Coal

Supporting economic development through sustainable energy investment

CASE STUDY:

COAL-BED METHANE POTENTIAL OF SOUTH AFRICAN COAL MINES

PJ Lloyd (Energy Research Institute)

September 2003

Contents:

A. The Proposed Study

It is proposed through this study to update previous studies of the coal-bed methane [CBM] potential of South African coalmines. The published studies were undertaken as part of the preparation of South Africa's National Communication in terms of the UNFCCC, and as such reflect the situation in 1994 with a likely business-as-usual baseline extending through 2020. Unfortunately the National Communication itself has not been published yet and access to the unpublished material is rather restricted.

However, it can be said that, in general, the CBM potential was found to be significantly lower than was originally predicated on the basis of the IPCC default factors. This appeared to be the result of geotectonic heating of the coal measures during their geological history, with a consequent driving-off of the methane generated in the early part of the coalification process. Since that the earlier study, there have been ongoing measurements of methane releases from the mines, both in-panel and in the return air. The latter measurements are, unfortunately, somewhat suspect because it is the practice in South African coalmines to use excessive ventilation in order to stay well clear of any risk of approaching the explosion limits. Pockets of methane are widespread, and even with what might otherwise be regarded as "excessive" ventilation, in-panel measurements can show occasional high concentrations – which in turn makes the evaluation of the average methane content of the coal difficult.

The study drew together a number of lines of investigation that are currently in progress. These include some continuous high-precision measurements in return airways and some continuous in-panel measurements aimed at getting a better idea of the distribution of the released methane values as a function of geological setting. It is known, for instance, that the frequency of methane "pockets" increases as igneous dykes that intersect the coal measures vertically are approached during mining. Together these measurements should permit a better evaluation of the CBM potential then currently exists. In addition, there have been ongoing studies of cleating in South African coals, and an endeavour was made to synthesize the results.

The **Energy Research Institute of the University of Cape Town** was commissioned by **The Regents of the University of California, Ernest Orlando Lawrence Berkeley National Laboratory**, through the **Energy and Development Research Centre (EDRC), University of Cape Town** as part of the project: "Supporting economic development through sustainable energy investment".

Interim report

The coal-Bed methane Potential of south African coal mines

Feb 2003

1. Summary

High-precision measurements of methane in the return air from six underground collieries were made approximately weekly for 2 months, and both hourly over 24h and every 5 minutes over one hour on a typical colliery. The collieries were selected to cover a range of *in situ* methane contents from 1.27 to 0.01 m^3 methane per ton, which is typical of underground mines at a depth of 80 to 120 m below surface. The return air contained from approximately 50 to 450 ppm methane by volume, and ventilation volumes were such that emission rates varied from 9 to 250 litres methane/s.

The hourly and daily samples were consistent, in that it appeared the same population was being sampled (when the populations were compared statistically). However, the random weekly samples represented a different population, and it was apparent that possible reasons for large fluctuations in these readings were being missed.

The data were analysed in spite of this difficulty, employing the statistical evaluation of the weekly readings to estimate the average, and the 68 percentile upper and lower bounds, of the methane emissions. A preliminary model was developed which showed that some of the methane was emitted from the coal immediately after mining; some was retained in the coal until it left the mine and only released later; and some was released from unmined coal left in floor, roof and pillars.

The collieries studied represented about 20% of the total coal mined from underground Extrapolating these preliminary findings to the whole industry suggested that at most the industry was emitting about 90 Gg/a, less than 30% of the 325 Gg estimated in producing the National Communication.

2. Introduction

The purpose of this project is to update previous studies of the coal-bed methane [CBM] potential of South African coalmines. The published studies were undertaken as part of the preparation of South Africa's National Communication in terms of the UNFCCC[1]. The greenhouse gases addressed in the National Communication are carbon dioxide, methane and nitrous oxide for the years 1990 and 1994. The inventories were prepared in accordance with to the 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines.

The total greenhouse gas emissions for 1990 were 347 346 Gg CO_2 equivalents and 379 842 Gg CO_2 equivalents for 1994. The total emissions for each sector, calculated as carbon dioxide equivalents show that the energy sector contributed 75% of the total emissions in 1990, and 78% in 1994; agriculture contributed 11.6% of the total emissions in 1990, and 9.3% in 1994; industrial processes contributed 8.9% in 1990, and 8.0% in 1994; and waste contributed 4.4% and 4.3% to the total emissions in 1990 and 1994 respectively.

The main source of carbon dioxide emissions was from the energy sector, which generated 89.7% of the total carbon dioxide emissions in 1990 and 91.1% of the total carbon dioxide emissions in 1994. The high level of emissions from the energy sector relates to the high energy intensity of the South African economy, which is dependent on large scale primary extraction and processing, particularly in the mining and minerals beneficiation industries.

The total methane emissions amounted to 2 053 Gg in 1990 and 2 057 Gg in 1994. In terms of carbon dioxide equivalents, methane emissions contributed 12.4% in 1990 and 11.4% in 1994 of the total greenhouse gas emissions. The main sources of methane were agriculture, energy (fugitive emissions) and waste.

---

[1] *Initial National Communication under the United Nations Framework Convention on Climate Change*, Dept. Environment Affairs & Tourism, Pretoria, August 2002.

In the energy sector, fugitive emissions contributed 323 Gg of methane in 1990 and 327 Gg in 1994, which represents about 16% of the total methane emissions. In 1990 methane emissions from coal mining contributed almost 100% of the fugitive emissions and 97% in 1994 when emissions from natural gas processing were included. Of the coal mining fugitive emissions, 88% were from underground mines.

Emission factors from coal mining activities have been developed for South African conditions. The tonnage of coal mined is multiplied by 1.00 in the case of open cast mines, 1.23 for long wall and stooping operations and 1.98 for bord and pillar operations.

