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Investigation of Methane Emissions From an Advancing Face in the Belle Isle Domal Salt Mine, Louisiana

By A. T. Iannacchione, G. L. Finfinger, T. M. Kohler, and D. M. Hyman

UNITED STATES DEPARTMENT OF THE INTERIOR

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LIST OF ABBREVIATIONS

cm	centimeter	mi	mile
ft	foot	min	minute
g	grams	pct	percent
hr	hour	t	metric ton
km	kilometer	ton	short ton
m	meter	wt-pct	weight-percent

INVESTIGATION OF METHANE EMISSIONS FROM AN ADVANCING FACE IN THE BELLE ISLE DOMAL SALT MINE, LOUISIANA

By A. T. Iannacchione,[1] G. L. Finfinger,[2] T. M. Kohler,[3] and D. M. Hyman[1]

ABSTRACT

The Bureau of Mines measured methane emission rates from an advancing salt face ranging from 15 to 56 ft^3/ton (0.5 to 1.8 m^3/t). Small room size, use of a continuous miner, and a well-defined ventilation system made possible air velocity and methane concentration measurements. These measurements, representing data from 18 production days, were conducted in an area of abnormally low grade salt. Methane emissions occurred primarily during the advance of the salt face by continuous miner.

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INTRODUCTION

Since 1979 four of the Five Islands salt mines in southern Louisiana have been classified as "gassy" mines. Compliance with Part 57, Title 30 of the Code of Federal Regulations is presently being investigated to determine its influence on mining productivity. Basic information on methane emission rates, physical properties tests, and methane content of domal salt mines is needed to develop the safest and most economical way to control methane.

Bureau of Mines research is currently divided into three tasks:

1. Characterizing the quality, composition, and occurrence of potentially explosive gases with rapid changes in the geology and geochemistry of domal salt.

2. Determining the physical properties of domal salt, such as pressure gradients, permeability, and gas flow characteristics. This information will determine the potentials of directional in-mine drilling technology for degassing and/or avoiding outburst-prone areas. Outbursts, which occur in several Louisiana salt mines, are a sudden, violent release of occluded gases and salt under high pressure (7).[4]

3. Examining daily methane emissions from advancing faces to identify correlations with changes in production rates, atmospheric conditions, and geology of the advancing face. Characterization of the most important factors affecting methane emissions from working faces can then be made so that a safe mining method can be established.

ACKNOWLEDGMENTS

The authors wish to thank all of the operators and miners of the Five Islands salt mines of southern Louisiana for their help and cooperation. Special thanks are extended to Charles von Dreusche and Thomas Fudge of Cargill, Inc. (Belle Isle Mine) for helping locate a site for this investigation. J. D. Martinez, R. L. Thoms, and D. H. Kupfer of Louisiana State University provided valuable information on geological and engineering problems encountered in mining domal salt. Invaluable technical support was supplied by R. Wosniak of Ryan Laboratories, MSA Corp., Pittsburgh, Pa., in instrumentation design and V. G. Iannacchione of the Research Triangle Institute, Research Triangle Park, N.C., in statistical analysis.

ENGINEERING AND GEOLOGICAL SETTING

Location of Study Area

The Belle Isle mine, one of a group of four underground domal salt mines presently operating in southern Louisiana, is located 19 mi (30.6 km) southeast of Franklin, La. Within this mine a decline is being driven from the 1,200-ft (366-m) level to the 1,600-ft (488-m) level (fig. 1). The advancing face of this decline, which is being worked by a continuous miner, is 13 ft (4 m) high by 35 ft (11 m) wide. Normal production faces in domal salt mines are 30 ft (9 m) high by 60 to 160 ft (18 to 40 m) wide and are advanced by blasting 5- to 15 ft (2- to 5-m) cuts into the face. The advancing decline is ideal for a methane emissions study because of the comparatively small room size, presence of a rigid exhaust duct, and use of a continuous miner.

[4]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

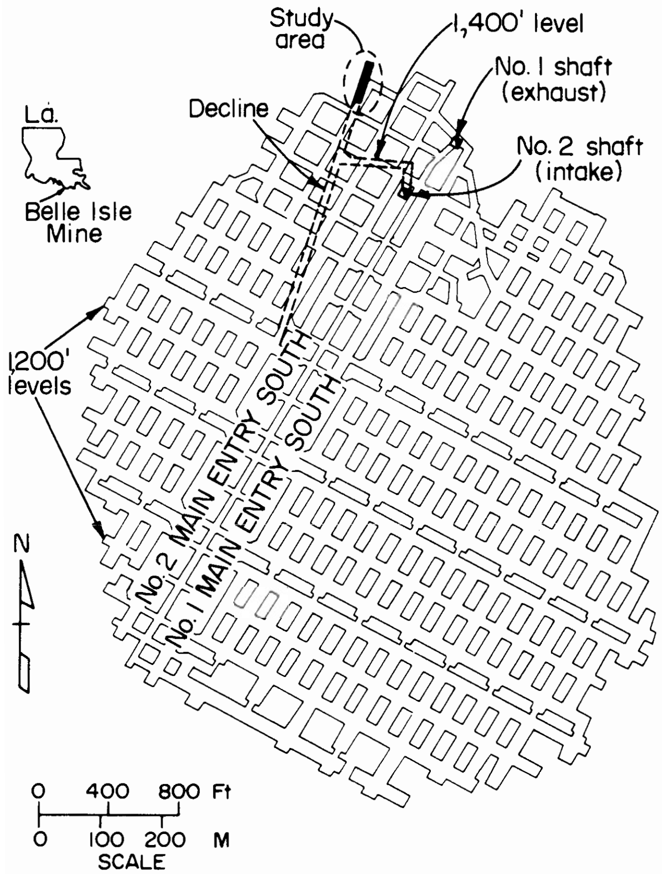

FIGURE 1. - Location of study area within decline of Belle Isle salt mine, Louisiana.

Design and Layout of Sensing System

The unique engineering design used in developing the decline facilitated the monitoring of emission rates. Intake air from the No. 2 shaft enters the decline at the 1,400-ft (427-m) level and is split to ventilate the decline up to the 1,200-ft (366-m) level and down to the advancing face (fig. 1). A 30-in (76-cm) rigid duct is used to exhaust the air from the advancing face of the decline to the 1,200-ft (366-m) level. Accurate air velocity and volume calculations of air ventilating the decline face can be made by measuring velocity inside the 30-in exhaust duct.

A sensing system was modified to record velocity and methane concentrations in the exhaust duct as well as methane concentrations in the intake entry (fig. 2). The system is comprised of three methane sensors, a sonic anemometer, a power supply, four amplifier units, and four strip-chart recorders (fig. 3). The three methane sensors detect methane in the range of 0 to 1 pct. Each of these sensing heads is constructed of stainless steel to prevent corrosion. The sonic

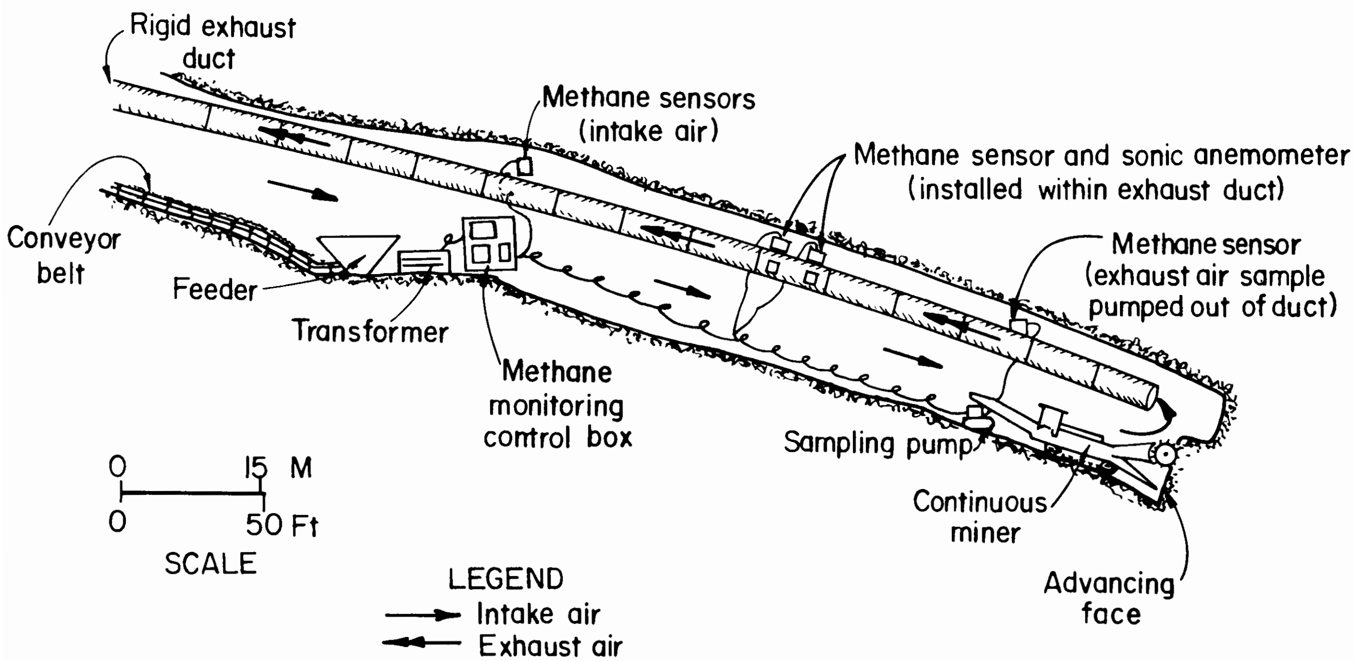

FIGURE 2. - Cross-sectional view of the locations of the instruments used to monitor velocity and methane concentrations from advancing decline face.

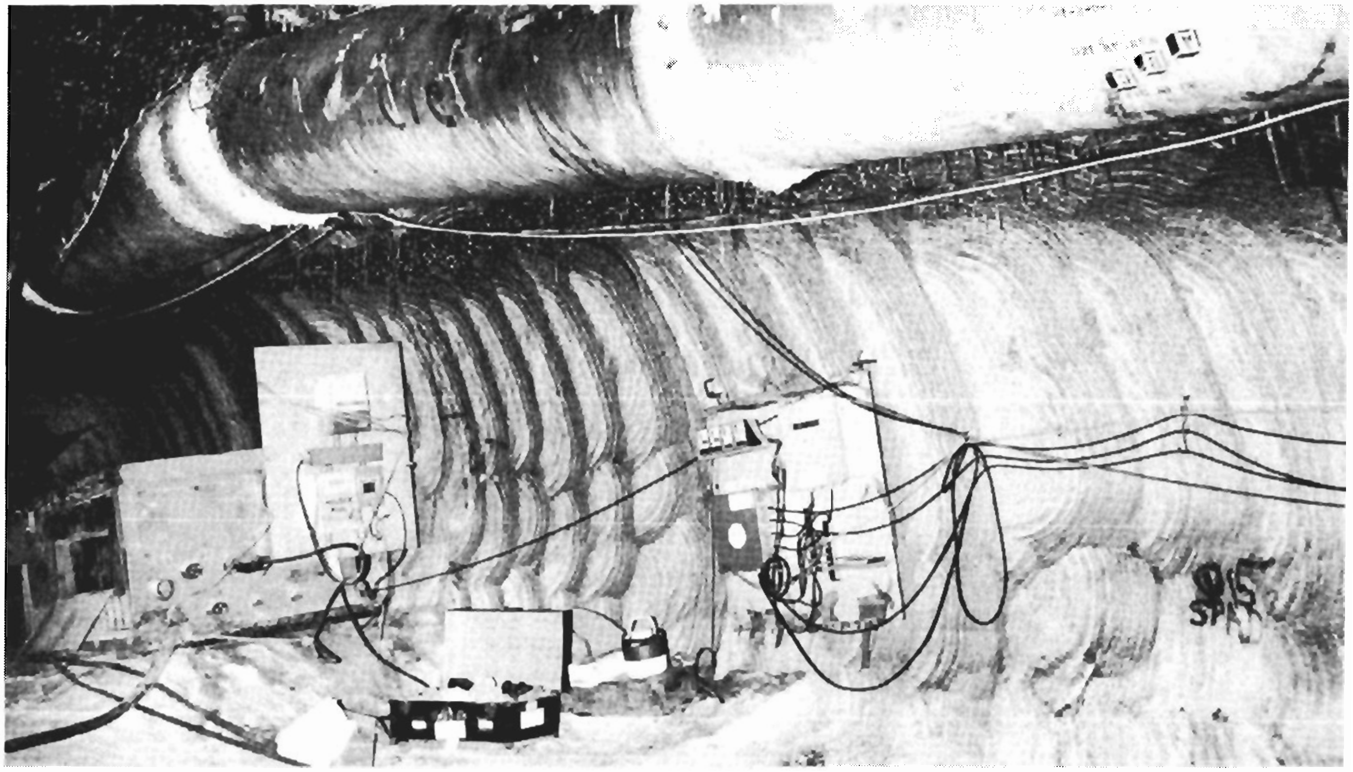

FIGURE 3. - Photograph showing the intake methane sensor, 30-in exhaust duct, transformer, and control system (power supply, amplifier, and strip-chart recorders).

