Estimation of methane emission from Australian coal mines

by

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ABSTRACT

A study of methane emissions from Australian coal mines was undertaken as part of a wider investigation into the extent of methane emission from various sources.

Most of the 'gassy' and a number of 'non-gassy' underground coal mines were approached for collection of their methane related data. Methane emissions from underground coal mines were estimated using the routinely measured methane concentration in mine main air returns. For the 'gassy' or 'class A' mines where a drainage system was operating, the amount of drained methane that passed through gas extraction plant was added to the methane flow rate in the ventilation body. For 'non-gassy' or 'class B' mines, the methane emission was estimated by using their air flow data and by assuming a constant methane concentration in the return shaft. The methane emission rates, coal production, gas content and coal properties data were investigated. Attempts were made to reveal the potential relationships between these parameters.

For open-cut coal mines, the methane emission has no impact on safety and coal production, with the consequence that there are little or no methane emission data available. To remedy this, some measurments of methane emission rate in a few open-cut coal mines were carried out to evaluate the rate of methane emission. Two procedures were employed, one direct, the other indirect. The indirect method consisted of measurement of the gas content of a fresh coal sample taken after blasting using newly developed CSIRO test equipment. The direct method consisted of measuring the crosswind concentration of methane and downwind velocity using an instrumented research vehicle.

It was estimated that underground mines emitted 0.7 Mt/y of methane of which 0.04 Mt/y were utilised for electricity generation. It was considered that a further 0.015 Mt/y evolved from 'gassy' coal after mining. Although open-cut operations account for bulk of coal production, they were estimated to produce only 0.046 Mt/y of methane.

INTRODUCTION

The origin of coalbed methane

The methane is a product of the coalification process. The transformation of decaying vegetation into coal occurs on geological time scales, many coal deposits having been formed 300-400 My ago. (Schobert, 1987) Initially, the dead vegetation is compacted into peat, with loss of H_2O along with some CO_2 and CH_4 due to biological processes, the carbon content increasing from 50% to 60% by weight on a dry, ash- free (daf) basis. Then, with increasing depth of burial, the peat loses more of its oxygen (as CO_2) to form brown coal or lignite. At this stage, the carbon content has risen to about 65%. Further increase in burial depth (and hence temperature) results in loss of more oxygen which transforms the brown coal into low rank sub-bituminous black coal. It is only after the formation of low rank black coal that further maturation increases the C/H ratio (and hence the rank of the coal) by the release of methane. This implies that there is little release of methane associated with the formation and mining of brown coal and data from the State Electricity Commission of Victoria support this conclusion (Ardern 1983). It should be noted however that data on the isotopic composition of coal seam methane indicate a more complex mechanism of formation than just simple pyrolysis (Smith et al, 1982, 1985). The bulk of the methane is generally retained within the coal seams through a combination of hydrostatic pressure and the adsorptive affinity of the coal for CH_4 (Hargraves, 1962). Extensive geological fracturing or uplifting of the coal measures can cause a significant reduction in the amount of methane retained within the coal. In general, however, the greater the depth of the coal measure, the higher the methane gas content. Deep, high rank, coals can contain more than 50 m^3 CH_4/tonne. It has been noted that coalbed methane contents are inversely related to the amount of mineral matter present, simply because the mineral matter has no affinity for methane (Faiz and Cook, 1991). Late stage intrusion of carbon dioxide can cause the replacement of methane by CO_2 and therefore reduces the methane content of coal seam.

Release of methane induced by mining

In order to predict the quantity of gas released during mining operations, many empirical studies have been undertaken. A number of models of gas release have been presented and used to assess the emission during mining. These models are either empirical and based on emission data from coal mining or are deduced from studies of the physics of gas flow and consequently converted to computer codes. In relation to mining of coal, two stages in gas emission can be identified, - emission during development (drivage of headings and delineation of future panels) and emission during mining. In both stages the first problem is to evaluate the extent of the zone of emission. This zone which , gives rise to methane during mining, is called 'influenced volume' or 'relaxed zone' or 'destressed volume' or anything else provided it corresponds to that volume of strata which is disturbed by mining and emits gas . In the case of development heading, the shape and size of relaxed zone is small and is relatively regular in time. In this case, mathematical modelling, based upon the physics of gas flow in porous medium and subsequent computer codes can be developed (Saghafi, 1991). In the second stage of mining, empirical models are more reliable and are used widely. Most of these models originated in coal mining countries of Europe during last few decades and were used by the European collieries (Jeger, 1978). These mines are much deeper compared to Australian coals and often consist of multi-seams. Some of these models have been modified and used to predict gas emission in longwall mining in Australia.(Williams, 1991). In these models a 'Specific Emission' parameter is defined which is the quantity of gas produced per tonne of mined seam. The variation of this parameter mainly with respect to coal productrion and time have been investigated by many researchers over the world. It appears that specific emission is relatively constant for a given mine and for a range of production. This quantity is dependent upon the in-situ gas properties of the coal seams and bearing strata as well as the method of mining and rate of coal production.

