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Prediction of Longwall Methane Emissions: An Evaluation of the Influence of Mining Practices on Gas Emissions and Methane Control Systems

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William P. Diamond and Fred Garcia

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cfm	cubic foot (feet) per minute	m^3/mo	cubic meter (s) per month
cm^3/g	cubic centimeter(s) per gram	m^3/sec	cubic meter(s) per second
ft	foot (feet)	min	minute(s)
ft^3/st	cubic foot (feet) per short ton	MMcf	million cubic feet
hr	hour(s)	MMcfd	million cubic feet per day
m	meter(s)	MMcf/mo	million cubic feet per month
m^3	cubic meter(s)	%	percent
m^3/d	cubic meter(s) per day		

PREDICTION OF LONGWALL METHANE EMISSIONS: AN EVALUATION OF THE INFLUENCE OF MINING PRACTICES ON GAS EMISSIONS AND METHANE CONTROL SYSTEMS

By William P. Diamond[1] and Fred Garcia[2]

ABSTRACT

As part of its mine safety and health research program, the National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, has been investigating the geologic and mining factors influencing methane gas emissions associated with longwall mining. A primary focus of this research has been the consequences of increasing longwall panel dimensions, particularly face width, in gassy coalbeds. Continuous longwall face emission monitoring studies were conducted at two adjacent mines operating in the Pocahontas No. 3 Coalbed, where longwall faces were to be extended from 229 to 305 m (750 to 1,000 ft). Average longwall pass methane emission rates for 229-m (750-ft) wide faces were 61% (0.072 m^3/sec (153 cfm)) higher at the VP-3 Mine than at the VP-1 Mine. It was predicted by regression analysis of methane emissions data from 229-m (750-ft) wide faces that extending faces to 305 m (1,000 ft) would increase methane emission rates by only 7%, or 0.009 m^3/sec (20 cfm), to 0.144 m^3/sec (304 cfm) at the VP-1 Mine. In contrast, it was predicted that extending faces to 305 m (1,000 ft) at the VP-3 Mine would increase methane emissions by as much as 13%, or 0.029 m^3/sec (65 cfm), to 0.268 m^3/sec (567 cfm).

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INTRODUCTION

The explosion or ignition of methane gas has been a major cause of multiple fatalities in U.S. underground coal mines. As part of its mine safety and health research program, the National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory (PRL), has been investigating methane emissions associated with longwall mining [Diamond et al. 1992; Diamond et al. 1994; McCall et al. 1993; Schatzel et al. 1992]. The fundamental goals of this research program are to develop an understanding of the influence of mining practices and geology on the release and migration of methane gas during longwall mining. With this knowledge, techniques can be developed to (1) predict underground methane emission levels and (2) improve methane control strategies designed to cope with the increased levels of methane emissions sometimes resulting from the use of high-productivity, advanced mining technology [Diamond et al. 1994].

To remain competitive in domestic and foreign markets, today's mining industry continually strives for higher production and greater recovery of valuable coal reserves. One means of reaching these goals is to increase the size of longwall panels. Unfortunately, along with the increase in coal production, mining larger panels can also intensify various mining problems, including methane emissions. In some instances, the productivity gains anticipated from increasing panel size and utilizing advanced mining technology are limited by mining delays caused by increased methane emissions. This potential for increased methane emissions is of particular concern in mines that are already nearing the statutory limits for methane concentrations underground.

The primary purpose of this field study was to predict the methane emission consequences of mining longwall panels of greater face width in the Pocahontas No. 3 Coalbed in Virginia. Longwall panel face widths at the VP-1 and VP-3 Mines were to be increased from 229 to 305 m (750 to 1,000 ft). However, since historically high methane emissions from the longwall face and gobs were already being experienced, there was a concern for further increases in methane emission rates. If higher emission rates were encountered on wider faces, it was preferable from a safety perspective to be prepared in advance, either with increased ventilation airflow, or with additional methane drainage.

The bleeder and methane drainage systems associated with the two study panels were also evaluated to fully characterize the methane liberation patterns and control system performance for each study area. Methane drainage, including vertical gob gas ventholes and underground horizontal boreholes drilled into the panel prior to longwall mining, has been practiced extensively at this mining complex for many years [Aul and Ray 1991; Kline et al. 1987].

STUDY AREA

The longwall methane emission studies were conducted in the VP-1 Mine and the adjoining VP-3 Mine located in Buchanan County, VA (figure 1). Additional mines in this complex, both active and inactive, are located to the east and south. The two study panels are approximately 1,600 m (1 mile) apart. The depth of cover ranged from approximately 485 m (1,590 ft) at the VP-1 site to 668 m (2,190 ft) at the VP-3 site. As can be seen in figure 2, the sites for both studies were near the startup end of the panels, and were beyond the first gob gas ventholes on each panel. Coal thickness ranged from 1.5 to 1.9 m (5.0 to 6.3 ft) at the VP-1 study site and 1.7 to 2.0 m (5.5 to 6.5 ft) at the VP-3 site.

INSTRUMENTATION AND MONITORING STRATEGY

Instrumentation for the gas emission monitoring system consisted of a sensor to measure methane concentration and an electronic data logger to continuously collect and store information. Methane concentrations were automatically measured and recorded every 30 sec during the monitoring of production shifts. Airflow quantities were periodically measured with a handheld anemometer at the methane monitoring locations. With these data, the methane emission rate (m^3/sec (cfm)) was calculated for each 30-sec measurement point. Methane emission volumes per unit time were calculated by applying the numerical integration version of the trapezoidal rule to the calculated 30-sec methane emission rate data. Average emission rate for specific time intervals was then correlated to the production time study data. The time study data included a detailed account of the longwall operations, including direction of pass, shearer location (relative to shield number) with time, specific operation (cutting or delay), the reason for any delays, and any other operational information that could influence the interpretation of the methane emission data.

Methane concentrations were monitored at two locations on the face at each mine site (figure 3). One instrument was attached to a shield over the pan line, close to the headgate side of each panel, to monitor the methane concentration in the intake air before it swept the longwall face. A second instrument was located near the tailgate side of each panel. Any methane in the intake air would have to be subtracted from the methane levels in the return air to determine the amount of methane released from the longwall face. However, no significant methane was measured in the intake air at either study site; therefore, the data from the monitoring location on the tailgate side of the panels did not have to be corrected. Two additional locations were monitored in the bleeders to determine the total methane volume liberated into the ventilation airflow from each panel, as well as the adjacent mined areas.

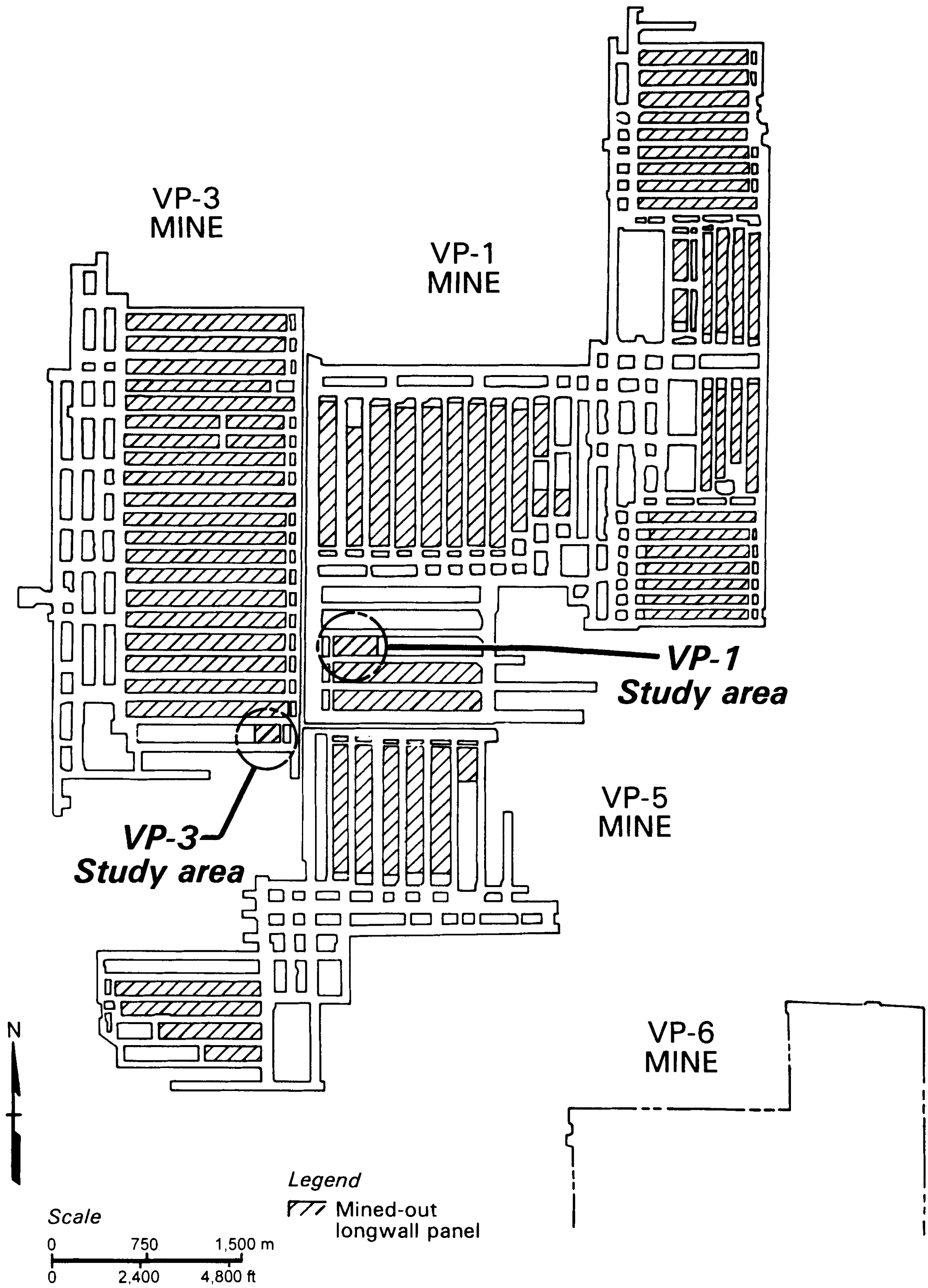

Figure 1.—Map of the VP Mine complex.

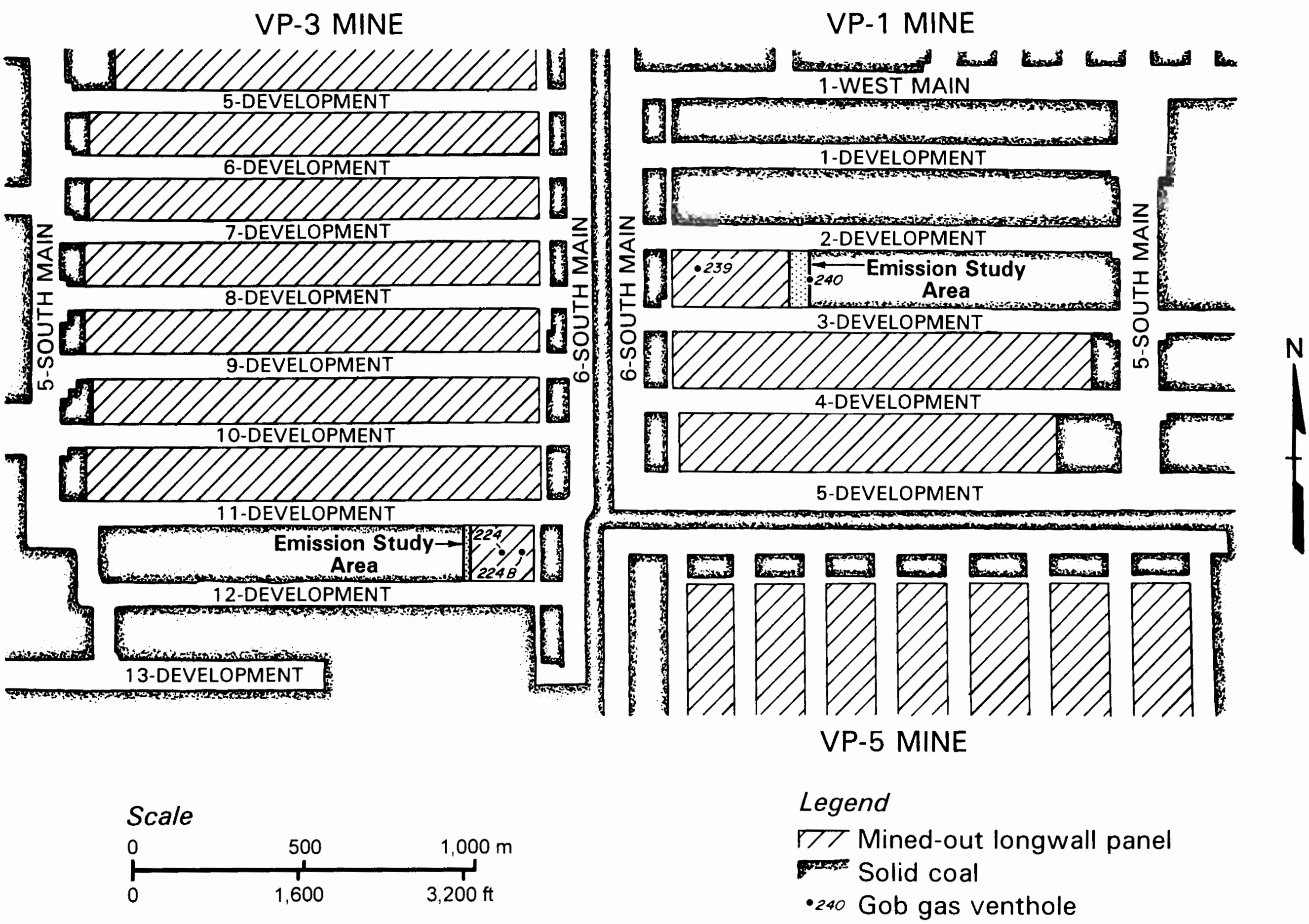

Figure 2.—Map of VP-1 and VP-3 Mine study areas.

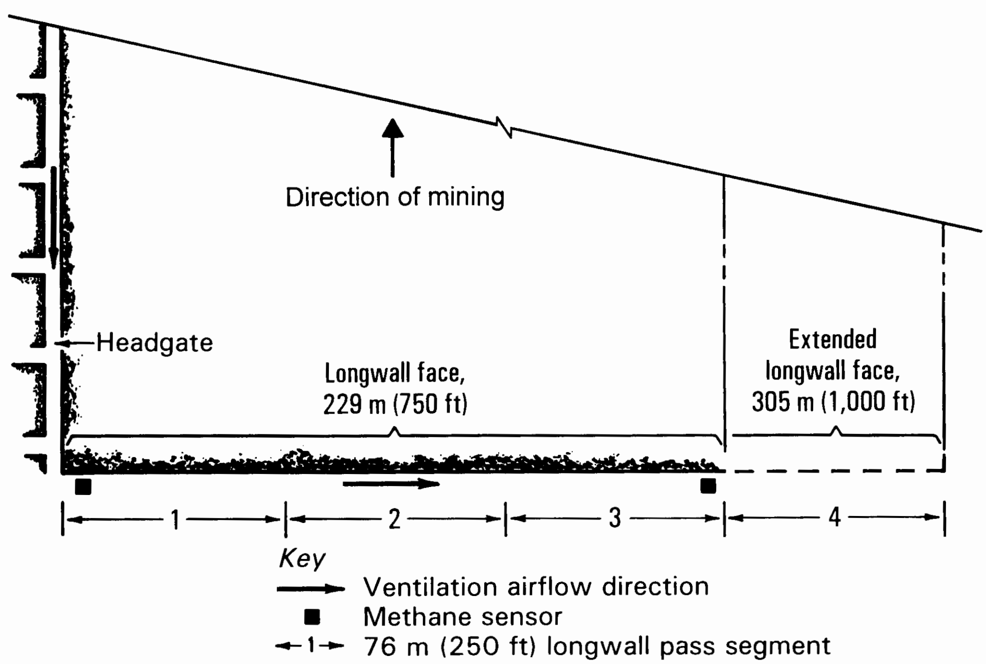

Figure 3.—Plan view of longwall face divided into equal-length segments for analysis and prediction of methane emission trends.

LONGWALL PASS METHANE EMISSION DATA

To predict the methane emission consequences of mining longwall panels of greater width, it was first necessary to determine if a cumulative increase in methane emission levels occurs with time (staircase effect), both during a longwall pass, and from pass-to-pass or day-to-day. Any differences in methane emissions related to direction of cutting, i.e., head-to-tail or tail-to-head, were also investigated. Characterizing the rate of methane gas emissions across the longwall face was facilitated by dividing each pass on the 229-m (750-ft) wide faces into three equal length segments of 76 m (250 ft) (figure 3). To evaluate emission rate trends during the mining of an individual pass, average methane emission rates of the second and third segments of a pass were compared to the respective rates of the previous segment. Emission trends established by this methodology were then extended to forecast the expected methane emission rate of an additional 76-m (250-ft) longwall pass segment, i.e., a 305-m (1,000-ft) face.

Baseline emission data were collected over the weekend prior to the start of production shifts on Monday. Three full days and two partial days of monitoring (three production shifts per day) were completed at the VP-1 Mine. During this time the face was advanced approximately 79 m (260 ft). Methane emission monitoring data and time study data were collected on 83 individual passes.

Two full days and one partial day (two production shifts per day) were monitored at the VP-3 Mine site. During this time, the face was advanced 37 m (120 ft). A total of only 38 passes were monitored due to a substantial number of delays. In fact, on average during the VP-3 study, delays accounted for 42.0% of the time necessary to complete a pass. In contrast, delays accounted for only 13.1% of the time needed to complete a pass during the VP-1 study. Because of the influence of delay time on emission rates, this marked difference in delay time made comparisons between the two mines more difficult.

It should be noted that the first segment of each longwall pass also included the "snake" or cutting-in of the shearer to begin the face pass. This procedure, which could involve as much as 30 m (100 ft) of the first 76-m (250-ft) pass segment, generally increased the time needed to mine this segment as compared to the remaining two pass segments. The summary tables in this report include emission results for the first pass of a segment both with and without the snake for completeness and general interest. Due to the longer time needed to mine the snake as part of the first segment of a pass, the emission rates are generally (but not always) slightly less for this segment when the snake portion is included in the calculation. Since the snake is part of the mining process, the emission results discussed throughout this report include the mining of the snake.

The longwall pass methane emission data for this study were generally evaluated on three bases related to the relative amount of delay time. Delay time, when used as a data evaluation basis in this report, refers only to delay times occurring during a pass. Delay times occurring between passes (generally most of the longer delays) are not included. The first evaluation basis (all passes with data) included all the passes with complete methane emission and time study data, regardless of the amount of delay time during a pass. The second evaluation basis (<50% delay time) included only those complete data passes where active mining constituted at least 50% of the total time required to complete a pass, i.e., any pass where the delay time was ≥50% of the total time needed to complete the pass was eliminated. Also, any pass that had a delay >15 min on any one-third of the pass, or that experienced a reported methane delay, was also eliminated.

