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METHANE EMISSIONS FROM OPEN-CUT MINES AND POST-MINING EMISSIONS FROM UNDERGROUND COAL

by

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SUMMARY

The methane emissions from most of the major open cut mines in Queensland and the Hunter Valley have been quantified by measurements of crosswind concentration profiles using an instrumented vehicle. Samples of fresh coal were obtained from each mine for gas content analysis. Post-mining emissions from coal mined underground were determined from gas content analysis of samples taken as they reached the surface.

The results showed that amount of methane emitted by the Queensland open cut mines was about factor of three smaller than from Hunter Valley mines for unit coal production. No gas was found in most of the Queensland open cut coals, whereas gas was present in most of the Hunter Valley samples.

On the basis of these data, the 1990 emissions from open cut mines were revalued upwards from 46,500t to 246,000 t. The results of residual gas analysis in underground coals meant that post miming emissions rose from 15,000t to 32,000t for the same year.

1 INTRODUCTION

Australian annual raw black coal production is currently about 200 Mt. A recent study of methane emissions from coal mining (Williams et al., 1992) concluded total emissions amounted to 769000 t/y of which 87% came from underground mining, despite the fact that 70% of production is mined by open-cut methods. Open-cut mining was considered to be responsible for 11% of emissions with the remaining 3% coming from residual emissions from underground coal stockpiled on the surface. Whilst the estimates of emissions from underground mining were based on a considerable amount of data, those for open-cut and residual emissions were much more uncertain.

The uncertainties arise because of the very sparse information on gas contents of open cut coal, as CH_4 is not a safety issue as it is underground. In the case of underground mines CH_4 emissions are considerably greater than that expected solely on the basis of in-situ gas contents because of damage to neighbouring (uneconomic) strata caused by the mining procedure. This effect would also be expected for open cut mines. A further finding by Williams et al. (1992) was that each tonne of open cut coal from NSW was generating 10 times as much methane as that from Queensland.

It is the purpose of this study to put the estimates of methane emissions on a firmer basis. and to better quantify the contribution from residual surface emissions from coal mine underground.

2 METHODOLOGY

2.1 Methane fluxes from open cut mines

The methodology adopted has been to attempt to measure the flux of methane from a mine or part of a mine by measuring the crosswind profile of the methane concentration using an instrumented vehicle. (The only other technique that has been attempted has been in the USA and employed long path FTIR to monitor the crosswind methane emissions (Kirchgessner et al., 1991). There are limits as to the length of path that can be attained, which puts constraints on this approach) The CH_4 concentration was continuously monitored with an Horiba Alpha hydrocarbon monitor which simultaneously measures both methane and total hydrocarbon (THC) concentrations with a resolution of about 0.02 ppm. In rural areas the contribution of non-methane hydrocarbons to THC is small (eg < 0.1 ppm) and fairly constant, so that in the vicinity of an open-cut coal mine, both channels measure the emitted CH_4. This aspect was useful as the CH_4 channel was influenced somewhat by vibration when travelling on rough terrain around the mine sites. On sealed roads, this was generally not a problem.

A value for the flux, Q, can be obtained from the crosswind concentration profile in conjunction with a knowledge of the horizontal wind speed, u, and an estimate of the height of the methane plume viz:

$$Q = C_{xav} * h * u * w$$

where C_{xav} is the excess CH_4 concentration averaged over the width, w, and the height, h, of the plume. The averaging can be performed numerically or through the use of a concentration distribution function (eg a Gaussian). Whenever possible, the vehicle surveys were carried out in the the first two or three hours after sunrise, whilst mixing heights were relatively small. This enhances the ground-level concentrations of CH_4 and minimises errors in estimates of plume thickness. However, the ability to carry out such surveys is limited by adequate access around the perimeter of the mine and the timing of the vehicle traverses was sometimes subject to mine operational requirements.

Wind speed was measured during the vehicle traverses with a tethersonde which could be raised to about 100m above the ground. On occasions this was able to detect the top of the mixed layer, thus providing values for u and h in the above equation. Otherwise h was estimated through standard plume dispersion modelling techniques. On occasions when traverses were made on the public roads eg en route to a mine, some spot measurements were made of wind speed and direction by videoing the motion of a small helium-filled balloon. This data was supplemented where possible with routine meteorological measurements that some of the mines carried out as part of their operations.