Two main coal mining techniques currently in use in Australia are longwall and bord and pillar with a trend twoards longwall mining. As longwall mining allows more coal production and higher efficiency, then, wherever the geological conditions permit, the bord and pillar mining is being replaced with longwall mining (Lama, 1991). In both methods, the extraction of coal will trigger caving of the above strata into the void behind the face. The collapse of the roof into goaf generates numerous fractures in above and below the seam being mined, creating a zone of destressed or relaxed strata around the working area. The methane contained in relaxed strata will move into the longwall face and goaf. The total amount of gas released depends upon the in-situ gas content of adjacent seams and the extent of disturbance induced into the bearing strata. In some countries, where mining operations are undertaken beneath urban areas, the void is refilled and less disturbance is produced in the bearing stata. In Australia, however the roof is allowed to cave into the floor and therefore the mining-influenced zone is relatively larger. In longwall mining the volume of the disturbed zone is larger than that produced by bord and pillar mining and more gas emission can be expected. Most of the 'gassy' coal mines, particularly longwall production mines, use a gas drainage system to relieve gas problems. The gas drainage boreholes are drilled either before or after mining the panel. Most of drainage boreholes are predrainage boreholes. They serve to drain the future longwall panel of its gas. Predrainage may take place for a few months to a year of drainage depending upon the gassiness of the area and available lead time before the start of mining. In Australia most of the predrainage boreholes are drilled in the plane of the seam being mined (in-seam boreholes), and measure from 50 m up to 200 m, corresponding to the width of pillars or panels. Recently long boreholes of up to 1000 m have been trialled and implemented in several Sydney Basin coal mines and some of the Bowen Basin coal mines (Hungerford *et al.*, 1988, Truong *et al.*, 1990)

With the mining of the panel the upper layer and under layer coal seams become very permeable due to mining induced strata fracturing. Gas contained in these seams and neighbouring strata starts to move into the goaf or mine roadways. To capture this gas, post-drainage boreholes are drilled at an angle above and below the seam being mined. These holes are not active until the longwall face becomes close enough to them. When the face passes, they begin to produce very high amount of gas, this continues after the face has advanced a few hundred meters passed the boreholes after which flow rates reduce sharply to a low steady value. Surface drainage boreholes are also included in post-drainage system. They are drilled from surface into the future goaf area and can capture significant quantity of gas. In Australia surface boreholes are still not very common.

ESTIMATION OF THE AMOUNT OF METHANE RELEASED BY MINING

So far, few studies have been carried out to assess the overall gas emission rate from coal mines. A report from U.S. EPA estimates a total of 6.8 Mt/yr, the worldwide methane emission from coal mines. The Australian contribution is presented to be 1.1 Mt/y (Kirchgessner, 1991). A recent report has given an estimation of 0.5 to 0.6 Mt/y of methane from mining (Lama, 1991). In most studies, coal production has been the principal variable used in statistical analysis of methane emissions. In the 'specific emission approach' a more analytical method is used: gas content and emission rate of different seams together with an assumed 'relaxed zone' are input to a model of specific emision. However the 'specific emission' only concerns the longwall panels and does not represent the total emission from whole mine. In the absence of such an analytical model and because we are dealing with B&P as well as LW mining, we have estimated methane emission from coal mining using different approachs for underground and open-cut mines. While in both cases the most important parameters are coal production and in-situ gas content of coal seams.

Australian raw coal production

In Australia, raw black coal production in 1990 was 201.3 Mt of which 60.5 Mt was sourced underground (ABCS, 1990). 96% of the raw coal was mined in New South Wales and Queensland, the breakdown between opencut and underground production being shown for the various States in Table 1.

Emission from underground coal mines

Underground mines in Australia are classified as being 'gassy' or 'non-gassy. In the case of 'gassy' or 'class A' coal mines, the methane concentration of the return air is routinely monitored. The concentration of methane is higher than 0.1 % for this class of mine and have specific emission of as high as 30-40 m^3/t . The concentration data together with air flow rate in the main return gives an assessment of the rate of methane emission into the ventilation system . The methane captured in drainage system is pumped to the gas plant instalation. Flow rate and composition of captured gas are continously monitored , therefore the flow rate of drained methane can be evaluated.