The third basis (<25% delay time) for evaluating the emission results was the most stringent, essentially cutting the previous criteria in half. This basis included only those passes whose active mining time constituted at least 75% of the total time required to complete a pass, i.e., all passes with a delay time ≥25% of the total time needed to complete a pass were eliminated. This basis also eliminated any pass from evaluation that had a delay ≥7.5 min on any segment and any pass that experienced a methane delay.

Passes with extended delays were eliminated from the second and third evaluation bases to support the concept of comparing the average methane emission results of the second and third segments of each pass to the previous segment in order to establish an emission trend that would estimate the emissions for a 305-m (1,000-ft) face. If a particular pass segment had an extended delay that caused a lower methane emission value, then comparing that result to a previous segment would yield a lower than "typical" increase in emissions from one segment to the next. Comparing the results from the pass segment with a delay to the next segment (without a delay) would result in a higher than "typical" increase in emissions from one segment to the next. A similar bias would occur when one segment of a pass includes a delay due to high methane emissions. Comparing that segment to other segments of the pass would again yield "atypical" results. The emission valves obtained by eliminating passes with various levels of delay time should be considered a representation of methane emission levels for an "ideal pass" with optimum mining rates, but not a "worst-case" emission scenario for mine planning purposes.

VP-1 MINE STUDY RESULTS

Baseline methane emissions for the VP-1 Mine study panel were approximately 0.024 m^3/sec (50 cfm). The start of mining can be seen in figure 4 as an increase in emissions shortly after midnight (beginning of day 1). Time study data were not

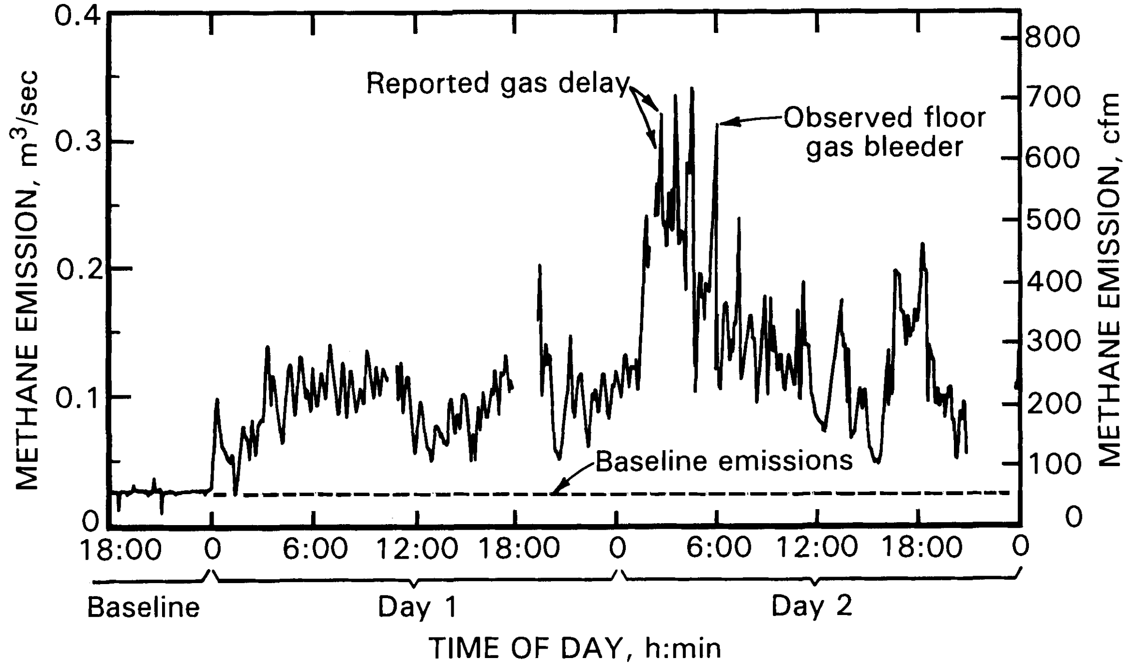

Figure 4.—Longwall face methane emissions for the baseline and days 1 and 2, VP-1 Mine.

collected until the start of the day shift on day 1; therefore, no analysis was made of passes completed for the first shift. Methane emission monitoring and time study data were collected essentially around-the-clock for all three production shifts through Friday morning. Data were collected for a total of 83 passes. However, occasional instrumentation problems and the loss of time study data due to logistical problems, primarily during shift changes, resulted in incomplete data sets for six passes. A total of 77 passes with complete data sets were evaluated for the VP-1 study site (table 1).

Although delay time was not excessive during the passes monitored for the VP-1 Mine emission study, it was still ideal to evaluate the emissions on as much of a delay-free basis as possible. This would also facilitate comparison of results to the VP-3 Mine, where delay time was considerably greater. Sixty-nine of the seventy-seven passes with complete data were evaluated for the <50% delay time basis for the VP-1 study (table 1). Sixty of the seventy-seven passes with complete data met the more stringent criteria of the <25% delay time evaluation basis.

Table 1.—Average longwall pass methane emission summary, VP-1 Mine

Calculation basis	No. of passes used	Average pass segment methane flow rate, m³/sec (cfm)						
		1st third		2nd third	Difference, 2nd/1st, %[1]	3rd third	Difference, 3rd/2nd, %	Total[1]
		Without snake	With snake					
				TOTAL				
All with data ...	77 of 83	0.112 (236)	0.110 (233)	0.123 (262)	+12.4	0.130 (276)	+5.3	0.118 (250)
<50% delay	69 of 77	0.111 (236)	0.110 (232)	0.128 (271)	+16.8	0.133 (281)	+3.7	0.120 (254)
<25% delay	60 of 77	0.113 (239)	0.111 (235)	0.130 (276)	+17.4	0.134 (284)	+2.9	0.121 (257)
				HEAD-TO-TAIL				
All with data ...	37 of 41	0.108 (230)	0.108 (230)	0.119 (252)	+9.5	0.125 (266)	+5.6	0.115 (244)
<50% delay	30 of 37	0.107 (226)	0.108 (228)	0.123 (261)	+14.4	0.129 (273)	+4.7	0.117 (248)
<25% delay	25 of 37	0.109 (232)	0.111 (236)	0.128 (272)	+15.4	0.131 (277)	+2.0	0.121 (255)
				TAIL-TO-HEAD				
All with data ...	40 of 42	0.115 (243)	0.112 (236)	0.129 (274)	+15.9	0.136 (287)	+4.9	0.122 (258)
<50% delay	39 of 40	0.115 (244)	0.111 (236)	0.133 (281)	+15.5	0.136 (289)	+2.8	0.123 (260)
<25% delay	35 of 40	0.115 (244)	0.110 (234)	0.131 (279)	+19.1	0.137 (290)	+4.0	0.122 (258)

[1]With snake.
Base VP-1 flow rate = 0.024 m³/sec (50 cfm).

Methane emissions increased 12.4% and 17.4% (depending on the evaluation basis) from the first to second pass segment during the VP-1 study (figure 5, table 1). As would be expected, the evaluation basis with the least amount of delay time (<25%) generally had the highest methane emission levels. Except where noted, the following discussions of the VP-1 emission study data refers to the <25% delay time evaluation basis. Emission rates were 0.111 and 0.130 m^3/sec (235 and 276 cfm) respectively for the first and second pass segments. Emissions increased only slightly from the second to third pass segment, averaging 2.9% higher on the final third of the pass as compared to the second third. This observation seems to indicate that the emission rate was leveling-off during the final third of a pass, and that mining a wider face might not be expected to result in significantly higher methane emission levels. The average methane emission rate for the final pass segment was 0.134 m^3/sec (284 cfm) and the average methane emission rate for a complete pass was 0.121 m^3/sec (257 cfm).

In addition to evaluating the average methane emissions for all passes, it was of interest to determine if there was any significant difference in the level of emissions related to the direction of mining. As can be seen in table 1, methane emissions were slightly higher for the tail-to-head mining direction. Table 2 presents time study data for head-to-tail and tail-to-head passes, respectively. Head-to-tail passes took several minutes longer to mine than tail-to-head passes, due to higher delay times (not methane-related) on the head-to-tail passes. The longer mining times for the head-to-tail passes, which allowed more time for gas to bleedoff, probably account for the slightly lower methane emission rate for this mining direction (table 1).

Table 3 is a summary of average mining and delay times by pass segment for the three bases by which the longwall pass methane emission rates were analyzed for the VP-1 Mine study site. Time needed to mine a complete pass (including the snake) averaged 39.9 min, with 1.0 min (2.5%) of delay time for the <25% delay time basis.

Average daily methane emissions by pass segment for all passes with data during the VP-1 study are presented in figure 6 and in table 4. The average total longwall pass methane emission rate for day 1 was 0.096 m^3/sec (203 cfm). Day 2 showed a marked increase in methane emission rates, to an average of 0.142 m^3/sec (300 cfm) due to a floor gas bleeder (figures 4 and 7). Reported methane delays of 1 min and 13 min occurred on day 2 (pass 5, figure 8) before the floor gas bleeder was observed (figure 4). Methane levels actually began to rise earlier on day 2 (figure 4), from an emission rate of about 0.118 to 0.142 m^3/sec (250 to 300 cfm) to >0.236 m^3/sec (500 cfm). During pass 5, when the first methane delay occurred, the emission rate exceeded 0.307 m^3/sec (650 cfm), and reached over 0.330 m^3/sec (700 cfm) at the end of the pass. Methane levels on the next pass (pass 6) were about 0.283 m^3/sec (600 cfm) for most of the pass and spiked to 0.330 m^3/sec (700 cfm) near the end; however, no mining delay was noted. It took several passes for the methane emission rates to decline to more typical levels.

After the steep rise in longwall pass methane emission rates on day 2, average daily emission rates declined on days 3 and 4 (figure 6, table 4). This decline is probably due to a diminishing influence of the floor gas bleeder, which occurred on day 2, and a 16-hr delay for mechanical reasons early on day 3, which allowed additional time for gas bleedoff before

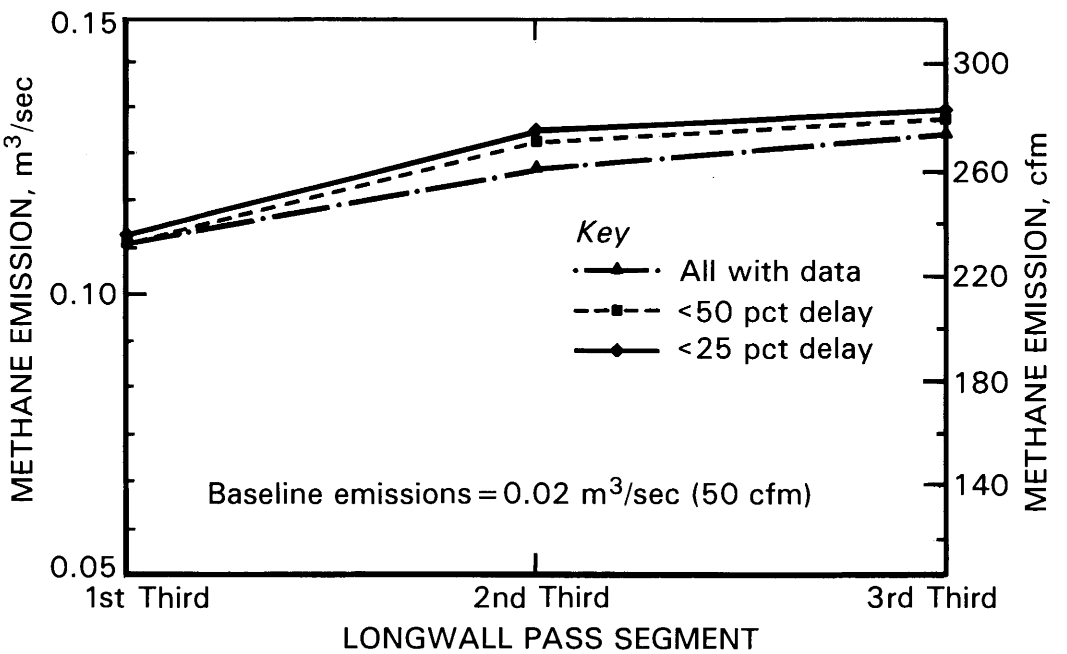

Figure 5.—Average methane emissions by pass segment, VP-1 Mine.

Table 2.—Average direction of pass mining and delay time summary, VP-1 Mine

Calculation basis	No. of passes used	Average pass segment time: 1st third, Without snake	1st third, With snake	2nd third	3rd third	Total, Without snake	Total, With snake
		HEAD-TO-TAIL TOTAL MINING TIME, min					
All with data	37 of 41	11.0	26.6	13.4	12.3	36.7	52.3
<50% delay	30 of 37	10.4	22.0	12.1	11.5	34.1	45.7
<25% delay	25 of 37	10.6	20.7	11.1	10.7	32.3	42.4
		HEAD-TO-TAIL DELAY TIME, min (%)					
All with data	37 of 41	1.0 (9.1)	5.6 (21.1)	2.8 (20.9)	1.5 (12.2)	5.3 (14.4)	10.0 (19.1)
<50% delay	30 of 37	0.4 (3.9)	1.3 (5.9)	1.5 (12.4)	0.7 (6.1)	2.6 (7.6)	3.5 (7.7)
<25% delay	25 of 37	0.3 (2.8)	0.9 (4.4)	0.4 (3.6)	0.1 (0.9)	0.8 (2.5)	1.3 (3.1)
		TAIL-TO-HEAD TOTAL MINING TIME, min					
All with data	40 of 42	10.3	20.1	10.1	9.5	29.9	39.8
<50% delay	39 of 40	10.3	20.2	9.7	9.5	29.6	39.4
<25% delay	35 of 40	10.0	19.6	9.7	8.9	28.5	38.2
		TAIL-TO-HEAD DELAY TIME, min (%)					
All with data	40 of 42	0.6 (5.8)	5.6 (27.9)	0.7 (6.9)	0.7 (7.4)	2.0 (6.7)	2.3 (5.8)
<50% delay	39 of 40	0.6 (5.8)	0.9 (4.5)	0.3 (3.1)	0.7 (7.4)	1.7 (5.7)	1.9 (4.8)
<25% delay	35 of 40	0.4 (4.0)	0.5 (2.6)	0.2 (2.1)	0.1 (1.1)	0.7 (2.5)	0.7 (1.8)

Table 3.—Average longwall pass mining and delay time summary, VP-1 Mine

Calculation basis	No. of passes used	Average pass segment time: 1st third, Without snake	1st third, With snake	2nd third	3rd third	Total, Without snake	Total, With snake
		TOTAL MINING TIME, min					
All with data	77 of 83	10.7	23.2	11.7	10.9	33.2	45.8
<50% delay	69 of 77	10.4	21.0	10.8	10.4	31.5	42.1
<25% delay	60 of 77	10.2	20.1	10.2	9.6	30.1	39.9
		DELAY TIME, min (%)					
All with data	77 of 83	0.8 (7.5)	3.2 (13.8)	1.7 (14.5)	1.1 (10.1)	3.6 (10.8)	6.0 (13.1)
<50% delay	69 of 77	0.5 (4.8)	1.1 (5.2)	0.8 (7.4)	0.7 (6.7)	2.0 (6.4)	2.6 (6.2)
<25% delay	60 of 77	0.4 (3.9)	0.6 (3.0)	0.3 (2.9)	0.1 (1.0)	0.8 (2.7)	1.0 (2.5)

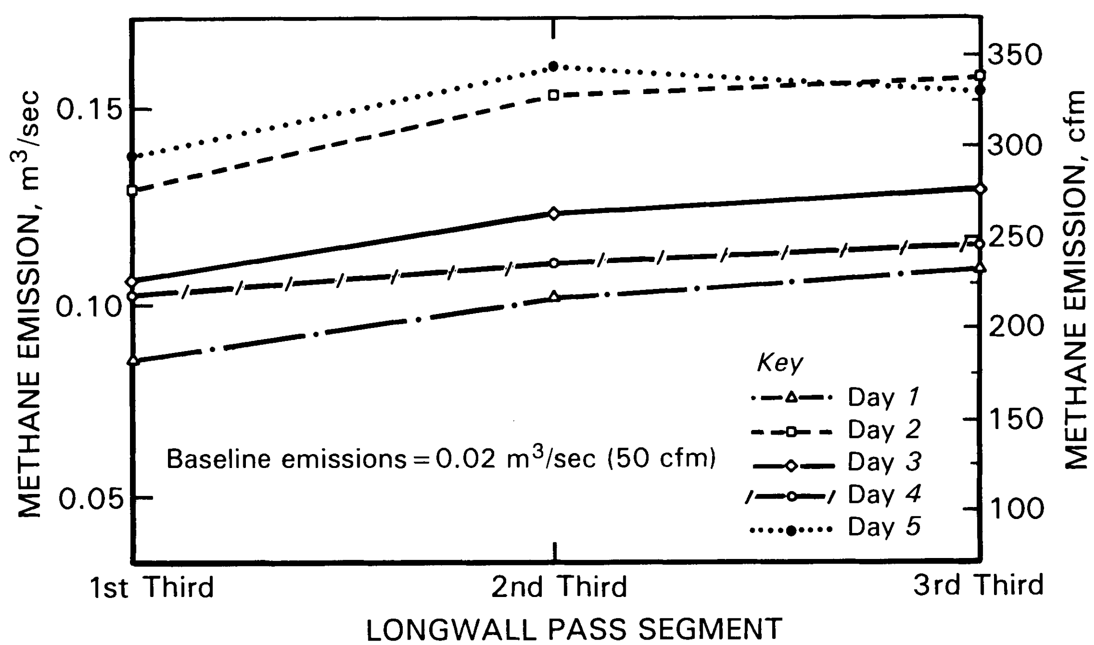

Figure 6.—Average daily methane emissions, all passes with data basis, VP-1 Mine.

Table 4.—Average daily longwall pass methane emission summary, all passes with data basis, VP-1 Mine

Day	No. of passes used	Average pass segment methane flow rate, m³/sec (cfm)						
		1st third		2nd third	Difference, 3rd/1st, %[1]	3rd third	Difference, 3rd/2nd, %	Total[1]
		Without snake	With snake					
1	17 of 19	0.087 (184)	0.086 (182)	0.103 (218)	+19.7	0.111 (234)	+7.7	0.096 (203)
2	20 of 21	0.140 (297)	0.130 (274)	0.155 (328)	+19.5	0.160 (340)	+3.5	0.142 (300)
3	11 of 13	0.106 (225)	0.106 (225)	0.124 (263)	+16.9	0.131 (278)	+5.5	0.118 (250)
4	25 of 26	0.102 (215)	0.102 (216)	0.111 (236)	+9.3	0.117 (247)	+4.5	0.108 (230)
5	4 of 4	0.138 (292)	0.138 (293)	0.162 (344)	+17.4	0.156 (331)	-3.6	0.149 (316)
Total	77 of 83	0.112 (236)	0.110 (233)	0.123 (262)	+12.4	0.130 (276)	+5.3	0.118 (250)

[1]With snake.

Base VP-1 flow rate = 0.024 m³/sec (50 cfm).