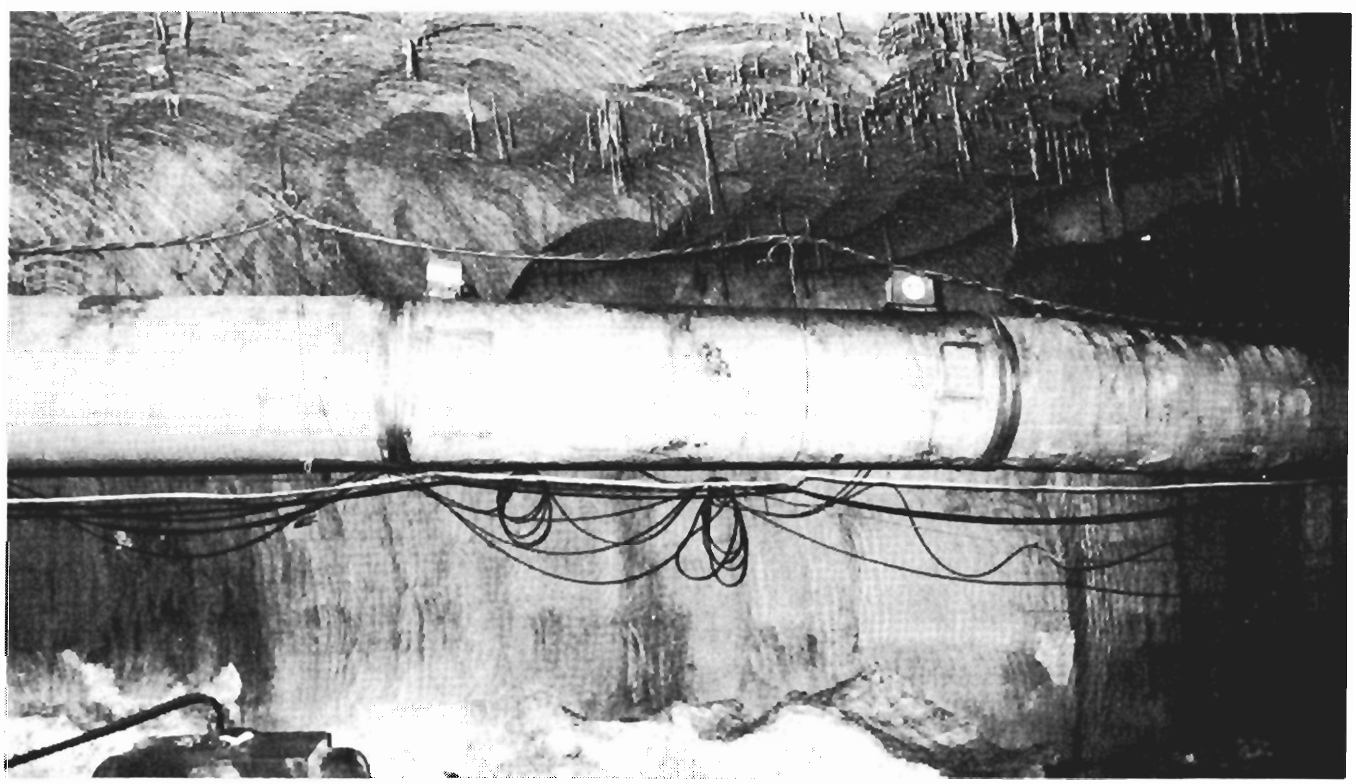

FIGURE 4. - Photograph showing the placement of the sonic anemometer and methane sensor in exhaust tubing.

anemometer, which employs the vortex shedding principle, measures velocities ranging from 1,500 to 10,000 ft/min (457 to 3,048 m/min) and is unaffected by air density changes. The sonic anemometer head and one of the methane sensor heads were placed directly into the exhaust tubing (fig. 4). Another methane sensor was placed directly into the intake air stream. A third methane sensor sampling air from the exhaust tubing did not operate during the preliminary investigation because of mechanical problems with the vacuum pump.

Geology of the Advancing Face

Three mappable geological units are represented in the study area (fig. 5). The upper or southern portion of the decline is predominantly a clean or normal production grade salt with occasional dark bands that are generally diffuse in density and light gray in color. The strike of these bands range from N 0° N to N 50° W in the upper or southern half of the decline. The second distinct mappable unit (fig. 5) has tightly folded darker bands that are

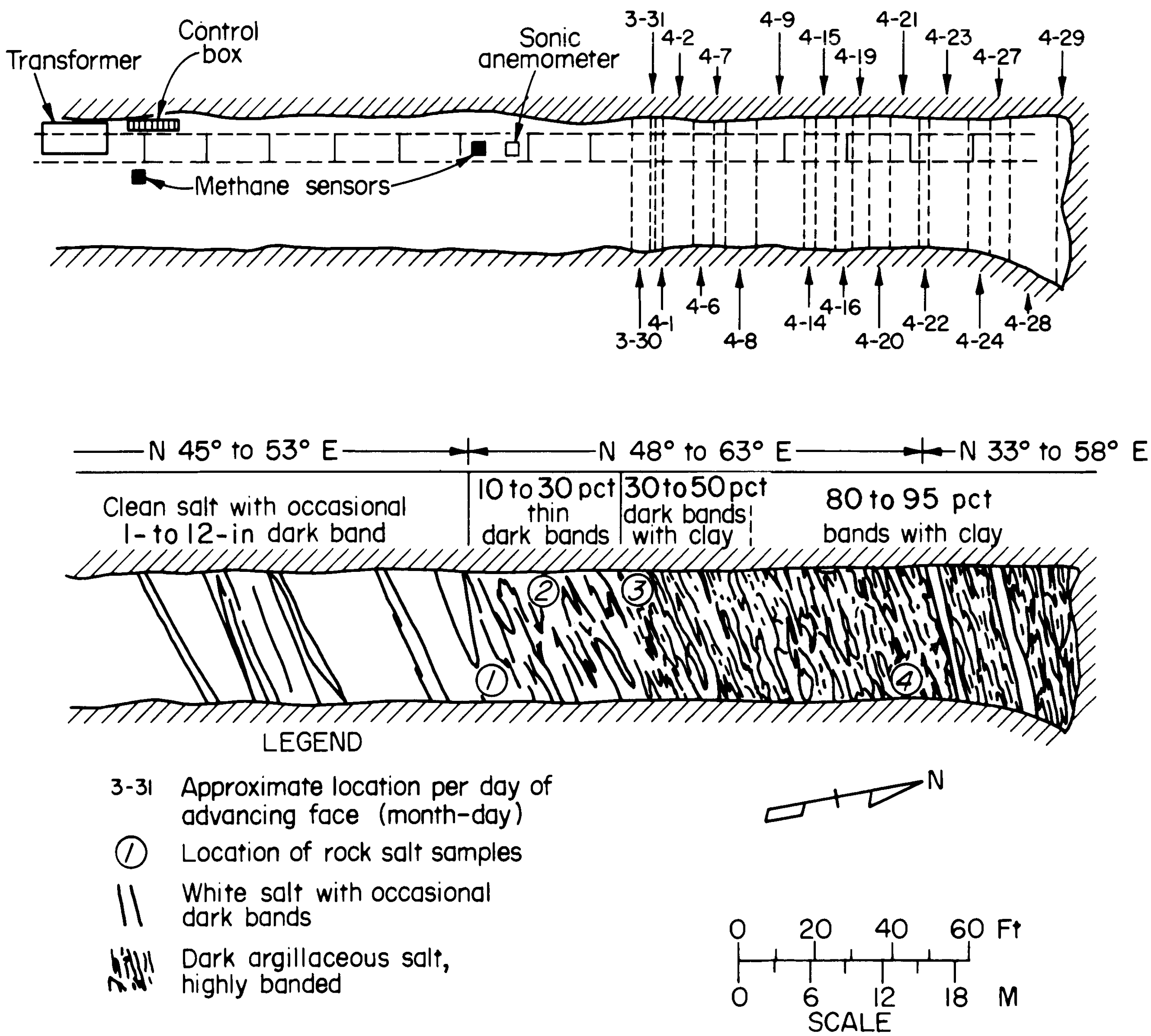

FIGURE 5. - A plan view of mappable geological units encountered within the lower portion of the decline and location of the advancing face during the 18 production days of this investigation.

relatively thin [1 to 3 in (2.5 to 7.5 cm)] and become thicker [2 to 12 in (5 to 30 cm)] towards the lower or northern end of the decline. Occasionally, dark clay balls are found in this salt.

The third mappable unit comprised the salt mined during the methane monitoring study (fig. 5). This salt unit, believed to be part of an anomalous zone described by Paine (5) and Kupfer (4), is shown in figure 6. The salt unit encountered in the study area is characterized by greater than 30 pct dark bands. Much of this unit has as much as 90-pct dark banding. These bands appear to be argillaceous and shaley.

The zone had several small brine seeps accompanied by the hissing and bubbling of gases. Dark clay balls, found throughout the unit, were up to approximately 6 in (15 cm) in diameter. Some of the balls were slightly elongated in the direction of banding. A sample of the dark, argillaceous salt (fig. 7), taken from the east rib about 40 ft from the face (sample 4, fig. 5), was analyzed for occluded gas content determination by the dissolution method (2). The sample contained approximately 2.2 cm^3 CH_4 per 100 g (0.7 ft^3/ton) of salt, 0.3 cm^3 CO per 100 g (0.1 ft^3/ton), and had a water-insoluble residue of approximately 9 wt-pct. Gas-enriched salt from the Five Islands salt domes have occluded methane contents ranging from about 0.2 to 10 cm^3 per 100 g of salt (2). The salt sampled from the study area popped and snapped when broken and/or dissolved similar to gas-enriched "popping" salt.

The salt encountered in the study area is essentially a dark, argillaceous salt

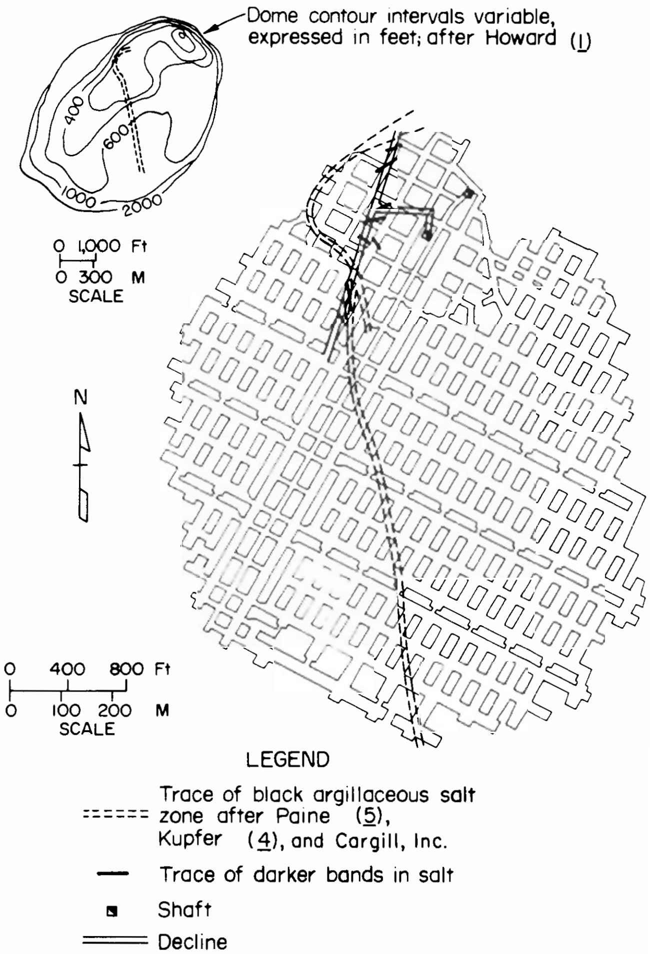

FIGURE 6. - Trace of dark, argillaceous salt zone (anomalous zone) within the Belle Isle salt dome.

associated with the trace of a large-scale, anomalous zone mapped elsewhere in the dome. It is a low-grade production quality salt. The occluded methane content of this anomalous salt is somewhat less than that of salt samples collected from areas where outbursts have occurred.

METHANE EMISSIONS FROM THE ADVANCING FACE

Methane was found to be emitted from a freshly mined underground salt face as well as from the broken salt being extracted from the face. Because the salt mined at this face emits a measurable amount of methane, comparisons are made based on the relative volumes of gas emitted per unit weight of mined salt.

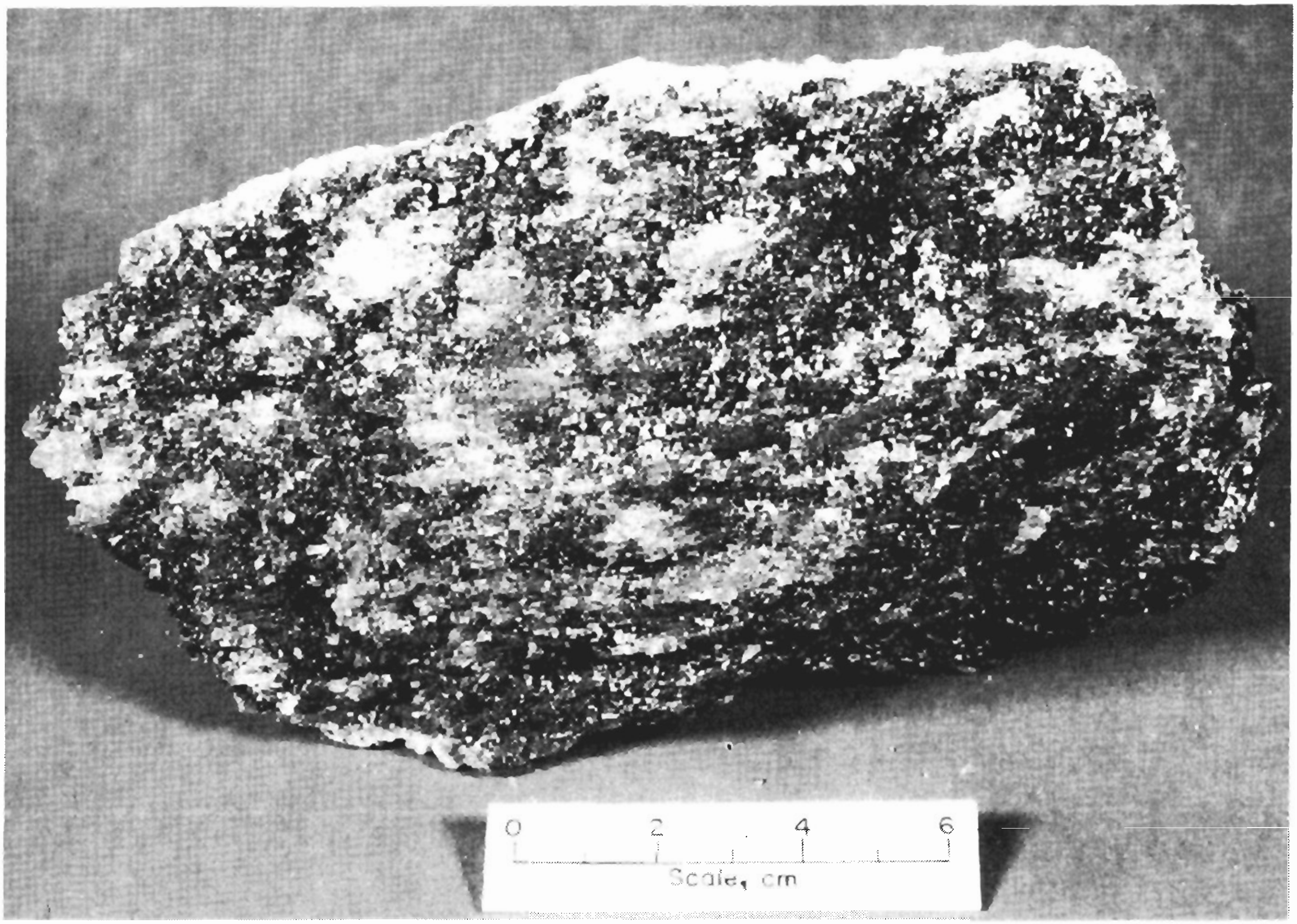

FIGURE 7. - Photograph of the dark, argillaceous salt occurring in the study area.