In the 'non gassy' or 'class B' coal mines the methane concentration in the ventilation air is rarely measured and is usually below or close to 0.01% .

The approach taken in this study has been to contact individual Class A mines for data on the methane content of their ventilation air, the air flowrate and the coal production rate. Data have been obtained that cover 78% of Australian underground production from gassy mines.

The Class A mines are listed in Table 2, along with the depths of the mined seam and annual production rates (JCB, 1990). All but four of the mines provided methane emission data.

In order to estimate the methane release from the remainder of the gassy mines for which we have no data, we have examined the data for correlations between the amount of methane released with in-situ methane content, depth of mining and annual mine production. These are displayed in Figures 1, 2 and 3 respectively. It can be seen that correlations are poor. However, better correlation is obtained by plotting methane emission rate against the product of mine production and gas content, which is displayed in Figure 4. This of course implies that there is some correlation between the individual parameters, mine production and gas content. We have used the the correlation:

$$(CH_4)_r = 4.95*MP*(CH_4)_i + 5.58$$

where $(CH_4)_r$ is the methane emission rate , MP is the annual mine production and $(CH_4)_i$ is the in-situ coal seam methane content to estimate methane production for the remainder of the gassy mines. This is the equation of the regression line in Figure 4.

The overall amount of methane released from these mines amounted to $1.14x10^3 Mm^3$ in 1990, based on ventilation flowrate and the methane content in the ventilation air. Approximately 70 Mm^3 were utilised for electricity production, leaving a net emission of $1.07x10^3 Mm^3$ from Class A mines or 0.66 Mt/y.

However, not all the methane in coal from 'gassy' underground mines is released during mining, there being subsequent release of residual methane as the coal awaits utilisation. Some of the residual methane may be combusted when released on pulverisation at power stations, but the bulk is likely to be emitted into the atmosphere. Residual methane contents generally lie within the range 0.5 - 1 m^3/t, depending on the nature of the coal. Thus, from a underground production of 33.8 Mt in 1990, another 17-34 Mm^3 of methane would be emitted, ie 10,000 - 20,000 t.

The Class B (or 'non-gassy' mines) are listed in Table 3. We have collected emission data for 8 of these mines. These have 0.01% methane in their ventilation air, which represents the lower limit of detectability of the methane monitoring system. To estimate emissions from the remainder, we have used the correlation between ventilation airflow, V, and mine production derived from the data on mines emissions (Figure 5) together with the assumption that methane concentration are 0.01 vol %.. We have used the equation:

$$V(m^3/s) = 102*MP + 88$$

The procedure leads to a value of 18.4 Mm^3/y or 11,000 t/y.

We estimate therefore that methane emissions from underground coal mines amounted to about 0.69 Mt in 1990. The estimates are summarised in Table 4.

Emissions from open-cut mines

As the coal production from Australia open-cut mines is 140 Mt or 2.5 times that of underground production, it is important to establish how significant methane release from this type of mining really is. However because methane is not a safety issue in open-cut mining, there are little or no data on in-situ methane contents of the mined seams. In these mines, coal seams are close to the surface, and therefore most of their methane have diffused away before mining.

We have measured the residual methane content of coal samples from Warkworth and Ravensworth open-cut mines in Hunter valley. The sample from Warkworth was fresh while the one from Ravensworth was from a high-wall which has been exposed for a few weeks. The results are as follows:

Warkworth coal 0.32m^3/t
Ravensworth coal 0.33m^3/t

We are currently measuring the residual gas contents of coal samples from few other open-cut mines. These data should provide an average value for the gas content for coal from open-cut mines. This gas content multiplied by the mining production rate can be used to estimate open-cut generated methane. With a residual gas content of 0.3 m3/t the Australian open-cut mines would produce 25 Mt/yr of methane. British data give an average value of 0.5 m^3/t for the in-situ methane content of their open-cut coals (Mc-Creedy, 1992).