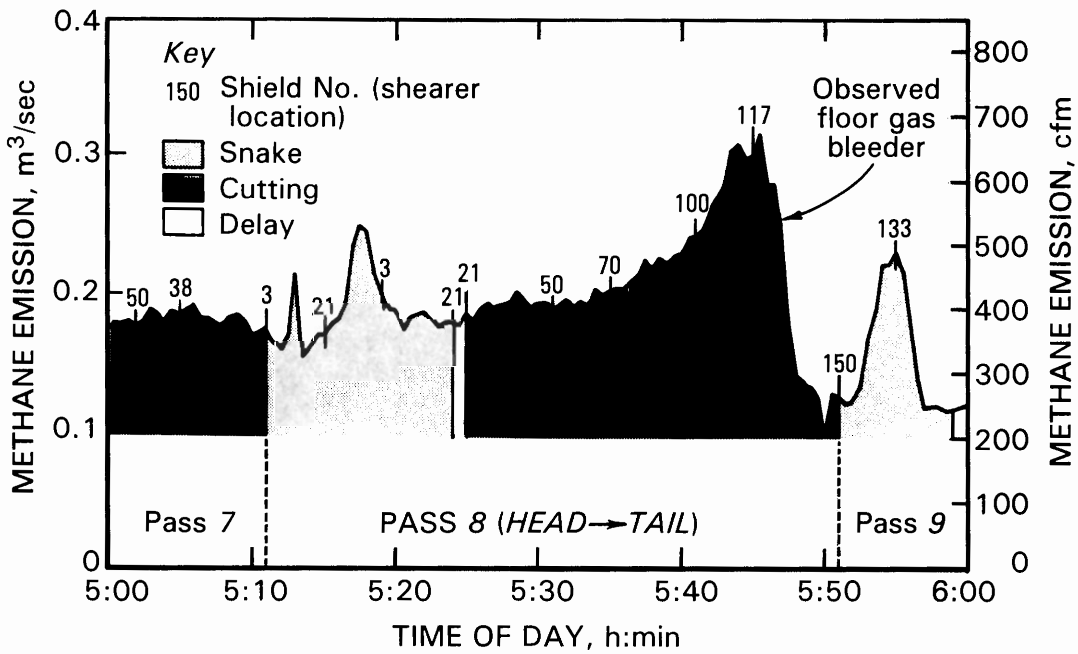

Figure 7.—Methane emissions associated with floor gas bleeder, pass 8, day 2, VP-1 Mine.

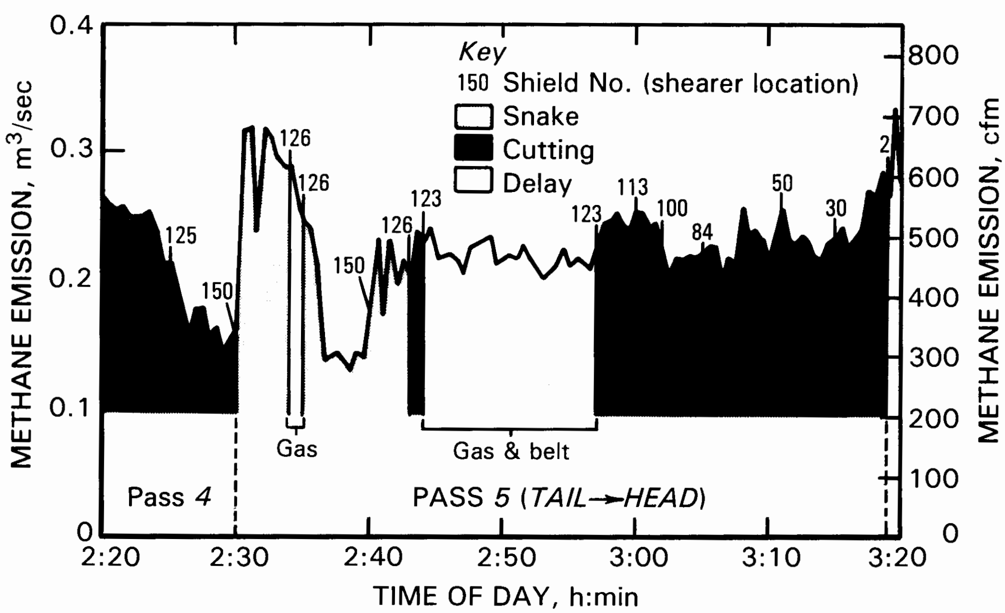

Figure 8.—Methane emissions and delays, pass 5, day 2, VP-1 Mine.

mining resumed (figure 9). Three additional major (>60 min) delays during production passes on day 3, as well as numerous shorter delays on day 4, also contributed to the observed decline in emission rates after day 2. Days 3 and 4, in general, experienced the most delay time during the VP-1 study.

The evaluation of emission trends with time, i.e., a day-to-day "staircase effect," was essentially lost for the VP-1 study site due to the impact of the floor gas event and major delays on days 2 and 3, which interrupted any longer term trends developing early in the study. However, a visual inspection of the methane emission curve (figure 10) suggests several time intervals prior to the floor gas event where the general emission rates were trending upward. A similar upward trend in emission rates occurs at the end of day 4 (figure 11). The only increase in average daily longwall pass methane emission rates after day 2 occurred on day 5 (figure 6, table 4). However, the high emission rates on day 5 were not attributed to any observable gas event and should probably not be considered indicative of the emission trend for that day, since only four passes were actually evaluated.

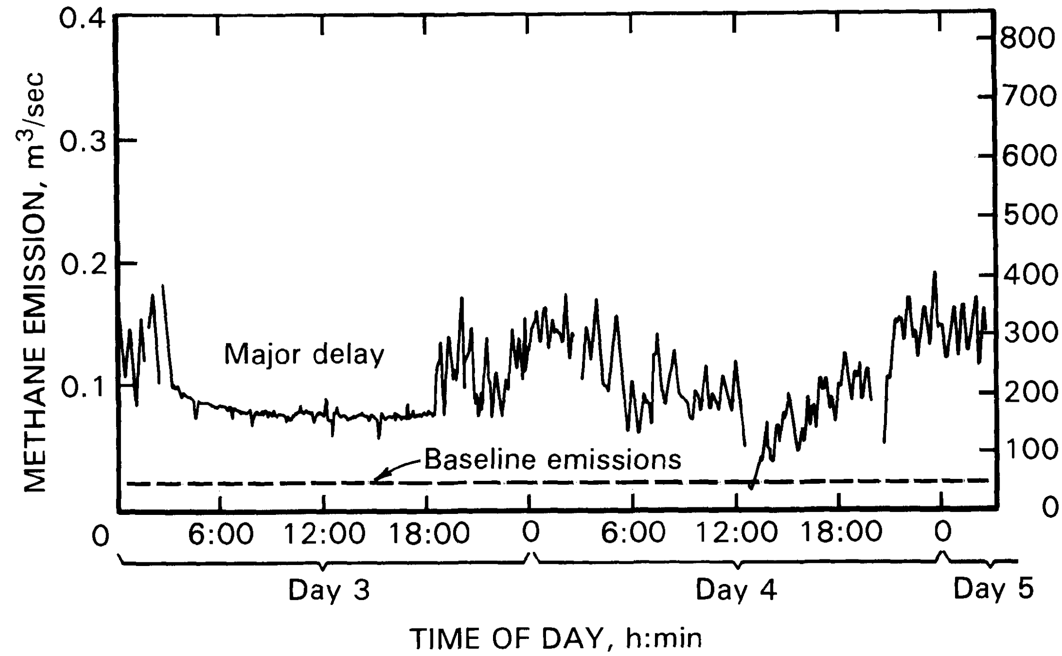

Figure 9.—Longwall face methane emissions for days 3-5, VP-1 Mine.

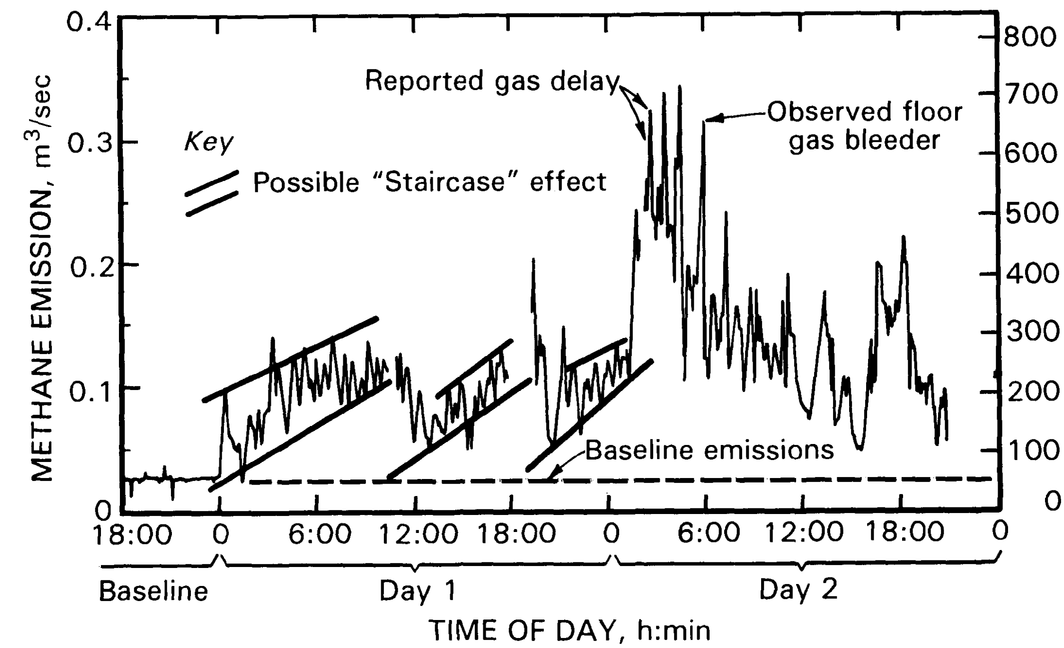

Figure 10.—Longwall face methane emission intervals exhibiting a possible "staircase" effect, day 1, VP-1 Mine.

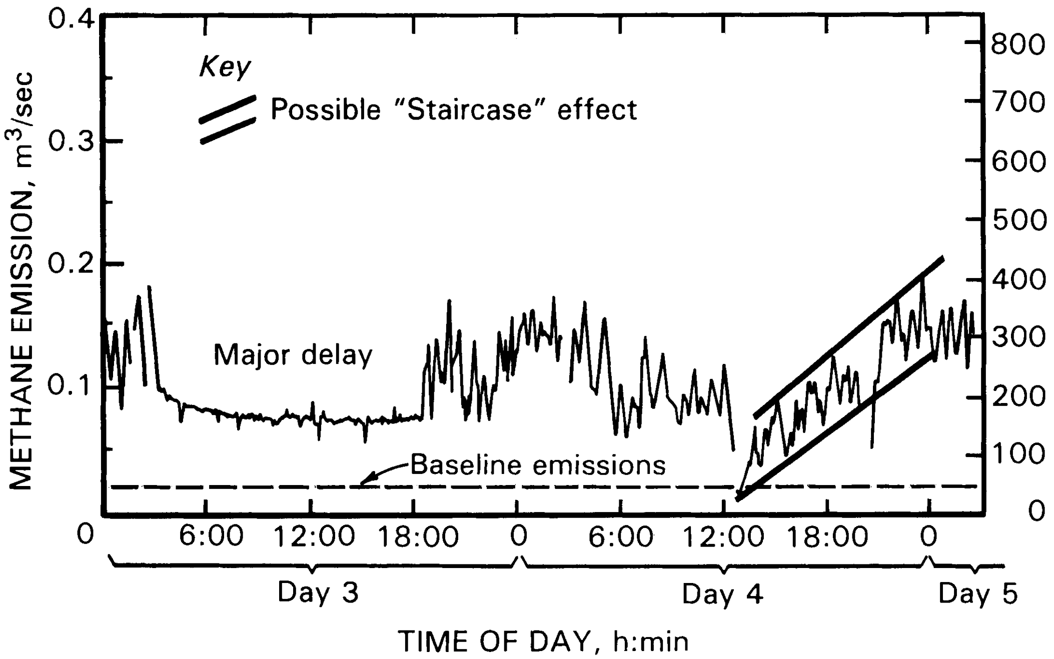

Figure 11.—Longwall face methane emission intervals exhibiting a possible "staircase" effect, day 4, VP-1 Mine.

VP-3 MINE STUDY RESULTS

Baseline methane emissions for the VP-3 study panel (figure 12) were approximately 0.071 m^3/sec (150 cfm), 0.047 m^3/sec (100 cfm) higher than those of the VP-1 study. The time study did not begin until the second pass of the day shift on Monday. Methane emission monitoring data were collected 24 hr per day, even though only two production shifts (day and night) were mining coal during the VP-3 study. Data were collected on 38 passes mined during the 3 days of the study (figures 12-13). The study was terminated after only 3 days due to the high proportion of mining delays (not methane-related) being experienced. The extended mining delays, when combined with fewer production shifts per day and logistical problems similar to those noted for the VP-1 study, resulted in only 27 passes with complete data sets being available for analysis of longwall pass methane emission trends. This is substantially fewer passes than the 77 passes evaluated for the VP-1 study.

Mining delays during the 27 passes with complete data sets were substantially more frequent than those experienced during the VP-1 study. Utilizing the same evaluation bases criteria (percent delay time) for determining average methane emissions as in the VP-1 study, only 11 passes were analyzed for the <50% delay time basis and 5 passes for the <25% delay time basis. The <50% delay time basis data were used to establish trends for average total emissions and average emissions by pass segment (table 5). Due to the small number of passes available for evaluation, only data on the "all passes with data" basis were considered for establishing day-to-day average daily emissions (table 6) and head-to-tail versus tail-to-head emission trends (table 5).

Longwall pass methane emissions increased by about 17.4% from the first to the second pass segment during the VP-3 study (figure 14, table 5). This increase in emission levels is quite similar to the 16.8% increase measured for the VP-1 study site (table 1) on the same delay time basis (<50%). However, the actual VP-3 average emission rate for the second pass segment was substantially higher–0.207 m^3/sec (438 cfm) versus 0.128 m^3/sec (271 cfm) for VP-1.

There is one significant difference in the emission trends between the two mine sites. The emission rate at the VP-3 study site continued to increase (14.6%) from the second to third pass segment. This level of increase is in marked contrast to the 3.7% average increase observed at VP-1 for the same basis (<50% delay time). For the VP-3 study site, the average methane emission rate for the third pass segment reached 0.237 m^3/sec (502 cfm), while the average emission rate for all VP-3 passes was 0.202 m^3/sec (427 cfm). The observed steady increase in average methane emission rates during mining of a pass may be an indication that levels would increase even further if wider panels were mined, potentially resulting in an increase in methane-related mining delays.

Table 6 summarizes the VP-3 average daily and pass direction methane emission results for the "all passes with data" basis. Average daily longwall pass methane emission rates progressively increased from 0.176 to 0.207 m^3/sec (373 to 438 cfm) over the 3 days of the study, indicating that a general "staircase effect" was present (figure 15). A visual inspection of the face emission curves for the VP-3 study (figures 16-17)

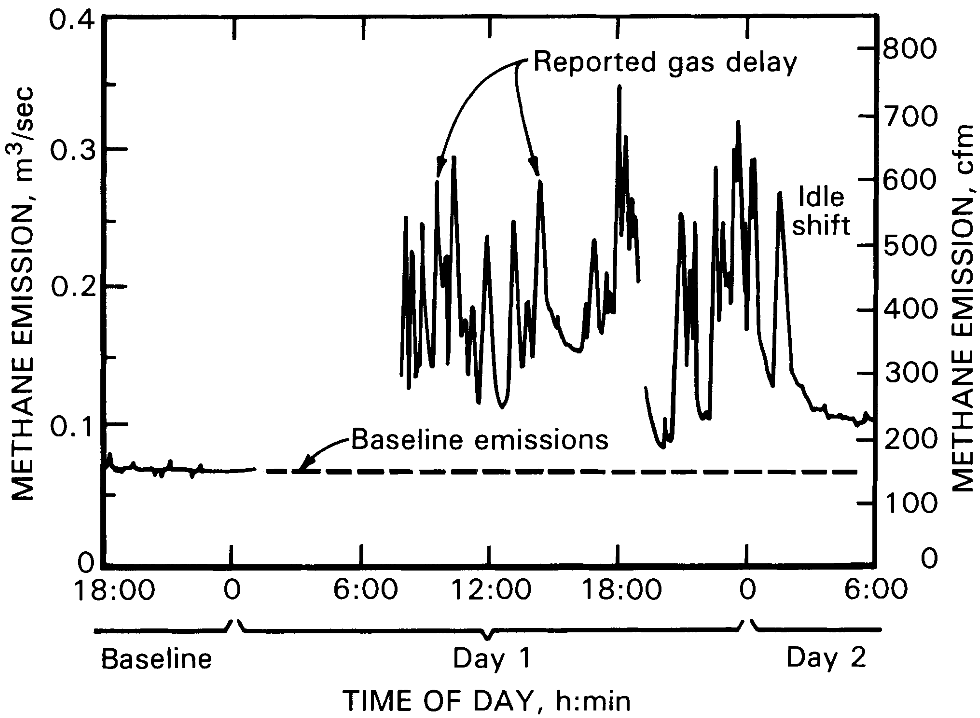

Figure 12.—Longwall face methane emissions for the baseline and day 1, VP-3 Mine.

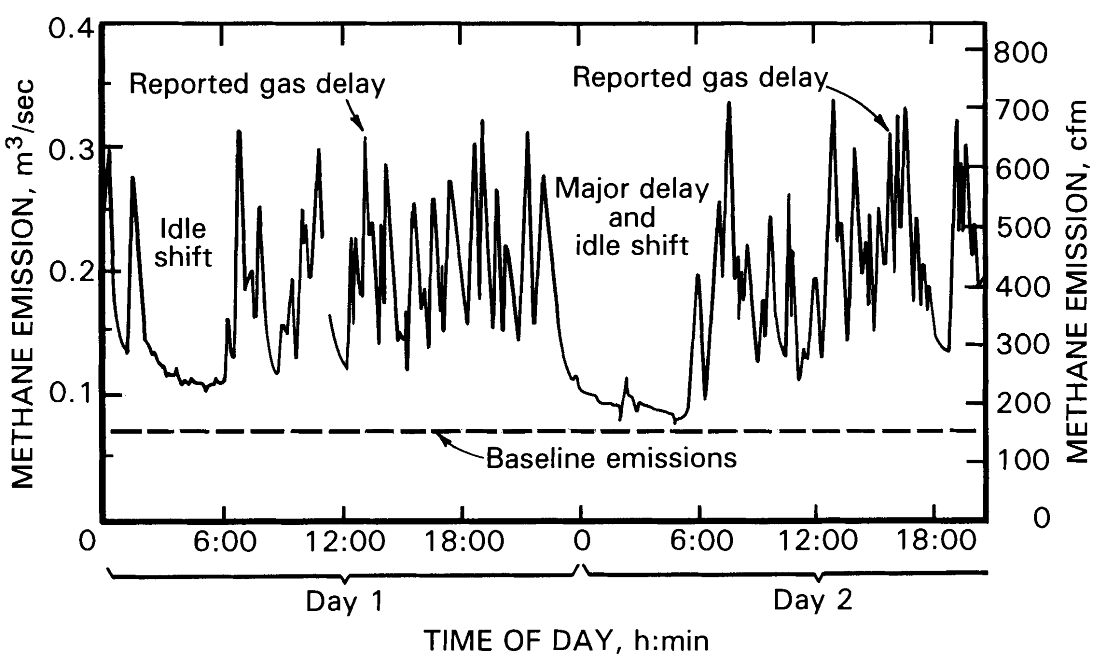

Figure 13.—Longwall face emissions for days 2 and 3, VP-3 Mine.