2.2 Methane content of coal

The CH_4 content of the coal was determined by crushing a known weight (~ 300g or ~ 1000g) of a sample of fresh coal to release its gas content. Gas volumes were measured by collecting over acidulated water and analysed for CH_4 content. (Williams and Saghafi, 1992).

The coal sample, usually a piece about 20 - 30 cm per side, was selected, with advice form mine personnel to be as 'fresh' as possible, ie taken from part of the seam that had been recently uncovered by the dragline or other excavator. In many cases, the dragline was stopped momentarily whilst some coal was ripped up from the exposed seam by a bulldozer. This is about as fresh as one can get. At other sites, the sample was taken from a seam that had been freshly blasted, but which had been uncovered for some days. The sample was roughly broken and about 300 g taken from the centre and put into a gas tight container for crushing. The crushing was performed in the afternoon of the same day that the sample was obtained. It transpired, early in the fieldwork, that the gas contents of the coal were so low that special precautions had to be observed. The temperature that the sample of coal was put into the container was carefully monitored to ensure that there was no chance of suck back after crushing, due to the container being at a lower temperature. An aliquot, ~0.25 ml, of any gas evolved was analysed by gas chromatography using a thermal conductivity detector.

2.3 Residual methane emissions

The bulk of underground mining occurs in NSW, mainly in the Newcastle and South Districts. Samples of coal were collected from a selection of mines with emphasis on gassy mines.

Samples of coal were collected as they emerge from the underground mine (eg from the conveyor belt) for gas content analysis as outlined in (a). In addition some samples were allowed to desorb without crushing to determine what gas remains in the coal just prior to utilisation. This ultimate residual gas is likely to be combusted in the power station or other combustion application.

3 RESULTS AND DISCUSSION

3.1 Open cut mine emissions

The open cut mines, which were surveyed, are listed in Table 1, along with their current run-of- mine (ROM) annual production :

Table 1. List Of Open Cut Mines Studied

District	*Mine*	*Production (Mt/y)*
Queensland		
Mackay	Goonyella/Riverside	12.5
	Peak Downs	9.5
	Saraji	7.0
	Norwich Park	4.9
Blackwater	Blackwater	5.5
	Curragh	6.0
	Gregory	4.2
Blair Atholl	Blair Atholl	8.5
Callide	Callide	3.9
Nanango	Meandu	5.4
	TOTAL	67.4
	TOTAL Qld	88.0
Hunter Valley		
Hunter	Bayswater	1.0
	Drayton	4.1
	Hunter Valley	6.2
	Lemington	3.1
	Mount Thorley	5.2
	Ravensworth	4.5
	Warkworth	4.0
	TOTAL	28.1
	TOTAL NSW	45.6

Thus, the mines that were surveyed in this study account for about 72% of open-cut production.

3.1.1 Gas contents of open cut coals

The results of measuring the gas contents of fresh open cut coals are listed in Table 2 for the Queensland coals and Table 3 for those in the Hunter Valley. It can be seen at once that gas was detected in samples from all but one mine in the latter region, but only in coal from one mine in Queensland, namely Curragh. The other noteworthy point is the frequent occurrence of CO_2 in the seam gas from Hunter Valley mines.

Table 2. **Gas Contents Of Queensland Open Cut Coals**

COLLIERY	SEAM	SAMPLE WT	GAS CONTENT	COMPOSITION (% vol)	
		(g)	(m^3/t)	CH_4	CO_2
Goon/R'side		380	n. d.		
		310	n. d.		
		360	n. d.		
Peak Downs	8S	390	n. d.		
	1S	220	n. d.		
Saraji	Bauh.	240	n. d.		
	Bauh	190	n. d.		
Norwich Park	7	250	n. d.		
	7	240	n. d.		
	5	110	n. d.		
	5	240	n. d.		
Blair Atholl		260	n. d.		
German Ck		280	0.11	100	
Gregory	8	400	n. d.		
	8	110	n. d.		
	8	390	n. d.		
Curragh	9	250	0.68	100	
	9	250	0.70	100	
	6	300	0.33	100	
Blackwater	15	280	n. d.		
	15	285	n. d.		
	aries 8	270	n. d.		
Callide			n. d.		
			n. d.		
Meandu			n. d.		
			n. d.		

n. d. means no gas detected in the coal. For the first four mines in the list the detection limit was ~ 0.03 m^3/t, and less than 0.01 m^3/t subsequently.