In addition to using data on the gas content of samples from open-cut mines, we have carried out a few direct measurements of methane flux downwind of the mine. The experimental procedure adopted has been to use either airborne or ground based equipment to measure the flux of methane in the plume emitted by the mine. This can be achieved, in principle, by traversing a methane monitor orthogonally across the plume to determine the horizontal crosswind concentration profile. The emitted methane moves away with the wind, dispersing horizontally and vertically at rates which are a function of the existing meteorology. If the vertical crosswind profile can also be measured or estimated, then the methane flux is the product of the two crosswind concentration profiles with the horizontal windspeed. In practice, allowance has to be made for the fact that the traverses are seldom orthogonal to the wind direction; also it is difficult to measure the vertical profile. For the latter parameter, it is usually assumed that the plume is mixed vertically, so that the problem comes down to estimating the vertical thickness of the plume. With visible smoke plumes this is can be done photographically, an option not available for invisible methane plumes. However, experience with smoke plumes permits reasonable estimations of plume heights for a given meteorology.

The ground-based experiments were performed with the instrumentation mounted in a special research vehicle, based on a Ford F150 chassis. Spot measurements of windspeed and direction could be measured at a height of 9 m, when the vehicle was not traversing. Alternatively, many mines measure these meteorological parameters routinely and their data can be used.

The airborne investigation used the CSIRO F27 research aircraft which is equipped with an inertial navigation system (INS). The aircraft position, altitude, outside air temperature and humidity were routinely recorded as were wind speed and direction which were computed from the INS data.

Direct measurement of methane flux using an instrumented vehicle

An estimate of the flux of methane downwind of a mine was attained by measuring the crosswind profile of the methane concentration using an instrumented vehicle. A value for the flux, Q, can be obtained from this data, in conjunction with a knowledge of the horizontal windspeed, u, and an estimate of the height of the methane plume viz:

$$Q= Cx_{av}hu$$

where C_{av} is the excess methane concentration averaged over the width, w, and the height, h, of the plume.

The ability to carry out such surveys is limited by adequate access around the perimeter of the mine. Vehicle based surveys have been made at three open-cut mines viz Blackwater, South Blackwater (Qld) and Warkworth (NSW). The results are summarized as follows:

Blackwater

This mine is located about 50 km south of Blackwater and extends for about 20 km in a N-S direction. Annual production is about 5 Mtonnes (QCB, 1990). The windspeed during the survey averaged about 6m/s from 160°. There were three currently active portions of this extensive mine and each of these was circumnavigated by the instrumented vehicle. Also measurements were made along the public access road which lays just to the west (ie down-wind) of the northern half of the mine.

No significant methane concentrations were detected, in excess of the normal background atmospheric concentration, in any part of the survey around the currently-mined pits. ie maximum observed values did not exceed 0.05 ppm (1ppm = $1cm^3/m^3$) above background and values generally were less than 0.03 ppm above ambient. Measurements along the public access road varied by less than 0.02 ppm above ambient.

If it is assumed that, with the wind direction close to the axis of the excavations, the plume width was 500 m for each of the three actively mined sites and that h was 200 m then:

$$Q< 3*500*200*6*0.02*10^{-6}= 3.6*10^{-2}\ m^3/s$$

which is equivalent to less than 600 tonnes annually. This implies that the methane content of the coal is less than 0.2 m^3m/t.

South Blackwater

This mine is located some 30 km south of the previous mine. Annual production is about 2 Mt from the open-cut and about 0.5 Mt from the associated underground Laleham mine (QCB, 1990). Wind was from the south at 1 m/s, possibly a valley drainage flow. Suitable downwind access was very restricted, and measurements were limited to the access road which cut very obliquely across the plume.

The maximum observed methane concentration was 0.4 ppm above background, and averaged about 0.1 ppm. Plume width was estimated to be 3 km so that if h was 200 m then:

$$Q = 3000*200*1*0.1*10^{-6} = 6*10^{-2} m^3/s$$
$$= 1100 \text{ t/y}$$

Realistically, the value for Q probably lies in the range 500 - 2000 t/y. It should be noted that South Blackwater also operates an underground mine, Laleham No. 1, whose emissions may well have contributed to the measured methane burden. These emissions amount to 400 t/y. Hence the open-cut emissions amount to 100 - 1600 t/y.

Warkworth

The mine is located near Singleton in the Hunter Valley. Annual production is 2.5 Mt. The mine is situated within a triangle of roads making flux measurements a little easier.

Two runs were made. The data are summarized as follows, h is assumed to be 400 m:

Run	u	θ	w	C_{xav}	Q	
	m/s	(deg)	(km)	(ppm)	(m^3/s)	(t/y)
1	6	45	4.0	0.2	0.13	2500
2	4	9	3.5	0.4	0.23	4400

θ is the angle of the wind to the road and w is the width of the plume along the road. It seems likely, from the above data, that Q lies in the range 1500 - 6000 t/y for the Warkworth open-cut.