Table 5.—Average longwall pass methane emission summary, VP-3 Mine

Calculation basis	No. of passes used	Average pass segment methane flow rate, m^3/sec (cfm)						
		1st third		2nd third	Difference, 2nd/1st, %[1]	3rd third	Difference, 3rd/2nd, %	Total[1]
		Without snake	With snake					
TOTAL								
All with data	27 of 38	0.172 (365)	0.169 (359)	0.196 (415)	+15.6	0.233 (494)	+19.2	0.190 (403)
<50% delay	11 of 27	0.177 (376)	0.176 (374)	0.207 (438)	+17.4	0.237 (502)	+14.6	0.202 (427)
HEAD-TO-TAIL								
All with data	14 of 18	0.166 (352)	0.160 (339)	0.203 (431)	+27.2	0.249 (528)	+22.6	0.192 (407)
TAIL-TO-HEAD								
All with data	13 of 20	0.177 (376)	0.177 (375)	0.191 (404)	+7.8	0.216 (458)	+13.2	0.188 (399)

[1]With snake.

Base VP-3 flow rate = 0.071 m^3/sec (150 cfm).

Table 6.—Average daily longwall pass methane emission summary, all passes with data basis, VP-3 Mine

Day	No. of passes used	Average pass segment methane flow rate, m^3/sec (cfm)						
		1st third		2nd third	Difference, 2nd/1st, %[1]	3rd third	Difference, 3rd/2nd, %	Total[1]
		Without snake	With snake					
1	10 of 13	0.164 (348)	0.158 (335)	0.180 (381)	+13.7	0.231 (490)	+28.5	0.176 (373)
2	9 of 12	0.172 (364)	0.180 (380)	0.194 (411)	+8.0	0.230 (487)	+18.6	0.196 (415)
3	8 of 13	0.178 (377)	0.181 (384)	0.225 (478)	+24.5	0.238 (505)	+5.6	0.207 (438)
Total	27 of 38	0.172 (365)	0.169 (359)	0.196 (415)	+15.6	0.233 (494)	+19.2	0.190 (403)

[1]With snake.

Base VP-3 flow rate = 0.071 m^3/sec (150 cfm).

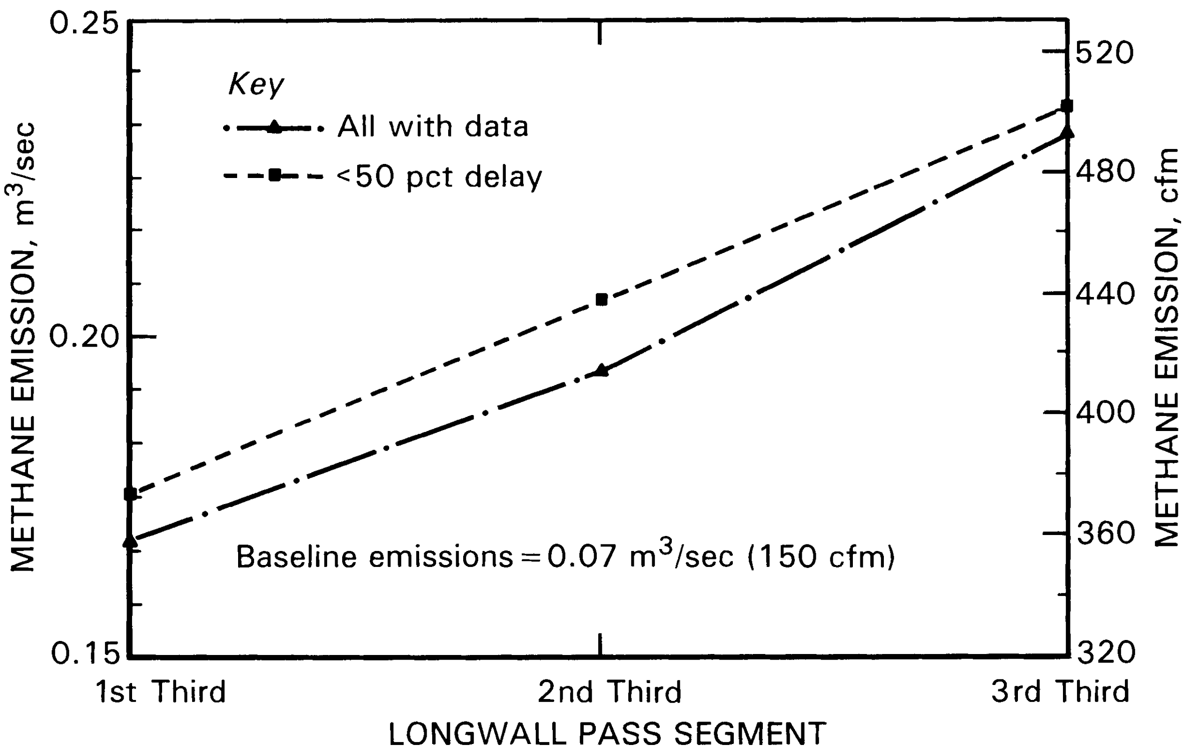

Figure 14.—Average methane emissions by pass segment, VP-3 Mine.

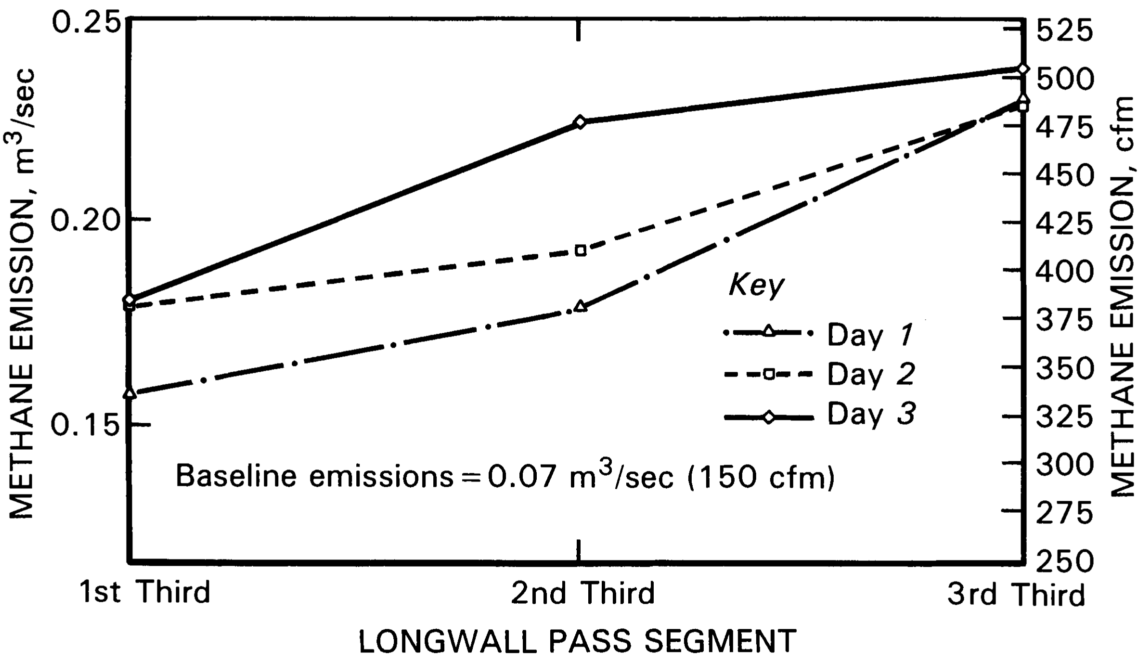

Figure 15.—Average daily methane emissions, all passes with data basis, VP-3 Mine.

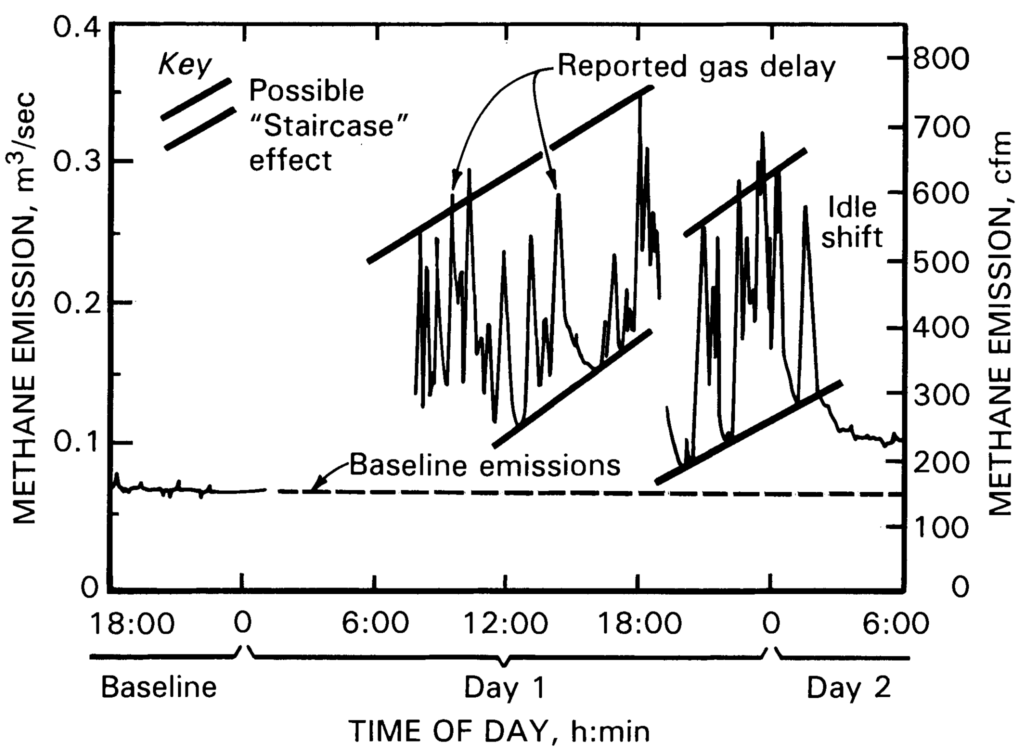

Figure 16.—Longwall face methane emission intervals exhibiting a possible "staircase" effect, day 1, VP-3 Mine.

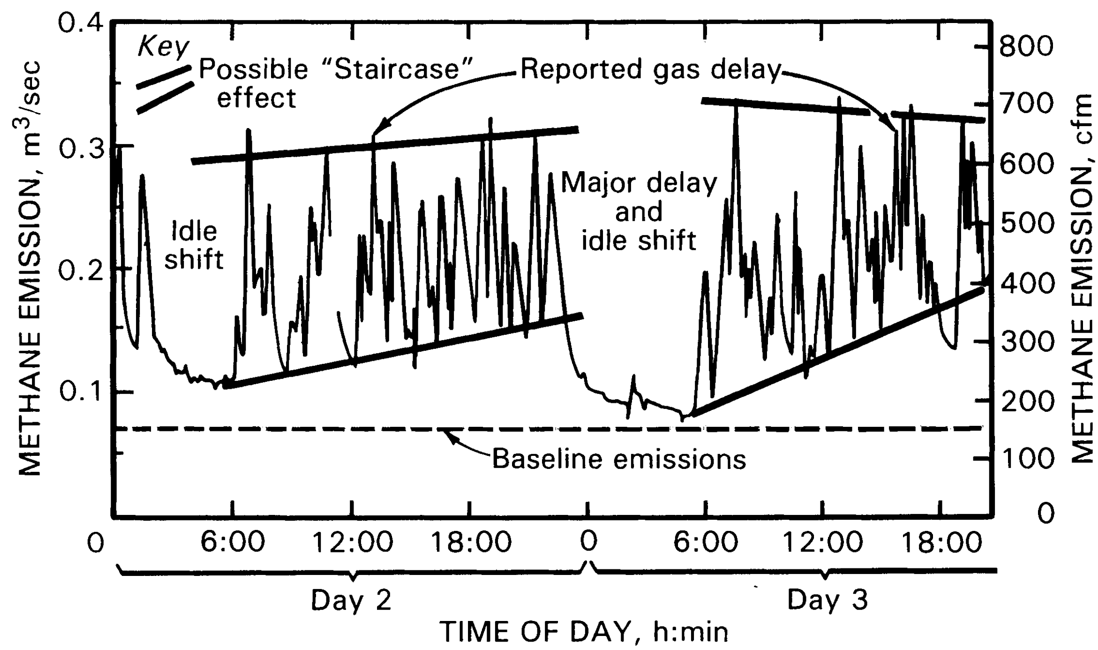

Figure 17.—Longwall face methane emission intervals exhibiting a possible "staircase" effect, days 2 and 3, VP-3 Mine.

suggests several time intervals where emissions were trending upward. Average methane emission rates were higher on passes mined from head to tail than those mined from tail to head (table 5). This is in contrast to the slightly higher emission rates in the tail-to-head mining direction at VP-1.

As mentioned previously, delays (not methane-related) during the VP-3 study were substantially higher in both frequency and duration. Average pass mining time at VP-3 was 65.9 min (table 7), compared to only 45.8 min (table 3) for passes at VP-1 on the same basis (all passes with data). Actual average pass delay time was 27.7 min (42.0%) for VP-3 and 6.0 min (13.1%) for VP-1. On a direction of mining basis (table 8), tail-to-head passes experienced significantly more total average delay time–35.1 min versus 20.9 min. Total average pass mining time was 76.2 min for tail-to-head passes, compared to 56.5 min for head-to-tail passes. The longer mining time for tail-to-head passes may explain the lower methane emission levels for this mining direction, as was speculated for the VP-1 study for the head-to-tail passes.

There were four short methane delays noted during the VP-3 longwall emission study. Methane delays of 4 min and 1 min occurred during passes three and seven on day 1 (figures 18-19). Additional methane delays of 4 min and 8 min were reported on day 2 (figure 20) and day 3 (figure 21), respectively. Emission rates associated with the delays were approximately 0.283 to 0.307 m^3/sec (600 to 650 cfm), similar to the rates associated with methane delays during the VP-1 study. However, emission rates prior to the methane delays were approximately 0.165 to 0.189 m^3/sec (350 to 400 cfm), or about 0.047 m^3/sec (100 cfm) higher than those during the VP-1 study. This figure reflects the same difference (0.047 m^3/sec (100 cfm)) between the measured baseline emissions of the two study sites. Since methane delays were observed at about the same emission rate at each mine, less margin existed for methane emission increases at the VP-3 site. On several other occasions during the study at VP-3, the methane emission rate exceeded 0.283 m^3/sec (600 cfm) (figures 12-13); however, no methane delays were indicated in the time study data.

Table 7.—Average longwall pass mining and delay time summary, VP-3 Mine

Calculation basis	No. of passes used	Average pass segment time: 1st third, Without snake	1st third, With snake	2nd third	3rd third	Total, Without snake	Total, With snake
		TOTAL MINING TIME, min					
All with data	27 of 38	13.6	34.4	17.4	14.2	45.2	65.9
<50% delay	11 of 27	9.9	22.0	14.1	13.5	37.5	49.6
		DELAY TIME, min (%)					
All with data	27 of 38	6.1 (44.9)	16.9 (49.1)	7.1 (40.8)	3.7 (26.1)	16.9 (37.4)	27.7 (42.0)
<50% delay	11 of 27	2.7 (27.8)	5.5 (25.0)	2.9 (20.6)	3.0 (22.2)	8.6 (22.9)	11.5 (23.2)

Table 8.—Average direction of pass mining and delay time summary, VP-3 Mine

Calculation basis	No. of passes used	Average pass segment time: 1st third, Without snake	1st third, With snake	2nd third	3rd third	Total, Without snake	Total, With snake
		HEAD-TO-TAIL TOTAL MINING TIME, min					
All with data	14 of 18	11.8	29.5	12.9	14.0	38.8	56.5
		HEAD-TO-TAIL DELAY TIME, min (%)					
All with data	14 of 18	5.7 (48.3)	13.0 (44.1)	3.8 (29.5)	4.1 (29.3)	13.6 (35.1)	20.9 (37.0)
		TAIL-TO-HEAD TOTAL MINING TIME, min					
All with data	13 of 20	15.5	39.6	22.2	14.3	52.1	76.2
		TAIL-TO-HEAD DELAY TIME, min (%)					
All with data	13 of 20	6.5 (41.9)	21.2 (53.5)	10.6 (47.8)	3.3 (23.1)	20.4 (39.2)	35.1 (46.1)

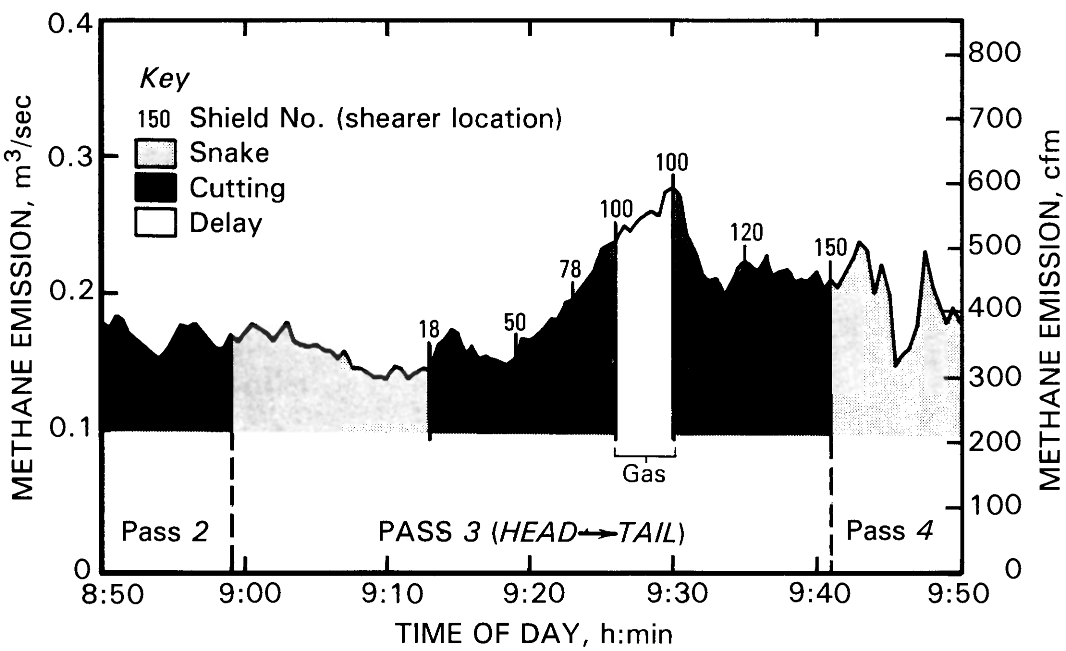

Figure 18.—Methane emissions, pass 3, day 1, VP-3 Mine.