Table 3. Gas Contents Of Hunter Valley Open Cut Coals

COLLIERY	SEAM	SAMPLE WT	GAS CONTENT	COMPOSITION (% vol)	
		(g)	(m^3/t)	CH_4	CO_2
Bayswater	Grasstrees	825	0.19	100	
	Bayswater	1090	0.12	100	
	Balmoral	890	0.15	100	
Muswellbrook	Muswellbrook	830	0.11	25	75
Warkworth	Warkworth	144	0.29	100	
Hunter Valley	Piercefield	198	0.06		100
	Piercefield	925	0.01		100
Lemington	Mt Arthur (#1)	248	0.38	35 (32 N_2)	33
	Mt Arthur (#7)	1010	0.41	41 (25 N_2)	34
Ravensworth	Bayswater	1135	n. d.		
	Bayswater	272	n. d.		
Drayton	Bayswater	1005	0.02	20	80
	Bayswater	250	0.02	20	80
Mt Thorley	Glen Munro	1150	0.14	5	95
	Glen Munro	268	0.14	5	95

n.d. gas content < 0.01 m^3/t

3.1.2 Flux measurements from open cut mines

Methane was detected emanating from all open cut mines that were surveyed. It was not possible to get good data from all mines due to a combination of difficult access and weather conditions. The problem with weather was either a difficult wind direction or so low a wind speed that there was no coherent methane plume.

Examples of the data obtained by traversing the instrumented vehicle across a methane plume are shown in Figures 1 and 2.

The traverses in Figure 1 were made on June 4th on the way to Norwich Park and on June 5th along the Peak Downs highway when en route to the Blair Atholl mine near Clermont. Both were made in the early morning around sunrise when mixing heights were very small (50-100 m) so that CH_4 concentrations in the plumes were at their highest. Wind direction was measured by releasing a small helium-filled balloon at the start of each traverse. The June 4th plume emanated from Norwich Park, whilst the June 5th plume, approximately 42 km wide, was the result of the combined emissions from Peak Downs and Saraji mines and possibly Norwich Park. At this time of the day, the vertical thickness of a plume from a surface emission is unlikely to exceed 100 m. The peak value was only 0.15 ppmv above background. When concentrations are as low as this, the best data comes from such traverses on sealed roads, the rough mine site roads tending to introduce some noise into the measurements.

Figure 2 presents some examples of traverses around a mine (Lemington) with much stronger CH_4 emissions and made on a mix of sealed and unsealed roads. Note the CH_4 concentration scale, which is an order of magnitude greater than that in Figure 1. Also note that the site of a ventilation shaft is marked on the diagram. Lemington used to operate an underground mine, which has now been sealed. Examination of the data did in fact show a small peak downwind of the shaft and which may correspond to a CH_4 leak from the seal. However the breadth of the plume indicates that the bulk of the CH_4 is emitted from the open-cut. Indeed, a traverse along a mine side road upwind of the ventilation shaft, not shown in Figure 2, confirmed this. Emissions from underground ventilation shafts generally present themselves in the form of a regular Gaussian type crosswind concentration profiles, whereas those from open cut emissions are much more irregular.

Estimates of the methane fluxes are presented in Table 4 for the Queensland mines and Table 5 for the Hunter Valley. The Bowen Basin mines consisted of a number of pits, each about 1 km long, and oriented roughly N-S along the western edge of the Basin, where the coal measures approach the surface. On the days when we visited the Goonyella/Riverside, Peak Downs and Saraji mines, the wind were light, the direction being from the N or S ie along the mine. By traversing between some of the pits, it was possible to estimate the flux from the pit rather than the entire mine, although, as depicted in Figure 1, the plume from the entire mine could be traversed on another occasion. In the case of Goonyella-Riverside, however, only measurements of methane fluxes from part of the mine was possible. The absolute accuracy of these flux data is probably no better than a factor of two, however, on a relative basis, when comparing the fluxes, say, between the Hunter Valley mines and those in Queensland, then an accuracy of about ±30% would be expected.