Direct measurement of methane flux using CSIRO F27 research aircraft

The Blackwater and South Blackwater mines were also surveyed by aircraft when en route back to Sydney from Northern Territories field campaign. The mine complex was circumnavigated at a height of 150 m above ground at a distance of about 2 km from the workings. No excess methane was detected except for a weak narrow plume probably originating from the ventilation shaft of the Laleham underground mine at South Blackwater. The data are consistent with the ground based observations in that little or no emission of methane was observed.

It is obvious that to estimate emissions properly from open-cut mines, a substantial measurement program is required. However, the limited set of data presented above do provide a guide. If it is assumed that the Warkworth emission rates are typical of the Hunter and that the Blackwater rates apply to the Bowen Basin, when scaled by the coal production rate, then one can derive specific emission rates (SER) for methane release from these regions. The SER for the Hunter is about 2000t for each 1 Mt coal produced, whilst that for the Bowen Basin is around 200 Mt. As the Hunter accounts for about 75% of open-cut production in NSW and the majority of the Queensland open-cut mining occurs in the Bowen Basin, these SER values have been applied to the entire open-cut production in each state. On this basis, estimates of the annual methane release are presented in Table 4, which total 46,500 t in 1990.

CONCLUSIONS

Emissions of methane from coal mining are dominated by those from underground coal mining, particularly the Class A or gassy mines. These were estimated to be responsible for about 90% of coal derived methane, or 0.71 Mt in 1990, including residual emissions from stockpiles. The non-gassy underground mines were responsible for 11,000 t, whilst open-cut mining, by far the largest producer of coal, accounted for 46,500 t.

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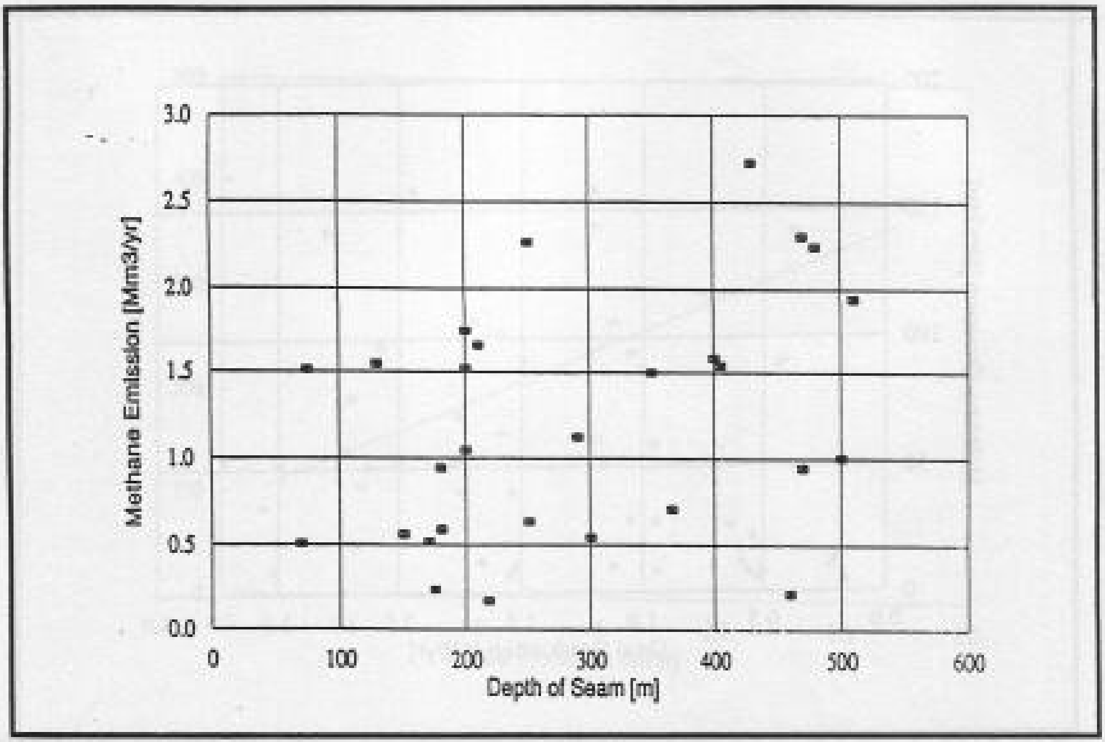

Figure 1. Methane emission as a function of seam depth.