The methane emissions study covered in this study report spanned 18 production days and several days of exploratory drilling of the face from March 30 to May 15, 1981. The methane emitted per ton of salt mined ranged from approximately 15 to 56 ft^3/ton (0.5 to 1.8 m^3/t). Four interesting points have been noted during this study:

1. Methane emissions occur mainly during mining.

2. Methane concentrations are very low during nonmining periods.

3. Methane concentrations decline to very low rates in about 1 to 4 hr after salt production.

4. Some variation in methane emission rates occurs during mining.

Methane Concentrations

Methane emissions were measured by recording methane concentrations with the sensor units. Methane was found to range from 0 to 0.2 pct inside the exhaust duct (see appendix). No measurable amount of methane was detected from the methane sensor in the intake air.

Gas samples from the face area collected in evacuated 20-ml glass cylinders were analyze in the laboratory to confirm the accuracy of the methane sensors. Samples were collected, approximately 1 ft (0.3 m) from the advancing face on March 28, March 30, and May 15, 1981. Analysis from table 1 were taken on a weekend several days after the last production shift. Table 2 contains analysis of gas collected immediately after the continuous miner was shut down for lunch. Analysis of gas samples collected from the face 10 days after the drilling of several exploratory drill holes is shown in table 3.

Methane concentrations as shown in table 1 average 0.0025 pct. Because the methane sensors have a sensitivity of 0.01 pct, the average methane percentage found in table 1 would be recorded as zero from the methane sensor.

TABLE 1. - Gas analysis from face area collected several days after the last production shift, pct

[Saturday, March 28, 1981 (No salt production)]

Sample	$O_2 + N_2$	Ar	CO_2	CO	CH_4	CH[1]
1	99.03	0.93	0.0376	ND	0.0048	0.0001
2	99.03	.93	.0407	ND	.0018	ND
3	99.03	.93	.0447	0.0004	.0037	ND
4	99.02	.93	.0425	.0005	.0009	ND
5	99.02	.93	.0505	.0004	.0017	ND
6	99.03	.93	.0383	.0004	.0017	ND
7	99.03	.93	.0410	.0003	.0026	ND
8	99.01	.93	.0552	.0005	.0060	ND
9	99.02	.93	.0441	.0002	.0007	ND
10	99.03	.93	.0394	.0005	.0019	ND
11	99.03	.93	.0366	.0004	.0013	.0004

ND Not detected. [1]Other hydrocarbons.

TABLE 2. - Gas analysis from face area collected immediately after a production shift, pct

[Monday, March 30, 1981 (Salt production)]

Sample	$O_2 + N_2$	Ar	CO_2	CO	CH_4	CH[1]
1	99.0	0.93	0.0450	0.0006	0.0110	ND
2	98.97	.93	.0456	.0004	.0523	0.0006
3	99.02	.93	.0407	.0004	.0099	ND
4	99.0	.93	.0532	.0003	.0154	ND
5	99.0	.93	.0469	.0006	.0269	ND
6	99.01	.93	.0430	.0004	.0178	ND
7	98.99	.93	.0518	.0004	.0292	.0002
8	98.97	.93	.0590	.0001	.0453	.0002
9	98.92	.93	.0636	.0002	.0870	.0003
10[2]	96.05	.90	.1115	ND	2.9321	.0120
11[2]	95.69	.90	.1123	ND	3.2829	.0134

ND Not detected. [1]Other hydrocarbons.
[2]Samples were collected directly from a thin, 6-in stream of gas and brine hissing from the face.

TABLE 3. - Gas analysis from face area collected after the drilling of several exploratory drill holes, pct

[Friday, March 15, 1981 (Several days after drilling exploratory holes)]

Sample	$O_2 + N_2$	Ar	CO_2	CO	CH_4	CH[1]
1	99.01	0.93	0.05	<0.0002	0.0043	<0.0002
2	99.01	.93	.06	<.0002	.0040	.0004
3	99.02	.93	.05	ND	.0035	<.0002
4	99.01	.93	.05	<.0002	.0046	.0006
5	99.01	.93	.05	ND	.0046	<.0002
6	99.01	.93	.05	<.0002	.0054	<.0002
7	99.00	.93	.05	ND	.0083	<.0002
8	99.00	.93	.06	ND	.0140	.0006
9	99.01	.93	.05	.0002	.0080	<.0002
10	99.03	.93	.04	ND	.0028	.0004
11	99.01	.93	.05	ND	.0078	.0004
12[2]	98.96	.93	.06	ND	.0500	.0008
13[2]	98.96	.93	.06	ND	.0600	.0005
14[2]	98.97	.93	.05	ND	.0333	.0003

ND Not detected. [1]Other hydrocarbons.
[2]Collected near a 150-ft (45-m) exploratory hole drilled May 5, 1981.

Gas samples taken immediately after production ceased (table 2) have an average methane concentration of 0.0328 pct (samples 1-9). At the same time, the methane sensor (inside the exhaust tubing) was recording methane concentrations of 0.03 to 0.04 pct. Samples 10 and 11 were collected from a thin stream of gas and brine hissing 6 in (15 cm) out from the face. This stream contained approximately 3 pct methane, ethane, propane, and butane, and 0 pct CO.

The third set of gas samples (table 3) contains an average methane concentration of 0.0151 pct. Samples 1 to 11 were collected several days after drilling the exploratory holes at the face. Samples 12, 13, and 14 were collected near the 150-ft (45-m) exploratory hole. (See section on Exploratory Drilling at Face.)

These analyses show the reliability of the data generated by the electronic methane sensing system. Baseline methane sensor readings of zero probably contain some trace amounts of methane. If an average baseline methane concentration of 0.0025 pct is assumed (table 1), approximately 0.3 ft^3/min (0.0085 m^3/min) of methane will be emitted from the freshly cut face. Because emissions of 0.3 ft^3/min (0.0085 m^3/min) are insignificant, this report will avoid further consideration of baseline methane emissions.

Velocity Determination

Velocity inside the 30-in rigid exhaust duct with two fans operating ranged from 2,900 to 3,300 ft/min (15 to 17 m/sec). Air density determinations and velocity pressure measurements from pitot tube surveys were used to determine velocity. The sonic anemometer was not used to determine the velocity of the air in the exhaust duct because of a nonlinear increase in voltage output with increasing velocity; it did provide a basis for establishing times of production and no production.

Pitot tube surveys were conducted by inserting the tube through a small hole in the exhaust duct, permitting velocity pressure to be measured with a manometer gage. Six 10-point transverses along a horizontal and vertical axis were conducted for each survey. Velocity pressure in inches of water is changed into velocity (feet per minute) by multiplying the square root of each velocity pressure by 4,000 (3). Average velocities from six pitot tube surveys were used to calculate an average velocity of 3,100 ± 100 ft/min (16 ± 1 m/sec).

Air density was considered in calculating true velocity. Temperature, barometric pressure, and relative humidity are variables that should be measured to determine density. Temperature and barometric pressure were measured on a daily basis at variable times and are shown in figure 8. Relative humidity was measured, but the reliability of these data are questionable, so this information was not included. Air density ranged from 0.071 to 0.078 lb/ft^3. True average velocity was calculated by multiplying the average velocity of 3,100 ± 100 ft/min (16 ± 1 m/sec) by the square root of the standard air density (0.075 lb/ft^3) divided by the measured air density (table 4). Air density measurements and true average velocity calculations for each of the 18 production days are given in figures A-1 to A-18.

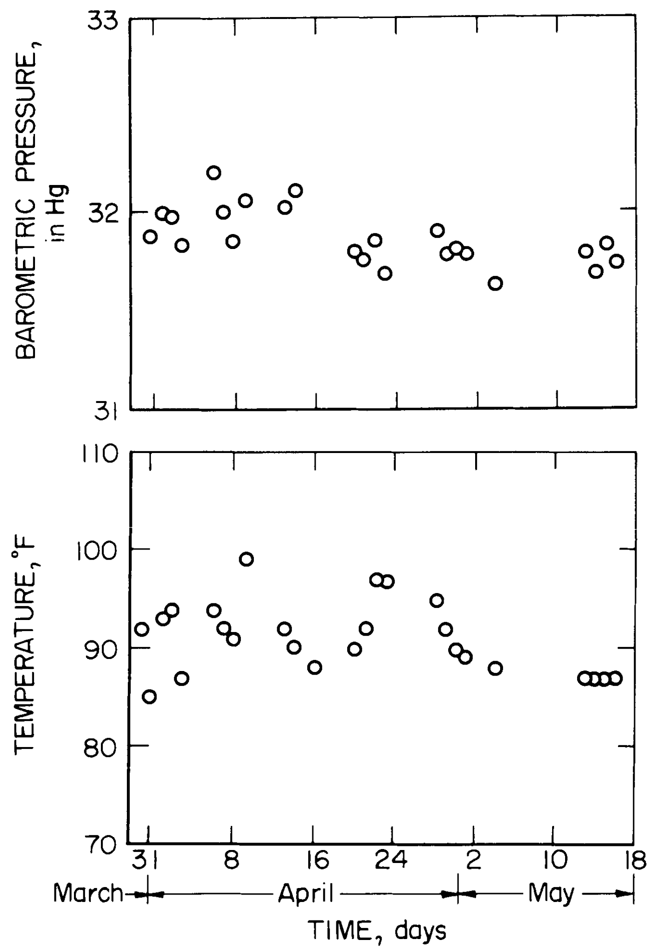

FIGURE 8. - Temperature and barometric pressure measurements recorded in the decline during the investigation.

TABLE 4. - Air velocity and quantity ranges within exhaust tubing for varying air densities

Air density, lb/ft^3	True velocity		Air quantity	
	Minimum, ft/min (m/sec)	Maxiumum, ft/min (m/sec)	Minimum, ft^3/min (m^3/sec)	Maximum, ft^3/min (m^3/sec)
0.071	3,100 (16)	3,300 (17)	15,200 (7)	16,200 (8)
.076	3,000 (15)	3,200 (16)	14,700 (7)	15,700 (7)
.077	3,000 (15)	3,200 (16)	14,700 (7)	15,700 (7)
.078	2,900 (15)	3,100 (16)	14,200 (7)	15,200 (7)

The sonic anemometer continuously recorded approximate centerline velocity within the exhaust duct. The sonic anemometer was not used to determine velocity because of nonlinear changes in output signal with changing velocity. Other possible factors impairing accurate velocity measurements were production of salt dust at the face, voltage surges from the operation of other electrical face equipment, and short calibration life. However, the sonic anemometer was useful in approximating the duration of salt production. Abnormal responses from the instrument are associated with salt production (figs. A-1 to A-18). Minutes of salt production time per day are approximated by adding intervals of abnormal responses from the sonic anemometer.

Methane Emission Rates

Methane was emitted from the advancing face at a rate ranging from 15 to 56 ft^3/ton of salt mined per day (0.5 to 1.8 m^3/t). Methane emission rates were determined by measuring the total quantity of methane emitted per day, determining a production rate from tonnage and production time data, and calculating a daily emissions rate per ton of salt mined per day. Each range of daily emission rates was then added and divided by the total number of production days to determine the average emissions rate for this preliminary study.

Daily methane emissions, which ranged from approximately 1,000 to 8,000 ft^3/day [28.3 to 226.6 m^3/day (fig. 9)], were

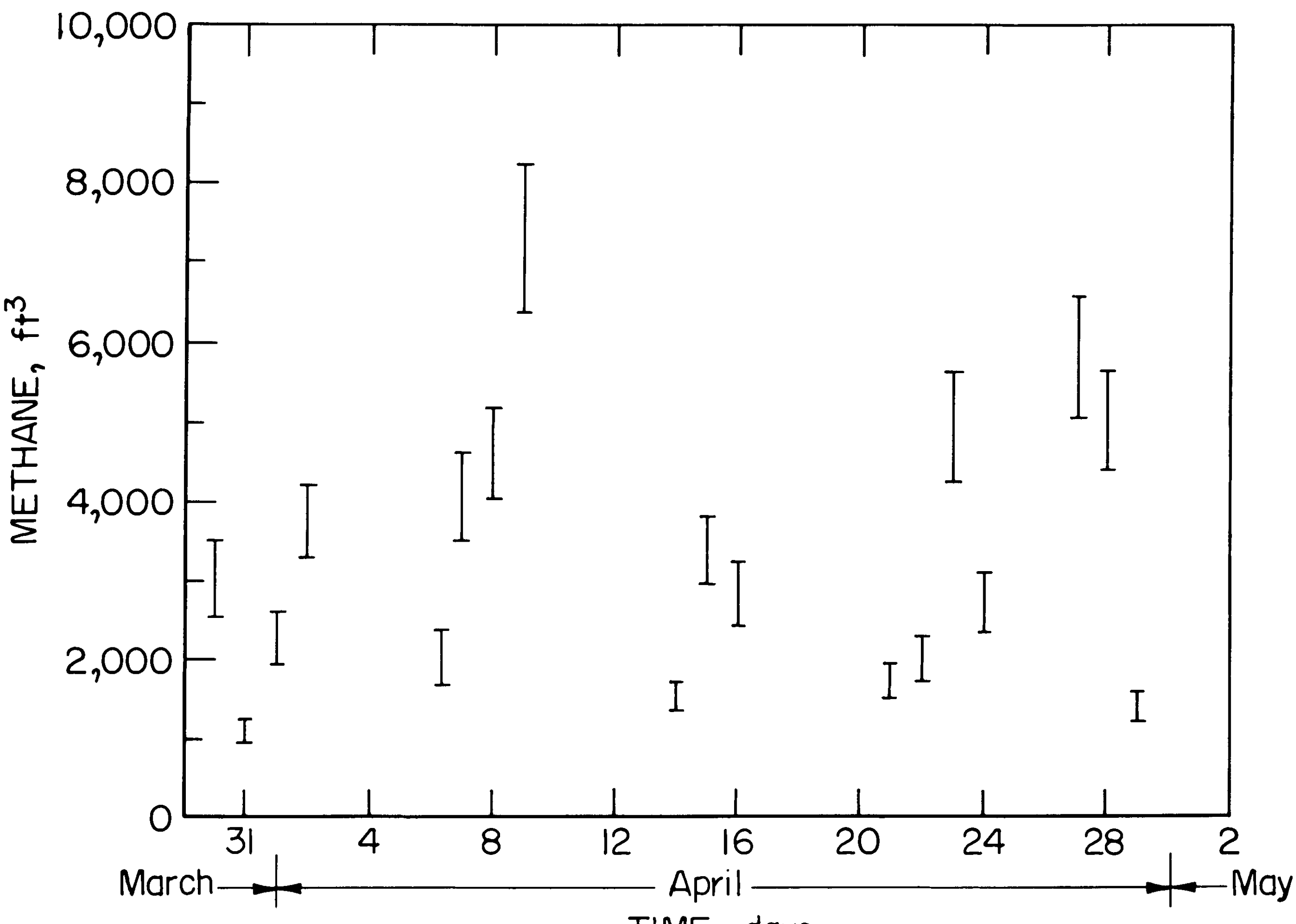

FIGURE 9. - Daily range of methane emissions from the advancing decline.

calculated as follows. The percentage of methane in the exhaust duct was measured every 15 min during a production shift with the sensor inside the tubing. The air velocity in the duct was considered constant for each production day (table 4), but methane concentration changed continuously (figs. A-1 to A-18). Instead of assuming a constant methane concentration between measurements, a numerical integration technique known as Simpson's rule was used (6). Simpson's rule interpolates a quadratic polynomial between each 15-min measurement of the methane concentration. Each of these curves were then integrated and their resulting areas summed to estimate the total amount of methane exhausted through the 30-in tubing during salt production.