The CBM potential was significantly lower than was originally predicated on the basis of the IPCC default factors. This appeared to be the result of geotectonic heating of the coal measures during their geological history, with a consequent driving-off of the methane generated in the early part of the coalification process. Since that the earlier study, there have been ongoing measurements of methane releases from the mines, both in-panel and in the return air.

The latter measurements are difficult because of the low concentrations of methane found. This is because it is the practice in South African coalmines to use excessive ventilation in order to stay well clear of any risk of approaching the explosion limits. Pockets of methane are widespread, and even with what might otherwise be regarded as "excessive" ventilation, in-panel measurements can show occasional high concentrations.

In this report, therefore, the question of the accurate measurement of the concentration of methane in return air is addressed.

3. Experimental

Sampling points were established just upstream of the main fan on six coal mines. The mines were selected on the grounds of:

- Covering a range of *in situ* methane concentrations in coal typical of the industry as a whole, and
- Having a main fan serving an identifiable number of production sections (on some mines return air is drawn by several fans from several different sections).

The mines and their shafts are listed in

Table 1.

Table 1: Characteristics of shafts chosen for test work

Mine	**Koornfontein**	**Twistdraai**	**Matla**	**Douglas**	**New Denmark**	**Boschmans**
Shaft	Gloria	Central	No.1	North	Okhozini	Main
Coal, t/day	14000	8850	11880	18000	4000	8500
Seam gas content, m^3/t	1.3	1.2	0.4	0.1	1.3	0.01
Average depth, m	110	120	100	90	140	60
Vent volume, m^3/s	590	590	361	460	200	187

The mining method is generally mechanised bord-and-pillar, although some of the New Denmark production comes from longwalling and on some of the other mines considerable amounts of stooping (recovery of coal from oversized pillars) is practised. Unfortunately the details of the mining methods being employed, and the tonnage arising from each method, were not recorded at the time of the sampling.

Ventilation volumes were measured by the Ventilation and Occupational Hygiene departments of the individual collieries.

Sampling was carried out into evacuated 5ℓ spheres that were then sealed and sent for methane analysis at the high-precision gas unit at the Pelindaba analytical laboratories of the Nuclear Energy Council of SA. On most mines samples were taken once a week for several months. In addition on Koornfontein samples were taken hourly over a period of 24h, and every 5 minutes for a period of 1h, to gain an indication of the short-term variability of the methane release.

Coal samples of approximately 20 kg mass were collected from the belt leaving the shaft and analysed for residual gas content.

4. Results

The results from the weekly sampling of all mines are given in Table 2; those for the hourly sampling of Koornfontein in Table 3; and those for every 5 minutes at Koornfontein in Table 4. The results of the analysis of coal samples for residual methane after mining are given in Table 5.

Table 2: The results of weekly sampling of the six mines, methane ppm by volume

Mine	Koornfontein	Twistdraai	Matla	Douglas	New Denmark	Boschmans
Shaft	**Gloria**	**Central**	**No.1**	**North**	**Okhozini**	**Main**
20-Jun-02	688					
3-Jul-02		200	208		56	
4-Jul-02	210			75		1
10-Jul-02		231	262		1[a]	
11-Jul-02	825			66		49
24-Jul-02		27	78		50	
26-Jul-02	263			31		21
1-Aug-02	1			12.5		1
2-Aug-02		68.5	1		88.5	
7-Aug-02		203	171		1	
8-Aug-02	418			34		31
14-Aug-02		100			215	
15-Aug-02	584			51		
Average	427	138	144	45	69	21
Standard deviation	291	84	104	23	79	21

[a] Nil production at time of sampling

Table 3: Results of hourly sampling at Koornfontein, 19-06-02

Time	Methane, ppm	Time	Methane, ppm	Time	Methane, ppm
06:00	732	15:00	793	00:00	680
07:00	732	16:00	758	01:00	655
08:00	764	17:00	743	02:00	669
09:00	686	18:00	743	03:00	702
10:00	674	19:00	682	04:00	693
11:00	660	20:00	738	05:00	673
12:00	696	21:00	668	06:00	681
13:00	738	22:00	723	Average	701.6
14:00	716	23:00	541	Std Deviation	49.6

Table 4: Results of sampling every 5 minutes at Koornforntein

Time	Methane, ppm	Time	Methane, ppm	Time	Methane, ppm
19:00	682	19:25	704	19:50	691
19:05	660	19:30	719	19:55	676
19:10	646	19:35	606	20:00	738
19:15	681	19:40	694	Average	666.2
19:20	681	19:45	483	Std Deviation	64.0

Table 5: Results of analysis of coal samples for methane

Mine	Koornfontein	Twistdraai	Matla	Douglas	New Denmark	Boschmans
Residual Methane, m^3/t	0.6	0.22	0.01	0.01	1.00	0.00
In situ Methane, m^3/t	1.30	1.23	0.42	0.08	1.27	0.010
Methane released, m^3/t	0.70	1.01	0.41	0.07	0.27	0.01

5. Discussion

What is surprising is the very large variation in the results from week to week. A t-test on the means from a 24-h test and a 1-h test at Koornfontein showed that there was about a 96% probability that the two sets represented the same population, but a similar test of the 24-h samples and the weekly Koornfontein samples showed a very low probability that they represented the same population.

The reasons for the large changes from week to week are not immediately apparent. In one case, at New Denmark, it was noted that there was no production on a day when the methane emission fell to low levels, which is encouraging as it shows that on this particular mine most of the methane may have been emitted from freshly mined coal, and that any remnant coal would not contribute significantly to the methane release. However, in other cases the methane fell to equally low levels for no apparent reason.