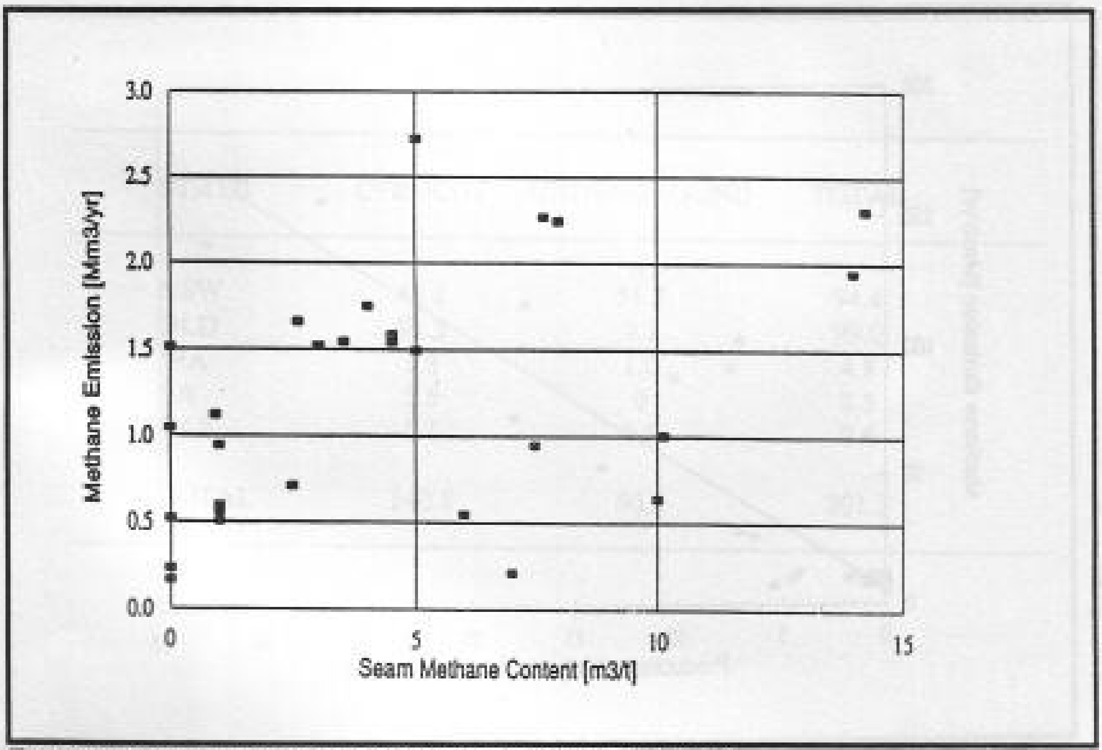

Figure 2. Methane emission as a function of in-situ CH_4 content.