Methane emission rates are compared with salt production rates. Two independent measurements of production rate were used. One measured the total minutes of salt production time (fig. 10), and the other the total tons of salt hauled by the load-haul-dump (LHD) machines (fig. 11). Both sets of data have error involved in estimating the tons of salt mined at the face. Measuring the minutes of production time does not differentiate continuous miner down-time while LHD's are operating. The tonnage data supplied by the operator was based on salt hauled by the LHD's, not by the actual tons mined by the continuous miner.

A more accurate estimation of the mining rate was obtained by comparing daily tonnage data with daily production time as determined from sensor system (figs. A-1 to A-18). Figure 12 is a comparison of the total tons of salt hauled per day by LHD's with the total minutes of salt production per day (estimated from sensor charts, figs. A-1 to A-18). These data provide a more realistic approximation of the mining rate of the decline advancing face. These charts A-1 to A-18 (see appendix) showed discrepancies between haulage data and production time

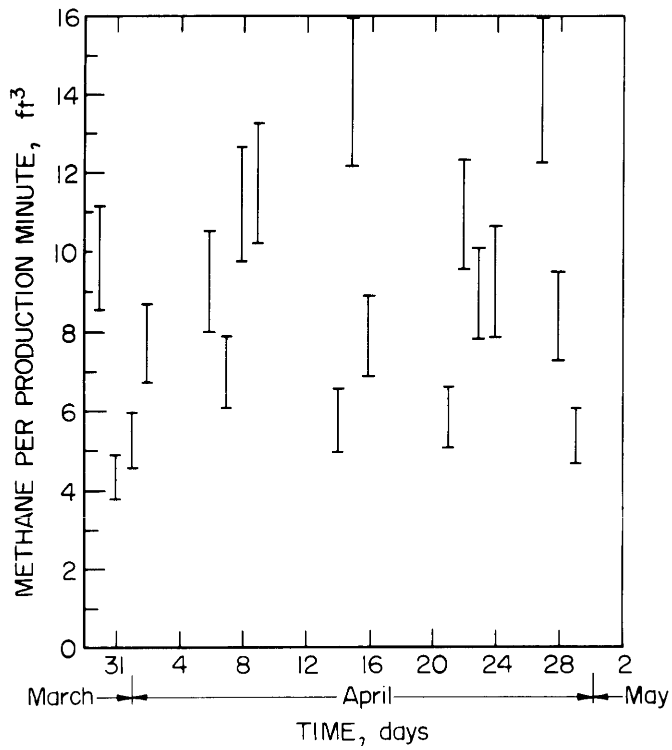

FIGURE 10. - Methane emission rates from advancing decline using production time for rate estimates. Minutes of production per day were measured from charts in the appendix (figs. A-1 to A-18).

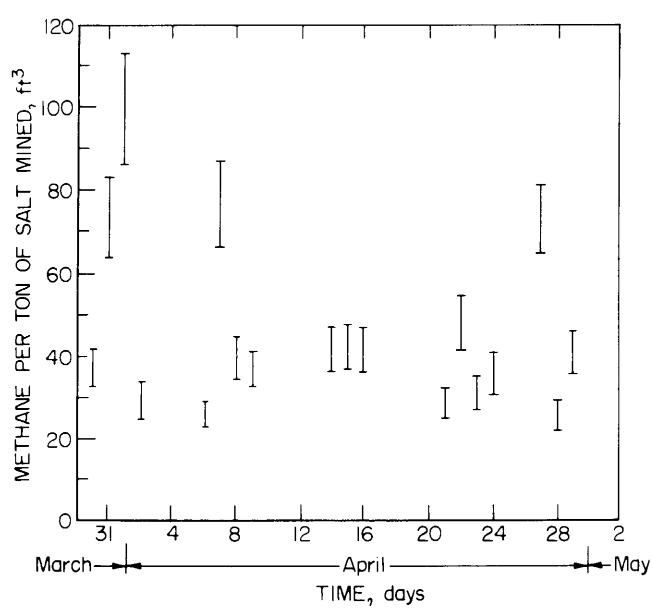

FIGURE 11. - Methane emission rates from advancing decline using tons of salt hauled for rate estimates. Tonnage data was supplied by the operator.

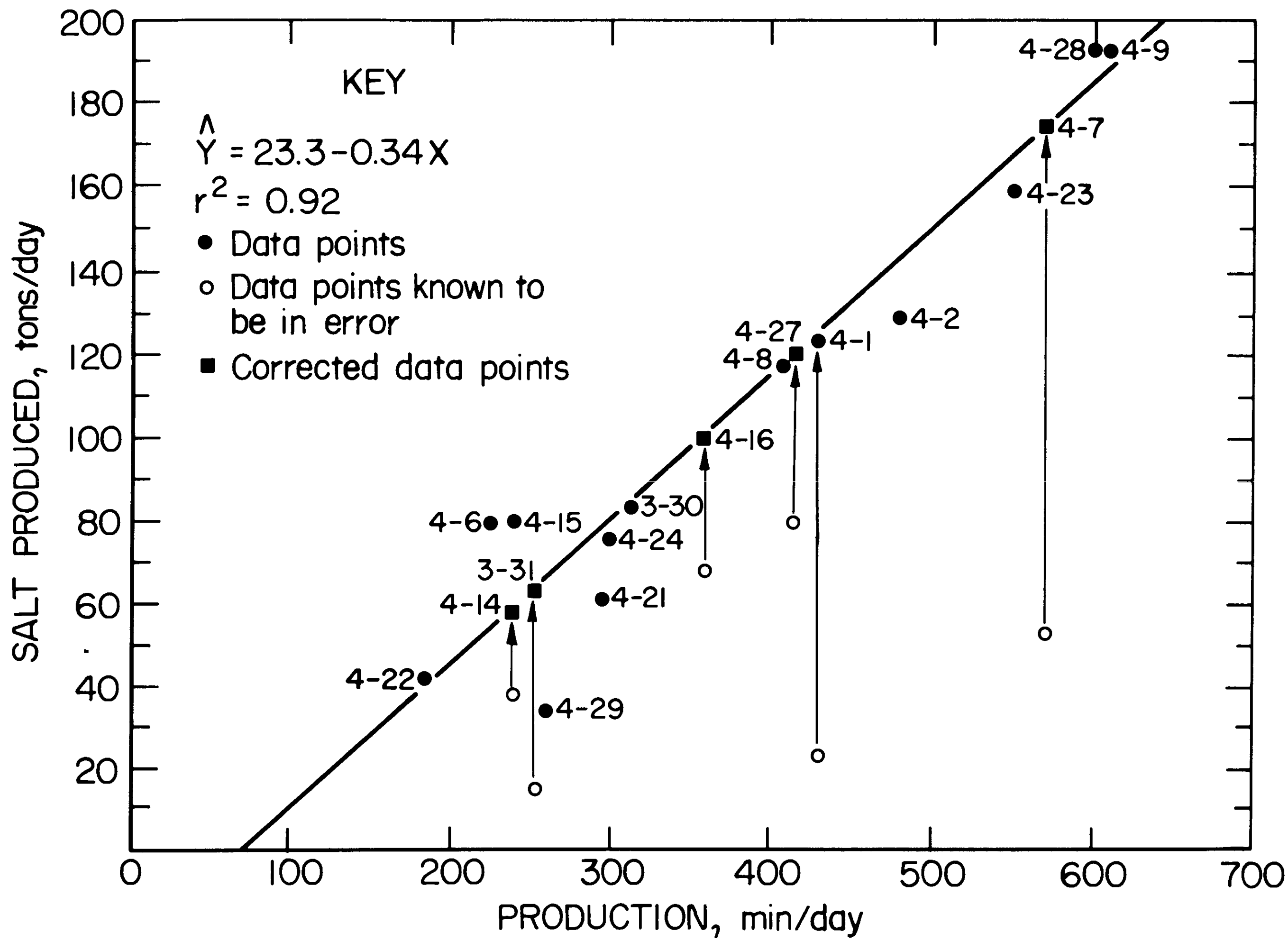

FIGURE 12. - A comparison of tonnage (salt hauled) with production time (measured from charts) enables calculation of decline production rate.

measurements. These discrepancies are shown as open circles in figure 12. Each of these data points represents inaccurate tonnage data, because salt was evidently mined but not hauled during one of the two production shifts. If these six misrepresented data points are ignored and linear regression is performed on the remainder, the equation for the line that best fits the data can be determined. Calculation of corrected tonnage data is done by substituting the minutes of production for each of the six misrepresented data points into the equation for the line representing production rate in the decline (fig. 12).

An approximate methane emissions rate, based on the cubic feet of methane emitted per ton of salt, was then calculated by dividing the total methane by the tons of salt mined at the face for each day. These data are shown in figure 13. Dashed bars in figure 13 represent inaccurate tonnage data determined from comparison of daily tonnage data with daily production time (fig. 12). The daily range of methane

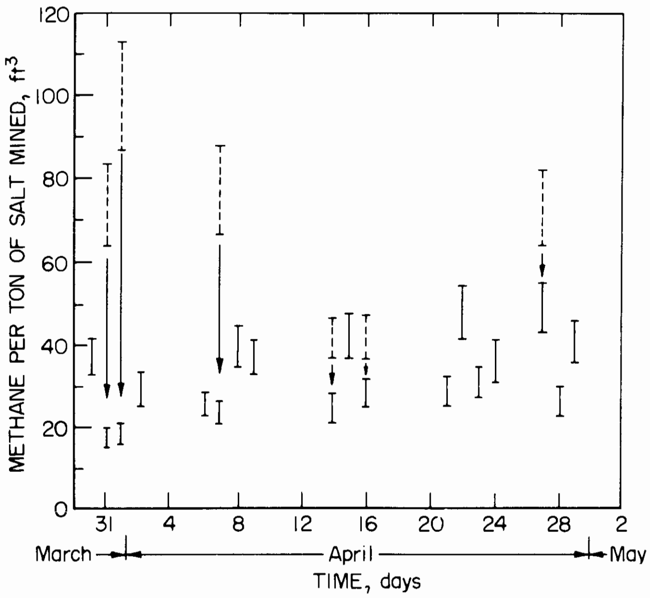

FIGURE 13. - Corrected methane emission rates for each of the 18 production days.

emissions rates for this preliminary investigation were 15 to 56 ft^3/ton (0.5 to 1.8 m^3/t).

Exploratory Drilling of Advancing Face

Several exploratory drill holes were drilled at various angles and lengths into the advancing face of the decline from May 2 to May 15, 1981. One hole emitted a total of between 39,000 and 49,000 ft^3 (1,104 to 1,388 m^3) of methane over a 3-day period. Initial methane flows were approximately 90 to 100 ft^3/min [0.04 to 0.05 m^3/sec (fig. 14)], but damped out to minimal amounts after 3 days. Methane emission measurements indicated the rest of the exploratory drill holes emitted no significant amounts of methane. Table 5 lists some analyses of gas samples taken from 1-ft (0.3 m) inside this 150-ft (45-m) exploratory drill hole.

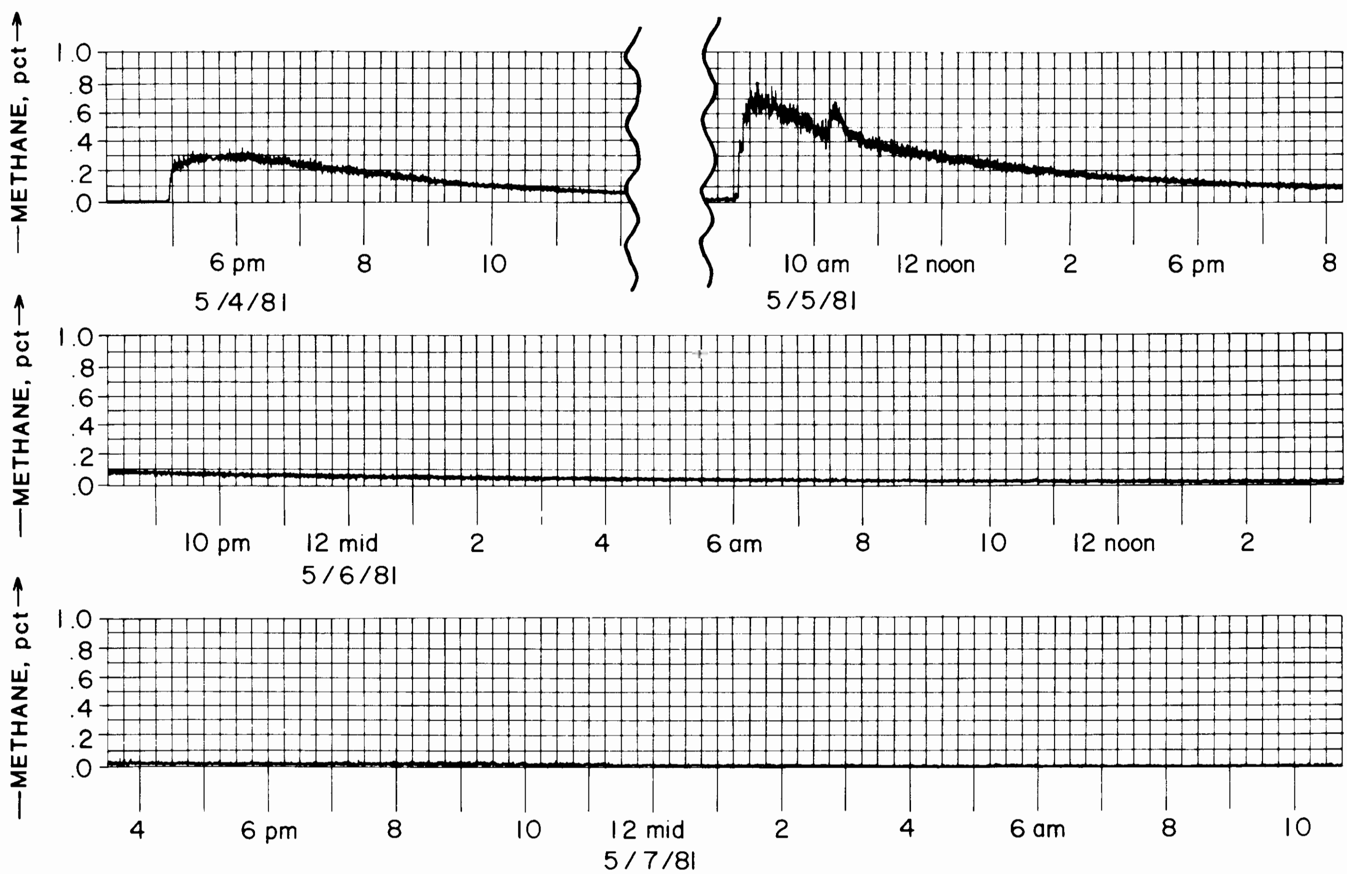

FIGURE 14. - Strip-chart recording of methane emissions during drilling of an exploratory drill hole.