It can be seen from Tables 4 and 5 that, just as there was more gas in the Hunter Valley coals, so more methane is emitted by these mines. However, the situation is clouded by CH_4 emitted by spontaneous combustion. This affects more mines in the

Hunter Valley than in Queensland and is the result of fires in waste, uneconomic coal seams present in a more complex stratigraphic environment. Nevertheless, this CH_4 is still caused by open-cut mining and should be included in the overall inventory.

The data in Tables 4 and 5 are re-presented in Tables 6 and 7, which list the amount of CH_4 emitted each year along with the annual ROM production. The values for the CH_4 emission rate for each mine, used in Tables 6 and 7 lie within the range of the measurements. If the emissions are normalised to the tonnage mined then, on average, the Queensland mines emit 1.2 m^3/t and the Hunter Valley mines 5.5 m^3/t. More than 40% of the latter emissions, listed in Table 7, come from the Lemington mine. As already noted, this mine used to operate an underground mine which now ceased operation and has been sealed, but the CH_4 appears to be coming from the open cut. It may be that the underground workings are draining gas from the adjacent coal seams and this reservoir of gas is diffusing into the open cut. If the Lemington mine emissions are excluded from the calculations then the Hunter Valley open cut mines emit about 3.2 m^3/t.

Table 4. Measured CH_4 fluxes from Queensland open cut mines

Colliery	pit/location	u (m/s)	z (m)	xs CH_4 (ppm)	Flux (m^3/s)	comments
Goonyella/R.	north end	2	300	0.1	0.02	no significant CH_4 in pit
	south half	2	300	0.1	0.02	
Peak Downs	south end	2.5	100	0.05	0.01	trace (0.1 ppm) CH_4 in pit
	north half	2.5	100	0.1	0.03	
Saraji	Coolibah/bauhinia	1.5	100	0.1	0.04	
	acacia	3.5	100	0.05	0.05	
		3.5	100	0.02	0.01	
PD + Saraji	whole mines	1	50	0.06	0.3	
Norwich Park	whole mine	1	40	0.25	0.06	
	south mine	1	50	0.17		
	south mine	1	50	0.3		
	south mine	2.5	250	0.17	0.1	
Blair Atholl	whole mine	7	200	0.25	0.05	mostly from fires?
Gregory	East pit	4	500	0.4	0.58	
	East pit	2.5	500	0.3	0.35	
	west pit	3	300	0.35	0.21	
	west pit	3	300	0.35	0.21	
Blackwater	south half	1	100	0.2	0.03	
	north half	1	100	0.35	0.08	
Curragh	D	5	100	0.15	0.1	
	E	5	100	0.2	0.1	
	whole mine	3	400	0.1	0.8	
Callide		3	70	0.2	0.2	
Meandu	whole mine	4.5	500	0.1	0.4	

The reasons for the difference between the two regions is not clear. Spontaneous combustion may be a contributing factor, however, the coals in the Bowen Basin mines were coking coals, bright and crystalline in appearance. They appeared to have a better developed cleat structure than the Hunter Valley coals and could be macro-porous to CH_4. This would explain why there was generally no gas in the Queensland coals, with the gas detected by vehicle exuding from the seam exposed in the high wall.

Table 5. Measured CH_4 fluxes from Hunter Valley open cut mines

Colliery	pit/location	u (m/s)	z (m)	xs CH_4 (ppm)	Flux (m^3/s)	comments
Hunter Valley	whole mine	2	500	0.2	0.3	
Lemington	whole mine		500	0.6	3.2	
	whole mine	1.5	100	5.5	2.7	
	whole mine	1.5	300	1.5	1.9	
	whole mine	4.5	500	0.35	2.4	12 km away
	whole mine		300	0.2		9 km away
Mt Thorley	whole mine	1.5	120	0.7	0.1	
	whole mine	1.5	300	0.1	0.04	
Drayton	W3	6.5	100	1.0	0.35	mostly from fires?
	W6	6.5	100	2.0	0.6	mostly from fires?
	W6	6.5	100	1.0	0.3	mostly from fires?
Bayswater		6.5	100	1.5	0.5	mostly from fires?
		6.5	200	1.0	0.4	mostly from fires?
Warkworth	whole mine	2	500	0.6	0.6	
Ravensworth	whole mine	2	100	0.3	0.25	fires?