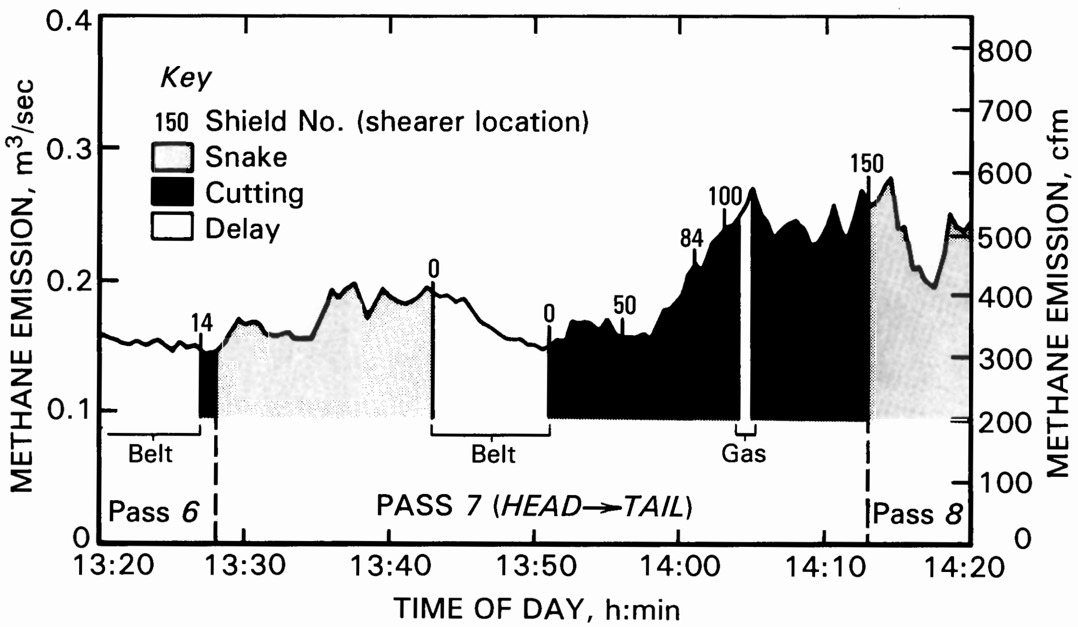

Figure 19.—Methane emissions, pass 7, day 1, VP-3 Mine.

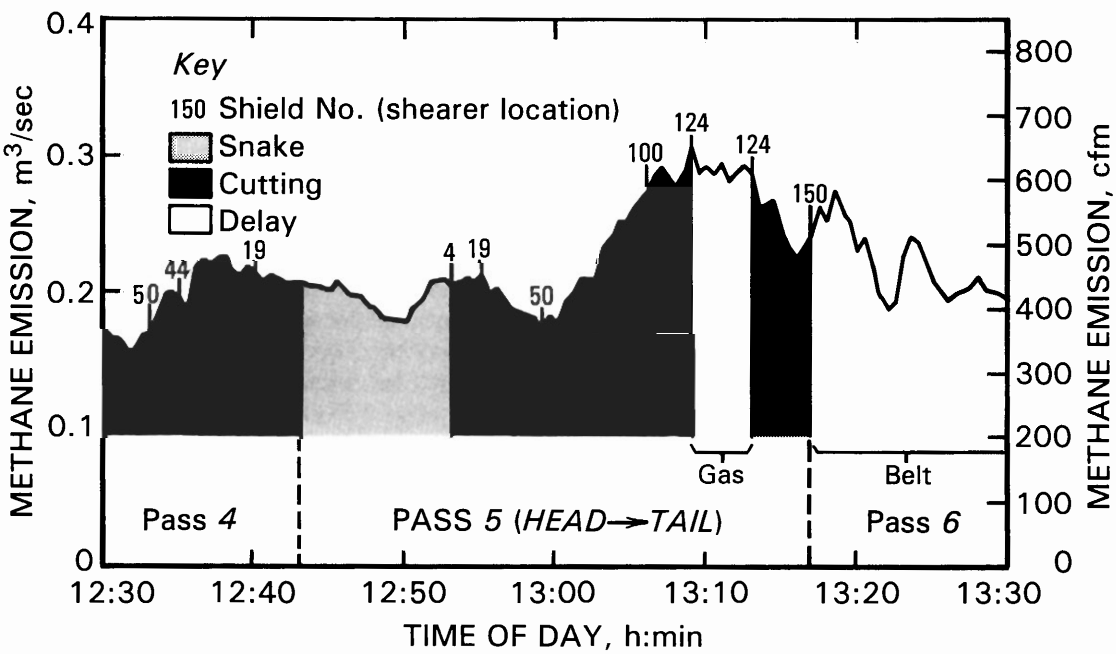

Figure 20.—Methane emissions, pass 5, day 2, VP-3 Mine.

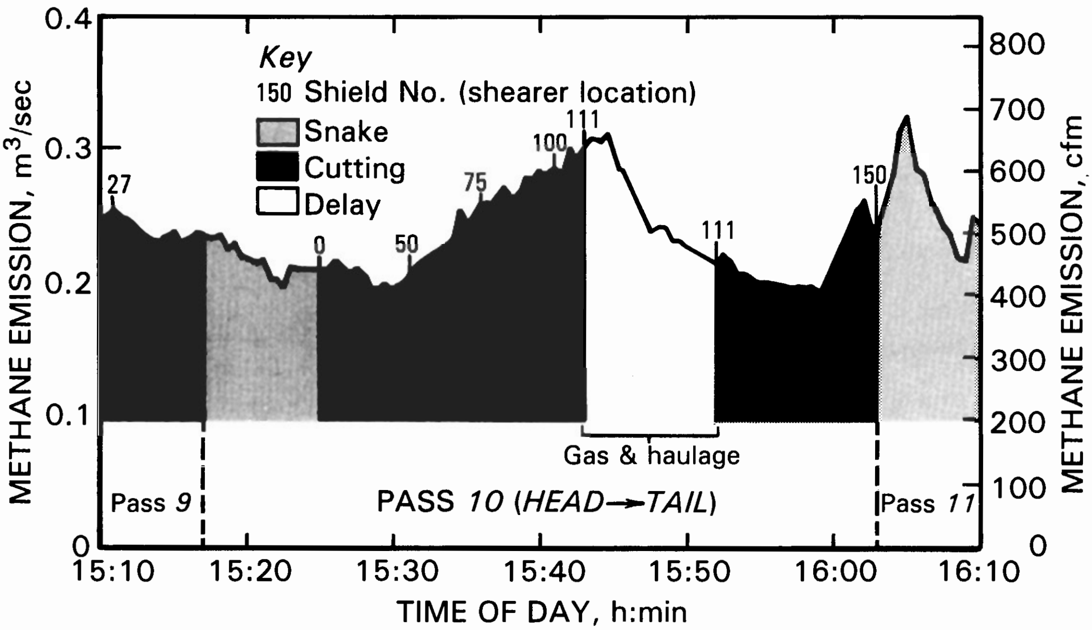

Figure 21.—Methane emissions, pass 10, day 3, VP-3 Mine.

PREDICTION OF METHANE EMISSIONS FOR 305-m (1,000-ft) LONGWALL FACES

The primary purpose of the longwall face emission studies at the VP-1 and VP-3 Mines was to predict the change in methane emission levels as faces were extended from 229 to 305 m (750 to 1,000 ft). These predictions were made by regression analysis of the average longwall pass segment emission values from the 229-m (750-ft) wide faces at each mine. The predicted average emission values for the additional 76 m (250 ft) of face length are not necessarily the "worst-case" scenarios, which would include sporadic high-methane emission events such as the floor gas bleeder observed at the VP-1 Mine.

VP-1 MINE

Longwall pass segment methane emission data for the <25% delay time basis (table 1) were selected for regression analysis for the prediction of emissions for an additional 76 m (250 ft) of face length at the VP-1 Mine. A power curve (figure 22) in the form $Y = 236.89X^{0.18}$, where Y = average pass segment methane emission rate and X = individual 76-m (250-ft) pass segment number, fit the measured data best (R^2 = 0.95).

Extending the regression curve to a fourth 76-m (250-ft) longwall pass segment (figure 22), i.e., to a face length of 305 m (1,000 ft), yields an average methane emission rate of 0.144 m^3/sec (304 cfm) for an additional 76 m (250 ft) of face width. The predicted value is a 7% (0.009 m^3/sec (20 cfm)) increase over the average measured methane emission value of 0.134 m^3/sec (284 cfm) for the third 76-m (250-ft) segment of the 229-m (750-ft) wide faces at the VP-1 Mine. At this relatively low predicted increase in methane emissions at the face, it is unlikely that methane emissions would be a limiting factor in increasing longwall face width to 305 m (1,000 ft).

VP-3 MINE

Longwall pass segment methane emission data for the <50% delay time basis (table 5) were selected for regression analysis for the prediction of emissions for an additional 76-m (250-ft) longwall pass segment at the VP-3 Mine. The small number of passes (five) meeting the more restrictive <25% delay time basis for the VP-3 Mine study was not considered sufficient to characterize existing emission trends for prediction purposes. A linear regression curve (figure 22) in the form Y = 309.6 + 64.25X, where Y = average pass segment methane emission rate and X = individual 76-m (250-ft) pass segment number, fit the measured data best (R^2 = 0.99).

Extending the regression curve to a longwall face length of 305 m (1,000 ft) yields an average methane emission rate of 0.268 m^3/sec (567 cfm) for the additional 76-m (250-ft) pass segment (figure 22). This predicted value is a 13% (0.029 m^3/sec (65 cfm)) increase over the average measured methane emission value of 0.237 m^3/sec (502 cfm) for the third 76-m (250-ft) pass segment of the 229-m (750-ft) wide longwall faces at the VP-3 Mine. Face emissions in the 0.283 to 0.330 m^3/sec (600 to 700 cfm) range at the VP-3 Mine occasionally resulted in short delays during the study. To ensure a safe underground workplace, methane emission rates at the levels predicted may require additional ventilation airflow on the face, or increased levels of methane drainage in advanceof longwall mining.

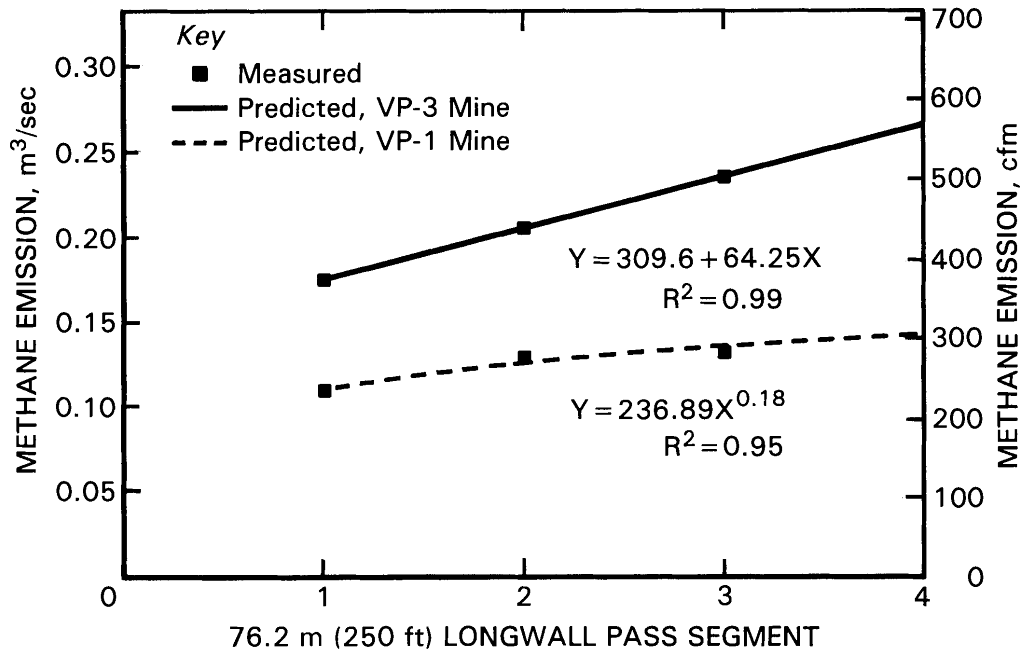

Figure 22.—Methane emission prediction curves for 305-m (1,000-ft) longwall faces, VP-1 and VP-3 Mines.

BLEEDER SYSTEM METHANE FLOW RATES

In addition to the longwall face emission studies, the bleeder system associated with each mine site was monitored. The bleeder system methane flow data were used to obtain a more comprehensive evaluation of how much of the methane in each mine's ventilation system was attributable to active mining on the study panel (table 9). As with the face emission portion of the study, the bleeder systems were monitored over the idle weekend to establish a methane flow baseline. Methane volumes above the baseline could then be attributed to the active study panel.

Table 9.—Bleeder system methane flows during VP-1 and VP-3 Mine emission studies

	Methane flow rate, 10^3 m³/d (MMcfd)	
	VP-1 Mine	VP-3 Mine
Minimum (base)	104.8 (3.7)	133.1 (4.7)
Maximum	184.1 (6.5)	175.6 (6.2)
Average	141.6 (5.0)	152.9 (5.4)
Differential[1] (maximum-minimum)	79.3 (2.8)	42.5 (1.5)
Average[1]	36.8 (1.3)	22.7 (0.8)

[1]Methane flow attributable to active mining on study panel.

VP-1 MINE

The VP-1 bleeder system monitoring location is shown on the study area map (figure 23). The monitoring location included methane contributions from the face and gob of the study panel as well as from the gobs associated with the two previously mined panels. A true baseline was not actually established, since the methane flow rate was still declining at the time mining resumed on Monday morning (figure 24). The minimum flow rate was about 104.8 × 10^3 m³/d (3.7 MMcfd).

As soon as mining began on the study panel, the methane flow rate in the bleeders began to rise, and generally continued to rise throughout the 5 days of the emission study (figure 24). Methane flow in the bleeders averaged 141.6 × 10^3 m³/d (5.0 MMcfd) after the base level (minimum flow rate) was established (table 9). The maximum methane flow rate of about 184.1 × 10^3 m³/d (6.5 MMcfd) was measured in the bleeder system on the final day of the study. The 79.3 × 10^3 m³/d (2.8 MMcfd) differential between the maximum and minimum bleeder system methane flow rates is inferred to be an estimate of the maximum methane liberation into the mine's bleeder ventilation system as a result of active mining during the face emission study. The average methane liberation rate into the bleeders as a result of mining on the active study panel was 36.8 × 10^3 m³/d (1.3 MMcfd).

At the end of the emission study, methane concentrations in the bleeders were approaching their allowable limit. By this time, the longwall face had advanced far enough away from the previously intercepted gob gas venthole (239) that its influence on methane levels in the bleeders was diminishing, and the next gob gas venthole (240) was not yet on production (figure 23). During the week of the study, a larger centrifugal exhauster was installed on venthole 239, which stabilized methane flow in the

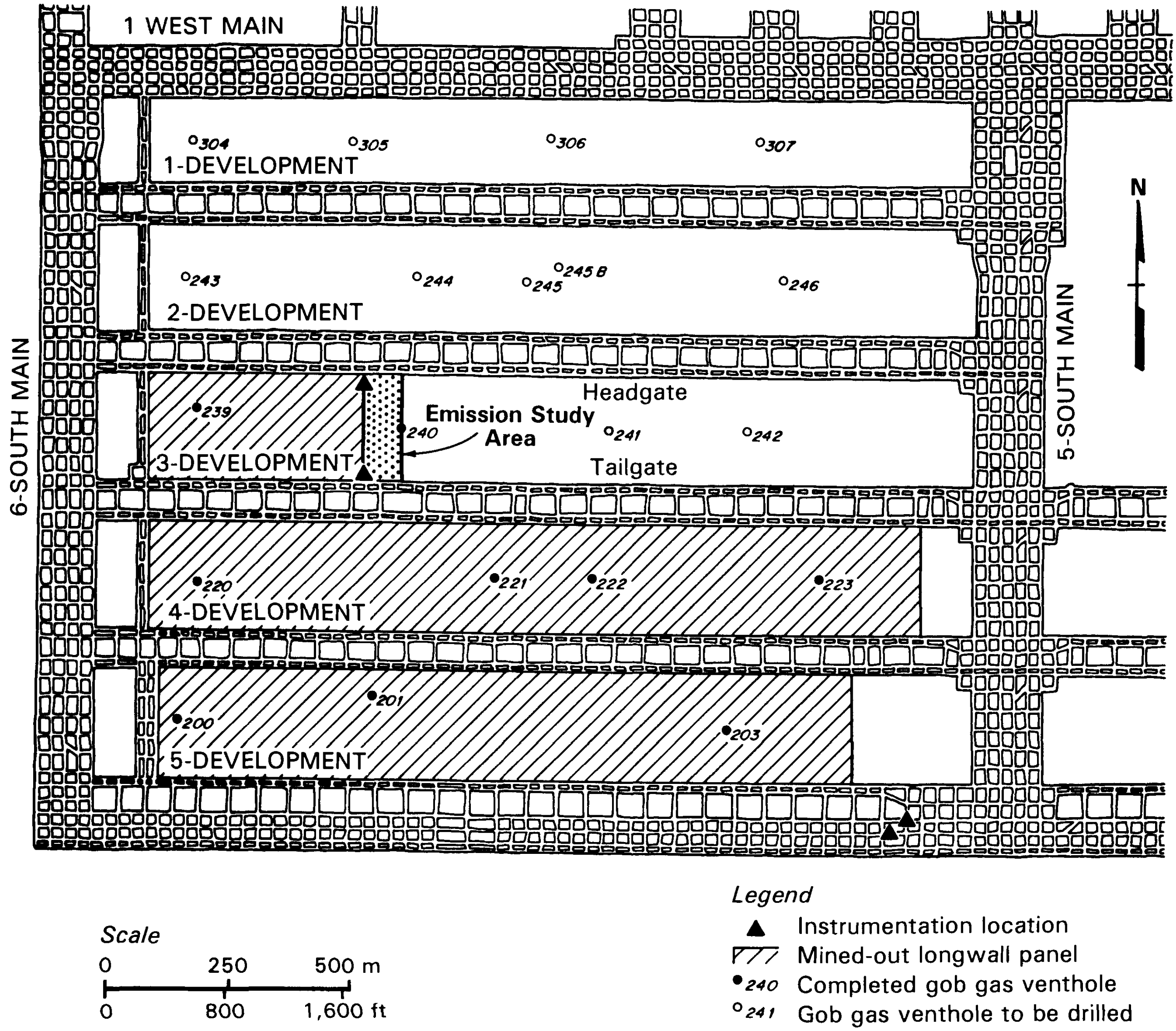

Figure 23.—Detailed map of VP-1 Mine study area.

bleeders at approximately 161.4 × 10^3 m^3/d (5.7 MMcfd) for about 12 hr during the first half of day 4, before the methane flow climbed once again, as shown in figure 24.