TABLE 5. - Gas analysis taken approximately 1-ft (0.3 m) inside the collar of a 300-ft (91-m) exploratory drill hole, pct

(Friday, May 15, 1981)

Sample	$O_2 + N_2$	Ar	CO_2	CO	CH_4	CH[1]	SO_2[2]	CH_3SH[2]
1........	35.18	0.33	2.12	ND	61.52	0.83	0.0058	0.0017
2........	34.41	.32	2.10	ND	62.30	.85	.0071	.0025
3........	40.45	.38	1.90	ND	56.45	.82	.0058	.0018
4........	76.19	.72	1.78	ND	21.10	.21	.0026	.0011

ND Not detected. [1]Other hydrocarbons.
[2]Concentrations represent minimum values.

SUMMARY AND CONCLUSIONS

In driving a decline, the advancing face emits methane at a rate ranging from 15 to 56 ft^3/ton (0.5 to 1.8 m^3/t). Daily methane emissions from the decline were approximately 1,000 to 8,000 ft^3/day (28.3 to 226.6 m^3/day). The average production time was approximately 6.3 hr/day, while the average tonnage was 105 tons/day.

The investigation showed that:

1. Measurable methane emissions do occur within the low-grade salt during production.

2. Methane emissions decrease with time after a production shift.

3. Methane concentrations in the return air were less than 0.01 pct within several hours after production.

4. Variations in methane emission rates occur during face advancement.

This study found that geologic and geochemical characteristics of domal salt influence methane emission rates during production from advancing faces.

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APPENDIX.--STRIP-CHART DATA OF METHANE SENSOR AND SONIC ANEMOMETER INSIDE EXHAUST DUCT DURING THE 18 PRODUCTION DAYS USED TO CALCULATE METHANE CONCENTRATIONS, PRODUCTION TIMES, AND EMISSION RATES

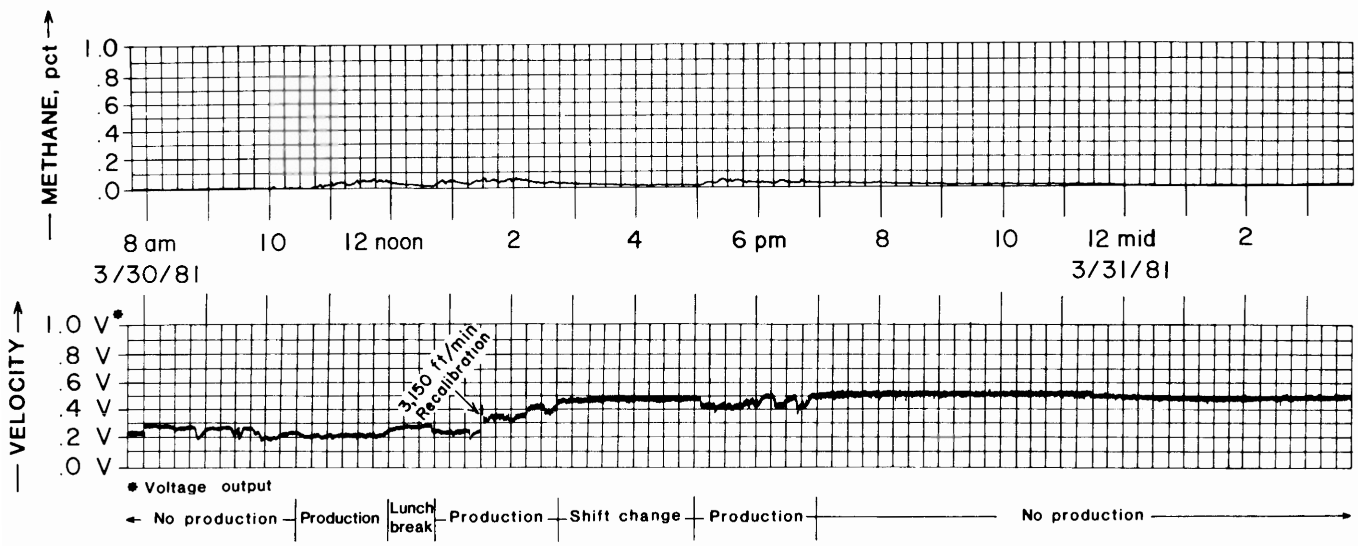

FIGURE A-1. - Day 1: Air density = 0.077 pcf and average air velocity = 3,100 ± 100 ft/min.

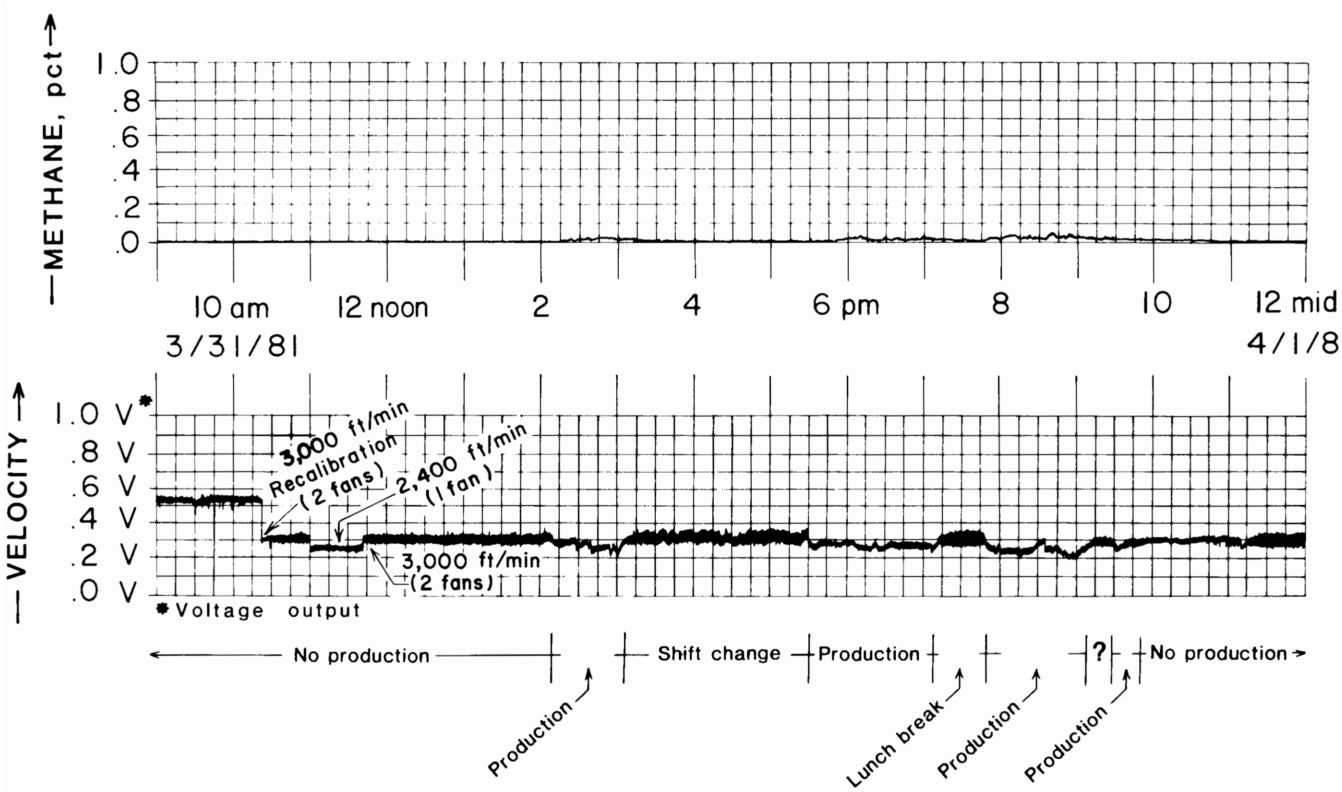

FIGURE A-2. - Day 2: Air density = 0.077 pcf and average air velocity = 3,100 ± 100 ft/min.

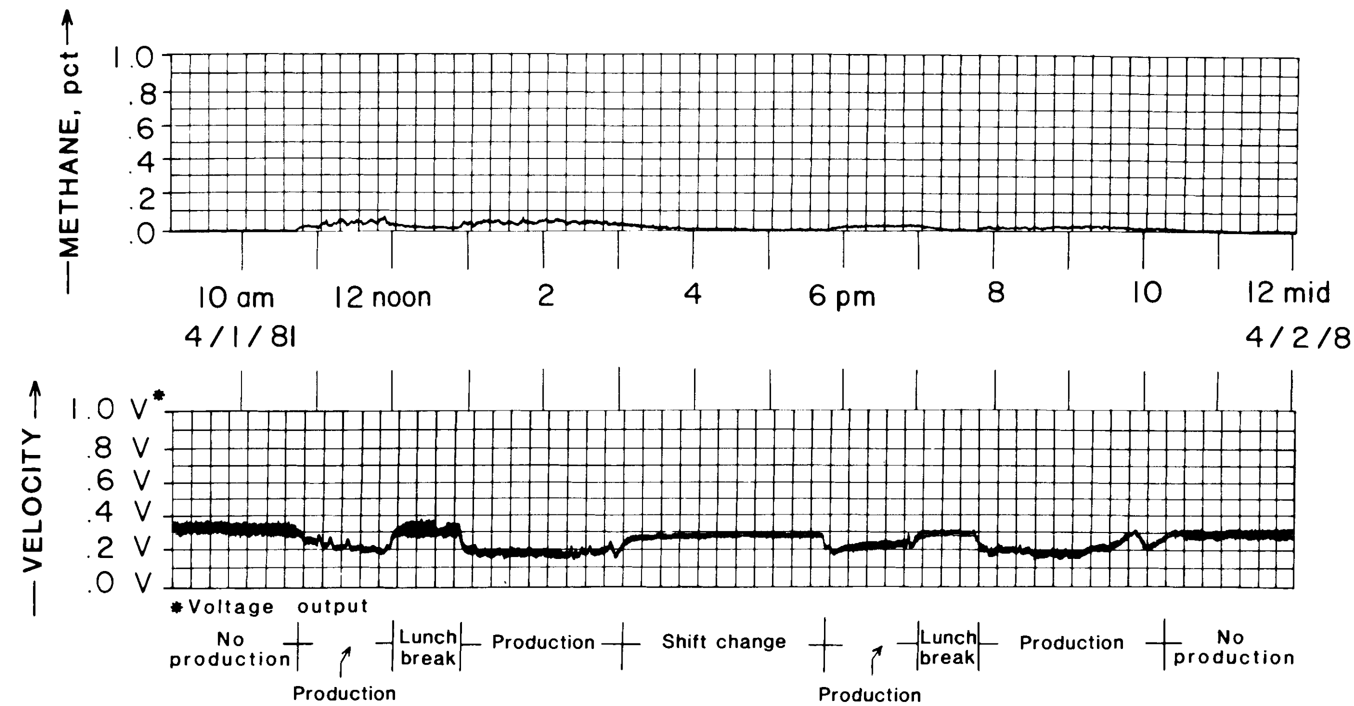

FIGURE A-3. - Day 3: Air density = 0.078 pcf and average air velocity = 3,000 ± 100 ft/min.

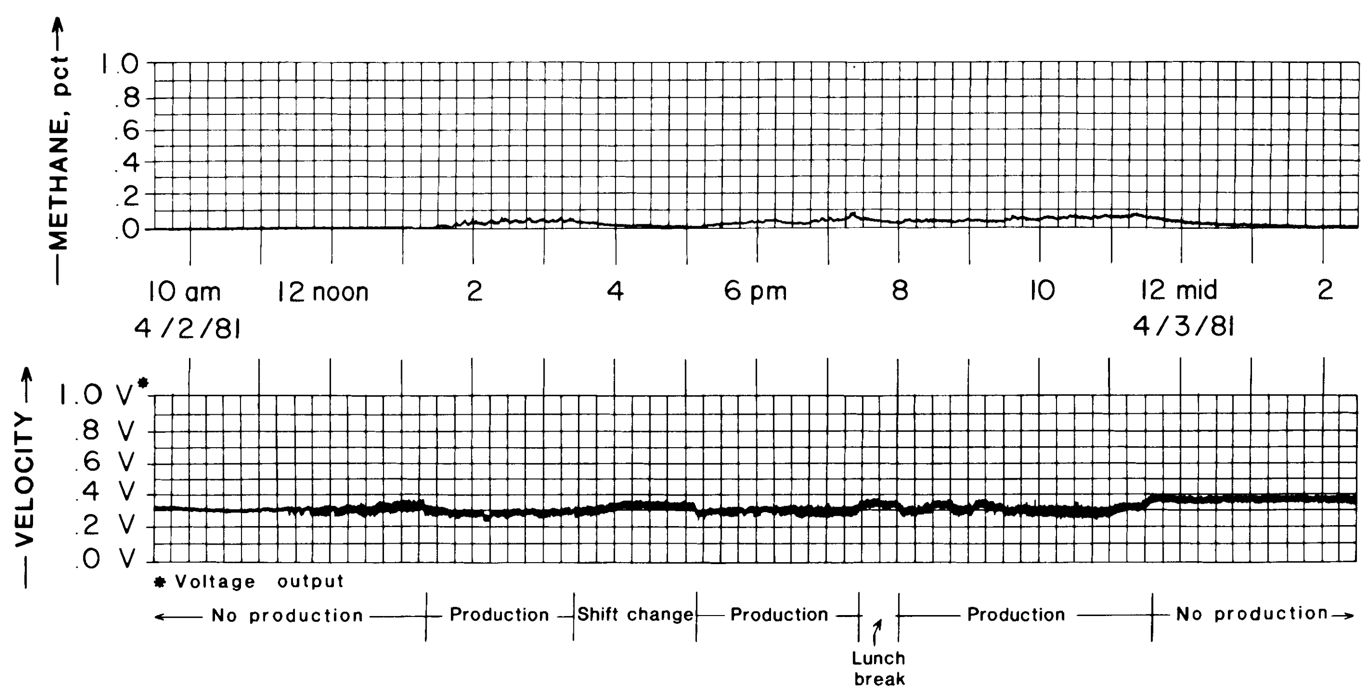

FIGURE A-4. - Day 4: Air density = 0.077 pcf and average air velocity = 3,100 ± 100 ft/min.