The specific gas content of coal would be expected to correlate quite highly with the gas emitted from the mine. The correlation is shown in

Figure 1, which gives an average estimate for the methane emitted, a maximum (average plus one standard deviation) and a minimum (average less one standard deviation) plotted against the product of the specific gas content of the coal and the rate of production of coal.

It seems as if there is a reasonable chance that more methane is emitted than is instantaneously produced, which can happen if significant amounts of coal containing methane remain in pillars, the floor or roof, and that methane is emitted more slowly. However, if this were so, there should be a background level of methane such that if there were no production, the residual methane would report to the return air. However, on six occasions, and on 4 shafts, only 1 ppm methane was reported.

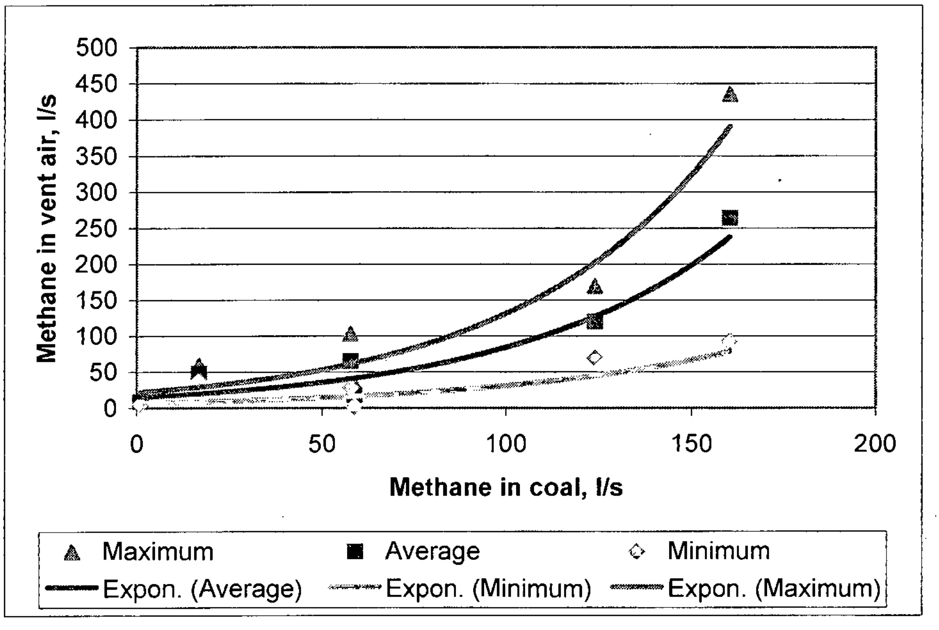


Figure 1: Relationship between the methane in the coal mined and that in the return air

Only on Twistdraai and Douglas was there any evidence that retained methane might have an effect.

However, the data of Table 5 tend to contradict this. At Koornfontein, Twistdraai and New Denmark significant quantities of methane **are** retained in the coal after mining. As a check, therefore, the exercise shown in Figure 1 was repeated plotting the methane released immediately against the methane in the return air, with the results shown in **Figure 2**.

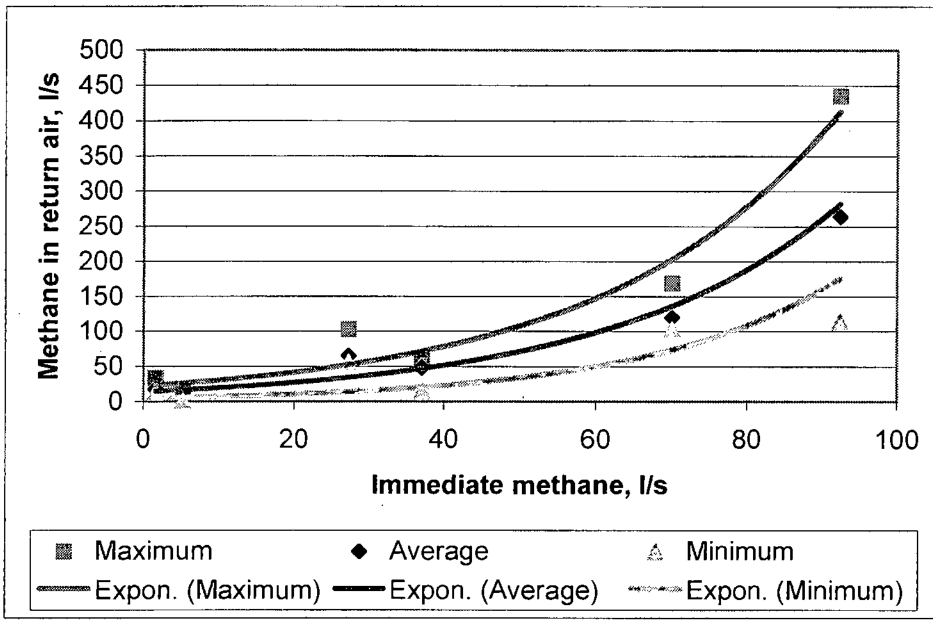


Figure 2: Relationship between methane released from mined coal and that in return air

Now there is considerable delayed methane release from roof, floor and pillars. The relative contributions can be estimated for the average methane in return air as given in Table 6.

Table 6: Emission of methane from mined coal

	Koornfontein	Twistdraai	Matla	Douglas	New Denmark	Boschmans
In situ Methane, m^3/t	1.30	1.23	0.42	0.08	1.27	0.010
CH_4 released immediately, m^3/t mined	0.70	1.01	0.41	0.07	0.27	0.01
CH_4 released from roof floor etc, m^3/t mined	0.63	0.66	0.01	0.03	0.18	0.15
CH_4 released after leaving mine, m^3/t mined	0.6	0.22	0.01	0.01	1.00	0.00
Approximate unmined coal, t/t mined	64%	55%	2%	43%	14%	1516%

The results tend to indicate ~60% extraction of coal from the seams except in the case of Matla, the long wall at New Denmark (~85% extraction) and ~5% at Boschmans. These estimates seem reasonable, and may indicate that the average values for the methane content of the return air are not seriously in error.