VP-3 MINE

In addition to the study panel, 10 other previously mined panels to the north were also part of the VP-3 bleeder system (figure 1); this significantly complicated meaningful analysis of the data and comparisons to the VP-1 study. Baseline monitoring (figure 25) indicated a minimum methane flow rate of about 133.1 × 10^3 m^3/d (4.7 MMcfd), approximately 28.3 × 10^3 m^3/d (1.0 MMcfd) greater than that for the VP-1 study (table 9). The bleeder system monitoring location was on the western end of the No. 1 Development entries, seven panels north of the area shown in figure 26. One reason for the relatively high methane flow rates during baseline monitoring is the larger associated gob area compared to VP-1. Barometric pressure changes also may have influenced the outgassing of the large gob area [Garcia et al. 1995]. Finally, higher in situ methane contents associated with the mined coalbed, as well as the surrounding strata in this area, may have contributed to the high bleeder baseline methane flow rates.

Methane flow rates in the VP-3 bleeder system peaked at about 175.6 × 10^3 m^3/d (6.2 MMcfd), late on day 3 of the study (figure 25), then declined into day 4 due to an extended mining delay (not methane-related). Methane flow in the bleeders averaged 152.9 × 10^3 m^3/d (5.4 MMcfd) after the base level was established (table 9). The peak flow rate in the VP-3 bleeder system was 8.5 × 10^3 m^3/d (0.3 MMcfd) lower than the peak flow rate observed at the VP-1 Mine.

The 42.5 × 10^3 m^3/d (1.5 MMcfd) differential between the minimum and maximum bleeder system methane flow rate for the VP-3 site is 36.8 × 10^3 m^3/d (1.3 MMcfd) less than the 79.3 × 10^3 m^3/d (2.8 MMcfd) differential for the VP-1 study panel (table 9). However, the average methane flow rate of 152.9 × 10^3 m^3/d (5.4 MMcfd) is 11.3 × 10^3 m^3/d (0.4 MMcfd) higher than the average rate for the VP-1 site. The difference of 42.5 × 10^3 m^3/d (1.5 MMcfd) between the maximum and minimum methane levels in the bleeders is inferred to be an estimate of the maximum methane liberation rate into the bleeders as a result of mining on the active study panel at the VP-3 Mine (table 9). The average methane liberation rate into the bleeders as a result of mining on the active study panel was 22.7 × 10^3 m^3/d (0.8 MMcfd).

The reason for the lower maximum methane flow rate in the VP-3 bleeders, in spite of the higher face emissions, is not conclusively known, but may be related to the higher amount of delay time (42.0% versus 13.1%) and/or fewer monitoring days (3 days versus 5 days) at the VP-3 site, as compared with the VP-1 study site. The lower differential between the minimum and maximum bleeder system methane flow rate at the VP-3 site, as compared to the VP-1 site, may be related to the higher base level bleeder flow rate at VP-3 site, which in turn, may be related to the larger gob area.

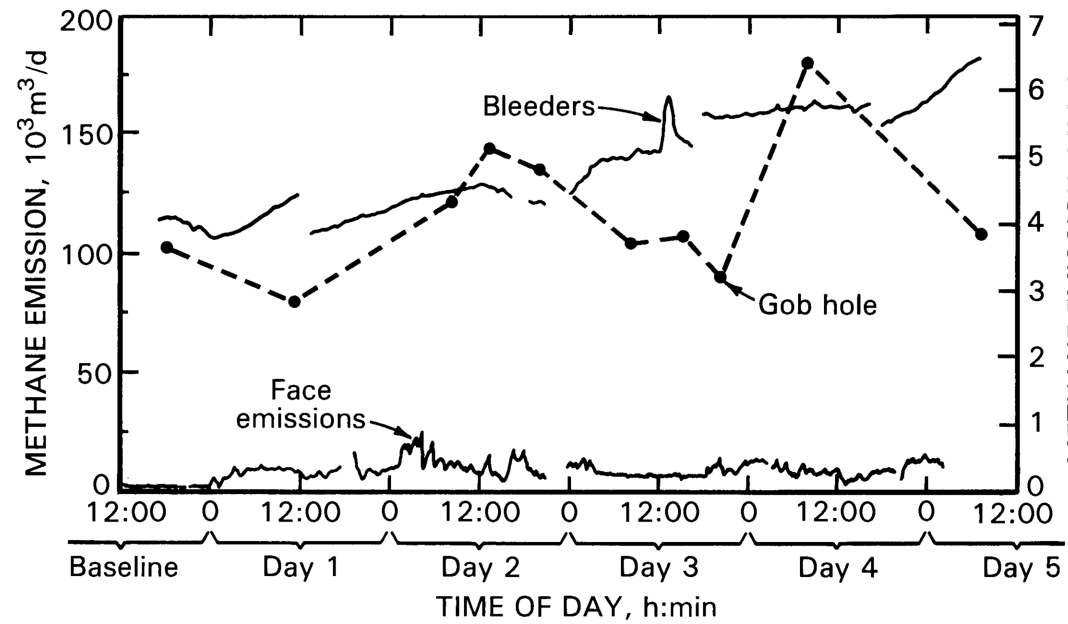

Figure 24.—Methane flows and emissions during mining of the VP-1 Mine study site.

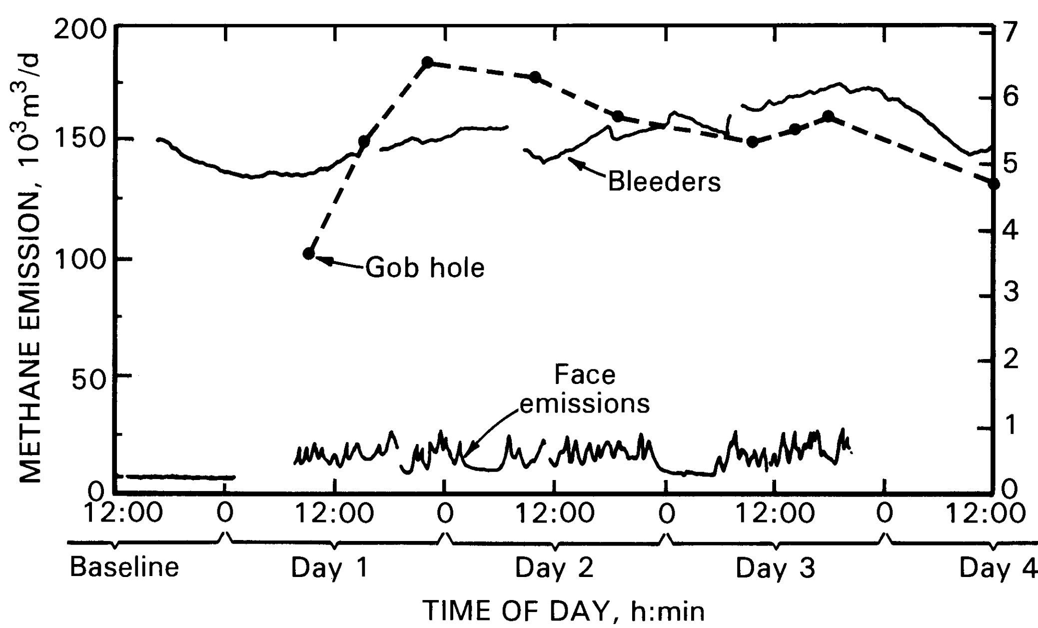

Figure 25.—Methane flows and emissions during mining of the VP-3 Mine study site.

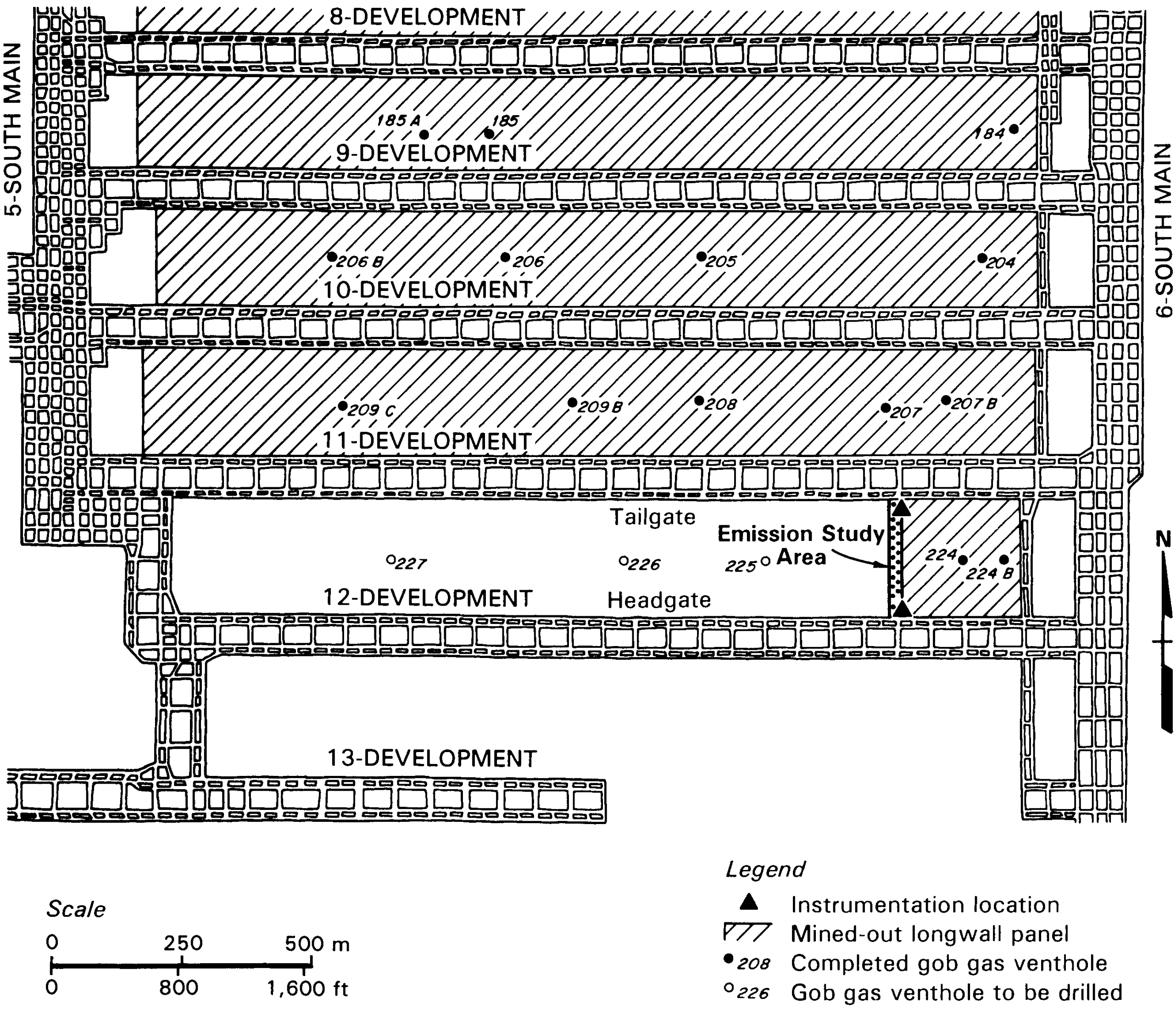

Figure 26.—Detailed map of VP-3 Mine study area.

METHANE DRAINAGE

To completely investigate the methane emission characteristics of each study site, it was necessary to evaluate all methane control systems in use prior to and during the face emission studies. Methane drainage has generally been necessary to effectively control underground methane levels in deep mines operating in the Pocahontas No. 3 Coalbed [Aul and Ray 1991; Kline et al. 1987; Schatzel et al. 1992].

Methane drainage practices employed at the VP-1 and VP-3 Mine study sites included horizontal boreholes drilled into the outlined longwall panels to drain gas in advance of mining, and the use of postmining vertical gob gas ventholes. Horizontal methane drainage borehole drilling and gas production records were used to estimate the volume of gas removed from the study panels at each mine site. Gob gas venthole production records, supplemented with more detailed gas production monitoring during the face emission studies, were used to document this component of the methane control system.

HORIZONTAL BOREHOLES: VP-1 MINE STUDY PANEL

A total of 29 horizontal boreholes (7 on the tailgate and 22 on the headgate) were drilled for gas drainage on the VP-1 study panel (figure 27). The tailgate holes were drilled progressively from the startup (west) end of the study panel, and covered about one-third of the panel length. The holes

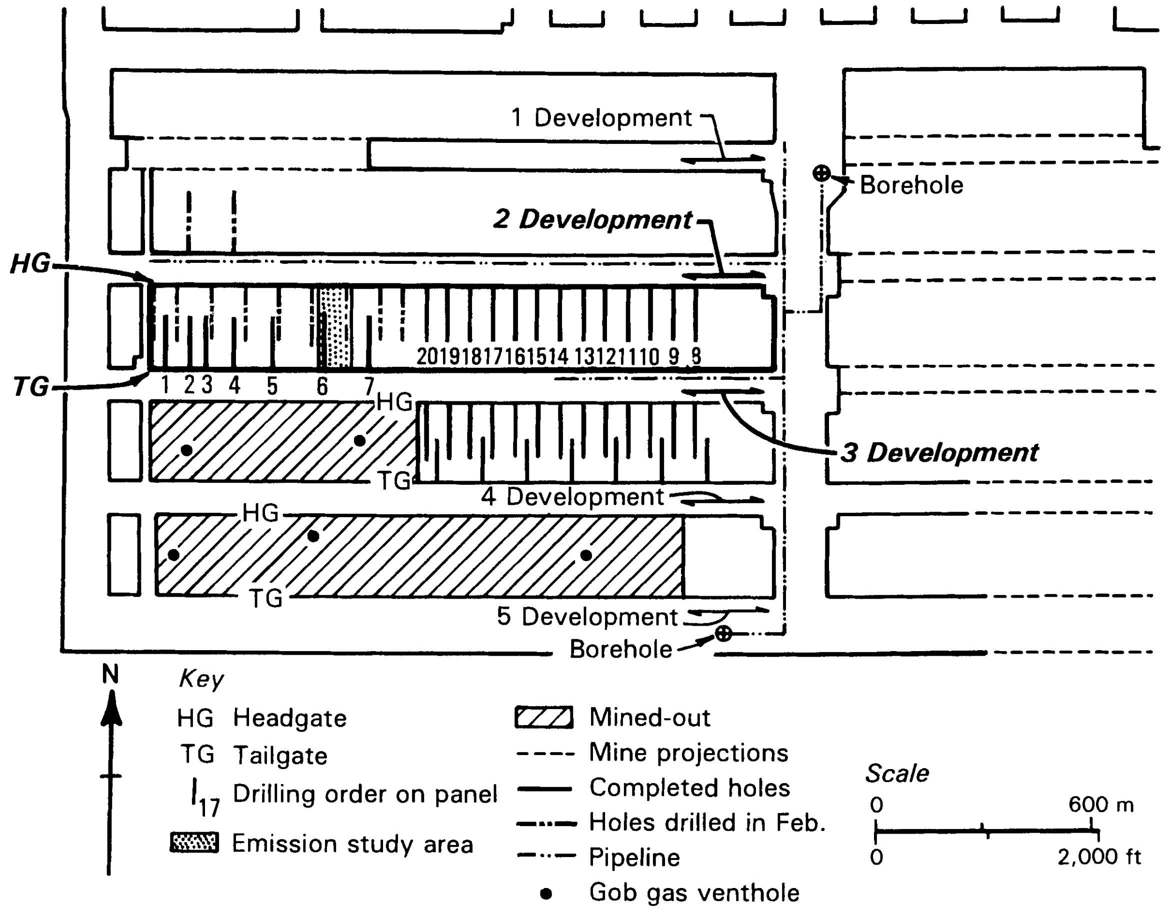

Figure 27.—Location of horizontal methane drainage boreholes, VP-1 Mine study panel.

were drilled 46 to 137 m (150 to 450 ft) apart, with the spacing generally increasing to the east, away from the startup end of the panel. These holes, and the holes drilled from the headgate side of the panel, were drilled to within about 69 m (225 ft) of the opposite side of the panel. The seven tailgate holes had a cumulative methane production of about 0.14×10^6 m^3 (5.0 MMcf) over approximately 2 months (figure 28, table 10). Methane production from the tailgate horizontal holes ended approximately 5 months prior to the start of mining on the study panel and about 7 months prior to the mining of the study site.

The first headgate horizontal methane drainage boreholes were drilled starting from the completion (east) end of the study panel, and new holes were progressively drilled closer to the startup end of the panel (figure 27). Drilling the holes in this sequence resulted in the last holes drilled being the first holes mined through by the longwall. If sufficient drainage time is not allowed before the start of mining, the methane control effectiveness of the holes at the startup end of the panel could potentially be reduced. However, in this case, there were also seven horizontal holes drilled from the tailgate side on the startup end of the study panel, which enhanced methane drainage in this area.

The headgate horizontal holes were drilled approximately 91 m (300 ft) apart on the startup end of the panel, where horizontal holes were also drilled from the tailgate side of the panel. Borehole spacing for the headgate holes was decreased to 61 m (200 ft) on the rest of the panel beyond the area of tailgate holes. The earliest drilled headgate holes began production approximately 6 months prior to the start of mining on the study panel and 8 months prior to mining of the study site (figure 28). The headgate holes drilled within the study site were completed and on production 5.5 months prior to the methane emission study. The total methane volume produced from the headgate horizontal holes was about 2.01×10^6 m^3 (71.0 MMcf) through the end of the longwall face emission study (table 10).

Gas production from the horizontal holes declined rapidly after peak production of 0.67×10^6 m^3/mo (23.5 MMcf/mo) was reached, 4 months after the first headgate holes were drilled and 2 months prior to the start of mining (figure 28). By the time

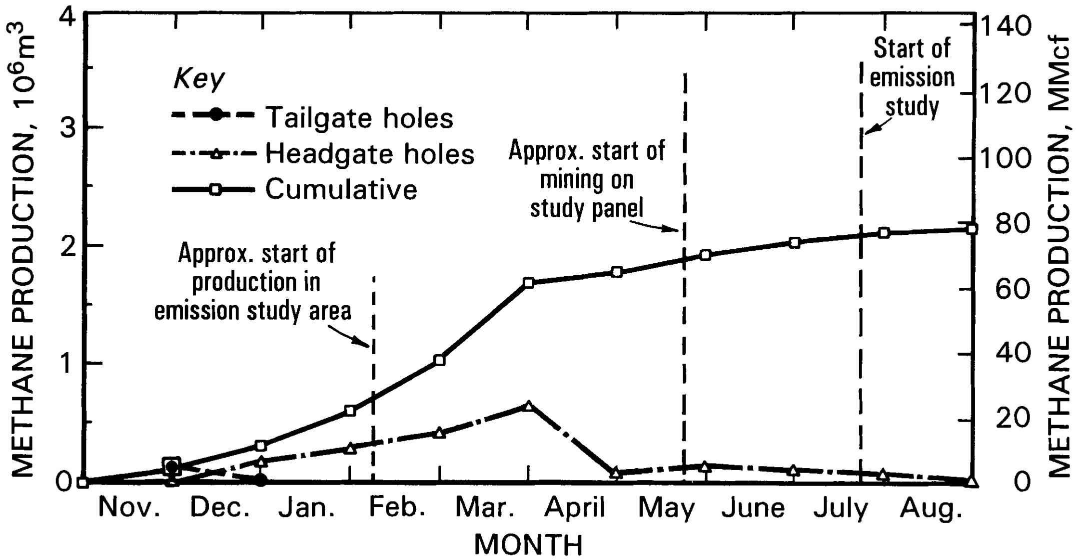

Figure 28.—Horizontal methane drainage borehole production, VP-1 Mine study panel.