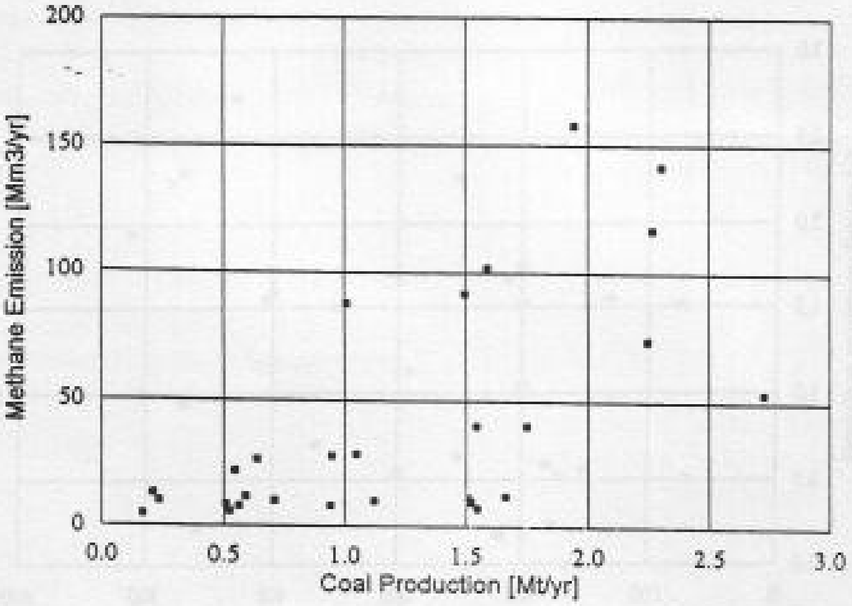

Figure 3. **Methane emission as a function of annual mine production**

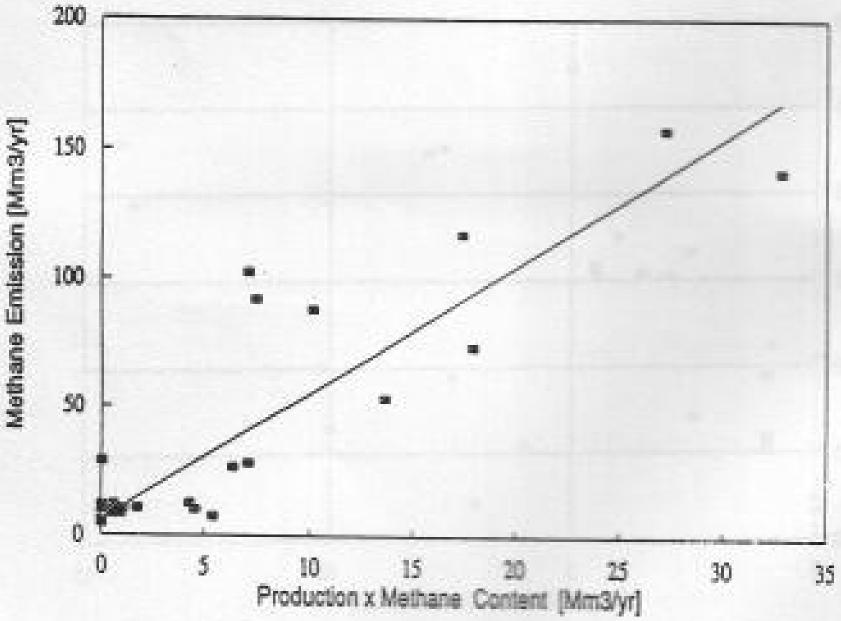

Figure 4. **Methane emission as a function of the product of the annual coal production and gas content**

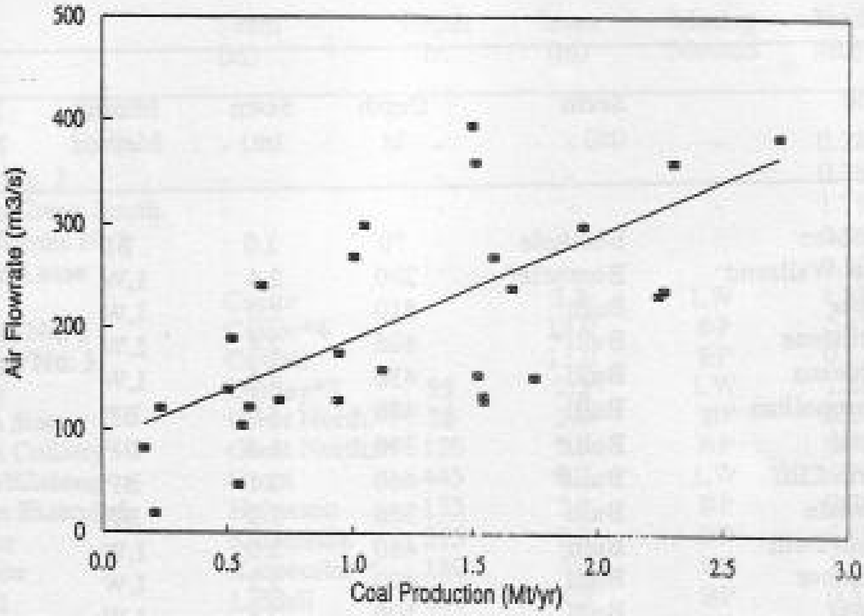

Figure 5. **Correlation between ventilation flow rate and mine production**

STATE	OPENCUT	UNDERGROUND	TOTAL
NSW	43.1	51.3	94.4
QLD	91.3	7.7	99.0
WA	3.8	1.0	4.8
SA	2.5	0	2.5
TAS	0.1	0.5	0.6
TOTAL	140.8	60.5	201.3