The sample of collieries employed in this study does not, superficially, seem unrepresentative of the industry as a whole. If we assume 330 days operation per annum on average, then the output of this sample represents about 20% of the coal mined underground in South Africa. Then the total contribution from the whole industry would be close to 70 Gg/a, a little over 20% of the contribution calculated in the National Communication. Even if one were to employ a model represented by the maximum shown in Figure 2 the whole industry would only produce about 90 Gg/a, less than 30% of that estimated for this sector in the National Communication. All estimates are, of course, well below those derived from the IPCC default factors.

We may conclude that, while the data on emissions from collieries are somewhat suspect because it is clear that not all sources of variation were accounted for during sampling, the preliminary indications are that the methane releases from the industry are significantly lower than those estimated in the National Communication, which in turn were significantly below those estimated from the IPCC defaults.

Final report

The coal-Bed methane Potential of south African coal mines

May 2003

1. Summary

Previous tests have shown that the emission of methane from South African coal mines was difficult to interpret. The variance of week-to-week samples was quite different from that of hour-to-hour or minute-to-minute samples. Occasionally the methane content of the return air fell to nil.

A test was designed to clarify the situation, which involved the determination of the methane in the return ventilation air during a production shutdown. The results showed that:

1. The methane increased after the shutdown, then slowly decreased.
2. When mining restarted, the methane initially increased and then fell to zero.

These results indicate that, on the mine concerned, the IPCC model involving the release of much of the seam gas content of the coal from the freshly mined coal, with significant contributions from coal left in pillars, floor and roof, is unlikely to hold true on many South African mines. The conclusion is that in most (5 out of 6) cases studied, the methane in the ventilation air does not emanate primarily from the freshly mined coal, and that the methane in the freshly mined coal largely remains in the coal until it has left the mine.

As a result, an alternative model is proposed, involving:

1. Displacement of the methane from the coal by geothermal heating after its deposition, and retention of some of the released methane in fissures in the coal bed.
2. Release of that methane when the advance of the coalface during mining intersects one of the fissures.
3. Minimal release of the seam gas content of the coal itself during and immediately after mining

There may however be mines on which the IPCC model is at least partially applicable.

To test this model it is recommended that:

1. A further test be carried out to determine the dynamics of methane release within an operating section during a production shutdown on a shaft such as Gloria, Twistdraai or New Denmark, and
2. A similar test is carried out at Matla, which is the only one of the six mines where the IPCC model may hold.

Further it is recommended that:

1. More SGC measurements should be made at New Denmark and Gloria shafts, and
2. Several more measurements should be made of the methane released from mined coal outside the mine on each of the mines studied to date.

2. Introduction

In an endeavour to quantify the release of methane from South African underground coalmines, efforts have been made to develop a model that will represent the release in a consistent way. The Intergovernmental Panel on Climate Change has some default factors based upon a model involving:

1. The even distribution of the methane throughout the seam
2. Retention of the methane within the coal measures due to hydrostatic pressure
3. Release of the pressure and thus of the retained methane because of mining
   3.1. Firstly from the broken surface of the newly mined coal
   3.2. Secondly, and more slowly, from deeper in the newly mined coal, and
   3.3. Finally, more slowly still, from pillars, roof and floor created by mining.

Thus as long as mining continued, there would be a general and reasonably constant release of methane, which would reduce shortly after the rate of mining was reduced, and more slowly once mining ceased, when the only methane sources were the floor, roof and pillars.

A test of this model was accordingly carried out in an attempt to quantify the contributions from freshly mined coal, from coal once it had left the mine, and from floor, roof and pillars. The results were equivocal[2], and it appeared the basic model was invalid. This report therefore provides a 'straw dog' of a model, which fits some of the observations to date, and which should provide a working hypothesis to design further experiments to prove or refine the model further.

3. Experimental

Samples were taken of the return air at the main shaft fans on a number of coalmines, chosen because they were known, from sampling of methane levels on the face, to have different quantities of methane. The samples were pumped under pressure into containers at 500kPa, sealed and shipped for high-precision gas chromatographic analysis at the laboratories of the NEC at Pelindaba. The laboratories are certified to international standards.

Coal from the face exposed by mining was sampled. The sample was immediately milled under conditions such that all gas was retained, to determine the seam gas content (SGC). Itasca Africa has developed and validated the method [3].

Coal from the belt leaving the mine was similarly sampled and milled to determine the residual gas content.

Because the results proved difficult to interpret (for reasons that are discussed below), methane in the return air was sampled during a production shutdown to check on the background release from roof, floor and pillars when no fresh methane was being produced from current mining.

[2] PJ Lloyd The coal-bed methane potential of South African coal mines Report, Energy Research Institute, UCT, February 2003.

[3] Cook, A.P., J. van Vuuren, J.M.. (2000). Methane contents of major South African coal seams. Coal Indaba. FFF/ SAIMM Johannesburg.