Table 10.—Horizontal borehole methane production, VP-1 and VP-3 Mines

Hole locations	No. of holes	Cumulative production, 10^6m^3 (MMcf)			Average production per hole, 10^6m^3 (MMcf)
		To start of mining	To end of emission study	Total	
VP-1 Mine:					
Tailgate . . .	7	0.14 (5.0)	0.14 (5.0)	0.14 (5.0)	0.02 (0.7)
Headgate . .	22	1.81 (64.0)	2.01 (71.0)	2.06 (72.7)	0.09 (3.3)
Total	29	1.95 (69.0)	2.15 (76.0)	2.20 (77.7)	0.08 (2.7)
VP-3 Mine:					
Tailgate . . .	17	3.54 (125.0)	3.79 (134.0)	38.3 (135.2)	0.23 (8.0)

longwall mining began, gas production from the headgate horizontal holes was down to 0.11×10^6 m^3/mo (4.0 MMcf/mo), and the holes ceased production 3 months after the start of mining, 1 month after the face emission study was completed. Total horizontal borehole methane production for the VP-1 study panel was 2.20×10^6 m^3 (77.7 MMcf) (table 10). Average methane production for the VP-1 study panel was 0.08×10^6 m^3/hole (2.7 Mmcf/hole).

HORIZONTAL BOREHOLES: VP-3 MINE STUDY PANEL

The first horizontal methane drainage boreholes drilled at the VP-3 Mine were on the panel investigated for longwall face emissions during this study (figure 29). A total of 17 holes were drilled on the tailgate side of the study panel (11 Development), beginning at the startup (east) end of the panel. The horizontal holes were drilled on approximately 91-m (300-ft) spacing, to within about 38 m (125 ft) of the headgate side of the panel. The holes were drilled progressively toward the completion (west) end of the panel, ahead of the active face on the adjoining panel that was mining in the same direction. This drilling sequence allowed for the maximum time for methane drainage before longwall mining began for the holes closest to the startup end of the study panel.

The first four holes, including those in the face emission study area, were drilled and producing gas 8.5 months prior to the start of mining, and 10 months prior to the emission study (figure 30). At the time drilling of the horizontal holes began, the study panel was not yet completely outlined by development entries. In fact, the development entries on the headgate side of the panel were only completed about 3 months prior to the start of mining and 4.5 months prior to mining of the study site. The entries of the 12-Development section were advanced from the completion end of the panel toward the startup end. At the time of the drilling and during initial production of methane from the holes on the startup end of the panel, including the study site, the holes were producing gas from an unlimited, downdip virgin gas reservoir (figure 1). The horizontal holes at the startup end of the study panel were on production for about 5 months before the 12-Development entries were completed and the panel completely outlined.

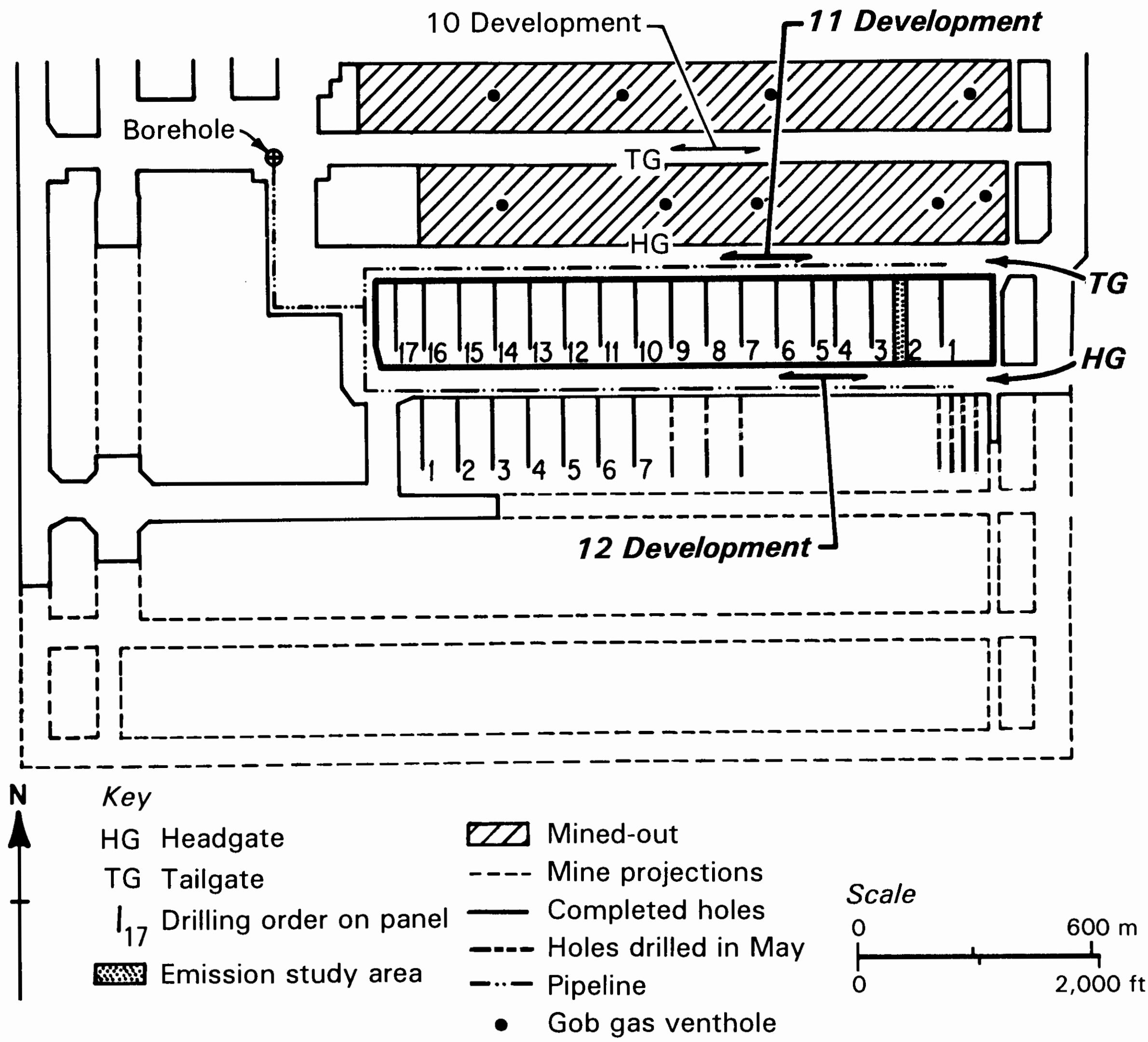

Figure 29.—Location of horizontal methane drainage boreholes, VP-3 Mine study panel.

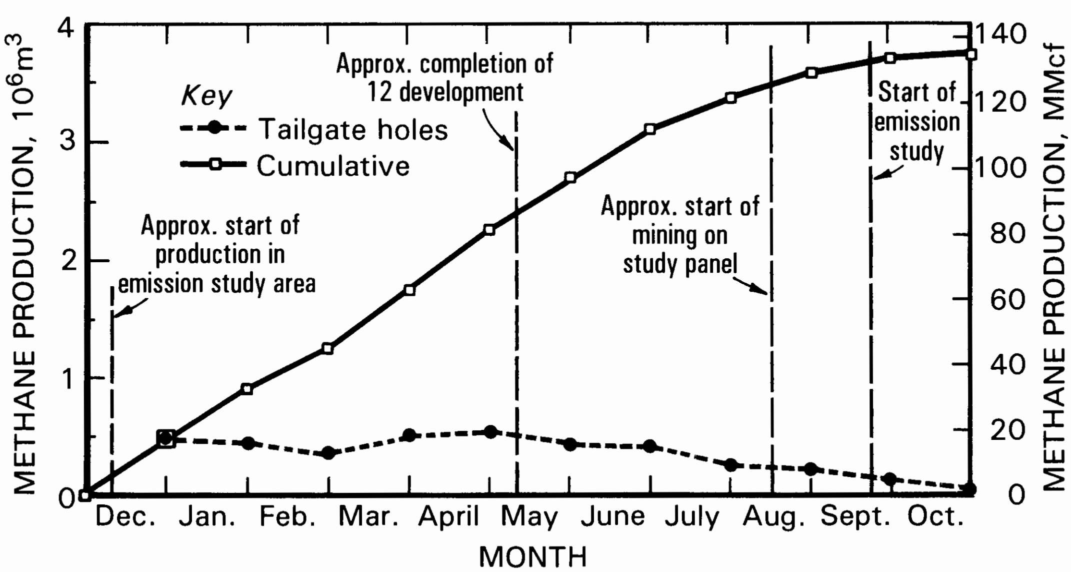

Figure 30.—Horizontal methane drainage borehole production, VP-3 Mine study panel.

Gas production rates from the horizontal holes on the VP-3 study panel were high (>0.28 × 10^6m³/mo (>10 MMcf/mo)) for 7 months (figure 30). In contrast, there were only 3 months of horizontal borehole methane production at that level on the VP-1 study panel, where the area had been isolated from the virgin coalbed gas reservoir for 18 months. Total methane production from the horizontal drainage holes was 3.83 × 10^6 m³ (135.2 MMcf) over 11 months of production, considerably more than the 2.20 × 10^6 m³ (77.7 MMcf) over 10 months for the VP-1 study panel (table 10). Average methane production was 0.23 × 10^6 m³/hole (8.0 MMcf/hole), also substantially higher than the 0.08 × 10^6 m³/hole (2.7 MMcf/hole) average for the VP-1 study panel. Production from the horizontal methane drainage boreholes ended approximately 2 months after mining began on the VP-3 study panel.

GOB GAS VENTHOLES: VP-1 MINE STUDY PANEL

Four gob gas ventholes were drilled on the VP-1 study panel. The first hole intercepted by the longwall (No. 239, figure 23) was located 122 m (400 ft) from the startup end of the panel and 320 m (1,050 ft) from the face emission study site. This venthole was on production 40 days prior to the face emission study (figures 31-32), producing a total of 2.8 × 10^6 m³ (98.9 MMcf) of methane at an average rate of 70.8 × 10^3 m³/d (2.5 MMcfd). Approximately 0.6 × 10^6 m³ (20.5 MMcf) of methane at an average rate of 116.1 × 10^3 m³/d (4.1 MMcfd) was exhausted by this venthole during the 5 days of the study. Gob gas venthole 239 produced 5.6 × 10^6 m³ (196 MMcf) of methane during its 104 days of production. The bottom hole location of gob gas venthole 240 was intercepted (or was close to being intercepted) near the end of the emission study. However, the first measured gas production from the venthole was on the fifth day (third working day), after the end of the emission study.

Total methane production for the four gob gas ventholes on the study panel was 38.3 × 10^6 m³ (1,351 MMcf) through 19 months (566 days) of production (figure 32, table 11). Two holes (Nos. 240 and 242) were still on production through the end of the available production data, more than 13 months after panel completion. Figure 31 shows the combined total daily methane production for all gob gas ventholes on the study panel. The highest single-day gob gas production for the panel was 274.7 × 10^3 m³/d (9.7 MMcfd). Methane production averaged approximately 226.5 × 10^3 m³/d (8.0 MMcfd) for 35 days when the last hole on the panel (No. 242) came on production. The highest daily methane production for individual holes ranged from 121.8 to 158.6 × 10^3 m³/d (4.3 to 5.6 MMcfd). Cumulative methane production for individual holes ranged from 5.6 to 12.9 × 10^6m³ (196 to 456 MMcf).

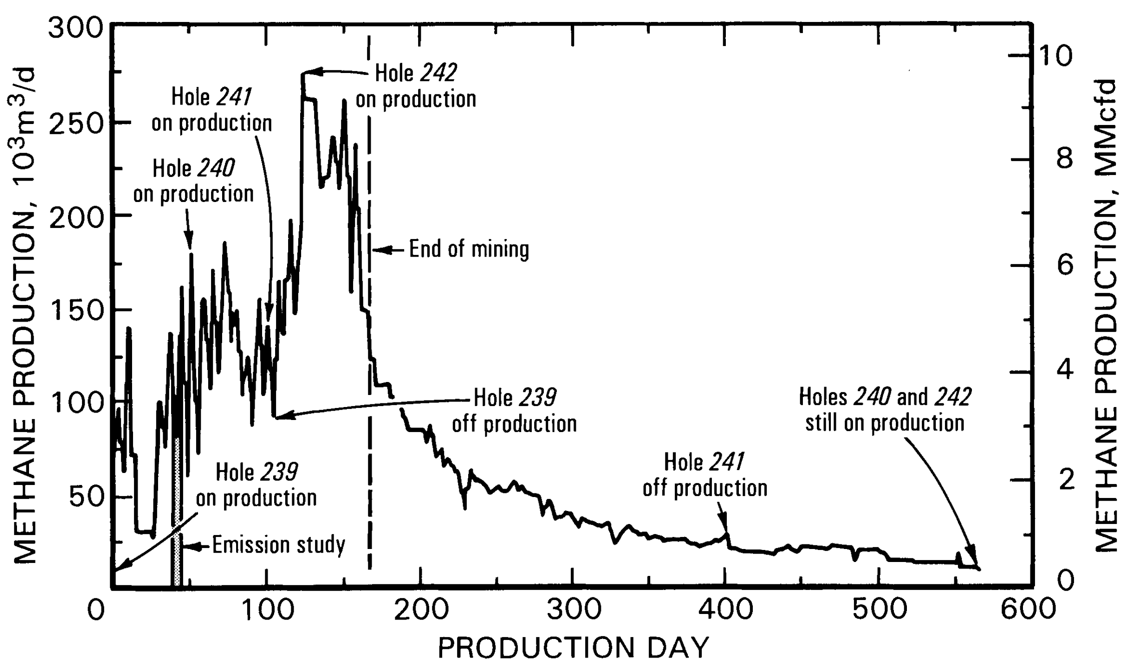

Figure 31.—Daily total gob gas venthole methane productions, VP-1 Mine study panel.

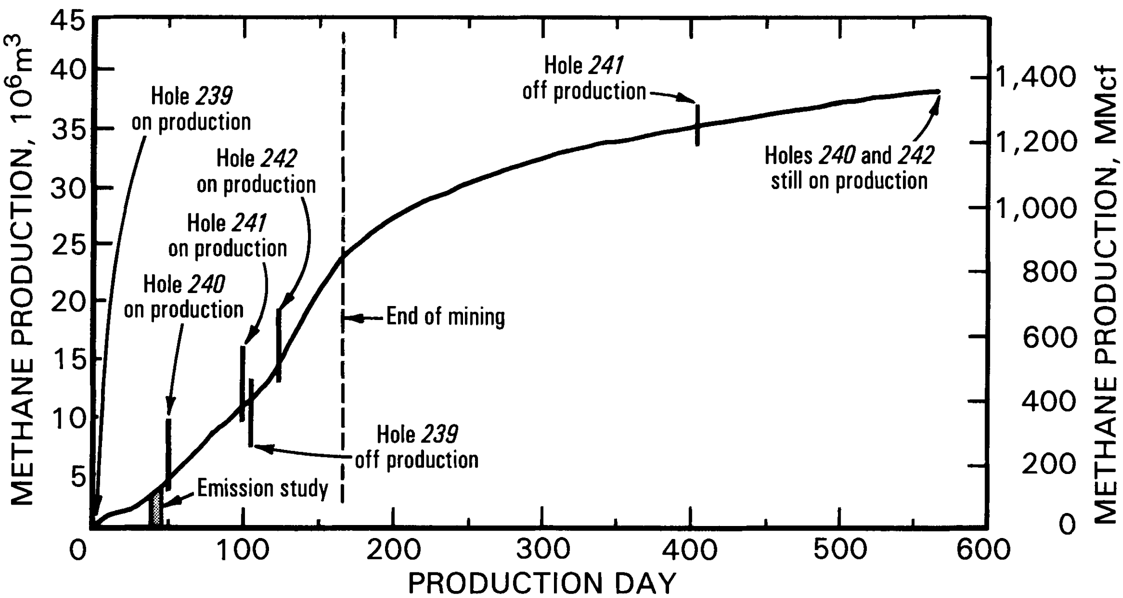

Figure 32.—Cumulative gob gas venthole methane production, VP-1 Mine safety panel.

Table 11.—Gob gas venthole methane production, VP-1 and VP-3 Mines

Hole No.	No. of production days	Cumulative production, 10^6 m^3 (MMcf)	Average production, $10^3 m^3/d$ (MMcfd) 100 days	200 days	300 days	Highest single-day production, $10^3 m^3/d$ (MMcfd)
VP-1 Mine:						
239	104	5.6 (196)	55.2 (1.95)	NAp	NAp	158.6 (5.6)
240	[1]517	[1]9.4 (331)	77.6 (2.74)	47.3 (1.67)	35.1 (1.24)	130.3 (4.6)
241	304	7.2 (255)	49.6 (1.75)	32.3 (1.14)	24.1 (0.85)	121.8 (4.3)
242	[1]445	[1]12.9 (456)	81.6 (2.88)	52.4 (1.85)	38.5 (1.36)	152.9 (5.4)
Average per hole	NAp	NAp	66.0 (2.33)	44.0 (1.55)	32.6 (1.15)	NAp
Panel total	[1]566	[1]38.3 (1,351)	103.9 (3.67)	133.9 (4.73)	107.3 (3.79)	274.7 (9.7)
VP-3 Mine:						
224B	415	6.7 (235)	43.6 (1.54)	27.2 (0.96)	20.1 (0.71)	104.8 (3.7)
224	411	6.1 (215)	42.8 (1.51)	25.5 (0.90)	18.7 (0.66)	79.3 (2.8)
225	[1]375	[1]10.3 (363)	57.8 (2.04)	43.0 (1.52)	32.6 (1.15)	107.6 (3.8)
226	[1]337	[1]17.5 (618)	93.4 (3.30)	69.9 (2.47)	56.6 (2.00)	135.9 (4.8)
227	[1]282	[1]4.4 (155)	26.3 (0.93)	18.4 (0.65)	NAp	59.5 (2.1)
Average per hole	NAp	NAp	52.8 (1.86)	36.8 (1.30)	32.0 (1.13)	NAp
Panel total	[1]431	[1]44.9 (1,585)	130.3 (4.60)	144.4 (5.10)	127.1 (4.49)	220.9 (7.8)

NAp Not applicable.
[1]Production ongoing.

GOB GAS VENTHOLES: VP-3 MINE STUDY PANEL

Five gob gas ventholes were drilled on the VP-3 study panel (figure 26). The first two ventholes on the startup end of the panel (224B, 224) had been intercepted by the longwall and were both on production (28 days and 24 days, respectively) at the time of the longwall face emission study (figures 33-34). In comparison, venthole 239 on the VP-1 study panel had been on production 40 days at the start of the emission study at that mine. Combined methane production from the two VP-3 holes was 2.4 × 10^6 m^3 (86.4 MMcf) at an average rate of 87.8 × 10^3 m^3/d (3.1 MMcfd) prior to the emission study. During the 3 days of the emission study, 0.4 × 10^6 m^3 (12.6 MMcf) of methane was produced at an average rate of 118.9 × 10^3 m^3/d (4.2 MMcfd), a rate almost identical to the 116.1 × 10^3 m^3/d (4.1 MMcfd) for the VP-1 emission study.