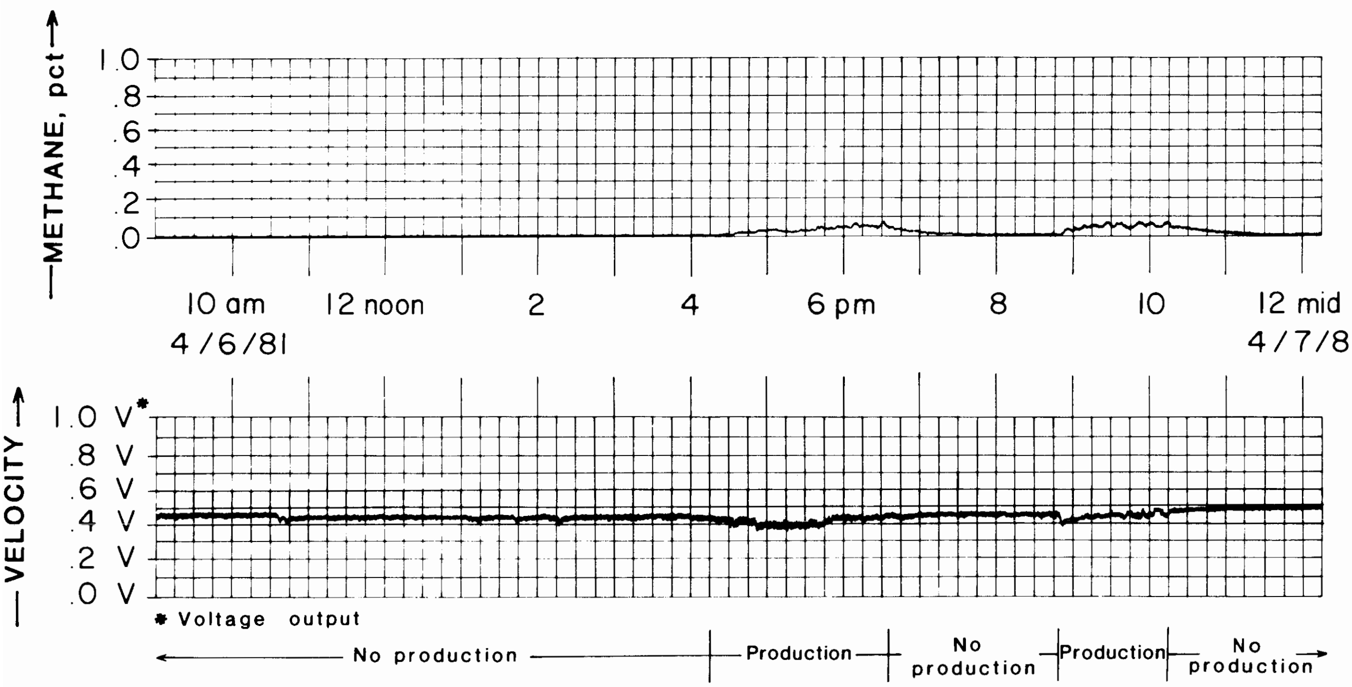

FIGURE A-5. - Day 5: Air density = 0.077 pcf and average air velocity = 3,100 ± 100 ft/min.

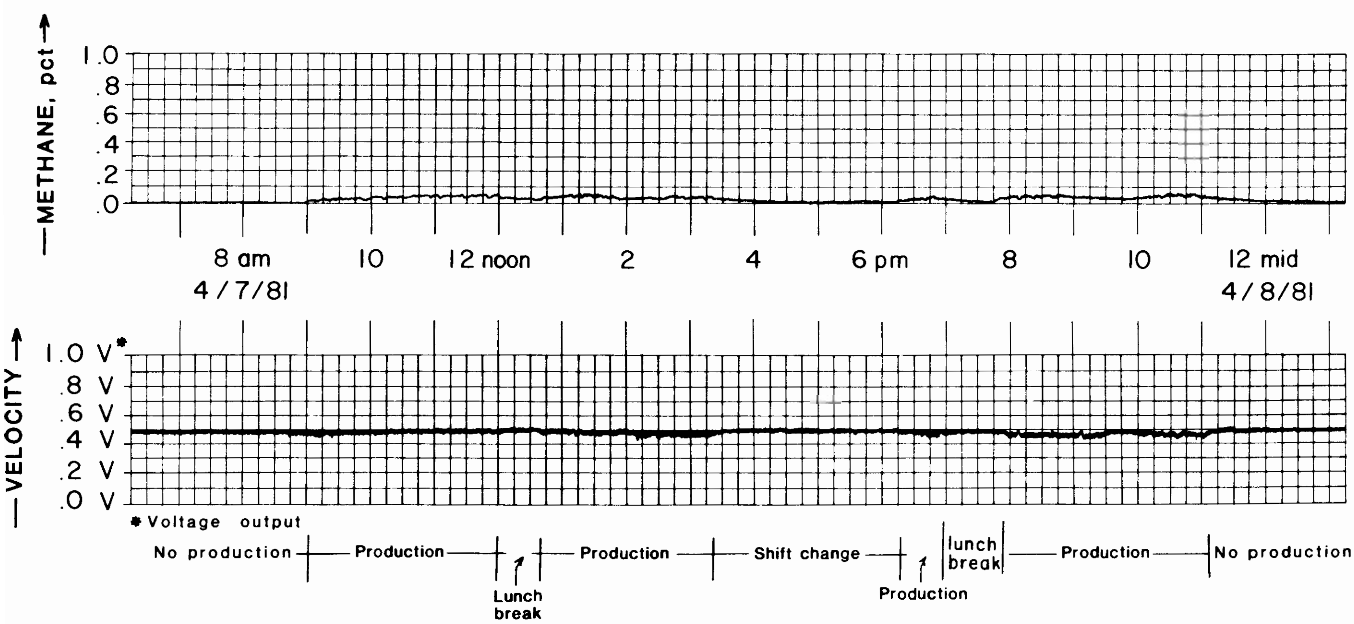

FIGURE A-6. - Day 6: Air density = 0.077 pcf and average air velocity = 3,100 ± 100 ft/min.

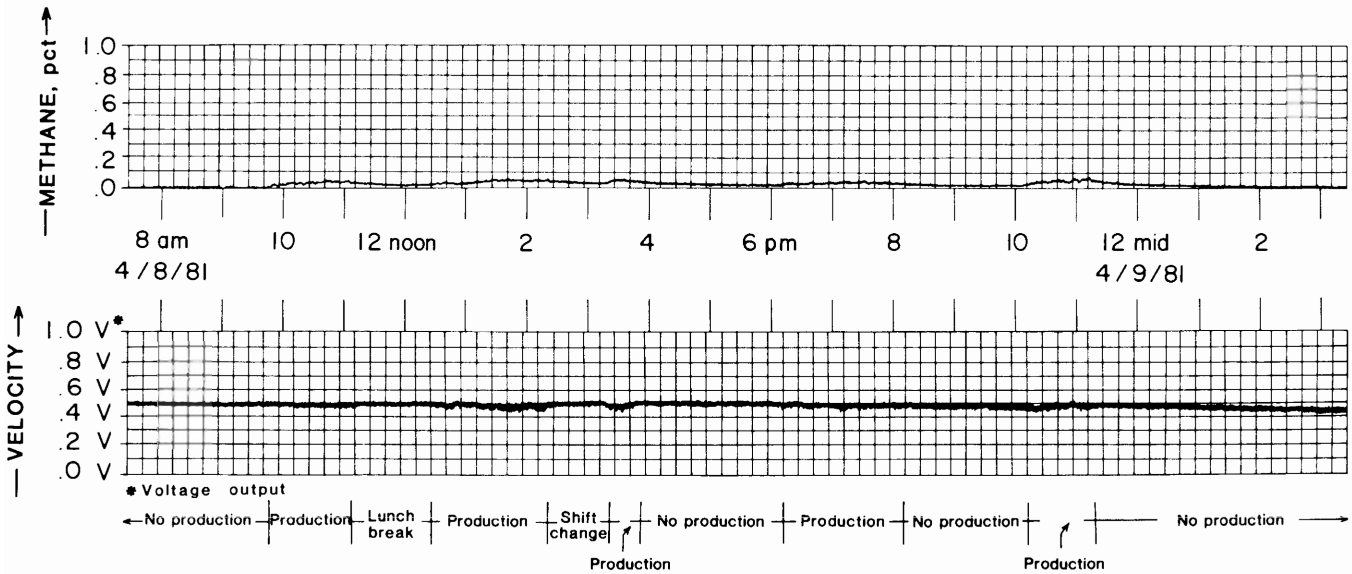

FIGURE A-7. - Day 7: Air density = 0.077 pcf and average air velocity = 3,100 ± 100 ft/min.

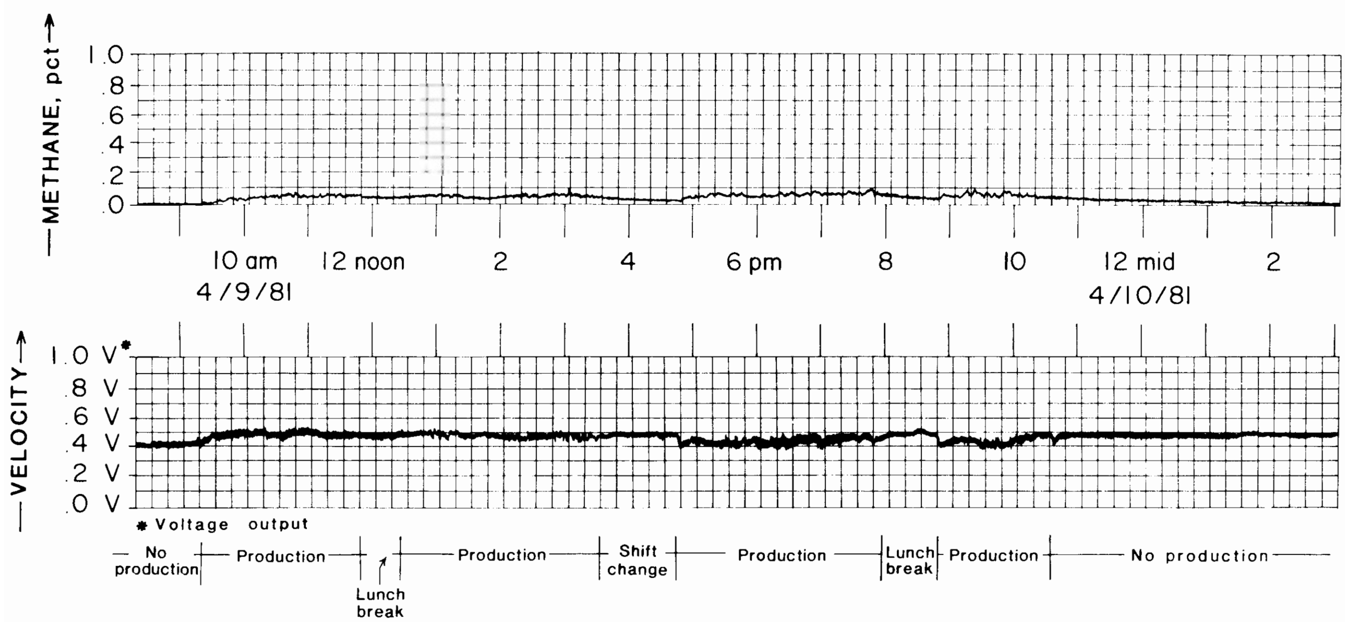

FIGURE A-8. - Day 8: Air density = 0.076 pcf and average air velocity = 3,100 ± 100 ft/min.

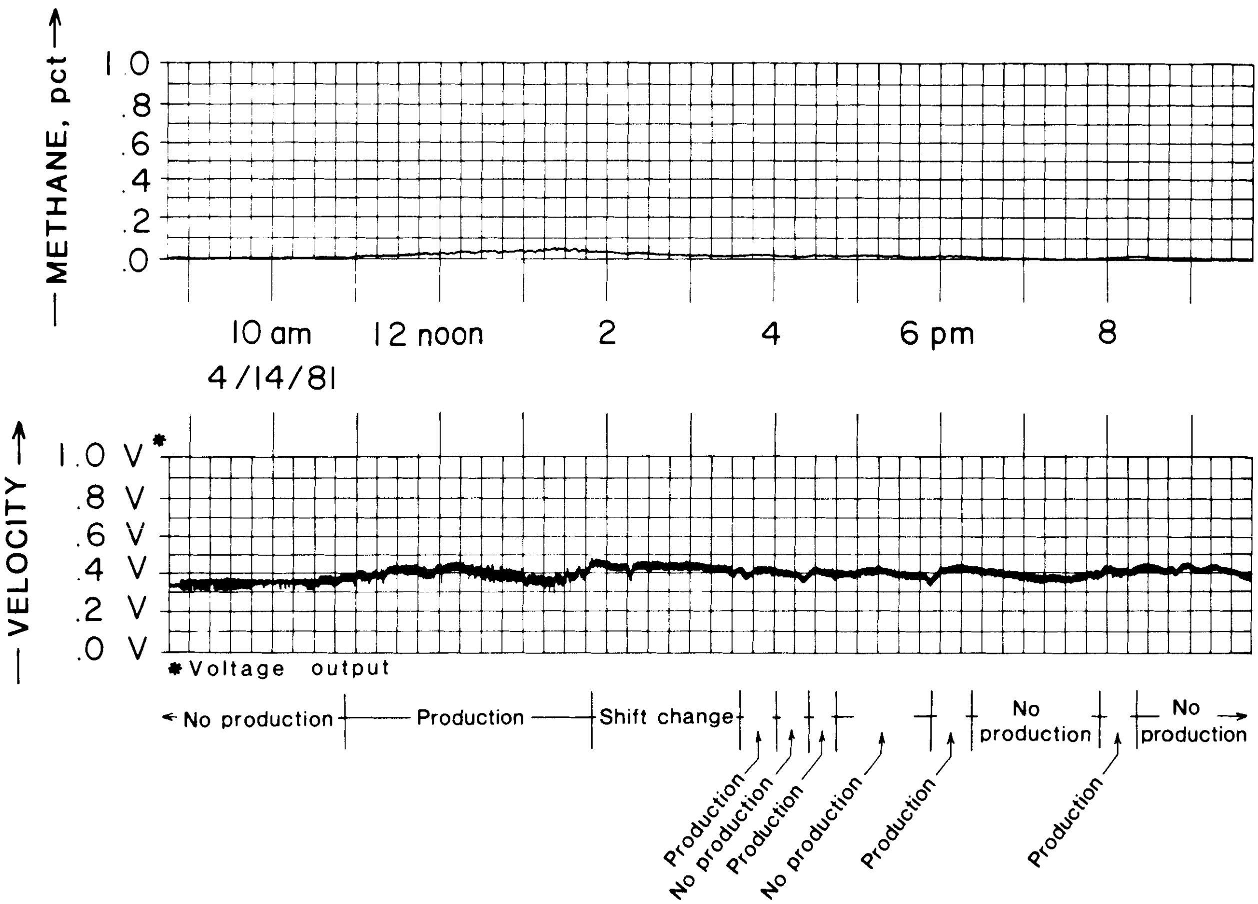

FIGURE A-9. - Day 9: Air density = 0.077 pcf and average air velocity = 3,100 ± 100 ft/min.