4. Results

Table 7 Results from random weekly sampling of air from return shafts, ppmv

Shaft	Gloria	Twistdraai	Matla	Douglas	New Denmark	Boschmans
Average	447	203	180	104	87	48
Standard deviation	291	84	104	23	79	21
20-Jun-02	688					
3-Jul-02		200	208		56	
4-Jul-02	210			75		1
10-Jul-02		231	262		1*	
11-Jul-02	825			66		49
24-Jul-02		27	78		50	
26-Jul-02	263			31		21
1-Aug-02	1			12.5		1
2-Aug-02		68.5	1		88.5	
7-Aug-02		203	171		1	
8-Aug-02	418			34		31
14-Aug-02		100			215	
15-Aug-02	584			51		
Minimum	1	27	1	12.5	1	1

* Nil production of coal during sampling

Table 8 Methane sampled hourly from Koornfontein Gloria Shaft

Time	CH_4, ppm	Press. mbar	Time	CH_4, ppm	Press. mbar	Time	CH_4, ppm	Press. mbar	Time	CH_4, ppm	Press. mbar
06:00	732	851.5	12:00	696	853.2	18:00	743	854	00:00	680	855.3
07:00	732	852	13:00	738	852.8	19:00	682	854.4	01:00	655	855.6
08:00	764	852.8	14:00	716	852.7	20:00	738	854.7	02:00	669	855.4
09:00	686	853.4	15:00	793	852.9	21:00	668	855.2	03:00	702	855.3
10:00	674	854.1	16:00	758	852.9	22:00	723	855.6	04:00	693	855.4
11:00	660	853.8	17:00	743	853.6	23:00	541	855.4	05:00	673	855.8
Average	701.6		Std Deviation	49.6							

Table 9 Methane sampled every 5 minutes from Koornfontein Gloria Shaft

Time	CH_4, ppm	Time	CH_4, ppm
19:00	682	19:35	606
19:05	660	19:40	694
19:10	646	19:45	483
19:15	681	19:50	691
19:20	681	19:55	676
19:25	704	20:00	738
19:30	719		
Average	666.2	Std Deviation	64.0

Table 10 Determination of SGC, m^3/t

Shaft	Gloria	Twistdraai	Matla	Douglas	New Denmark	Boschmans
Average SGC, m^3/t	1.19	1.25	0.423	0.116	1.265	0.023
Std. Dev., m^3/t	1.30	0.55	0.245	0.145	0.19	0.037
No. of samples	5	24	9	8	2	10
Minimum, m^3/t	0	0.29	0.13	0	1.13	0
No. of samples with 0	1	0	0	3	0	7

Table 11 Methane immediately released and retained in coal until after leaving mine, m^3/t

Shaft	Gloria	Twistdraai	Matla	Douglas	New Denmark	Boschmans
Immediate methane release, m^3/t	0.7	1.01	0.41	0.07	0.27	0.01
Methane release outside mine, m^3/t	0.60	0.22	0.01	0.01	1.00	0.01

Table 12 Methane release at Gloria during production shutdown

Time	CH_4, ppm	Press. mBar	Time	CH_4, ppm	Press. mBar	Time	CH_4, ppm	Press. mBar	Time	CH_4, ppm	Press. mBar
06:00	180	841.9	12:00	262	842	18:00	295	839.8	15:00	153	840
07:00	195	842.7	13:00	317	841.2	10:00	142	840.7	16:00	250	839.8
08:00	208*	842.7	14:00	363	841	11:00	178	840.6	16:30	4	839.7
09:00	208	842.6	15:00	295	840	12:00*	205	840.9			
10:00	185	842.2	16:00	364	840	13:00	225	840.9			
11:00	252	842.2	17:00	347	839.4	14:00	210	840.4			
Average	241.7		Std Deviation	68.3							

*Production ceased at 08h30 on 13-03-03 and restarted at 12h30 on 14-03-03

5. Discussion

Superficially the results appear to support the conventional model of the IPCC. The basic calculation is shown in Table 7. On each shaft, the total methane release is known from the average ventilation rate and the average methane content in the return air (ventilation rates are essentially constant). The mining rate does not vary significantly over the day or during the week, so the average rate of coal production and the SGC give the methane available from the mined coal, while the same rate of production and the methane released from the coal on surface give the rate of methane release on surface. The difference between these two is the rate of methane release from freshly mined coal underground, and the difference between the total release and the rate of production from freshly mined coal the gives the rate of slow methane release from roof, floor and pillars.

Table 13 Estimation of various sources of methane release from various shafts

Shaft	Gloria	Twistdraai	Matla	Douglas	New Denmark	Boschmans
Ventilation, m^3/s	590	590	361	460	200	187
Total methane,l/s	264	120	65	48	17	9
Coal, t/s	0.162	0.102	0.138	0.208	0.046	0.098
Seam gas content, l/t	1190	1210	420	80	1270	10
Mined coal methane,l/s	193	128	58	24	59	2.3
Mined coal u/g release, l/s	96	105	57	22	13	1.6
Mined coal surface release, l/s	97	23	1	2	46	0.7
Slow u/g release, l/s	168	15	8	26	4	7.4
Minimum observed total, l/s	0.6	15.9	0.4	5.8	0.2	0.2

However, any error analysis of the known errors in the determination of the total methane emission and the SGC soon makes it apparent that the errors on the estimated parameters are very large, even without errors of estimation in, for instance the release of methane from coal on surface (for which there have been only single measurements).

Moreover, while the calculated slow release of methane was positive from all mines, **it was significantly higher than the minimum observed total release in all but one case**. As this methane is supposed to be the background release, it is essential to ask **how it is possible that any observed total releases can possibly be far less than the calculated background**.

Sampling and analytical errors were soon ruled out. The observation of trace quantities might have been due to the loss of sample in transit, but this would have meant loss of sample pressure, and this was not observed.

An error analysis [2] showed that there were significant differences between the populations of samples derived from week-to-week and the hourly samples, although the hourly and 5-minute samples evidently came from the same population. It therefore appeared that the background might be shifting in ways not fully understood.

To evaluate the background, hourly sampling was carried out during a production shutdown, as reported in Table 6. The results are shown in Figure 1.

Unfortunately there was no sampling overnight, but nevertheless it is clear that the methane in the return air **increased** after mining ceased – in fact, it nearly doubled. Moreover, a few hours after mining restarted, the methane in the return air fell to virtually zero.