Table 6. Annual methane emission from Queensland open cut mines

District	*Mine*	*Production (Mt/y)*	CH_4 emission (Mm^3)
Mackay	Goonyella/Riv	12.5	1.5
	Peak Downs	9.5	3
	Saraji	7.0	3
	Norwich Park	4.9	3
Blackwater	Blackwater	5.5	3
	Curragh	6.0	25
	Gregory	4.2	19
Blair Atholl	Blair Atholl	8.5	1.5
Callide	Callide	3.9	6
Nanango	Meandu	5.4	12
	TOTAL	67.4	77

3.2 Post-mining methane emissions from underground coal

The data on the amount of gas retained by coal from gassy underground mines when it reaches the surface are summarised in Table 8. The extracted seam for all mines but German Creek in Table 8 is Bulli seam. The values of gas content of coal samples collected from conveyor belt at surface ranged from about 1 to 5 m^3/t. The high values are generally for coal from mines that do not pre-drain their longwall panels. We are unsure, however, if that was the case for the high gas Tahmoor sample. The data show even for one mine, the amount of gas retained is quite variable. Because of the range of gas contents it is difficult to get an average, but a value 0f 1.5 - 2 m^3/t would not be unreasonable. Another factor that has to taken into account is the amount of CO_2 in the gas.

Table 7. Annual methane emission from Hunter Valley open out mines

District	*Mine*	*Production* (*Mt/y*)	CH_4 emission (Mm^3)
Hunter	Bayswater	1.0	15
	Drayton	4.1	24
	Hunter Valley	6.2	10
	Lemington	3.1	75
	Mount Thorley	5.2	2
	Ravensworth	4.5	10
	Warkworth	4.0	18
	TOTAL	28.1	154

Table 8. Residual Gas Contents In Underground Coal

COLLIERY	SAMPLE WT (g)	GAS CONTENT (m^3/t)	COMPOSITION (% vol) CH_4	CO_2
Brimstone	1255	4.36	19	81
	253	1.31	100	
Tower	1045	1.37	98	2
	228	1.36	98	2
Cordeaux	970	5.61	98	2
	262	5.22	98	2
Appin	1005	0.68	100	
	268	0.71	100	
	1105	0.66	83	17
	1135	0.66	85	15
Tahmoor	220.5	1.33	57	43
	14.5	1.31	57	43
	293	4.45	48	52
	300	4.02	47	51
	275	2.64	55	45
West Cliff	300	1.40	8	92
German Ck	260	1.82	100	
	260	1.06	100	

Table 9. Update of Estimated Methane Emissions From Coal Mines, 1990

		CH_4	emission
Category	Production	Williams et al., (1992)	this study
Underground mines	(Mt/y)	(t)	
Class A	38.4	660,000	660,000
Class B	26.5	11,000	11,000
Residual		15,000	32,000
Total	64.9	686,000	703,000
Opencut mines			
state			
NSW	43.1	35,000	178,000
QLD	91.3	11,500	68,000
Total	134.4	46,500	246,000
TOTAL		732,500	949,000

We can now see if the results of this study have any impact on estimated methane emissions. The previous assessment of Williams et al., (1992) for 1990 are listed in Table 9, along with the revised values for open-cut and post mining emissions. For post mining emissions a residual gas content of 1.7 m^3/t of which 25% is CO_2 has been used for gassy coal, It can be seen that this study has substantially increased these estimates by a factor of 5 for open cut mines and 3 for post mining emissions, increasing the overall total by more than 200,000 t for 1990.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

D.J. Williams, J.N. Carras, A. Saghafi, A. Lange, C.J. Thomson, R.J. Francey, L.P. Steele, R.L. Langefenlds and P.J. Fraser. 1992. Measurement of the fluxes and isotopic composition of methane emissions. Energy Research and Development Corporation, End-of- Grant Report, Project 1460.

A. Saghafi and D.J. Williams. 1992. Estimation of methane emissions from Australian coal mines. Proc. symposium on coalbed methane research and development in Australia. Townsville, 19-21 November, vol 5, p 7-20.

D.J. Williams, A. Saghafi, M.S. Drummond and D. B. Robert. 1992. Development of a new equipment for rapid determination og coal gas content. Proc. symposium on coalbed methane research and development in Australia. Townsville, 19-21 November, vol 4, p 21-30.