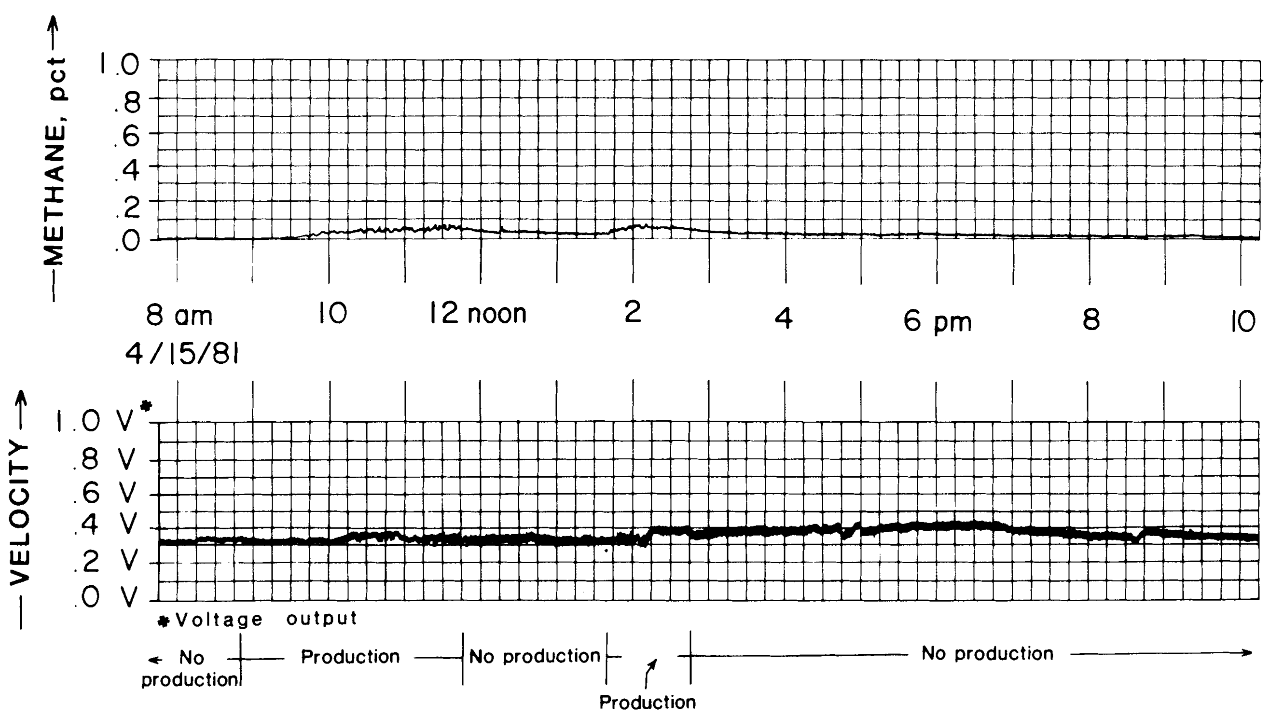

FIGURE A-10. - Day 10: Air density not available, average air velocity = 3,100 ± 100 ft/min.

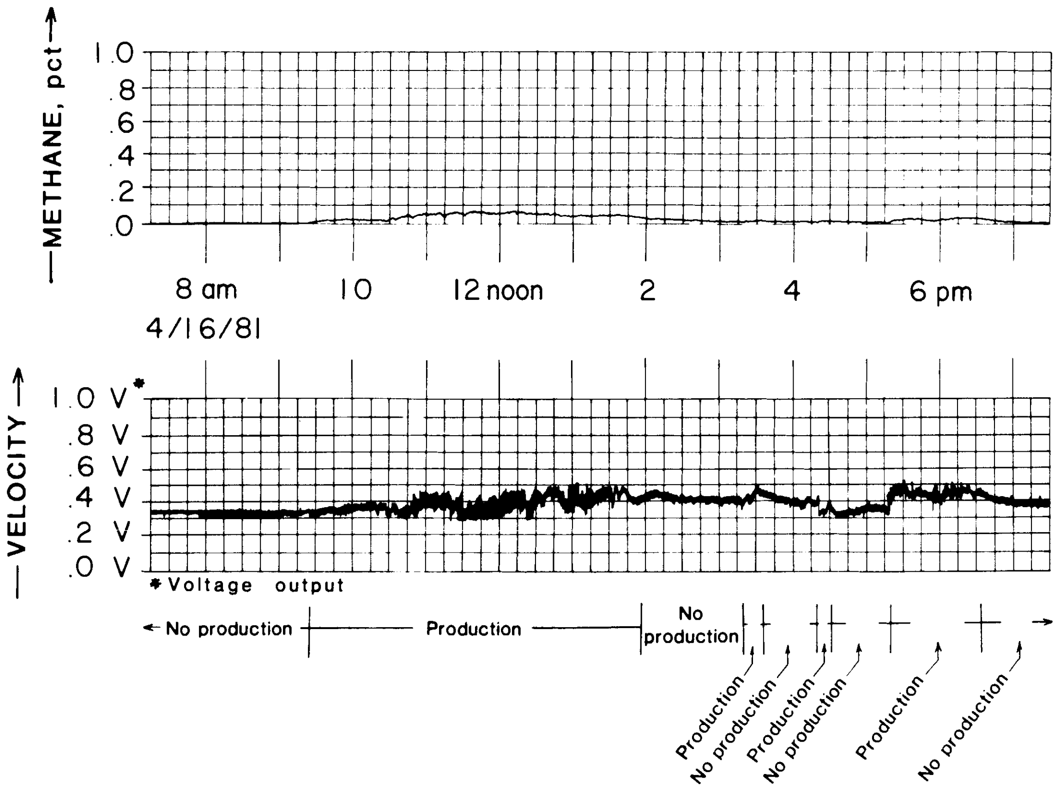

FIGURE A-11. - Day 11: Air density = 0.071 pcf and average air velocity = 3,200 ± 100 ft/min.

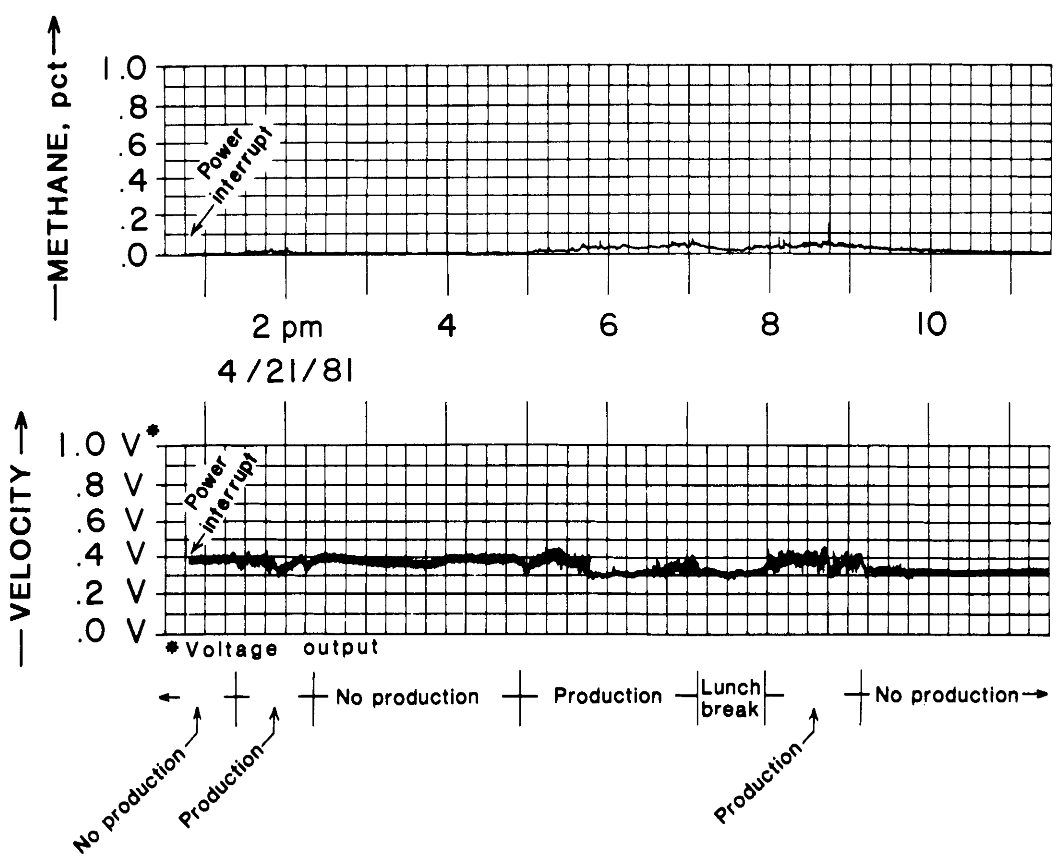

FIGURE A-12. - Day 12: Air density = 0.076 pcf and average air velocity = 3,100 ± 100 ft/min.

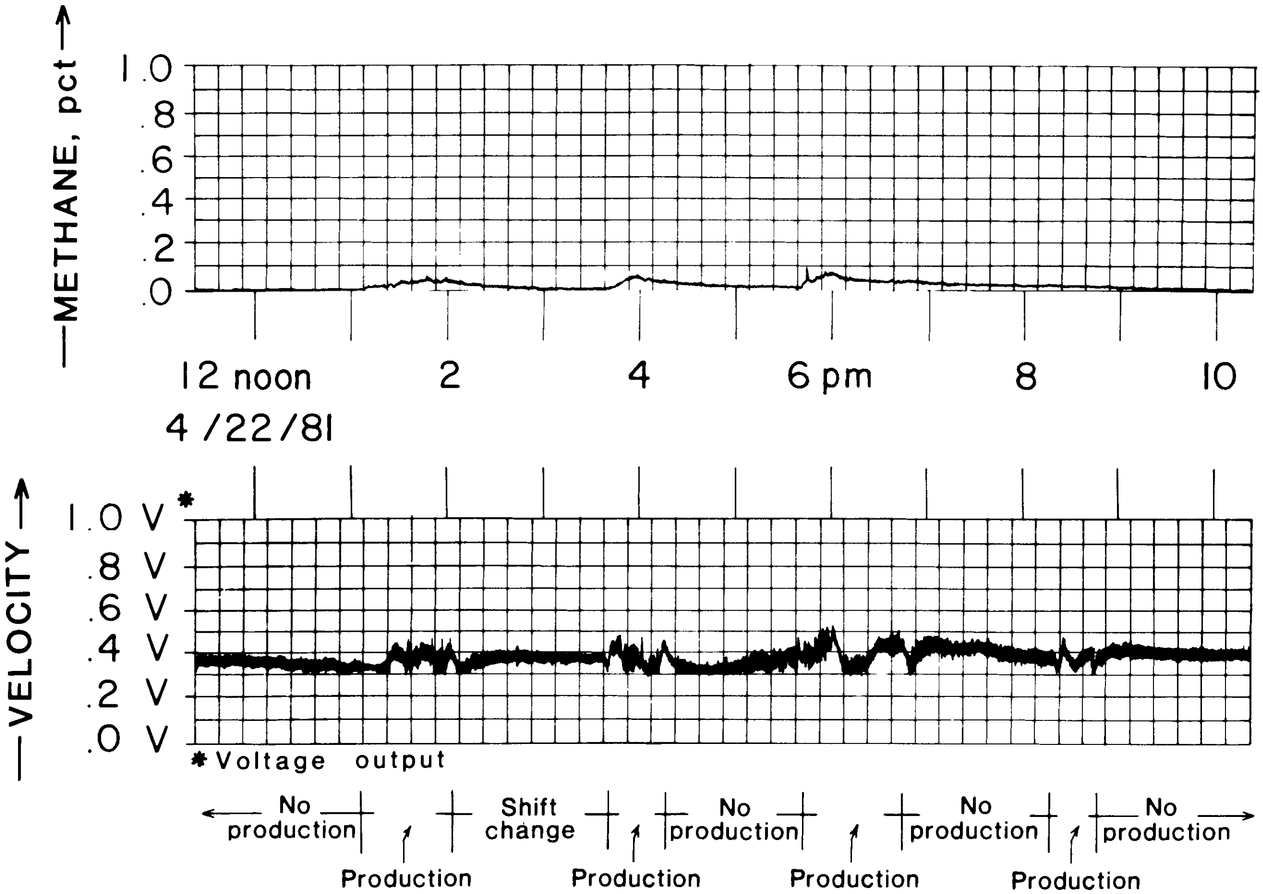

FIGURE A-13. - Day 13: Air density = 0.076 pcf and average air velocity = 3,100 ± 100 ft/min.

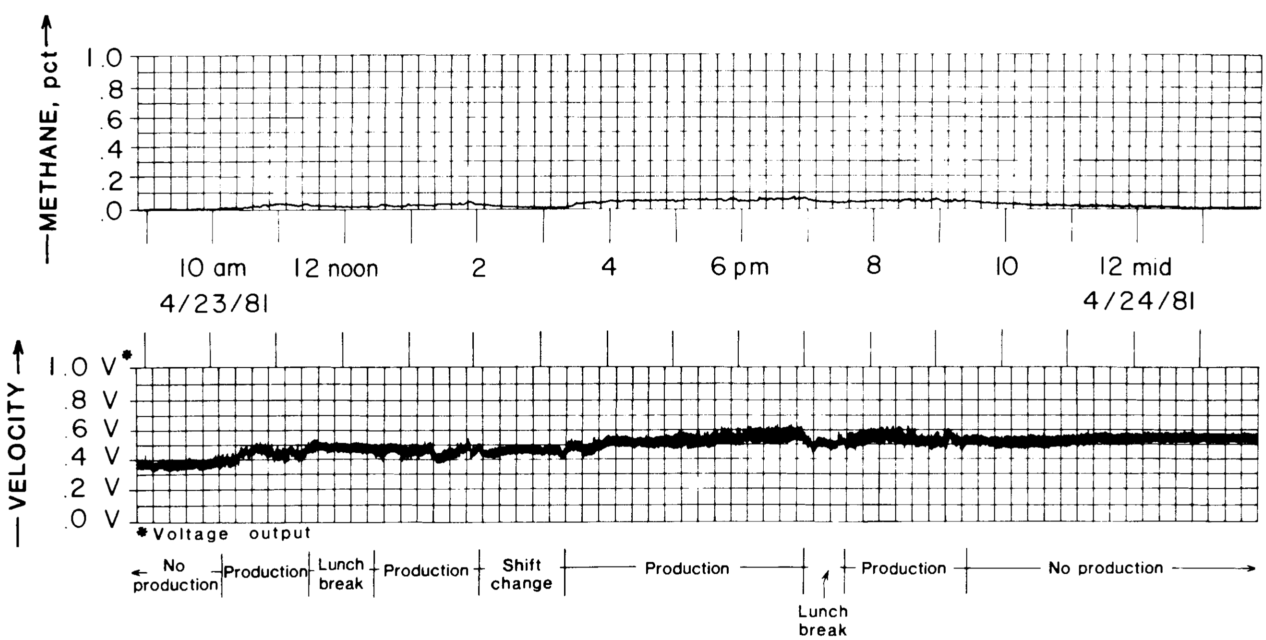

FIGURE A-14. - Day 14: Air density = 0.076 pcf and average air velocity = 3,100 ± 100 ft/min.