Clearly the direct link between coal mined and methane emitted is low. One question is whether the coal size is reduced during mining to a sufficient extent to release any of the methane inherently in the coal.

A second question is whether the coal being mined at the time of the test contained any methane to be released – Table 4 shows that methane is regularly absent from the coal itself. In this connection it should be noted that during this test the average methane concentration, 242ppm, was significantly lower than it was during the previous hourly sampling test, 701ppm, reported in Table 2, although the standard deviation on both sets of estimates was similar (68 and 50ppm respectively). This may mean that the SGC was low at the time.

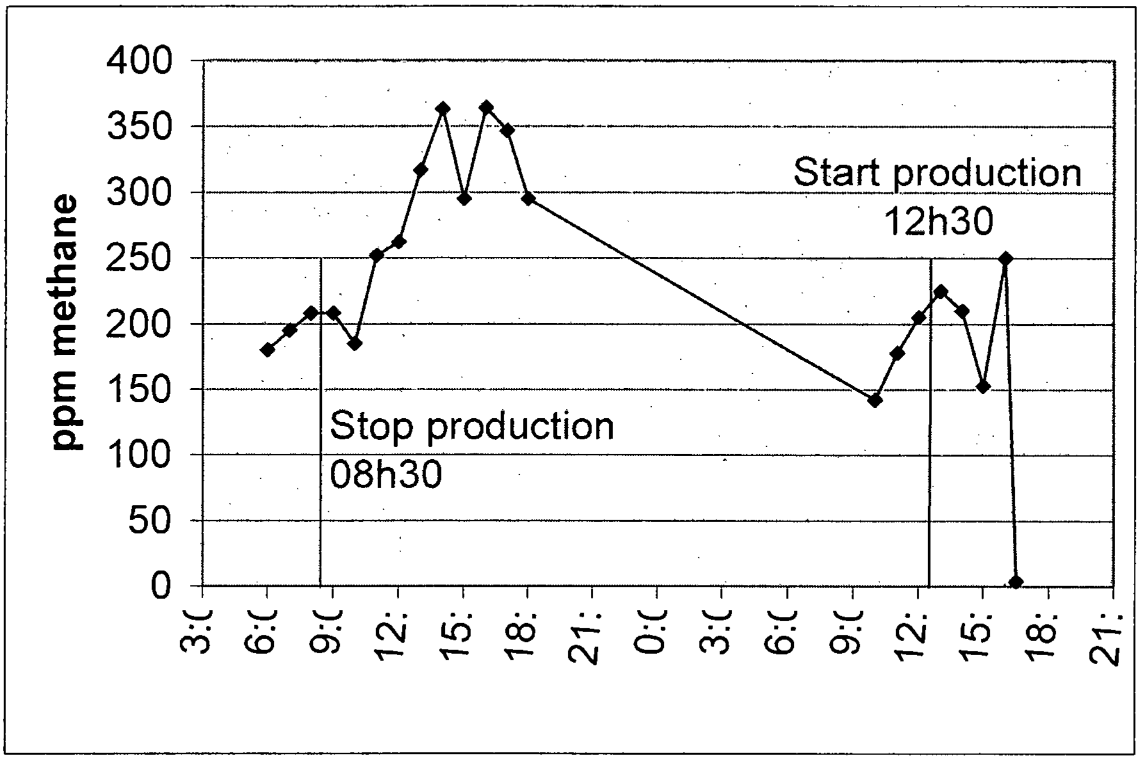


Figure 3 Change in methane release during production shutdown at Gloria shaft

Clearly, however, the conclusion of this test is inescapable – **the IPCC model for methane release is inapplicable.** The question we must therefore face is what model could replace it.

One question that required resolution was whether there was any effect due to atmospheric pressure. The results for the hour-by-hour tests are shown in Figure 2. In neither the first test in June 2002, nor in the second test in March 2003, is there any evidence of a correlation between pressure and the rate of methane emission. Moreover, the results of the first test taken as a whole, and compared to the results of the second test, show that lower methane emission rates occurred at lower atmospheric pressures.

A model that fits many of the observations is one that has free methane retained within cleats and other fissure structures within the coal seam, and that methane is then released as mining intersects these structures. Methane would be released only so long as there was a direct connection between the voids and the mine atmosphere. Once the methane contained within the voids was exhausted, then the observed methane release would fall to zero quite rapidly.

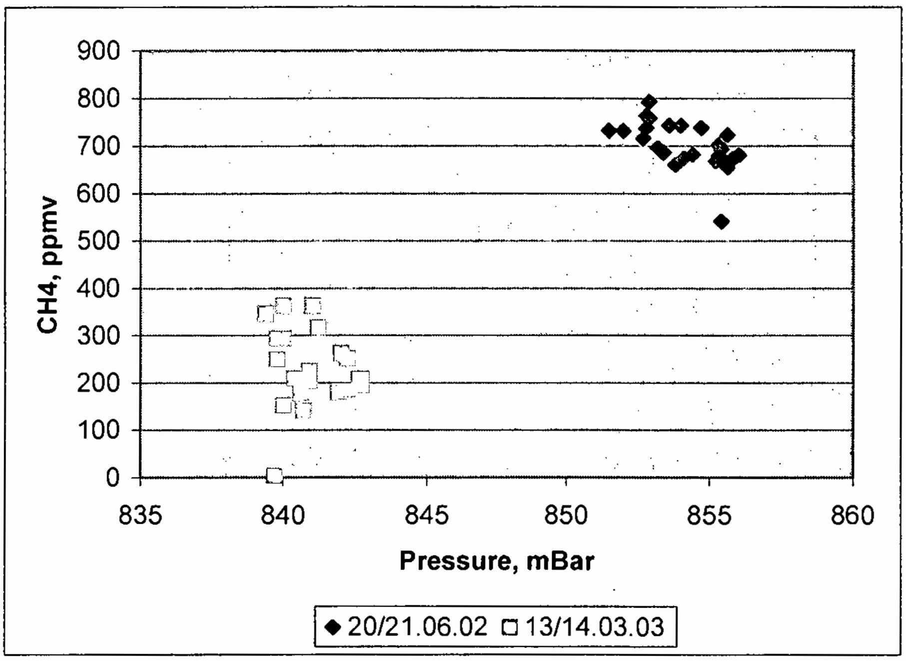


Figure 4 Comparison of methane emission rates and pressure

Thus the observations recorded in Table 6 and Figure 1 might be explained as follows:

