set of geological parameters. In its simplest form, high gas conditions in combination with faulting directly lead to outbursting conditions. The relative importance of rock stress is uncertain.

The values and parameters listed below are tentative and summarise the geological requirements for outburst proneness to date.

1. Seam gas properties:
    - emission value greater than $1.1 cm^3/g$,
    - coal rank greater than 1.2% vitrinite reflectance,
    - desorbable gas content greater than $7m^3/t$ (approximate), and
    - gas composition - dominantly carbon dioxide.
2. Faulting:
    - strike-slip with a coal gouge width greater than 0.3m, and
    - thrust faults with throws greater than 3m.
3. Other contributing factors:
    - high vitrinite content,
    - proximal igneous intrusions, and depth of cover greater than 210m.

By virtue of its relationship to "gassiness", coal strength and geological deformation, coal rank shows promise as a regional outburst proneness indicator at Collinsville. The high level of rank at the present topographic surface and the high coalification gradient appear to have laid the foundation for the outburst-prone conditions at relatively shallow depths.

Faulting, in association with high gas, has directly promoted outbursting conditions. The amount and regularity of coal mylonitization is thought to explain the varying outburst response on different faults in the same outburst area. Strike-slip faults with coal gouge zones around 0.5m thick have resulted in the greatest regularity and frequency of outbursts. Thrust faults with throws of greater than 3m have had outbursts associated with them. The most severe outbursts occurred on a thrust fault which was associated with an igneous intrusion and a normal fault. Normal faults with throws up to at least 2m do not appear to be outburst-prone.

Variations in the character of outbursts around faults could also be explained by differing stress patterns occurring in their proximity. Stress conditions in the State and No. 3 Mines appear to have been more important in outbursting and ground stability generally than in No. 2 Mine.

A rapid variation in coal type toward a vitrinite rich coal was an important contributing factor to Outburst No. 16. Because the Bowen Seam is particularly variable in coal type, the determination of areal outburst proneness should include a study of coal type variations.

It is possible that areas associated with igneous intrusions are more outburst prone because coal rank is increased in the vicinity of intrusions, and these intrusions may be a source of the carbon dioxide.

ACKNOWLEDGEMENTS

The Collinsville Coal Company Pty. Ltd. is acknowledged for permission to publish this paper. The opinions expressed are those of the authors and not necessarily those of the company.

REFERENCES

Biggam, F.B., Robinson, B. and Ham, B.W., 1980. Outbursts at Collinsville — a case study, Symp. on *Occurrence, prediction and control of outbursts in coal mines*, Australas. Inst. Min. Metall. Brisbane.

Cribb, H.G.S., 1956. Inspection No. 3 West Dip Face No. 1 Tunnel, State Coal Mine, Collinsville, in *Report of the Royal Commission into State Coal Mine, Collinsville*, p. 277 (Queensland Government).

Edwards, G.E., 1975. Marketable resources of Australian coal, in *Australian Black Coal — its occurrence, mining and use*, (ed. A.C. Cook), p.p. 85-108, Australas. Inst. Min. Metall.

Ettinger, I.L., 1952. Basic factors which determine the gas capacity of mined coals at atmospheric pressure. *Izvestiya Akademii Nank SSSR, Otdeleine, Tekhnicheskikh Nank*, 3:423-432.

Ettinger, I.L., Eremin, I., Zimakov, B. and Yanovskaya, M., 1966. Natural factors influencing coal sorbtion properties. 1 — Petrography and the sorbtion properties of coals. *Fuel* 45:267-275.

Hargraves, A.J., 1958. Instantaneous outbursts of coal and gas, *Proc. Australas. Inst. Min. Metall.* No. 186:21-67.

Hargraves, A.J., 1962. Gas in face coal, Proc. Australas. Inst. Min. Metall, No. 203:7-44.

Hargraves, A.J., 1967. Instantaneous outbursts of coal and gas in Australia, in *Proceedings — General, Vol. 6* (ed. J.T. Woodcock, R.T. Madigan and R.G. Thomas). p.p. 871-885 (Eighth Commonwealth Mining and Metallurgical Congress: Melbourne).

Krevelen, D.W. van, 1961. *Coal*, Elsevier: Amsterdam, London, New York, Princeton: 514p.p.

Marshall, P., Griffiths, L. and Lama, RD. 1980. Occurrence of Outbursts at Westcliff *Symp on occurrence, prediction and control of outbursts in coal mines*, Australas. Inst. Min. Metall. Brisbane.

McCulloch, C.M. and Diamond W.P., 1976. Inexpensive method helps predict methane content of coal beds. *Coal Age* 81, 6:102-106.

Mengel, D.C., 1975. Collinsville Coal Measures, in *Economic Geology of Australia and Papua New Guinea* (ed. D.M. Traves and D. King), p.p. 83-89, Australas. Inst. Min. Metall.

Nikolin, V.I., 1974. Causes of outbursts of coal and gas forecasting of outburst — proneness in coal seams, *Symp. on sudden coal and gas outbursts*, Econ. Comm. for Europe Coal Committee, Donetsk (Ukrainian SSR).

Reid, J.H., 1929. Geology of the Bowen River Coalfield, *Publs. Geol. Surv. Qld.*, 276.

Shepherd, J., Rixon, L.K. and Creasey, J.W., 1980. Analysis and prediction of geological structures associated with outbursts at Collinsville, Queensland, *Symp on occurrence, prediction and control of outbursts in coal mines*, Australas. Inst. Min. Metall, Brisbane.

Staines, H.R.E. and Koppe, W.H., 1979. The geology of the North Bowen Basin, *Qld. Gov. Min. J.*, 80, 930:172-195.

Webb, E.A. and Crapp, C.E., 1960. The geology of the Collinsville Coal Measures, *Proc. Australas. Inst. Min. Metall.* No. 193-23-88.