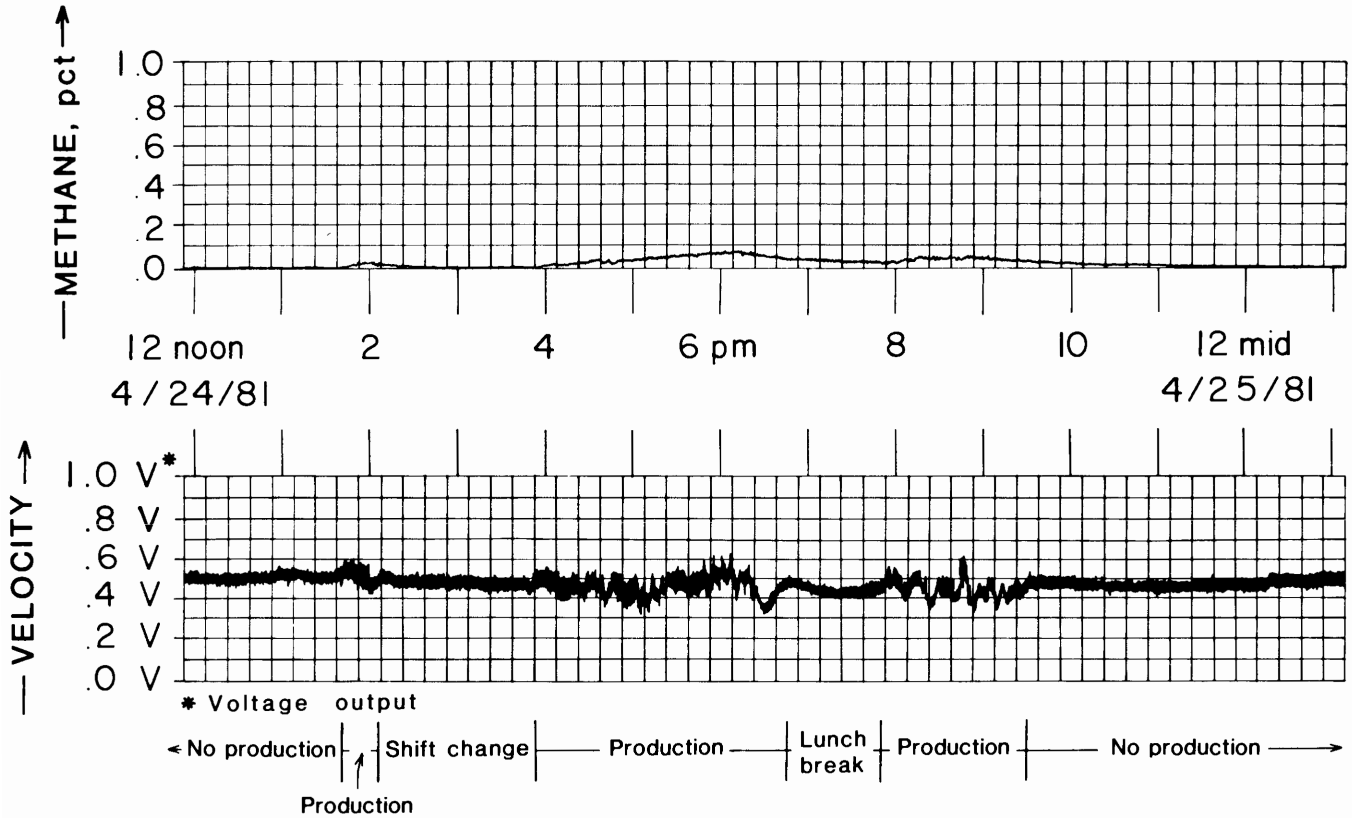

FIGURE A-15. - Day 15: Air density not available, average air velocity = 3,100 ± 100 ft/min.

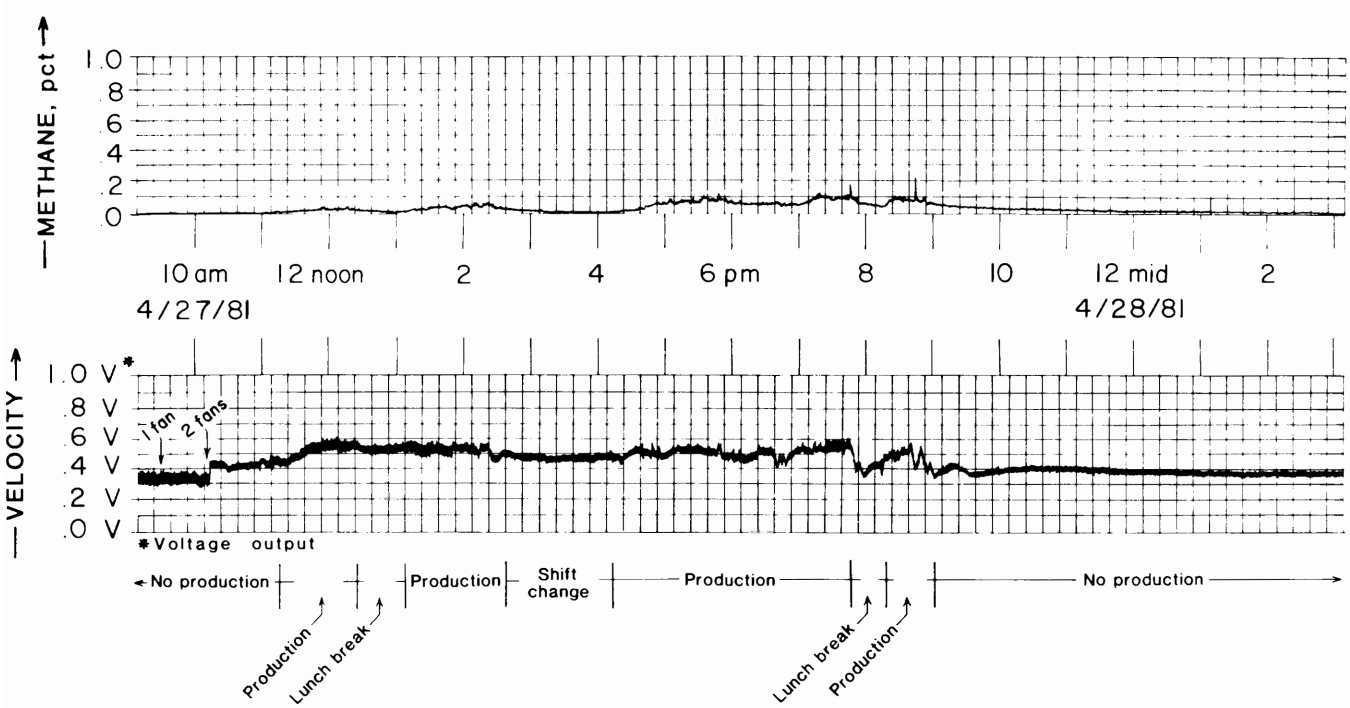

FIGURE A-16. - Day 16: Air density not available, average air velocity = 3,100 ± 100 ft/min.

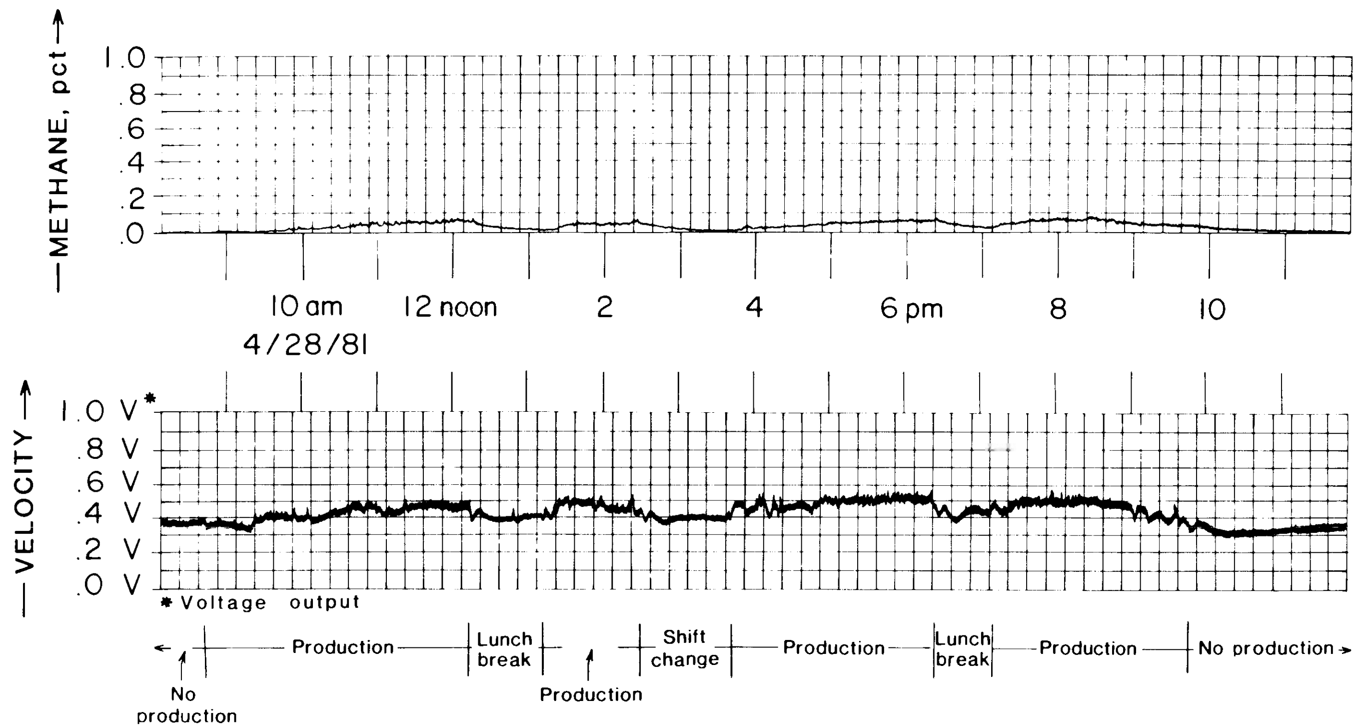

FIGURE A-17. - Day 17: Air density = 0.076 pcf and average air velocity = 3,100 ± 100 ft/min.

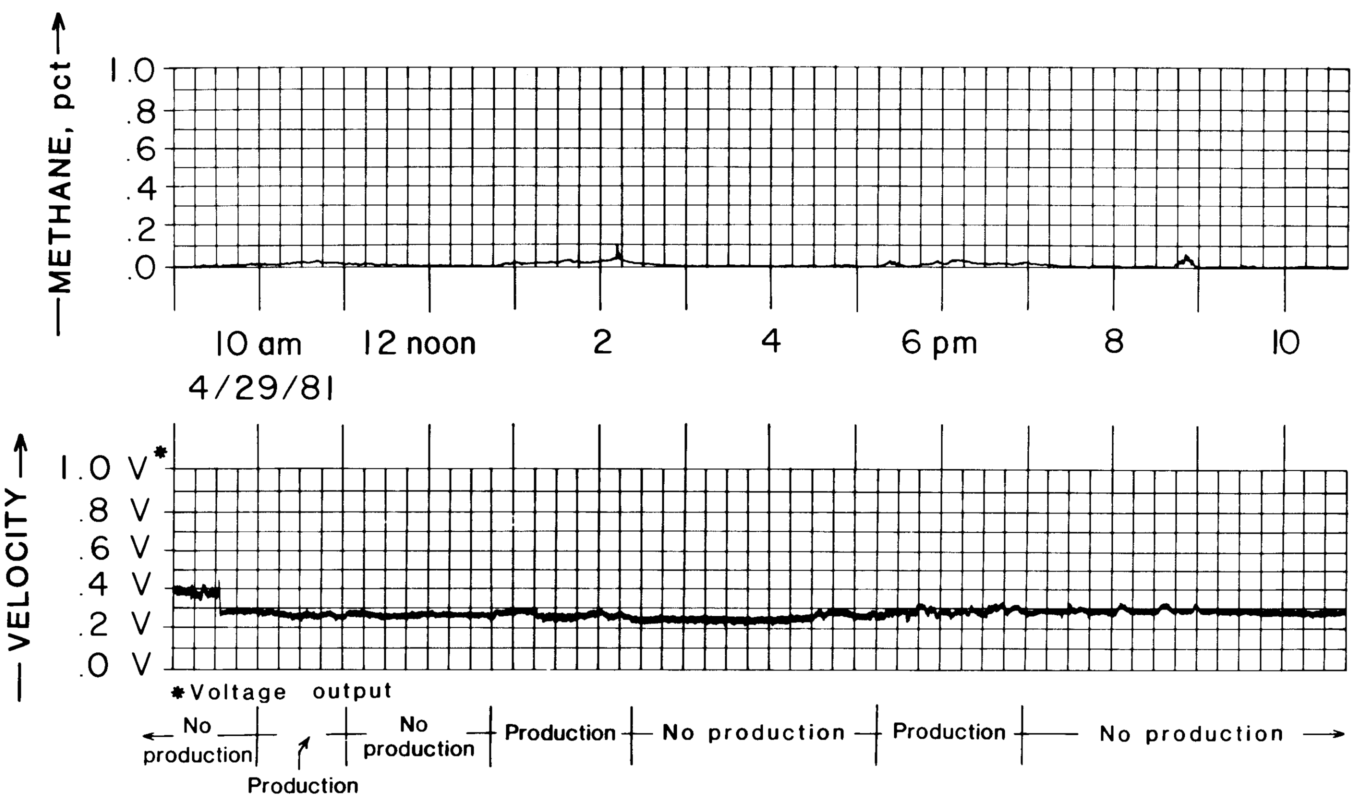

FIGURE A-18. - Day 18: Air density = 0.076 pcf and average air velocity = 3,100 ± 100 ft/min.

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