Table 1. **1990 Raw black coal production by states (million tonnes)**

Mine	Seam (m)	Depth ht	Seam (m)	Mining Method	Prod. Mt/yr
Lambton	Borehole	70	2.0	BP	0.51
West Wallsend	Borehole*	200	2.4	LW	1.75
Appin	Bulli	510	3.0	LW	1.94
Brimstone	Bulli*	405	2.4	LW	1.54
Cordeaux	Bulli	430	2.6	LW	2.73
Metropolitan	Bulli	470	3.0	BP	0.95
Nattai	Bulli*	300	1.6	BP	0.54
North Cliff	Bulli*	460	2.1	BP	0.21
Oakdale	Bulli	366	2.2	BP	0.71
South Bulli	Bulli	480	2.0	LW	2.24
Tahmoor	Bulli	400	2.2	LW	1.59
Tower	Bulli	500	2.4	LW	1.01
Westcliff	Bulli	470	2.5	LW	2.30
Moura No. 2	D seam	250	4.0	BP	0.64
Myuna Colliery	Fassifern	150	2.9	BP	0.56
Newvale Colliery	Fassifern	218	2.8	BP	0.17
Wyee State	Fassifern	210	3.1	LW	1.66
Oaky Creek	German Creek	130	2.8	LW	1.54
German Creek Cent.	German Crk	200	2.0	LW	1.52
Cooranbong	Great North.	75	2.7	LW	1.51
Munmorah State	Great North.	200	2.7	BP	1.05
Newvale Colliery	Great North.	175	2.6	BP	0.23
Newvale No 2	Great North.	170	2.7	BP	0.52
Gunnedah No. 2	Hoskisson	180	2.5	BP	0.59
Lemington	Mt Arthur	250	2.9	BP	2.27
Wambo	Whybrow	180	3.5	LW	0.94
Newstan Y.	Wallsend	290	2.7	BP	1.12
Teralba Y.	Wallsend	350	2.8	LW	1.50
TOTAL					33.84

* denotes mines for which methane emission data not obtained.

Table 2. List of Class A mines

Mine	Seam (m)	Depth ht	Seam (m)	Mining Method	Prod. Mt/yr
Bocum	-	-	-	-	0.28
Bowen No. 2	-	-	-	-	0.38
German Creek South.	-	-	-	-	1.79
M.W.Haenke No2	-	-	-	-	0.26
Western Lease	-	-	-	-	0.39
Cook	Castor		2.8	LW	1.28
Laleham No. 1	Castor*4		13.0	BP	0.41
Oakleigh No. 3	Cowell		13.0	BP	0.12
Gretley	Dudley*2	95	2.2	LW	1.28
Awaba State	Great North.**	38	3.0	BP	0.64
Myuna Colliery	Great North.**	120	2.5	BP	0.48
Pelton/Ellalong	Greta	445	3.3	LW	1.79
Preston Extended	Hokisson	133	3.1	BP	0.34
Canyon	Katoomba	215	2.3	BP	0.19
Clarence	Katoomba**	180	3.1	BP	1.82
Liddell	Liddell	150	4.5	BP	0.51
Liddell State	Liddell**	80	3.3	LW	0.91
Angus Place	Lithgow	250	5.0	LW	0.84
Baal Bone	Lithgow	125	2.5	LW	2.10
Blue Montains	Lithgow	148	2.4	BP	0.27
Charbon	Lithgow	100	2.7	BP	0.49
Invanhoe No. 2	Lithgow	70	2.8	BP	0.28
Invincible	Lithgow	100	2.4	BP	0.32
Kandos	Lithgow	210	2.7	BP	0.12
Western Main	Lithgow	25	2.3	BP	0.52
Muswellbrook No.2	Mus'brook*3	65	5.0	BP	0.28
South Blackwater	Pollux**	150	3.5	LW	0.62
Bloomfield	Rathluba	148	2.4	BP	0.27
Great Greta	Tangorin**	180	3.5	BP	0.28
Ulan No. 2	Ulan	165	10.0	LW	2.20
Chain Valley	Wallarah**	160	2.4	BP	0.95
Myuna Colliery	Wallarah**	80	2.2	BP	0.43
Monee	Wallarah*2	100	3.4	BP	0.68
Wallarah	Wallarah*2	133	3.1	BP	0.73
Avon	Wongawilli	170	3.2	BP	0.29
Nebo	Wongawilli	315	3.0	BP	0.48
Wongawilli	Wongawilli	340	3.0	BP	0.65
Total					25.67

** mines for which methane emission data was obtained.
*n denotes number (n) of seams being mined.

Table 3. List of Class B mines

	Category	Production (Mt/y)		CH_4 emission (t)
Underground Mines				
	Class A	38.4		660,000*
	Class B	26.5		11,000
	Residual			15,000
	Total			686,000
Opencut mines				
	state		ser ($*10^3$)	
	NSW	43.1	1.5	65,000
	QLD	91.3	0.2	18,000
	Total			83,000
	TOTAL FROM ALL MINES			769,000

NB * allowance made for utilisation of 40,000 t

NB ser is the specific mass emission rate of CH_4 per unit wt of coal.

Table 4. **Methane emissions from coal mines, 1990.**