1. In the hours preceding the stopping of production, there was a release from a partially opened fissure structure.
2. Shortly after production ceased, ground movement caused by the relaxation of mining-induced stresses opened a further fissure structure, which then contributed to the total methane release.
3. Methane release then fell during the production stoppage and was variable (possibly due to atmospheric pressure changes) when production restarted
4. After several hours of renewed production, all open fissure structures were fully exhausted of their retained methane and the methane in the returned air fell to zero, and would be expected to remain there until such time as a new fissure structure was intersected.

This model would also explain why the weekly observations regularly showed very low methane emissions. If no methane-containing structures were open to the mine atmosphere at the time of sampling, then no methane would be observed (as was the case). It would also explain why, in general, the hourly samples or the 5-minute samples showed a much lower variance than the weekly samples – in the former cases the chance of finding a nil release was low.

Such a model may be the result of the geological history of the Eastern Highveld coalfields. Igneous intrusions are common, and often associated with dolerite sills overlying the coal measures. This igneous activity clearly postdates the deposition of the coal measures, because the coal in the vicinity of an igneous dyke is usually 'burnt' for several metres on either side of the contact.

Thus we hypothesize that widespread heating caused by this igneous activity largely drove the methane from its adsorption sites in the coal, and concentrated it under pressure in the void structures present in the coal seams.

There are a number of confirmatory pieces of evidence for this hypothesis. Firstly, we know that the methane content of South African coals is markedly less than that which would be shown if it were at hydrostatic equilibrium. This strongly suggests that the inherent methane has been displaced during the coal's geological history. Secondly, attempts to produce coal-bed methane from deep-level seams have often shown that there is a distinct lack of open cleats, so that it would be entirely possible to retain pockets of methane within the coal measures. Thirdly, during exploration drilling, blowouts often occur in the vicinity of dykes, as might be expected because it is in this vicinity that desorption would be most complete. Finally, it has long been the practice on South African coal mines to employ far greater volumes of ventilation air than on similar mines elsewhere in the world, which suggests that outbursts of methane are the rule rather than the exception, and that the 'excessive' ventilation is indeed required to minimize the risk of explosion.

Equally, of course, there are observations that do not conform to this model. The SGC's are generally higher than the observed methane released external to the mine, for instance. However, this is not fully confirmed – the SGC's have significant variances associated with them, while we have only single measurements of the release of methane from the coal external to the mine. The lack of confirmation is apparent in Table 8.

Table 14 Comparison of SGC and methane in coal after mine

Shaft	Gloria	Twistdraai	Matla	Douglas	New Denmark	Boschmans
Average SGC, m^3/t	1.19	1.25	0.423	0.116	1.265	0.023
Std. Dev., m^3/t	1.30	0.55	0.245	0.145	0.19	0.037
Minimum, m^3/t	0	0.29	0.13	0	1.13	0
Methane release outside mine, m^3/t	0.60	0.22	0.01	0.01	1.00	0.01

At Gloria, Twistdraai, Douglas and Boschmans the methane released outside the mine could well represent the SGC, because the observed methane outside the mine is greater than the minimum SGC observed, while at New Denmark the single reading after the mine is just below the lower (of two samples) previously seen, so could well represent the SGC. Thus it is only really at Matla that the apparent lack of confirmation of the hypothesis is strong.

The corollary is that there may well be no methane released from the newly mined coal, which is a surprising conclusion but one that has a statistically high probability of being valid.

This immediately suggests a first test of the model, namely measurements of the methane at the coalface during a production shutdown. If the model is true, then there should be little change in the methane content of the mine air after the production ends, and certainly not the significant drop that would be expected if the IPCC model were valid. The test should be carried out at one of the mines where the methane released outside the mine could possibly represent the SGC, such as Gloria or Twistdraai.

Equally, it may be at Matla, where the model is not sustained, that there is evidence for release of the SGC soon after mining. A similar test should be undertaken there, to provide a basis for comparison with the results from the other mine(s).

The end result may be that there are both the fissure model and the IPCC model play roles to varying extents on the various mines, with the fissure model dominating on the majority of the mines that have been studied to date.

It must also be noted that the average methane content of the coal seams is significantly lower than had previously been estimated. A model based on the correlation between the fixed carbon content of the coal and its ability to absorb methane, and the subsequent alteration of the coal to reduce the methane content to 20% of the theoretical capacity, was employed in developing South Africa's National Communication [4]. This model indicated a probable release of 320Gg CH_4 per annum from the whole of the coal mining industry, over 90% of which came from underground. Because of the errors in estimation in this report, the total emitted from underground can be estimated to lie in the range 60 to 90Gg CH_4 per annum, roughly one-fifth of the earlier estimate.