The five gob gas ventholes on the VP-3 study panel produced 44.9 × 10^6 m^3 (1,585 MMcf) of methane during the 431 days for which production data were available (table 11). Three holes were still on production at the end of the available data. The highest single-day methane production from gob gas ventholes on the VP-3 study panel was 220.9 × 10^3 m^3/d (7.8 MMcfd), 20% lower than the 274.7 × 10^3 m^3/d

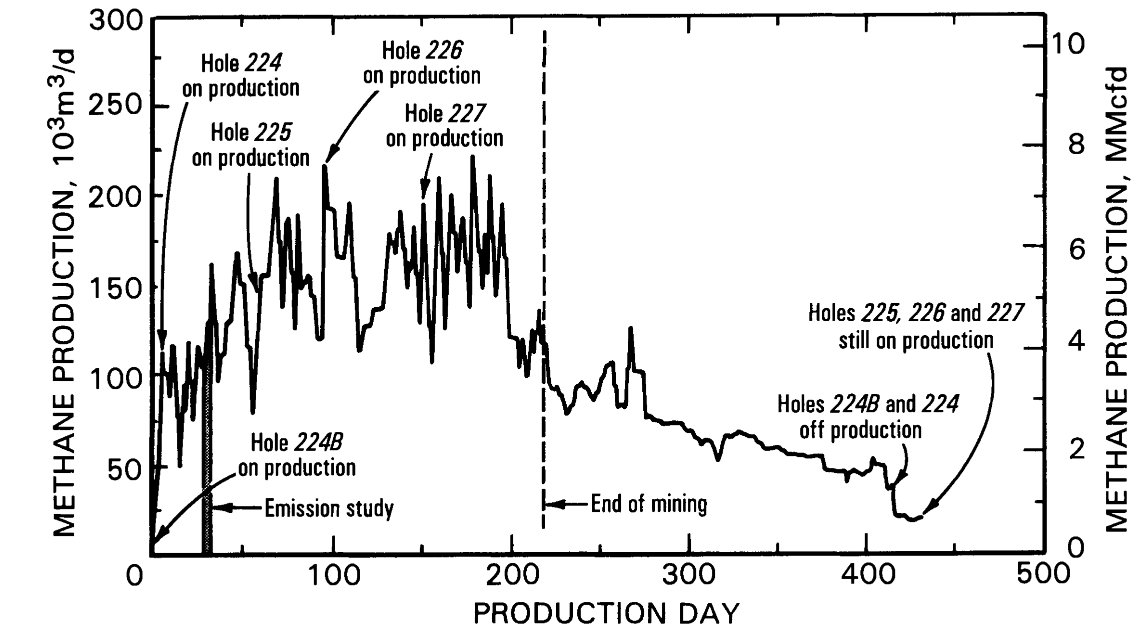

Figure 33.—Daily total gob gas venthole methane production, VP-3 Mine study panel.

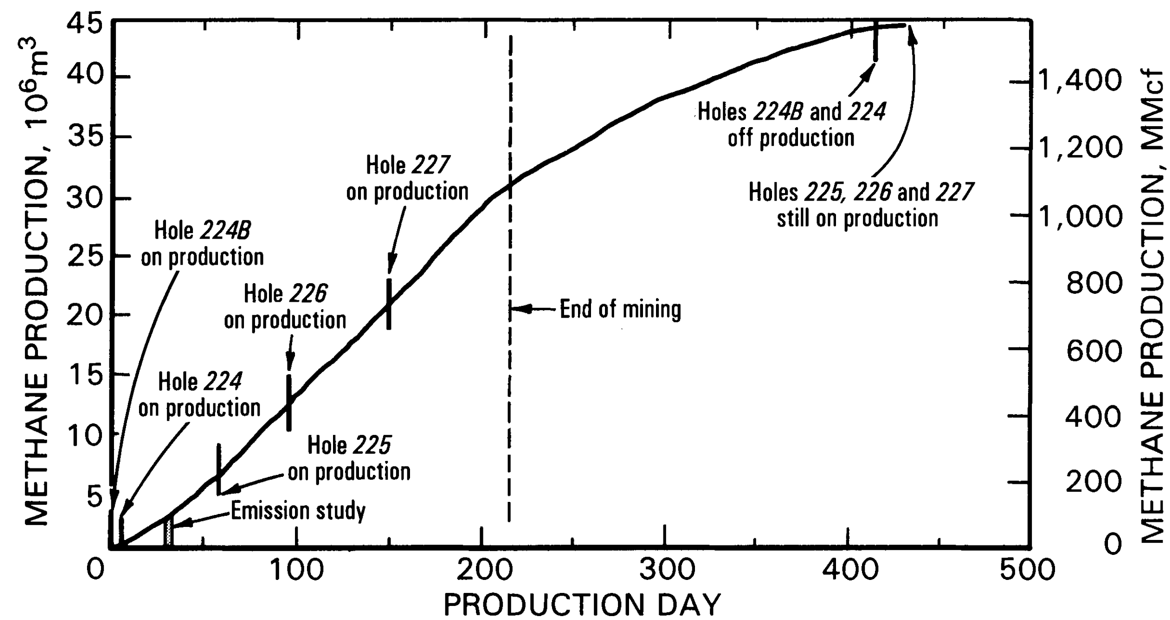

Figure 34.—Cumulative gob gas venthole methane production, VP-3 Mine study panel.

(9.7 MMcfd) recorded at the VP-1 site. The highest daily production for individual holes ranged from 59.5 to 135.9 × 10^3 m^3/d (2.1 to 4.8 MMcfd), slightly lower than the production for VP-1. Cumulative production for individual holes on the VP-3 study panel ranged from 4.4 to 17.5 × 10^6 m^3 (155 to 618 MMcf). A comparison of the average daily methane production rate per venthole for the same time intervals for both study panels (table 11) shows a convergence to an almost identical rate at 300 days.

DISCUSSION OF RESULTS

VARIATION IN LONGWALL PASS METHANE EMISSION LEVELS

The methane emission characteristics were quite different at the two study sites. Baseline methane emission levels were 0.047 m^3/sec (100 cfm) higher, and average longwall pass emissions were approximately 0.072 m^3/sec (153 cfm) higher (all passes with data basis) at the VP-3 site. Methane emission levels were higher at the VP-3 Mine even though there were only two daily production shifts compared to three at the VP-1 Mine. There were also significantly more mining delays (not methane-related) at VP-3, which should have allowed for additional "natural" bleedoff of methane. Additionally, there was a floor gas bleeder at the VP-1 Mine, which generally raised the average methane emission levels for about 2 days. Given these circumstances, lower methane emission rates might have been expected at the VP-3 Mine than at the VP-1 Mine.

The observed variation in methane emission rates are perhaps unexpected for two mining operations located only about 1,600 m (1 mile) apart in the same coalbed. However, a closer look at the mine design factors associated with the sites helps to explain the observed differences. When comparing the two sites, probably the most significant mine design factors influencing the variation in methane emission levels at the face, as well as the gas production rates from the horizontal boreholes, are (1) proximity and relative exposure to the virgin coalbed gas reservoir, and (2) gas bleedoff time prior to horizontal borehole methane drainage and longwall mining. At the time of the studies, the VP-1 study panel was the third in a series of five longwall panels that were progressively mined to the north (figure 23). This block of five panels in the southwest corner of the mine had been outlined by main entries 3.5 months prior to the mining of the first panel. The area to the north of this five-panel block was mined 3 to 12 years prior to the outlining of the block. This part of the VP-1 Mine is also bordered by the VP-5 Mine to the south and the VP-3 Mine to the west (figure 1). From these factors, it is inferred that the extensive mine development surrounding the VP-1 study panel has very effectively isolated the area from methane migration from the downdip virgin coalbed gas reservoir.

This mining sequence is optimum from a methane control viewpoint. In addition to the general isolation of the southwest corner of the VP-1 Mine from gas migration, the in situ gas volume within the five-panel block has had a substantial length of time to bleedoff into the surrounding entries. The first and the third (study) panels in the five-panel block were separated from the surrounding coalbed gas reservoir by development entries and bleeding off gas for about 6 months and 18 months, respectively, prior to mining. This relatively long period for in situ gas content reduction within the isolated five-panel block, in particular for the later mined panels, should result in progressively lower gas emissions at the face.

Company engineering staff reported that the first panel mined in this isolated block was one of the gassiest at the VP-1 Mine, and that supplemental horizontal methane drainage boreholes had to be drilled to control the higher emissions. However, as each new panel in the block was mined, methane emissions generally decreased. Even with the additional bleedoff time prior to mining, it was still necessary to utilize horizontal methane drainage boreholes on the study panel to further control methane emissions. However, the increased panel isolation and natural gas bleedoff time at VP-1 resulted in considerably lower horizontal borehole gas production rates and cumulative production than at VP-3.

Mine design parameters for the area of the VP-3 Mine where the study panel was located were quite different, and less desirable, from a methane-control viewpoint. The study panel was the 11th in a series of panels mined in the southeast corner of the mine (figure 1). Virgin coal reserves were adjacent to this area of the mine both to the west and south. Unlike the isolated block of five panels at the VP-1 study area, the series of panels in the VP-3 Mine had not been surrounded by main entries prior to mining of the panels. The panels in the VP-3 study area were progressively developed and mined to the south (figure 26). Each successive panel in the series was therefore connected to the virgin coalbed gas reservoir until the development entries for the panel were completed. The VP-3 study panel was surrounded by development entries and ventilation airflow just 3.5 months prior to the start of mining on the panel and less than 5 months prior to the emission study. Therefore, there was very little time for in situ gas content reduction by bleedoff into the mine's ventilation system prior to mining of the study panel. These conditions resulted in both higher gas emission rates on the face and higher horizontal borehole gas production than was observed at the VP-1 Mine study site.

It is probable that at the time of the emission studies, the in situ gas content on the VP-3 study panel was significantly higher than that on the VP-1 study panel due to the shorter time available for bleedoff of gas into the mine's ventilation system prior to mining. It is also possible that the virgin gas content may have been higher at the VP-3 mine site. The VP-3 Mine study panel lies under a depth of cover that is about 183 m (600 ft) greater than the VP-1 Mine study panel. In general, the gas content of a coalbed increases with increasing depth [Diamond 1982]. Based on limited available gas content data from the mine complex area, it is estimated that the virgin gas content of coal at the VP-3 study site could be about 1.3 cm^3/g (40 ft^3/st) higher than that at the VP-1 study site. However, this is probably not a significant enough difference to account for the substantial differences in longwall face methane emissions or horizontal borehole production rates observed between the two mines.

Another factor known to influence emission rates at this mine complex is the relative proximity of the overlying, gas-bearing, Pocahontas No. 4 Coalbed. High emission rates are experienced when the interval between the two coalbeds is <7.6 m (25 ft). Other geologic factors identified by the mine engineering staff as influencing methane emissions and/or methane drainage rates include variations in the physical properties of the coal and proximity to geologic structures such as sand channels, faults, and rolls. Insufficient geologic data were available to evaluate the potential influence of these various geologic parameters on the observed methane emission rates at the two sites.

SIGNIFICANCE OF VENTILATION AND GAS DRAINAGE FOR METHANE CONTROL

Figures 24-25 and table 12 show the individual contributions of the ventilation and methane drainage components to the overall methane control system during the VP-1 and VP-3 Mine longwall face emission studies, respectively. These data show that face emissions are a relatively small contributor to the total methane emissions resulting from the mining of the panels.

Table 12.—Ventilation system and borehole methane flows during VP-1 and VP-3 Mine emission studies

Source	Average methane flow rate, 10^3 m^3/d (MMcfd)	
	VP-1 Mine	VP-3 Mine
Bleeders	141.6 (5.0)	152.9 (5.4)
Bleeders[1]	36.8 (1.3)	22.7 (0.8)
Horizontal holes	2.8 (0.10)	3.4 (0.12)
Gob gas ventholes	116.1 (4.1)	118.9 (4.2)
Total	260.5 (9.20)	275.2 (9.72)
Total[1]	155.7 (5.5)	145.0 (5.12)
Face	9.6 (0.34)	16.4 (0.58)
Face, % of total	3.7	6.0
Face, % of total[1]	6.2	11.3

[1]Methane flow attributable to active mining on study panel.

Average methane flow in the bleeders during the VP-1 emission study was 141.6 × 10^3 m^3/d (5.0 MMcfd). The active gob gas ventholes on the study panel were producing methane at an average rate of 116.1 × 10^3 m^3/d (4.1 MMcfd) during the emission study, while horizontal boreholes (not shown in figure 24) were producing at an average rate of only 2.8 × 10^3 m^3/d (0.10 MMcfd). The 9.6 × 10^3 m^3/d (0.34 MMcfd) of methane emissions from the face was only about 3.7% of the average of 260.5 × 10^3 m^3/d (9.20 MMcfd) total methane emissions/borehole production measured at the VP-1 Mine study site. However, the 9.6 × 10^3 m^3/d (0.34 MMcfd) of methane emissions from the face was about 6.2% of the average of 155.7 × 10^3 m^3/d (5.50 MMcfd) total methane emissions/ borehole production attributable to mining of the study panel.

At the VP-3 Mine, where the study panel had been directly connected to the virgin coalbed gas reservoir until shortly before mining began, face emissions were a higher portion of the total methane emission/borehole production (table 12). During the emission study, the average methane flow rate in the bleeders was 152.9 × 10^3 m^3/d (5.4 MMcfd). Gob gas ventholes were producing methane at an average rate of 118.9 × 10^3 m^3/d (4.2 MMcfd). Most of the horizontal borehole methane production occurred prior to mining of the panel, and the average production had declined to 3.4 × 10^3 m^3/d (0.12 MMcfd) during the study (not shown in figure 25). The 16.4 × 10^3 m^3/d (0.58 MMcfd) of methane emissions from the face was 6.0% of the total of 275.2 × 10^3 m^3/d (9.72 MMcfd) methane emissions/borehole production measured at the VP-3 study site. However, the 16.4 × 10^3 m^3/d (0.58 MMcfd) of methane emissions from the face was about 11.3% of the average of 145.0 × 10^3 m^3/d (5.12 MMcfd) total methane emissions/borehole production attributable to mining of the study panel.

The importance of horizontal borehole methane drainage to supplement the ventilation system, especially given the conditions at the VP-3 Mine, can be demonstrated by converting the production volumes to a m^3/sec (cfm) basis. Horizontal boreholes at the VP-3 Mine produced methane at an average rate of about 11.6 × 10^3 m^3/d (0.41 MMcfd), or 0.135 m^3/sec (285 cfm) over their 11-month production life. Adding this value to the 16.4 × 10^3 m^3/d (0.58 MMcfd), or 0.190 m^3/sec (403 cfm) average face methane emission rate for the VP-3 Mine during the study, yields a potential average face emission rate of 0.325 m^3/sec (688 cfm), if horizontal borehole methane drainage had not been utilized. This emission rate is similar to those associated with reported methane-related delays at this mine.

SUMMARY

The primary purpose of this investigation at the VP-1 and VP-3 Mines was to predict the methane emission consequences of increasing longwall panel face widths from 229 to 305 m (750 to 1,000 ft). The predictions were based on emission trends established by continuous monitoring of methane emission rates on the existing 229-m (750-ft) faces. It was predicted that average emissions would increase from 0.134 to 0.144 m^3/sec (284 to 304 cfm), or 7% on longwall faces extended an additional 76 to 305 m (250 to 1,000 ft) at the VP-1 Mine. This level of increase alone was not expected to present any particular mining problem.

Analysis of emission trends from the VP-3 Mine study site suggest that average methane emissions could increase from 0.237 to 0.268 m^3/sec (502 to 567 cfm), or 13% on faces extended to 305 m (1,000 ft). This level of methane emissions predicted for the additional face width at the VP-3 Mine is just below the general range of 0.283 to 0.330 m^3/sec (600 to 700 cfm), where methane delays are occasionally experienced. It is likely that increased ventilation airflow, and/or additional methane drainage would be required to safely realize the gain in coal production anticipated from mining larger panels at this mine site.

Since this study was completed, the mine's engineering staff reported that several panels with 305-m (1,000-ft) wide faces were completed at the VP-3 Mine, without experiencing the predicted higher methane emission levels. An enhanced methane drainage program that provided both increased hole length and additional time for the horizontal boreholes to drain gas in advance of mining is credited with maintaining the methane emissions at a lower than predicted level.

Methane emission levels were significantly different between the two mine study sites even though the sites were only about 1,600 m (1 mile) apart. Baseline methane emission levels at the VP-3 Mine study site were 0.047 m^3/sec (100 cfm) higher than those at the VP-1 Mine. Average longwall pass methane emission levels were 0.190 m^3/sec (403 cfm) at the VP-3 Mine and only 0.118 m^3/sec (250 cfm) at the VP-1 Mine. Study panels at both mines utilized in-mine horizontal borehole and vertical gob gas venthole methane drainage to supplement the mine's ventilation system. The higher level of methane emissions at the VP-3 Mine study site is primarily attributed to (1) the closer proximity and longer exposure to the adjacent virgin coalbed gas reservoir and (2) the shorter time for in situ gas content reduction by horizontal methane drainage boreholes, and bleedoff into the ventilation system prior to mining.

In addition to the influence on methane emission levels, panel isolation time also affected methane drainage rates from the horizontal boreholes at the study sites. The horizontal boreholes on the VP-3 study panel which had a shorter isolation time from the virgin coalbed gas reservoir produced 74% more total gas than those at the VP-1 site. In contrast, average methane production rates from the gob gas ventholes were actually quite similar at both mine sites.

Average longwall pass methane emissions were slightly higher when mining from tail to head during the VP-1 study. Conversely, emissions were higher when mining from head to tail during the VP-3 study. At both mine sites, it seems that the variation in emissions relative to pass direction is related to the amount of delay time. The pass direction with the lowest average delay time had the highest methane emission level. The amount of delay time also had a general influence on average pass methane emission levels at each mine, as seen when comparing the emission levels for the various delay time calculation bases. The basis with the least amount of delay time had the highest methane emissions at each mine. These observations are particularly significant for mine operators attempting to increase coal production by utilizing advanced mining technology in gassy coalbeds while maintaining a safe underground workplace.

The final point of interest evident from this study is that methane released at the face during active mining constitutes a relatively small portion of the overall methane liberation from an active longwall section. At the VP-1 Mine site, methane emissions from the active longwall face averaged only 3.7% of the 260.5 × 10^3 m^3/d (9.20 MMcfd) total methane emissions/borehole production measured during the emission study. However, methane emissions made up a higher portion of the total at the VP-3 Mine, where the study panel had been directly connected to the virgin coalbed gas reservoir until shortly before mining began. At this study site, methane emissions from the face averaged 6.0% of the 275.2 × 10^3 m^3/d (9.72 MMcfd) total methane emissions/borehole production.

The importance of methane drainage in supplementing the face ventilation system is quite clear. If even a small fraction of the gas handled by the methane drainage systems were encountered in the face area, both mine safety and the expected increase in coal production could be adversely affected.

ACKNOWLEDGMENTS

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