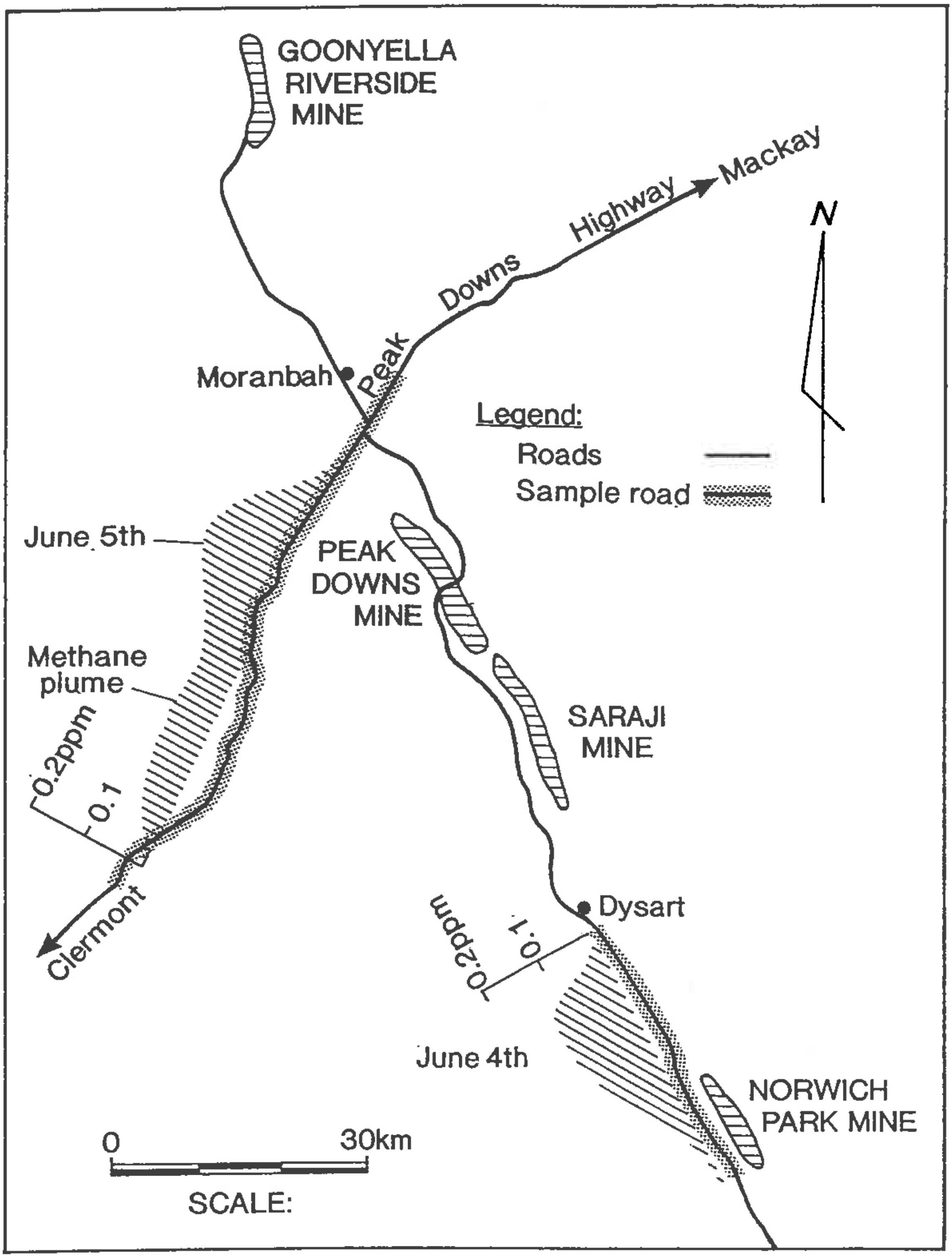
GOONYELLA RIVERSIDE MINE
Peak Downs Highway
Mackay
N
Moranbah
Legend:
Roads
Sample road
June 5th
PEAK DOWNS MINE
Methane plume
SARAJI MINE
0.2ppm
0.1
Clermont
Dysart
0.1
0.2ppm
June 4th
NORWICH PARK MINE
0
30km
SCALE:

Fig. 1.