[4] Department of Environment Affairs and Tourism 2002 National Communication in terms of the UN Framework Convention on Climate Change, DEAT, Pretoria

It has to be asked whether there is any hope for a coal-bed methane industry in South Africa. At present only the lower sections of the Waterberg coalfield show any promise. These are thick (80m) seams that lie at a depth of about 180m. The coal is distributed in a series of bands with shale interleavings, so when mined *en masse* it has a very high ash content. For these reasons it is almost certain that it will never be mined by conventional methods underground. Extensive exploration has been carried out and it is estimated that the *in situ* reserve amounts to about 120 million m^3/km^2 of gas averaging 70% methane, 25% CO_2 and 5% N_2, over a total area of some $300km^2$. [5]

Other potential sources have proved essentially barren even after extensive testing. South Africa's coal seams are generally shallow. The average depth of underground mining is 80m, and a recent review of changes in the expected practice over the next decade showed that the average depth would not increase – and might decrease if ways could be found of extracting the remnant pillars from previous bord-and-pillar mined areas that are now accessible for opencast mining.

6. Conclusions and recommendations

Tests on six mines have shown that the IPCC model for the release of methane from coal mines is most unlikely to be generally applicable. The majority of the results are best explained by a model involving:

1. Displacement of the methane from the coal by geothermal heating after its deposition, and retention of the released methane in fissures in the coal bed.
2. Release of that methane when the advance of the coalface during mining intersects one of the fissures.
3. Minimal release of the seam gas content of the coal itself during and immediately after mining

There may however be mines on which the IPCC model is at least partially applicable.

To test this model it is recommended that:

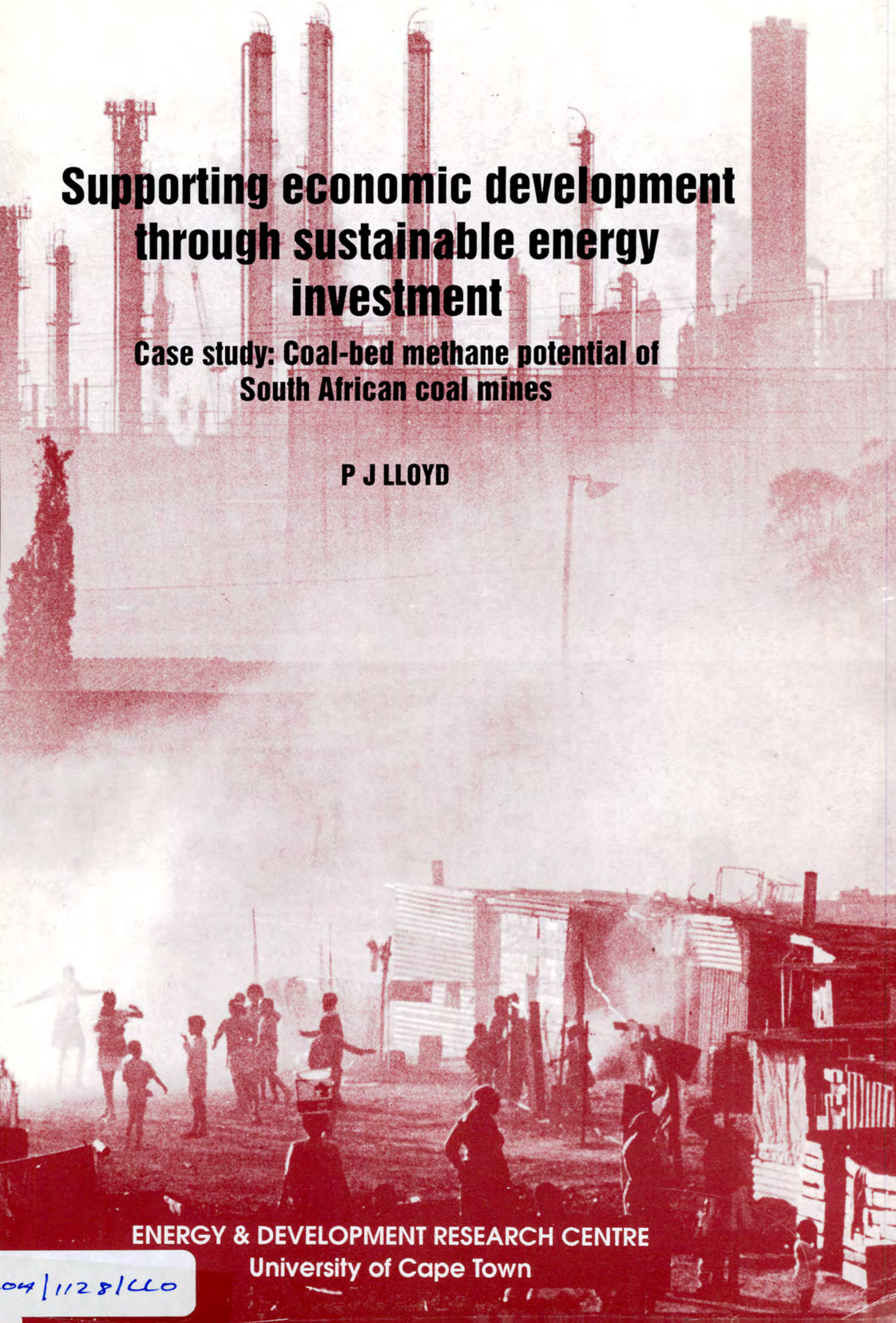
1. A further test be carried out to determine the dynamics of methane release within an operating section during a production shutdown on a shaft such as Gloria, Twistdraai or New Denmark, and
2. A similar test be carried out at Matla, which is the only one of the six mines where the IPCC model may hold.

Further it is recommended that:

1. More SGC measurements should be made at New Denmark and Gloria shafts, and
2. Several more measurements should be made of the methane released from mined coal outside the mine on each of the mines studied to date.

[5] R Wrottesley, Anglo-American Corp of SA 1999, Presentation to Fossil Fuel Foundation workshop on Waterberg Opportunities, Grootegeluk, Nov 1999.

EDRC REPORT SERIES



Supporting economic development through sustainable energy investment

Case study: Coal-bed methane potential of South African coal mines

P J LLOYD

ENERGY & DEVELOPMENT RESEARCH CENTRE
University of Cape Town