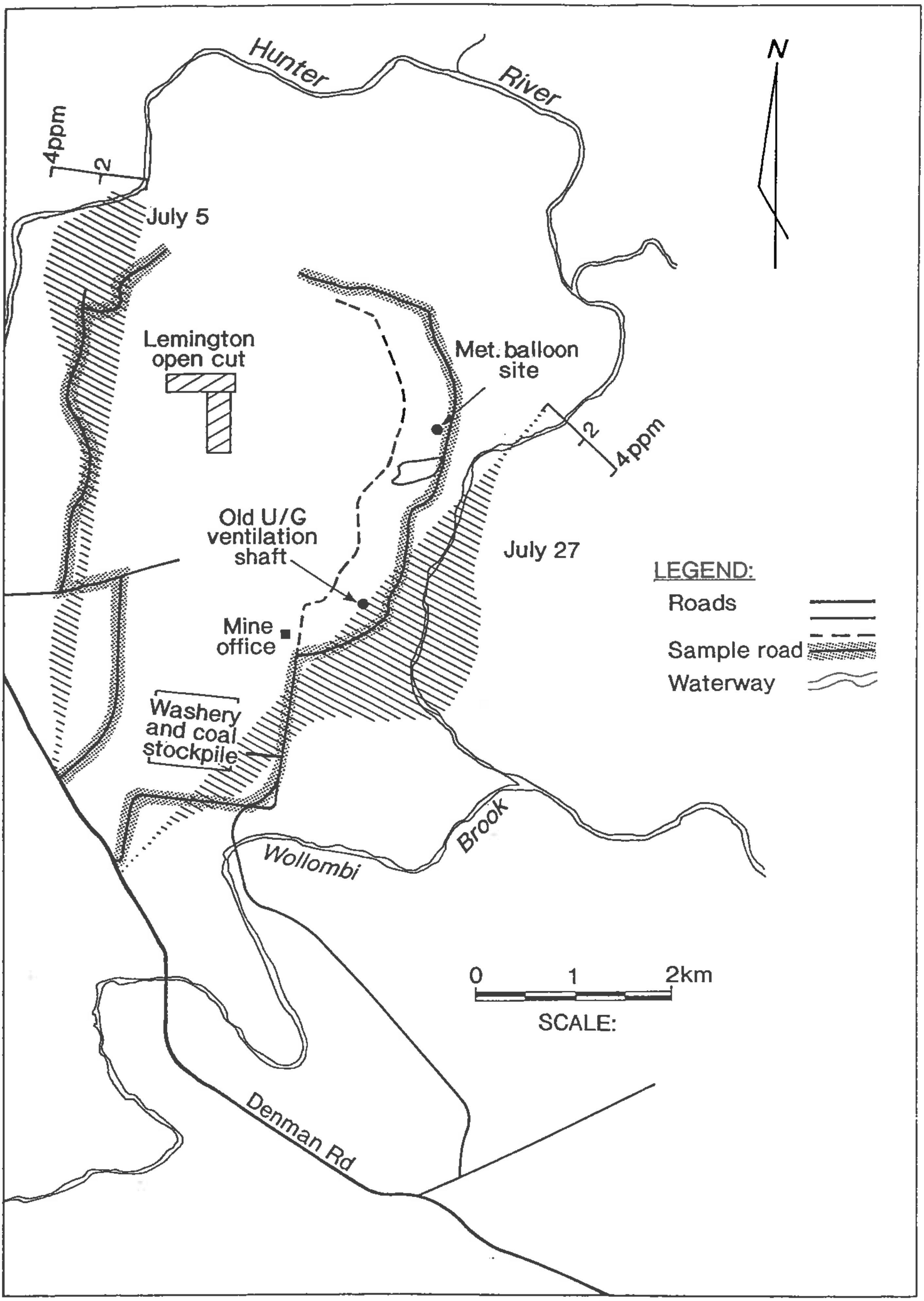
Hunter River
N
4ppm
2
July 5
Lemington open cut
Met. balloon site
2
4ppm
Old U/G ventilation shaft
July 27
LEGEND:
Roads
Sample road
Waterway
Mine office
Washery and coal stockpile
Wollombi Brook
0
1
2km
SCALE:
Denman Rd

Fig. 2